XLRotor

Reference Guide

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XLRotor Contents

XL Rotor™ by

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Alphabetical List of Help Topics

This is an alphabetical list of all help topics within this help file. You can jump to any topic by clicking on it with your mouse.

Installation Notes

See also

XLRotor Overview
Reinstalling the XLRotor Toolbar

Installation

Installation of XLRotor is a 3 step process:

1. **Insert the installation disk** into a drive.

2. **Run SETUP.EXE.** If the computer has multiple Windows login accounts, first login to the Windows user account in which XLRotor will be used. Administrator privilege is not required to install XLRotor. If you prefer to install XLRotor with administrator privilege, right-click this file and select **Run as administrator**.

   Follow the installation prompts. If you have been provided a USB security dongle, insert it into any working USB port. The key utilizes drivers which are included in Windows. When plugged in the first time, Windows may display a notice that drivers are being installed, and that the device is then ready for use. A small light on the key will always be ***on*** if the key is working properly. If the light is not on, try a different USB port. Otherwise contact support@xlrotor.com for help.

   The installer will create a program group on the Windows Start button with icons for XLRotor, tutorials and the example files.

3. **Install the XLRotor toolbar**. This step should happen automatically near the end of running SETUP.EXE. If it does not, after SETUP has finished, click Start, Programs, XLRotor, and select **Setup Toolbar** (this runs SETUP TOOLBAR.XLS). This will start Excel and load the XLRotor toolbar into the Excel environment. Depending on how Excel is currently configured, you may be instructed to change some Excel macro security settings. Excel should then be closed to save the configuration change.

   In Excel 2003 or earlier, the XLRotor toolbar and pull down menu will appear. When you are using Excel but have not opened any XLRotor files, the XLRotor toolbar and menu should not appear. They should appear only when you have opened XLRotor files.

   In Excel 2007 or later, the XLRotor ribbon tab will appear. The XLRotor ribbon tab should always be visible, even when no XLRotor files are open.

In summary, the setup program will install files in the following folders:

The folder you designate during installation (e.g., **C:\Program Files (x86)\XLRotor** for admin installs, or **C:\Users*username*\AppData\Local\Programs\XLRotor** for non-admin installs) will contain all program files and online Help files. This folder contains a subfolder named \Network containing instructions and associated files for the XLRotor network license server.

An applicaton data folder named **C:\ProgramData\XLRotor** in Windows Vista and later, or for Windows XP **C:\Documents and Settings\All Users\Application Data\XLRotor**. This folder will contain:

- Files that can be altered by either XLRotor or the end user. It is essential that this folder <u>not</u> be restricted by the Windows operating system security settings.
- Tutorial pdf files.
- A folder named Examples containing all example files.
- A folder named Templates containing all templates for rotor models, bearings and seals.

Network Installation

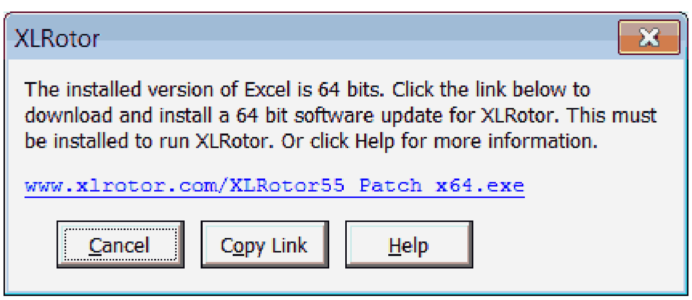
To install XLRotor for shared use in a local network environment, look for a folder named "Network" on the XLRotor installation CD or in the XLRotor program folder on the hard drive. Network installation instructions are in that folder.

Uninstallation

To uninstall XLRotor, use the Uninstall command in the XLRotor program group on the Windows Start button.   There is no item in the Windows Add/Remove Programs applet to uninstall XLRotor.

64 Bit Support

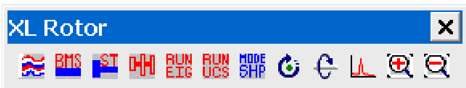
XLRotor works with both 32 bit and 64 bit versions of Excel. Excel 2010 was the first version available in 64 bits. An Office installation disc generally contains both, and either (but only one) may be installed. The XLRotor installation program uses a default installation folder of C:\Program Files (x86)\XLRotor. This destination folder can be used for either 32 or 64 bit versions of XLRotor. When first installed, XLRotor has all files necessary for 32 bit Excel, but may not for 64 bit Excel. The first time XLRotor is run, if Excel is 64 bit, the following prompt may be displayed.



Reinstalling the XLRotor Toolbar

See also

Installation Notes
XLRotor Toolbar



For Excel 2003 and earlier, the XLRotor custom toolbar is an essential part of the XLRotor program. Definitions for Excel toolbars are stored in an Excel setup file that has an extension of XLB, which is often located with other user specific files. The exact name and location of the *.XLB file depends on your versions of Excel and Windows. Definitions for custom toolbars include the directory location of the file which contains the macros that the buttons execute. For the XLRotor toolbar, this is the XLROTOR.XLA addin file. The toolbar definition includes the directory location of this file.

For Excel versions 2007 and later, the toolbar is installed to maintain compatibility with old XLRotor files, but the toolbar will not be visible in Excel. Instead, an XLRotor ribbon tab will appear on the Excel ribbon.

For instructions on setting up the XLRotor toolbar or ribbon for the first time, see Installation Notes. This results in saving the location of XLROTOR.XLA within the EXCEL.XLB toolbar file.

There are situations where you may have to reinstall the XLRotor toolbar:

1. When you move XLROTOR.XLA and associated files to another directory.
2. If the toolbar becomes corrupted or accidentally deleted from within Excel.

To Reinstall the Toolbar Automatically

Load the file Setup Toolbar.xls which is located in the XLRotor program directory. Whenever this file is opened, it checks for the presence of the XLRotor Toolbar in Excel. If the toolbar is missing, it is installed. If the toolbar is present, but was installed from a different folder, you are prompted for permission to reinstall the toolbar.

If you have moved the entire XLRotor program directory to a new location on your hard drive. All you need to do is manually load the Setup Toolbar.xls file. You do not have to rerun the SETUP program to reinstall the software. However, if you want the icons on the Start menu to point the new directory, rerun SETUP.

Note:
The reinstallation of the toolbar is made permanent and saved to the EXCEL.XLB file when you exit Excel normally.

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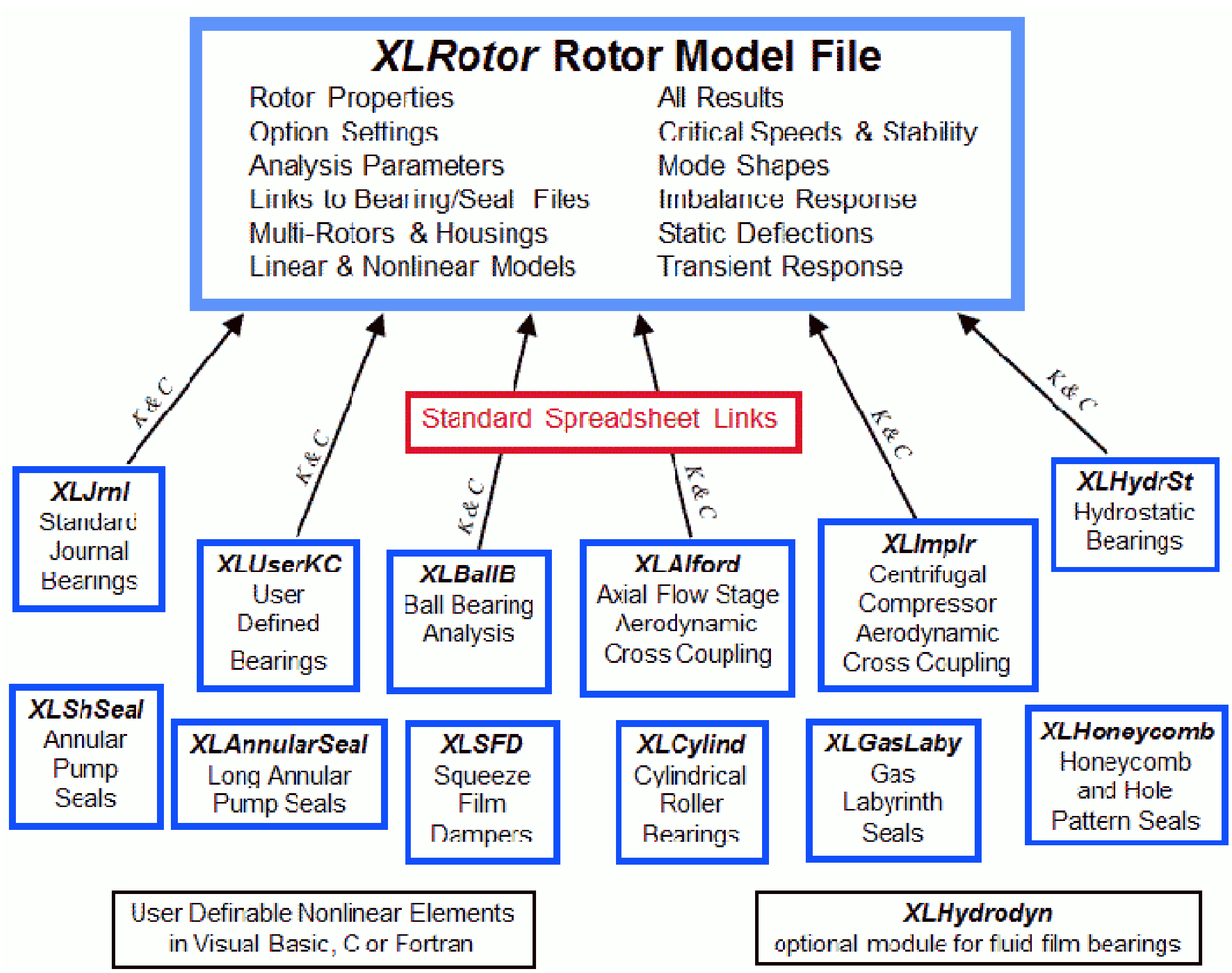
XLRotor Overview

See also

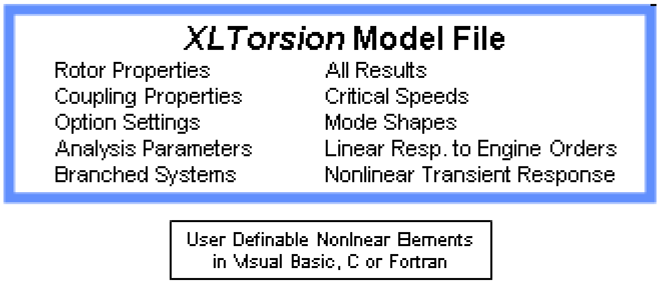
XLRotor Menu Commands
How to use this help file
Running XLRotor
Creating New Rotor Model Files
XLRGRPH.XLS Chart Template File

XLRotor Worksheet
Shaft Input Worksheet
Beams Worksheet
Stations Worksheet
Geo Plot Chartsheet
Transient Worksheet
Torsional Analysis
Other Sheets
Brg's Worksheet
Roots Damped Worksheet
Shapes Worksheet
Imb's Worksheet
Resp Worksheet
Transient Resp Worksheet
Coupled Lateral-Torsional Analysis

Lateral analysis with XLRotor



Torsional analysis with XLRotor



XLRotor consists of a collection of Excel workbook templates, an Excel Addin file of custom macros, and Windows Dynamic Link Libraries (DLL).

Using the various templates, you set up a model of a rotating machine, and set up bearings and seals for their stiffness and damping. Rotors, bearings and seals can be kept in separate files that are linked together, or can be all inside one file - you decide as you set up your model. With the click of the mouse, you then analyze the complete system for critical speeds, stability, mode shapes, and imbalance response and operating deflected shapes. The analysis results are appended to the rotor model workbook file, and are saved in that file, along with the rotor model.

XLRotor uses different types of Excel workbook files for lateral and torsional analysis. For lateral analysis you use a workbook template that is setup for working with a lateral rotordynamic model. For torsional analysis you use a workbook template that is setup for working with torsional models. For coupled lateral-torsional analysis you use a workbook template setup for working with coupled models.

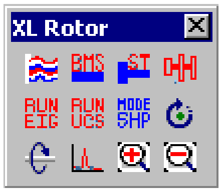
During the various phases of model construction and subsequent analysis, you execute various custom procedures special to XLRotor. The XLRotor Menu Commands provides access to all the features of XLRotor. These range from setting and changing options and running the analyses, to manipulating the results.

Everything is done within the Excel environment - from setting up your inputs to viewing the results. The entire process is easy and fast. Input and output formats can be user customized. Plots are especially easy to customize, and are readily copied to any Windows word processor. The benefits of using a full featured spreadsheet program as the working environment are practically endless.

XLRotor is compatible with all Excel versions starting with Excel 2000 up through Excel 2016. Excel 2007 should be avoided because it is much slower than all other versions. Excel can be either 32 bit or 64 bit.

All versions of Windows are supported from Windows XP to Windows 10. Windows can be either 32 or 64 bit.

XLRotor ToolBar and Ribbon



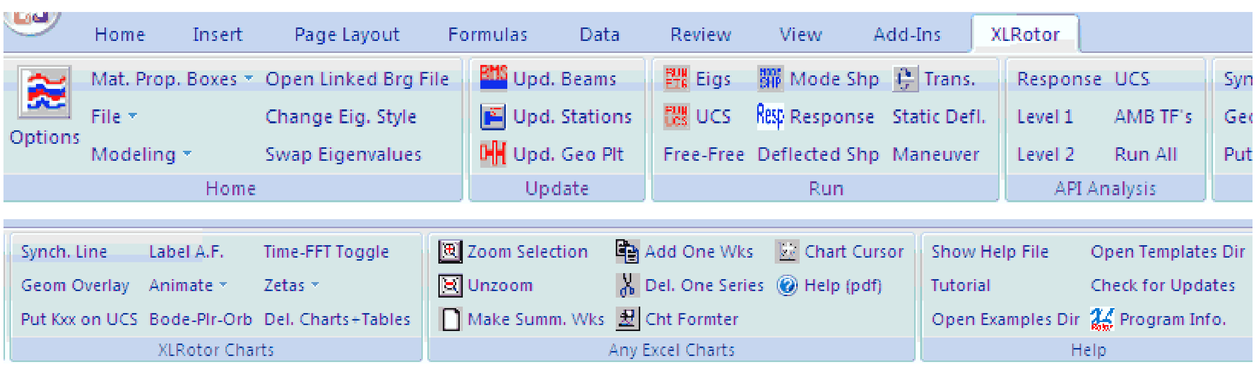
This is the XLRotor custom toolbar.   It appears only in Excel 2003 and earlier. Clicking on any of these buttons is equivalent to selecting the corresponding command from the XLRotor Menu Commands.   However, the two Zoom Selection buttons can **only** be accessed by way of this toolbar - they are not on the pull down menu.

Should the buttons ever fail to work, you may need to see Reinstalling the XLRotor Toolbar.

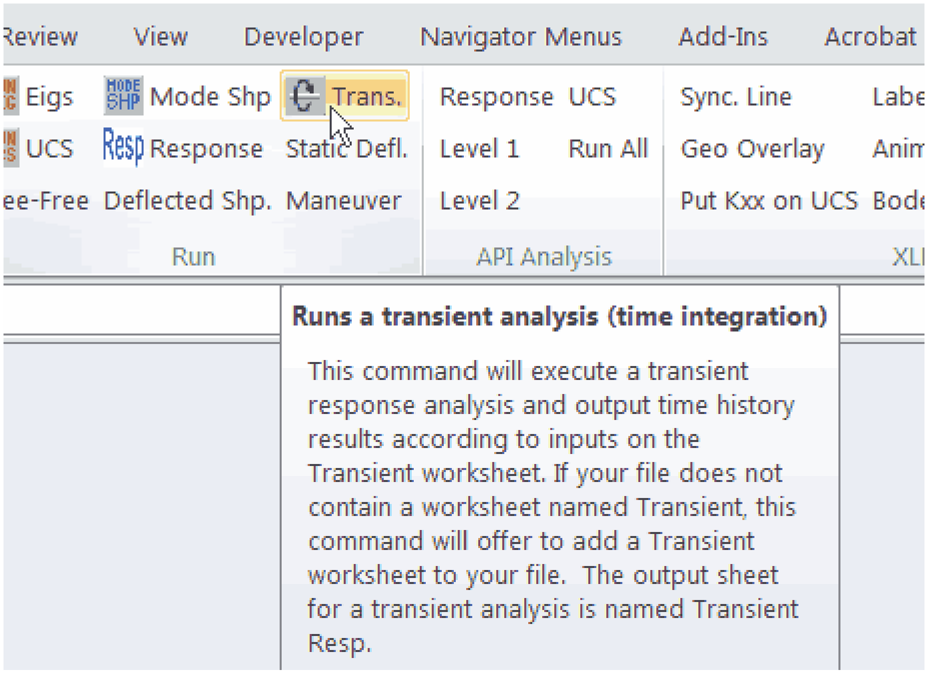
You can customize XLRotor's toolbar as you can any of Excel's own toolbars.   You can add or delete buttons, or edit the button's graphic image.   See Excel's online documentation to find out how to do this.

Starting with XLRotor version 3.94 when used with Excel versions 2007 and later, an XLRotor tab will appear on the Excel ribbon.   See Options|Other for more information about the toolbar and ribbon.   The XLRotor ribbon provides access to all program features, and displays detailed popup help for each command.

If using Excel 2003, but have not opened any XLRotor files, the XLRotor toolbar and menu should not appear.   They should appear only when an XLRotor file has been opened.   In Excel 2007 and later, the XLRotor ribbon tab should always be present.



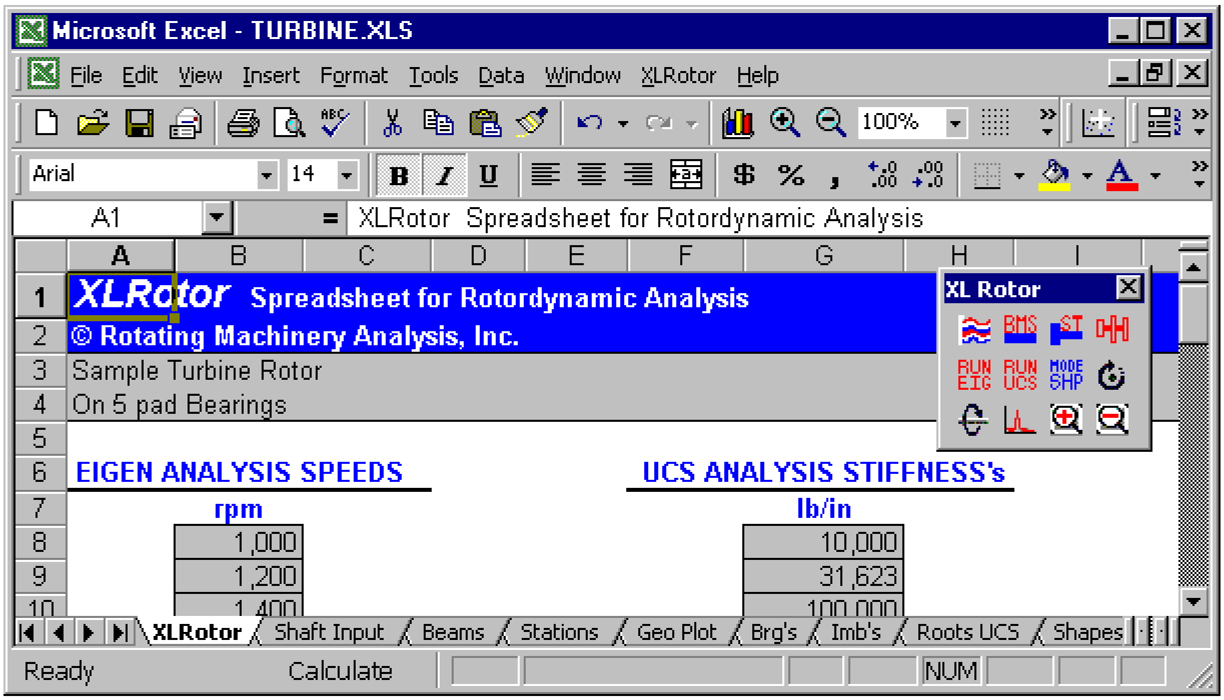
Example of popup help on the XLRotor ribbon tab.


Review
View
Developer
Navigator Menus
Add-Ins
Acrobat
Eigs
Mode Shp
Trans.
Response
UCS
Sync. Line
UCS
Response
Static Defl.
Level 1
Run All
Geo Overlay
Deflected Shp.
Maneuver
Level 2
Put Kxx on UCS
Run
API Analysis
Runs a transient analysis (time integration)
This command will execute a transient response analysis and output time history results according to inputs on the Transient worksheet. If your file does not contain a worksheet named Transient, this command will offer to add a Transient worksheet to your file. The output sheet for a transient analysis is named Transient Resp.

Running XLRotor

See also

- XLRotor Overview
- XLRotor Menu Commands
- Creating New Rotor Model Files
- XLRotor Worksheet
- Torsional Analysis with XLRotor
- Coupled Lateral-Torsional Analysis



The above picture shows the opening worksheet of an XLRotor rotor model workbook file. There are many other worksheets contained within this file. Each worksheet has a name which appears on a labeled sheet tab near the bottom of the Excel window. You can jump to another worksheet by clicking on its sheet tab. The first 7 sheet tabs shown, XLRotor through Brg's, are input worksheets where you set up your rotor/bearing model. These contain, among other things, the complete definition of the rotor shaft model, the bearing locations, and imbalance distribution. The remaining worksheets show the results of various analyses which you perform as part of your project.

The above picture also shows that XLRotor has its own pull down menu and custom toolbar. You use these to execute custom procedures which generate plots, conduct analyses, and manipulate the results.

Bearings and seals can be modeled in workbook files separate from the rotor model file. In which case the bearing file(s) are Linked to the rotor model file. Or bearing worksheets can be embedded within the rotor model file (see Embedded Bearings). Here are 3 possible ways you might organize your project.

1. Entire project in one file. Put all the bearing worksheets in the rotor model file.
2. Entire project in two files. The rotor model in one file, and all the bearing worksheets in another file.
3. More than 2 files. The rotor model file, and the bearings spread amongst a collection of files, perhaps each in its own file.

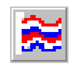
The procedure for using XLRotor to perform a complete rotordynamic analysis will be outlined. Generally, you move from left to right through the named worksheets depicted above. The exact sequence of steps is case dependent, however, according to what analysis results are required.

Proceed as follows:

1. Open one of the rotor model template files (see Creating New Rotor Model Files), and save a copy with a new name, using the **File|Save As** command on the pull down menu (click the Options button in the **Save As** dialog box to make sure the Read Only checkbox is disabled). You will now be working with your newly named file, and are ready to proceed.
2. On the XLRotor Worksheet enter the project titles. Also enter rotor speeds if you're going to do a damped eigenvalue analysis (Run|Eigenvalues), and bearing stiffness values if you're going to do an undamped critical speed analysis (Run|Undamped Crit. Spds). You can come back and change these at any time.
3. Go to the XLRotor pull down menu (XLRotor Menu Commands) and select the Options|General command . Set the options according to the machine you are analyzing. Most of the time you won't need to change any options, but now is a good time to begin familiarizing yourself with the various options. Click the Help button in the dialog box for additional details.
4. On the Shaft Input Worksheet enter the beam definitions which describe your rotor.
5. Execute an Update|Geometry Chart pull down menu command (or use the toolbar button) .
6. Inspect the geometry sheet (Geo Plot Chartsheet), the Beams Worksheet, and the Stations Worksheet to make sure the rotor model is correct. Use the Material Property Boxes command to help double check your model.
7. Go to the Brg's Worksheet and set up the bearing and seal locations on the rotor. Fill out the table with the various options for each bearing. At this point you can run an undamped critical speed analysis before creating bearing worksheets for the rotor model (Run|Undamped Crit. Spds command 

). This is the only type of rotor analysis you can do before creating bearing worksheets.
8. You can model each bearing/seal in a separate workbook file using any of the various templates as needed (see Bearing Template Files), and Link those files to the rotor model file. In cases where two or more bearings/seals are identical, you

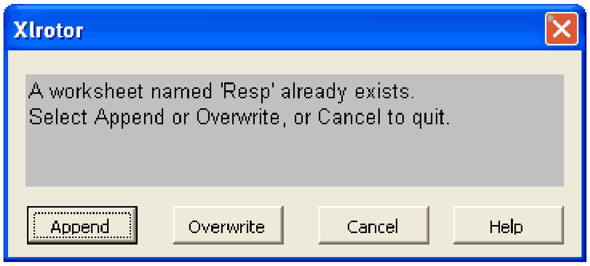
can link the same file more than once. Or, instead of separate files, you can embed the bearing worksheets directly in the rotor model file.

9. Execute an Update|Geometry Chart pull down menu command (or use the toolbar button) . Now check the geometry chart to make sure that the bearing locations are shown correctly.
10. At this point you have a complete rotor/bearing system model. You can run any type of eigenvalue analysis, or static deflection analysis, but you are not ready yet to run a response analysis.
11. Execute the Options pull down menu command  and go to the Response tab (Options|Response), and select or define the various options as needed.
12. Go to the Imb's Worksheet and enter the imbalance distribution, response speed ranges, and output stations. This step, and the preceding step, are required only if you plan to run a response analysis.
13. The model is now complete, and you are ready to start analyzing the rotor. Except where noted, the remaining steps are optional. You only need to perform the analyses required for the job.
14. Execute the Run|Free Free Modes command to compute the free-free natural frequencies of the rotor as functions of rotor speed. The results are placed on a Roots FF Worksheet.
15. Execute the Run|Undamped Crit. Spds command  to compute the synchronous undamped critical speeds as a function of bearing stiffness.
16. Execute the Run|Eigenvalues command  to compute the damped eigenvalues as a function of rotor speed.
17. If desired, compute mode shapes  for any of the eigenvalues calculated in the previous three steps. You must compute the eigenvalues before computing their mode shapes. All the mode shapes can be placed together on the same Shapes Worksheet, or on separate worksheets. If desired, you can use the mode shape animator (Animate Mode Shape) on the 3D mode shapes charts.
18. You may now wish to compute imbalance response as a function of rotor speed, by executing the Run|Response pull down menu command. Response results will be placed on a Resp Worksheet.
19. Other analyses you may want to execute are the Run|Deflected Shapes command or Run|Static Deflection. Deflected shapes for the speeds you entered in step 12 will be appended to the Resp Worksheet. Or you can rename the Resp sheet, so as to place new results onto a new Resp sheet.
20. You can access the online tutorial at ***Start/Programs/XLRotor/XLRotor Tutorial***, or when in Excel from the XLRotor pull down menu.

Append or Overwrite Worksheet

See also

Delete Charts and Tables
Running XLRotor with Macros



Append

When you compute mode shapes, response or deflected shapes, XLRotor will try to place the results onto either a Shapes Worksheet or a Resp Worksheet, as needed. XLRotor will create the required worksheet if it does not already exist. If it already exists, you will be prompted for permission to **append** the new data to it. If you want keep the old data, but do not want to append the new data, you must first *rename the worksheet.*

When appending, new data is appended to the right of existing data on the worksheet.

In the case of transient response, new data is appended to the bottom of existing data, and the transient response plots are updated to show all the data on the worksheet. The value of time, t, used to start the integration is the last value appearing on the Transient Resp worksheet. This makes it possible to easily "continue" an integration where it left off, and append the new results (see Final Conditions).

Overwrite

When you compute eigenvalues, XLRotor will try to place the results onto a Roots Damped Worksheet (or Roots UCS Worksheet or Roots FF Worksheet). If the worksheet does not already exist, XLRotor will create one. If it does exist, you will be prompted for permission to **overwrite** it. Confirming this action will cause all existing data on the worksheet to be cleared. If you do not want to lose the data that's currently on the worksheet, you must *rename the worksheet* **before** executing the analysis. In that way XLRotor will create a new copy of the "Roots" worksheet. Renaming the worksheet prior to the analysis is the best way to preserve the data it contains.

Note:
If you only want to save a few of the eigenvalues before overwriting, you can copy their values to a new *blank worksheet*, giving it a new name (for example, Summary).

Note:
When running XLRotor analyses from your own macros, you can supply the answer to this dialog from your macro. See Running XLRotor with Macros.

Running XLRotor with Macros

See also

XLRotor Menu Commands
Done Dialog

You can create your own macros that execute XLRotor's menu commands. Reasons for doing this include performing a standard sequence of analysis tasks, or conducting an iterative analysis such as when the properties of a bearing are amplitude dependent.

In Excel version 95 and earlier, XLRotor commands could be recorded by Excel's macro recorder. But the macro recorder in Excel 97 and later does not record these commands. But you can still run XLRotor commands from macros if you know what the commands are. An example macro is shown below along with a complete list of all XLRotor commands.

Some XLRotor commands may prompt you for instructions. For example, permission to overwrite an existing worksheet of eigenvalue results. Excel has a macro command called SendKeys that can be used to simulate keystrokes to answer these prompts. This works most of the time, but there are drawbacks to using the SendKeys. So XLRotor has some features to help your macros run without the need for SendKeys.

Suppressing the "Done Dialog" Message

To suppress the dialog box that is displayed at the successful completion of an analysis (see Done Dialog), have your macro execute the following Visual Basic statement.

```
Workbooks("xlrotor.xla").Sheets("lists").range("Show_Done_Dialog") = False
```

As an alternative to the above statement, you could instead use an Excel defined name. See Done Dialog for instructions on how that is done.

Suppressing the "Append " or "Overwrite" Prompt

All of the XLRotor primary commands that execute a rotordynamic analysis may prompt you for permission to **"append"** or **"overwrite"** a worksheet with new analysis results. When you call these commands from your own macro, you can tell it what to do by passing it an optional argument. The following example shows how:

```
Application.Run Macro:="CallDampedEigenvalues", Arg1:="overwrite"
```

An alternative which is equivalent to the above statement is:

```
Application.Run "CallDampedEigenvalues", "overwrite"
```

Skip Creating Charts

If you do not need the charts which are created after an analysis, your macro may run faster by skipping creation of the charts. This can be done with another optional argument. The following example shows how:

```
Application.Run Macro:="CallDampedEigenvalues", Arg1:="overwrite",
Arg2:=True
```

An alternative which is equivalent to the above statement is:

```
Application.Run "CallDampedEigenvalues", "overwrite", True
```

The following example macro can be found in the example file named "2-DISK with Command Macro.xls".

```
Sub Macro1()
    If MsgBox("Do you want to run Macro1?", vbOKCancel) <> vbOK Then Exit Sub

    'You can delete worksheets with commands like these that follow,
    'but excel will display a warning and prompt you for permission to delete the
        sheets.
    'You also could delete these manually before running this macro.
    'Sheets("Roots Damped").Delete
    'Sheets("Roots UCS").Delete
    'Sheets("Roots FF").Delete
    'Sheets("Shapes").Delete
    'Sheets("Resp").Delete

    Application.Run Macro:="XlrotorOptions"
    Application.Run Macro:="UpdateBeamSheet"
    Application.Run Macro:="UpdateStationSheet"
    Application.Run Macro:="CreateGeometryGraph"
    Application.Run Macro:="CallDampedEigenvalues", Arg1:="overwrite"
    Application.Run Macro:="CallUCS", Arg1:="overwrite"
    Application.Run Macro:="CallFreeFree", Arg1:="overwrite"
    ActiveSheet.Range("F3").Select
    Application.Run Macro:="CallModeShapeCode", Arg1:="overwrite"
    Application.Run Macro:="CallResponseCode", Arg1:="overwrite"

    Sheets("Shapes").Select
    ActiveSheet.ChartObjects(ActiveSheet.ChartObjects.Count).Activate
    Application.Run Macro:="CreateGeomShapeOverlay"

    Sheets("Roots UCS").Select
    ActiveSheet.ChartObjects(ActiveSheet.ChartObjects.Count).Activate
    Application.Run Macro:="OverlayBrgsOnUCS"
```

```
    'the Resp sheet has results on it we want to keep, so append these new results
    Application.Run Macro:="CallDeflectedShapeCode", Arg1:="append"
    Application.Run Macro:="CallStaticDeflectionCode", Arg1:="append"

    Sheets("Resp").Select
    Application.Goto [A1], True
    Application.ScreenUpdating = True
    ActiveSheet.ChartObjects(1).Activate
    Application.Run Macro:="PolarBodeSwitch"
    ActiveWindow.Visible = False
    Application.ScreenUpdating = True

    MsgBox "Macro1 is now finished running."
End Sub
```

Here is a complete list of the equivalent macro statements to run every command in XLRotor. The commands are listed in the same order they appear on the XLRotor pull down menu.

```
Application.Run Macro:="XlrotorOptions"
Application.Run Macro:="CallDampedEigenvalues" [,
     Arg1:="overwrite"|"append"]
Application.Run Macro:="CallUCS" [, Arg1:="overwrite"|"append"] 'Arg1 is
     optional
Application.Run Macro:="CallFreeFree" [, Arg1:="overwrite"|"append"] 'Arg1
     is optional
Application.Run Macro:="CallModeShapeCode" [, Arg1:="overwrite"|"append"]
     'Arg1 is optional
Application.Run Macro:="CallResponseCode" [, Arg1:="overwrite"|"append"]
     'Arg1 is optional
Application.Run Macro:="CallDeflectedShapeCode" [,
     Arg1:="overwrite"|"append"] 'Arg1 is optional
Application.Run Macro:="Call_Transient" [, Arg1:="overwrite"|"append"]
     'Arg1 is optional
Application.Run Macro:="CallStaticDeflectionCode" [,
     Arg1:="overwrite"|"append"] 'Arg1 is optional
Application.Run Macro:="CallManeuverResponseCode" [,
     Arg1:="overwrite"|"append"] 'Arg1 is optional
Application.Run Macro:="CallUpdateBeamSheet"
Application.Run Macro:="CallUpdateStationSheet"
Application.Run Macro:="CallCreateGeometryGraph"
```

```
Application.Run Macro:="Export_Geometry_To_Autocad"
Application.Run Macro:="Export_Geometry_To_SolidWorks"
Application.Run Macro:="Export_ROMAC_Modal"
Application.Run Macro:="ImportRappFile"
Application.Run Macro:="ImportDyrobesFile"
Application.Run Macro:="ImportRBTSFile"
Application.Run Macro:="DeleteChartAndTablesFromSheet"
Application.Run Macro:="OpenBearing"
Application.Run Macro:="SwapEigenvalues"
Application.Run Macro:="EigStyleDialog"
Application.Run Macro:="CustomHelp"
Application.Run Macro:="About_XLRotor"
Application.Run Macro:="CallAPI_UCS", [ShowPrompt = True] 'argument is
     optional
Application.Run Macro:="CallAPI_Response", [ShowPrompt = True] 'argument is
     optional
Application.Run Macro:="CallAPI_SVD", [ShowPrompt = True] 'argument is
     optional
Application.Run Macro:="CallAPI_StabilityLevel_1", [ShowPrompt = True]
     'argument is optional
Application.Run Macro:="CallAPI_StabilityLevel_2", [ShowPrompt = True]
     'argument is optional
Application.Run Macro:="CallAPI_AMB", [ShowPrompt = True] 'argument is
     optional
```

The following commands require being in edit mode on a chart.

```
Application.Run Macro:="ShowZetas"
Application.Run Macro:="HideZetas"
Application.Run Macro:="ShowSynchronousLine"
Application.Run Macro:="CreateGeomShapeOverlay"
Application.Run Macro:="Animate2"
Application.Run Macro:="OverlayBrgsOnUCS"
Application.Run Macro:="PolarBodeSwitch"
Application.Run Macro:="Time_Spectrum_Switch"
Application.Run Macro:="CallShow_Material_Property_Boxes"
Application.Run Macro:="Remove_Material_Property_Boxes"
Application.Run "LabelAmplificationFactor" [,MaxCOS] [,MinCOS] [,RatedCOS]
     [,CreateLabels]
'The preceding command requires that a chart series or chart point be selected.
```

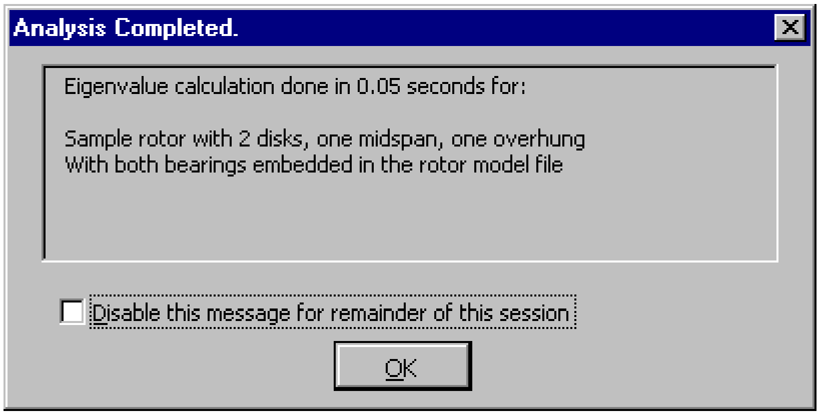
```
'The three COS arguments are numerical values >0.  <=0 suppresses display of
     that that speed.
'The CreateLabels argument is True or False.
```

Done Dialog

See also

> XLRotor Menu Commands
> Running XLRotor with Macros

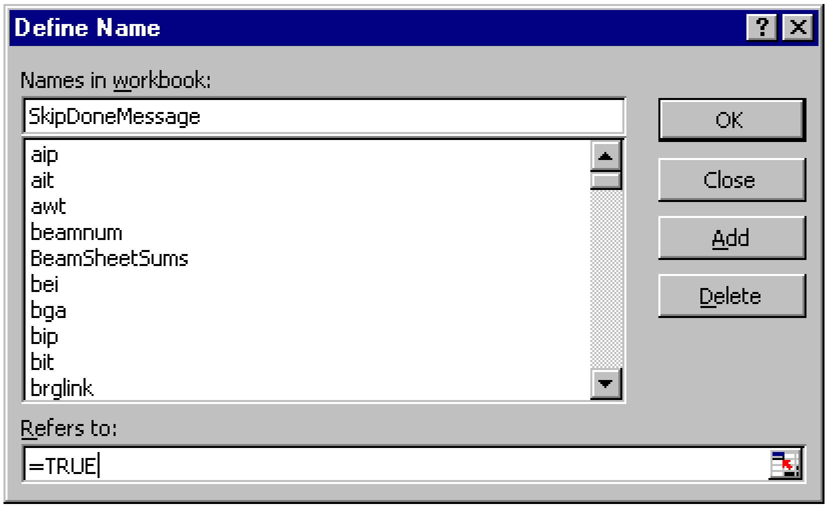
Every time XLRotor completes a calculation, a dialog like the one below is displayed.



You can disable the display of this dialog by checking the option button. But this setting is not remembered between sessions of XLRotor.

There is another way to disable the display of this message, but for a specific rotor model file, and which is saved with the rotor file.

1. Open your rotor file.
2. From the Excel menu do Insert/Name/Define (or press Control-F3).
3. In Excel 2003 in the "**Names in workbook:**" field type **SkipDoneMessage**. In Excel 2007 and later click the **New** button and enter **SkipDoneMessage** in the **Name** box.
4. In the "**Refers to:**" field type "**=TRUE**" without the quotes.
5. Display of the message will only be suppressed when "Refers to" is set to TRUE.
6. Whatever value you have this set to will be saved with the rotor model file, and applies only to that file.



See Running XLRotor with Macros for one additional way to suppress the "Done Dialog" message.

Creating New Rotor Model Files

See also

- XLRotor Overview
- Running XLRotor
- XLRotor Worksheet
- Torsional Analysis with XLRotor
- Coupled Lateral-Torsional Analysis

To create new **lateral** rotor models from scratch using English units, start with a copy of a template file described below, and save it with a file name of your choice. You can do this with any existing rotor model file, but a template is empty of most model data. See the topic Torsional Analysis with XLRotor if you want to perform a **torsional** analysis, or Coupled Lateral-Torsional Analysis for coupled models.

From the Windows Start button do **Start/All Programs/XLRotor/Shaft Model Templates** and select one of the following items. The one you pick determines the system of units for the model.

For lateral models:

- Xlrotor Shaft Model Template, English Units (in-lbf-lbm)
- Xlrotor Shaft Model Template, English Units (in-lbf-sn)
- Xlrotor Shaft Model Template, SI Units (m-N-kg)
- Xlrotor Shaft Model Template, SI Units (mm-N-kg)

For torsional models:

- XlTorsion Shaft Model Template, English Units (in-lbf-lbm)
- XlTorsion Shaft Model Template, English Units (in-lbf-sn)
- XlTorsion Shaft Model Template, SI Units (m-N-kg)
- XlTorsion Shaft Model Template, SI Units (mm-N-kg)

Note: the unit of mass "sn" is called a "snail", and is equal to 386.089 lbm (i.e. 9.80665/0.0254)

The template workbook files are marked as ***READ ONLY*** files to keep you from saving your work over the templates. The actual file names for the workbooks referenced by the above Start menu items are as follows:

XLROTOR (in-lbf-lbm).xls

XLROTOR (in-lbf-sn).xls

XLROTOR (m-N-kg).xls

XLROTOR (mm-N-kg).xls

XLTorsion (in-lbf-lbm).xls

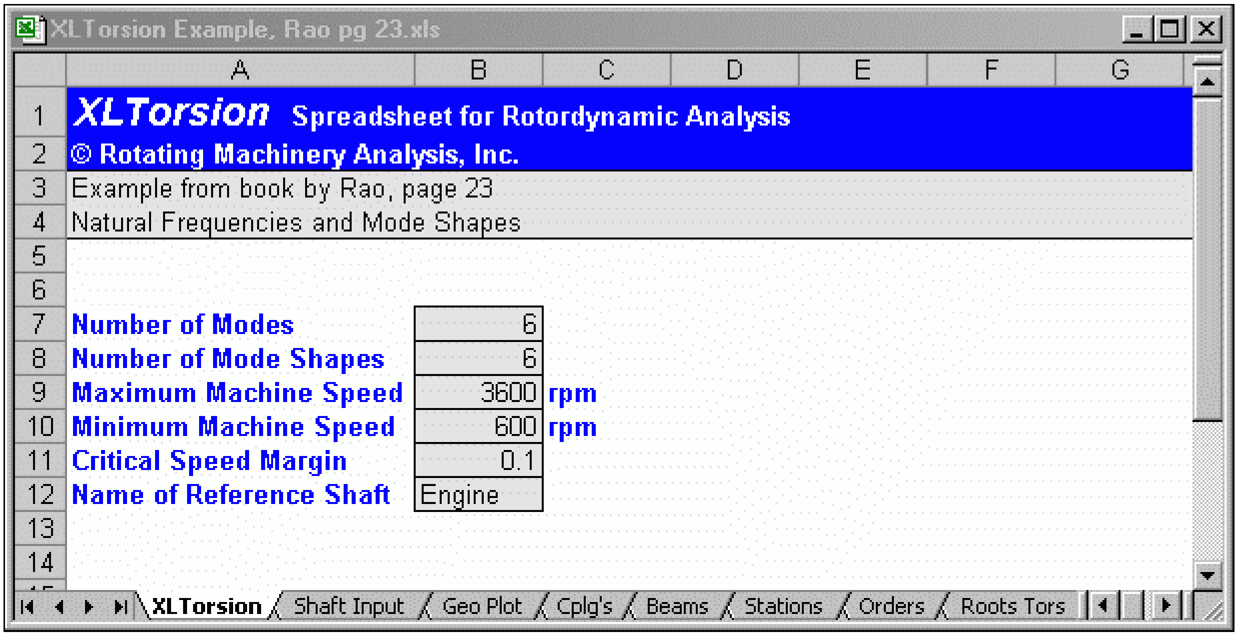
XLTorsion (in-lbf-sn).xls

XLTorsion (m-N-kg).xls

XLTorsion (mm-N-kg).xls

Each of the template workbook files is located in: for Windows Vista and later **C:\ProgramData\XLRotor\Templates**, or for Windows XP **C:\Documents and Settings\All Users\Application Data\XLRotor\Templates.**

Torsional Analysis with XLRotor



See also

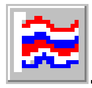
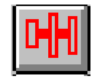
- Creating New Rotor Model Files
- Running XLRotor
- XLTorsion Worksheet
- Roots Tors Worksheet
- Coupled Lateral-Torsional Analysis

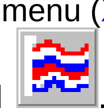
XLRotor uses three specially configured Excel workbook files, one for lateral analysis, one for torsional analysis and one for coupled lateral-torsional analysis. The files serve as templates setup for working with lateral, torsional or lateral-torsional rotordyamic models.

The following types of analyses can be performed on torsional system models.

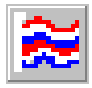
1. Damped or undamped critical speeds and mode shapes (torsional interference diagrams).
2. Linear response to harmonic shaft orders.
3. Linear transient response to arbitrary external forces.
4. Transient response of nonlinear models to external forces.

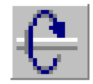
To start a torsional analysis, open the **XLTorsion (in-lbf-lbm).XLS** template file (for SI units open instead **XLTorsion (mm-N-kg).XLS**), and save the file with a name of your choice. Then in general you would follow the steps given below to perform the torsional analysis. These steps closely parallel those for performing a lateral analysis (see Running XLRotor).

1. On the XLTorsion Worksheet enter your project titles. Also enter the number of modes to compute, the number of mode shapes to display, and maximum machine speed. You can come back at any time to change these values.
2. Go to the XLRotor pull down menu (XLRotor Menu Commands)and select the Options|General command . Set the options according to how you wish to input model data and display the model geometry.
3. On the Shaft Input Worksheet enter the station definitions which describe your rotor.
4. Execute an Update|Geometry Chart pull down menu command (or use the  toolbar button).
5. Inspect the geometry chartsheet (Torsional Geometry Chart Sheet), the Beams Worksheet, and the Stations Worksheet to make sure the rotor model is correct. Use the Material Property Boxes command to help double check your model.
6. Go to the Cplg's Worksheet and set up the coupling locations on the rotor. Fill out the table with the various options and properties for each coupling. If the model has more than one level, the interconnections between levels must be setup on the Cplg's sheet before the Geometry Chart can be updated.
7. You are almost ready to compute the torsional critical speeds. Go to the Orders Worksheet and enter a the list of shaft orders. These will be displayed on the torsional interference diagram. Inputs for torque magnitude and phase are not needed until later.
8. Now you are ready to execute a Run|Eigenvalues command from the menu (or click 

on the toolbar). This will produce a table of damped eigenvalues, and a torsional interference diagram along with mode shapes. The roots and mode shapes will be on a single worksheet name Roots Tors.
9. Usually you would be done after computing the critical speeds. If you want compute response to shaft orders, continue with the next step.
10. Go to the XLRotor pull down menu (XLRotor Menu Commands) and select the Options|Response command . Set the options on the Response tab according to the machine you are analyzing.
11. On the Orders Worksheet finish specifying the shaft orders, response speeds, and output stations.
12. Execute a Run|Response menu command. This will produce a Torsional Resp Worksheet showing the results of the analysis. You can also compute response deflected shapes with the Run|Deflected Shapes command.

13. If you wish to perform a transient analysis, go to the Transient Worksheet and enter the forcing functions, define any nonlinear elements, and specify your output stations.

14. In the Options|Transient dialog  select your options for the transient analysis.

15. From the menu execute a Run|Transient command, or click the  button on the toolbar. Results of the analysis will appear automatically on a Transient Resp Worksheet.

Coupled Lateral-Torsional Analysis with XLRotor

See also

- XLCoupled Worksheet
- XLCoupled Shaft Input Worksheet
- XLCoupled Cplg's Worksheet
- XLCoupled Geometry Chart Sheet
- XLCoupled Imb's Worksheet
- XLCoupled Roots Damped Worksheet
- XLCoupled Shapes Worksheet
- XLCoupled Resp Worksheet

New in XLRotor version 5.5 is analysis of *coupled* lateral-torsional vibration. Lateral and torsional vibration are normally analyzed separately because coupling is normally negligible between these two fundamental types of vibration. A gear mesh is the most common source of coupling between lateral and torsional vibration because gear interaction forces give rise to both lateral forces and shaft torques. In general, if the gears are able to move laterally because of shaft and/or bearing flexibility, then L+T coupling could be significant. A common use for L+T analysis is to compute lateral deflection at vibration probes caused by a torsional excitation. Gear tooth flexibility can be included in the model, but is not required (i.e. coupling occurs via the gear mesh even with perfectly rigid teeth).

Coupled analysis is an advanced form of analysis because it inherently involves multiple rotors, and both lateral and torsional vibration modes and forced responses are generated simultaneously. Eigenvalue calculations typically will have a very large number of modes within the relevent speed range of consideration. So results must be examined carefully to reach correct conclusions. There are additional considerations to be dealt with in the definition of shaft and bearing properties. XLRotor endeavors to make this as easy and intuitive as possible. A list of considerations appears below.

An XLCoupled file is a merging of XLRotor and XLTorsion files.

The Shaft Input worksheet contains all the input columns which appear in <u>both</u> XLRotor and XLTorsion models (except for Gear Ratio discussed next). An important aspect of an XLCoupled file is that both lateral and torsional system models are constructed from the same station definitions given on the Shaft Input worksheet. Input columns for **Added Kt**, **Absolute Damping** and **Relative Damping** apply only to the torsional part of the model.

The Shaft Input worksheet of an **XLRotor** model has a **Speed Factor** column. The Shaft Input worksheet of an **XLTorsion** model has a **Gear Ratio** column. The Shaft Input worksheet of an **XLCoupled** worksheet <u>has</u> a Speed Factor column, but <u>not</u> a Gear Ratio column. The values in the Speed Factor column perform a similar role as for an XLRotor model, i.e. determines gyroscopic effects. However, in an XLCoupled file the Speed Factor is also used for evaluating lateral bearing force coefficients. In an XLTorsion file, the Gear Ratio column is used to reference all shafts to a common rotational speed, but this is not required for a L+T analysis because the kinematics of the gear mesh does this automatically.

An XLCoupled file contains both a Brg's Worksheet and a Cplg's Worksheet. The Brg's worksheet in an XLCoupled file is identical to one in an XLRotor file, and performs an identical role in defining the system model. The Cplg's worksheet in an XLCouped file performs the same role as in an XLTorsion file, but is extended to include additional inputs for defining gear mesh parameters.

XLCoupled files contain an Imb's Worksheet which is the same as one in an XLRotor file, except it also allows for specifying excitation torques, plus specifying torsional responses for output. As a consequence, an XLCoupled file does not contain an Orders Worksheet.

- In XLRotor, coupled L+T models are identified by having a worksheet named XLCoupled instead of XLRotor or XLTorsion.

- Direction of rotation is important. On the **Shaft Input** worksheet, enter negative values for **Speed Factor** for rotors which rotate cw (i.e. opposite the normal ccw direction). The **Speed Factor** tells the XLRotor program how fast and in what direction each rotor spins. Direction of rotation affects gyroscopics and bearing force coefficients. XLCoupled files do not have a Gear Ratio column.

- Bearing coefficients depend on direction of rotation. The program assumes that all bearing force coefficients have been calculated for rotors rotating ccw because journal bearing analysis programs typically assume ccw rotation. Therefore, for rotors which actually rotate cw, XLRotor will automatically reverse the signs of the cross-coupled force coefficients which appear on bearing worksheets.

- On the **Shaft Input** worksheet, values entered in columns for **Added Kt**, **Absolute Damping** and **Relative Damping** apply only to the torsional part of the model, and perform exactly the same function as for XLTorsion models.

- Mode shapes are more complicated.

  - Lateral and torsional mode shapes are displayed in separate plots.

  - Torsional mode shapes, to simplify interpretation, are always output as “equivalent shaft” (i.e. an option often used with XLTorsion models). That means the torsional mode shape is divided by the **Speed Factor**. For example, the rigid body rotation mode shape at zero frequency will have the entire model rotating in the same direction with the same magnitude.

  - Torsional mode shape amplitudes are multiplied by the average outer radius of all model elements. This is done so angles in radians of the torsional mode shape can be visually compared to deflections of the lateral mode shape.

  - Mode shape output includes the mean distribution of strain energy among the lateral, torsional and mesh stiffness portions of the model (three values which sum to 1).

  - Mode shape output includes the mean distribution of kinetic energy among the lateral and torsional portions of the model (two values which sum to 1).

◆ It is common to attempt to classify each mode as either a lateral mode, a torsional mode, or a coupled mode (i.e. blend of both lateral and torsional motion). This is typically done according to the three strain energy values output for each mode.

◆ A mode shape dominated by lateral strain energy could still have significant torsional motion by way of the gear mesh, and this will be indicated by the kinetic energy distribution. This situation occurs for modes where the gear itself exhibits significant lateral motion.

◆ Forced Response

◆ Any linear forced response analysis requires that all applied excitations be at exactly the same frequency (i.e. forces, torques and gear errors). Calculated responses are therefore also at this frequency.

◆ All response analyses should have all imbalances on rotors running at the same speed (i.e. same ±**Speed Factor**).

◆ When performing a forced response analysis with the synchronous option selected, all imbalances should be on rotors with **Speed Factor**=±1 (however, see the next item).

◆ A forced response analysis with imbalances on rotors with **Speed Factor**<>±1 requires using the asynchronous response option. However, when the Synchronous option has been selected, XLRotor will automatically use the asynchronous option when the analysis is run. See Resp Worksheet for more detail.

◆ In a forced response analysis, a potentially important source of excitation is **Gear Error.** It is specified on the Cplg's worksheet in units of length (i.e. inches or meters). Common sources are:

◆ Pitch line runout of an eccentric gear. The excitation frequency is 1X of gear speed, although higher harmonics could also be considered. This excitation can be applied simultaneously with imbalances on rotors at the same speed as the gear with pitch line runout.

◆ Tooth spacing error, for which the excitation frequency is 1x of gearmesh frequency, although higher harmonics could also be considered. This analysis requires using the asynchronous analysis option (i.e. the program will not automatically pick this option).

◆ Any rotor, say RotorA, connected to a gearbox via a flexible coupling does not necessarily require modeling with the detail typically used for a lateral-only analysis. For an accurate coupled L+T analysis, RotorA could be modeled with as few as one inertia. The purpose of the simple model is to represent the torsional effect of RotorA. The lateral effect is not needed because a properly selected flexible coupling isolates RotorA's lateral vibration from the gearbox. The lateral vibration of RotorA could be analyzed adequately with a separate lateral model of just RotorA in an XLRotor file. The advantage of using this sort of simplified model is the calculation of eigenvalues for the coupled system will have fewer modes (i.e. it will not include the purely lateral modes of RotorA).

Units in XLRotor

See also

Creating New Rotor Model Files
Options|General
Shaft Input Worksheet

XLRotor can work in either customary English or SI units. You make your choice by choosing a template file setup in the units you prefer.

English Units

There are two template files available in the Templates folder for creating shaft model in English units.

XLRotor (in-lbf-lbm).xls (look for XLTorsion for torsional models)

XLRotor (in-lbf-sn).xls (look for XLTorsion for torsional models)

Note that sn = snail = 1 lbf-s^2/in = 386.088582677 lbm (i.e. 9.80665/0.0254).

The Templates folder can be accessed either from the Windows Start/Programs/XLRotor program group, or from the menu in Excel (see XLRotor Menu Commands).

When using either of the English unit templates for the shaft model, we recommend using English unit templates for all bearings (see Bearing Template Files). However, XLRotor will automatically convert bearing units to the units of the rotor model when any analysis is preformed.

SI Units

There are also two shaft model template files for working in SI units, and there are SI unit versions for each of the bearing templates.

XLRotor (m-N-kg).xls (look for XLTorsion for torsional models)

XLRotor (mm-N-kg).xls (look for XLTorsion for torsional models)

When using either of the SI unit templates for the shaft model, we recommend use of SI unit templates for all bearings (see Bearing Template Files). However, XLRotor will automatically convert bearing units to the units of the rotor model when any analysis is preformed.

You can change the units used in any rotor model to be **inches**, **meters**, or **mm** by simply editing the units displayed in the column heading for station Length on the Shaft Input Worksheet (usually cell B3). Then, the next time you perform an Update|Geometry Chart operation, XLRotor will change the rest of the shaft model units throughout the file to be consistent with your choice for shaft length.

Valid entries in cell B3 are **in**, **inches**, **m**, **meters** and **mm**. The program looks to see if the letters "**in**" are present in this cell, and if not then if "**mm**" is present, and if not then if "**m**" is present. If none of these are found the program displays an error message. According to what is found here, the units of all other inputs on the Shaft Input Worksheet are checked and changed if needed. No numerical input values are changed, only the unit strings in the column heading. All units appearing on the Beams Worksheet and Stations Worksheet are also updated to match those of the model.

When working with SI units, the units used for density can be either kg/m^3 or kg/mm^3. Simply edit the contents of the units cell in the Density column to be one of these two choices. Anything other than these two will cause the program to change it to kg/m^3.

D	G	H	I	J
STATION DEFINITIONS, MORE THAN ONE BEAM				
ID	Weight Density	Elastic Modulus	Shear Modulus	Added Weight
mm	kg/m^3	N/m^2	N/m^2	kg

The units for modulus can also use mm. Again simply edit the contents of the units cell directly on the Shaft Input Worksheet. Anything other than N/m^2 or N/mm^2 will cause the program to change it to N/m^2.

D	G	H	I	J
STATION DEFINITIONS, MORE THAN ONE BEAM				
ID	Weight Density	Elastic Modulus	Shear Modulus	Added Weight
mm	kg/mm^3	N/mm^2	N/mm^2	kg

Whenever you use mm on the Shaft Input Worksheet, some of the various formulas on the Beams Worksheet and Stations Worksheet may require correction factors like 1000^2 or 1000^3. These factors are inserted automatically every time you perform an Update|Geometry Chart operation. You can see these factors by inspecting the cell formulas on these worksheets.

The SI units for It and Ip must always be kg-m^2. Millimeters are not allowed for these inputs.

In torsional model input files, the SI units for Added Kt must always be N-m. Millimeters are not allowed for this input.

XLRGRPH.XLS Chart Template File

See also

XLRotor Overview
Installation Notes

Starting with XLRotor version 3.9, this file now exists in two versions; Xlrgrph2003.xls and Xlrgrph2007.xls. The old file named Xlrgrph.xls is no longer used. The 2003 file is used with Excel 2003 or earlier. The 2007 file is used with Excel 2007 or later.

This file contains templates of all charts created by XLRotor.

You can edit the charts in this file to change their formats, or otherwise alter their appearance to suit your needs For example, this file is the place to put company logos or other boilerplate text or graphics. Another situation where you may want to edit this file is if you want the Undamped Critical Speed chart to be something other than log-log, you just change the settings for its template. Also, changes you make to the size and shape of the template charts show up when they are used.

You must Save the file over the original to make your changes permanent. It is a good idea to keep at least one copy of the original on hand in case you need to recover any of the original chart formats.

For more information about customizing this file, see Start/All Programs/XLRotor/How to Edit the XLRGRPH File.

This file can be located in any of the following three places, which are searched in the following order:

1. In the folder of the current rotor model workbook file. For example, this allows you to have a version unique to a project, if you keep the files for the project in its own folder.
2. In the Program Data folder. In Windows Vista and later in the **C:\ProgramData\XLRotor** folder, or for Windows XP in the **C:\Documents and Settings\All Users\Application Data\XLRotor** folder.
3. In the XLRotor program folder. This is the default version, and will be used if there is no such file in the project folder or the ProgramData\XLRotor folder. This is the directory where the XLROTOR.XLA addin file is located. See Installation Notes for more information about this.

This file also contains formatting templates for the worksheets created when you do a Run|Eigenvalues, Run|Undamped Crit. Spds or Run|Free Free Modes analysis. The cell formatting for the table of roots is copied from the appropriate worksheet in this file to your file.

Notes:
The width of the mode shape charts and response charts have been set to match the

width of a specific number of worksheet columns. If you alter their width, check the result you get when you compute mode shapes or response (see Delete Charts and Tables).

Each chart in XLRGRPH.XLS has an assigned name which appears at the left end of the formula bar when the chart is selected. These names must remain intact since XLRotor refers to the charts by name when accessing this template file.

XLROTWKS.XLS Worksheet File

This file contains templates for several worksheets that XLRotor will copy to your file as needed. You should not alter the contents of this file, but it is okay to change cell and character formatting. The file should be located in: for Windows Vista and later **C:\ProgramData\XLRotor**, or for Windows XP **C:\Documents and Settings\All Users\Application Data\XLRotor.** There is also a backup copy in the XLRotor installation folder.

XLROTOR.TXT Analysis Tracking File

See also

Export System Stiffness Matrix

The file XLROTOR.TXT is a text file which is created or overwritten each time you perform any of the Run commands on the XLRotor pull down menu, toolbar or ribbon (XLRotor Menu Commands). It is created in the same directory that your rotor model file is stored in. Under normal circumstances, this text file contains a summary of the analysis performed most recently. This includes an echo of the model inputs, and the specific results of the analysis. When a calculation error occurs during analysis, this file may contain an error message.

If you have this file open in a text editor, XLRotor may not be able to overwrite it. In this case you may get a message that the file is open by another application, and must be closed.

Export System Stiffness Matrix (also damping & mass)

See also

XLROTOR.TXT Analysis Tracking File

You can instruct XLRotor to write the system stiffness, damping, and mass matrices to text files. This is done by creating Excel Defined Names with the exact names of:

ExportSystemStiffnessMatrix, with its value is set to **TRUE**

ExportSystemDampingMatrix, with its value is set to **TRUE**

ExportSystemMassMatrix, with its value is set to **TRUE**

See the help topic about the Done Dialog for instructions on how to create an Excel Defined Name. This name and its value are stored in the workbook in which they are created.

If set to **TRUE**, the system matrix will be written to a file named **Xlrotor_Stiffness_Matrix.txt** (with similar names for damping and mass) and will be placed in the same folder as your XLRotor file. The file is overwritten if it already exists. The file will be actually written during any of the following events:

1. When running a Static Deflection analysis.
2. When running an imbalance response analysis, but only for the first speed.
3. When running a deflected shape analysis, but only for the first speed.
4. When computing UCS, but only for the first stiffness.
5. When computing damped eigenvalues, but only for the first speed.
6. When computing mode shapes, but only for the first mode shape.
7. When computing transient response, but only at the start of the simulation.

The stiffness values are written to the file one matrix row per line, and the values are separated by tab characters. If any dof have been constrained with RIGID, PINNED or GUIDED constraints, these dof have been removed from the stiffness matrix prior to printing. The dof are listed in the order of their station numbers. For lateral models there are 4 dof per station (x,y,aboutx,abouty), and for torsional models there are 1 dof per station.

The damping matrix will include any gyroscopic values in its off diagonal locations of the form of Ip*omega where Ip are polar inertia values and omega is rotational speed in radians per second. Ip*omega values above the main diagonal are positive, and below the main diagonal are negative.

Note: The matrices can only be exported when the Finite Element solver is used. When the Transfer Matrix solver is used the full matrices are not created during the analysis, and so are not exported (see Options|General).

Corruption of XLRotor's File Structure

See also

Copy To Template

The inner workings of XLRotor rely heavily upon Excel ***named ranges***. Many of the columns of data, both your inputs and XLRotor's output, are in cell ranges which have assigned names (e.g., "length" for the column of station beam length).

In the unlikely event that the system of named ranges becomes corrupted, some of XLRotor's macros will not function properly, or may report a run time error. If this has happened, you can fix the problem by opening a fresh copy of the rotor model template file (see Creating New Rotor Model Files), and copy and paste **just the data** from the Shaft Input Worksheet. You can also copy and paste **just the data** from the Brg's Worksheet and Imb's Worksheet. The resulting new workbook file should work properly. If not, contact Technical Support for help.

Certain worksheets must be in every XLRotor file. The Names of the worksheets (displayed on the sheet tabs) are used to identify them. If you rename or accidentally delete one of these worksheets, XLRotor may tell you that a required worksheet is missing. You can either change its name back to its required name, or try ***copying*** the worksheet from another file.

Here is a list of the required worksheets:

Lateral analysis rotor model file:

XLRotor

Shaft Input

Beams

Stations

Geo Plot (this is a chartsheet, not a worksheet)

Brg's

Imb's

Torsional analysis rotor model file:

XLTorsion

Shaft Input

Beams

Stations

Geo Plot (this is a chartsheet, not a worksheet)

Cplg's

Orders

Hidden worksheets. There are two *hidden worksheets* in every XLRotor file. If either of these sheets is deleted or renamed, most of XLRotor's macros will not function properly, if at all.

GeoPltData Contains data for the model geometry plot

lists Contains document option settings which are set in the Options|General dialog box

---

Note: For some of these worksheets, there are times when you may desire to have multiple copies of them within one rotor model file. XLRotor does allow this. Whichever worksheet has the exact required name is the one that will be used when you execute XLRotor commands.

The **lists** worksheet does not have to be hidden. If it is unhidden, any of XLRotor's options can be changed by simply entering a new value in the appropriate worksheet cell on this worksheet, or by execution of statments in Visual Basic macros. For example:

```
Range("lists!include_gyroscopics") = False
```

When the XLRotor/Options dialog box is displayed, it is populated with the options on this worksheet. If any options are changed in the dialog box, the corresponding options on the lists worksheet are updated only if the **OK** button is pressed. By examining the lists worksheet, you can determine the various worksheet values which correspond to dialog box choices.

Run Time Errors

See also

Corruption of XLRotor's File Structure
Copy To Template

You run XLRotor's various macros by selecting a command from the pull down menu, or clicking a button on the tool bar or ribbon. It is possible that during execution of the macro you may receive an Excel Run Time Error. This is likely caused by the macro trying to access information which is not available. If you receive this message, check to see if:

1. You are trying to execute the command in its intended context. For example, the Synchronous Line command should be executed only while editing a natural frequency map located on a Roots Damped Worksheet (or Roots FF Worksheet).
2. One of XLRotor's option settings is missing from the current rotor model file. You can check for, and fix, this type of problem by opening the Options|General dialog box (any tab in the dialog will do). If any of the option settings are missing from the current model file, they will be added when the dialog is opened.
3. One or more of the many *named ranges* used by XLRotor has been deleted or corrupted. See Corruption of XLRotor's File Structure for more information on this.

If you still need help resolving the problem, contact Technical Support. When you do, please note the exact text of the error message, whether it is an Excel or XLRotor error message (see below), and the conditions under which the error occurred.

Note:
An error message may be generated by either Excel or XLRotor. The title bar of the error message box will tell you which. When you click the Help button while the error message is displayed, either Excel's or XLRotor's help file will appear.

Adding Missing Options

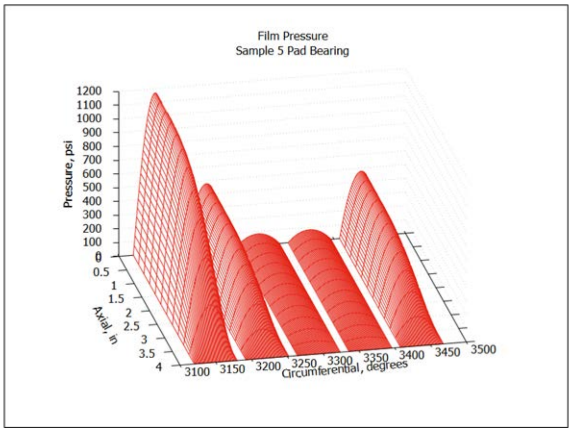
See also

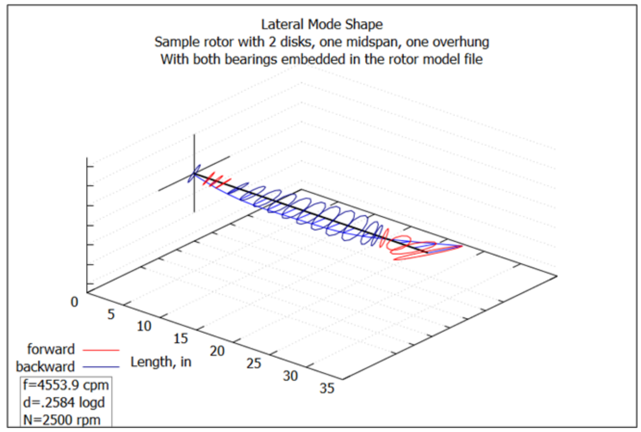
Options|General

All dialog box options (like the "Include Gyroscopics" check box on the Options|General dialog) are stored within the rotor model file. Any dialog box options which are new in an upgraded version of XLRotor will be missing in old rotor model files. XLRotor will automatically add default settings for new options when old files are opened. The new settings will be saved when the file is saved.

Except for very old files from version 1.x, any XLRotor file can be opened with the lastest software release, and should work without requiring any changes. If any problems are encountered, contact Technical Support for help.

Gnuplot Plotting Library



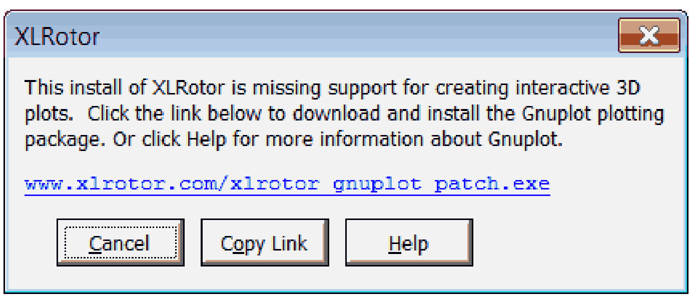


3D plots in XLRotor are made using the ***Gnuplot*** open source plotting application. Gnuplot can generate 3D graphics which Excel cannot.

http://www.gnuplot.info/

Gnuplot plotting is presently used for 3D mode shapes and 3D deflected shapes when the True 3D option is selected. It is also used for film pressure and temperature plots in XLHydrodyn.

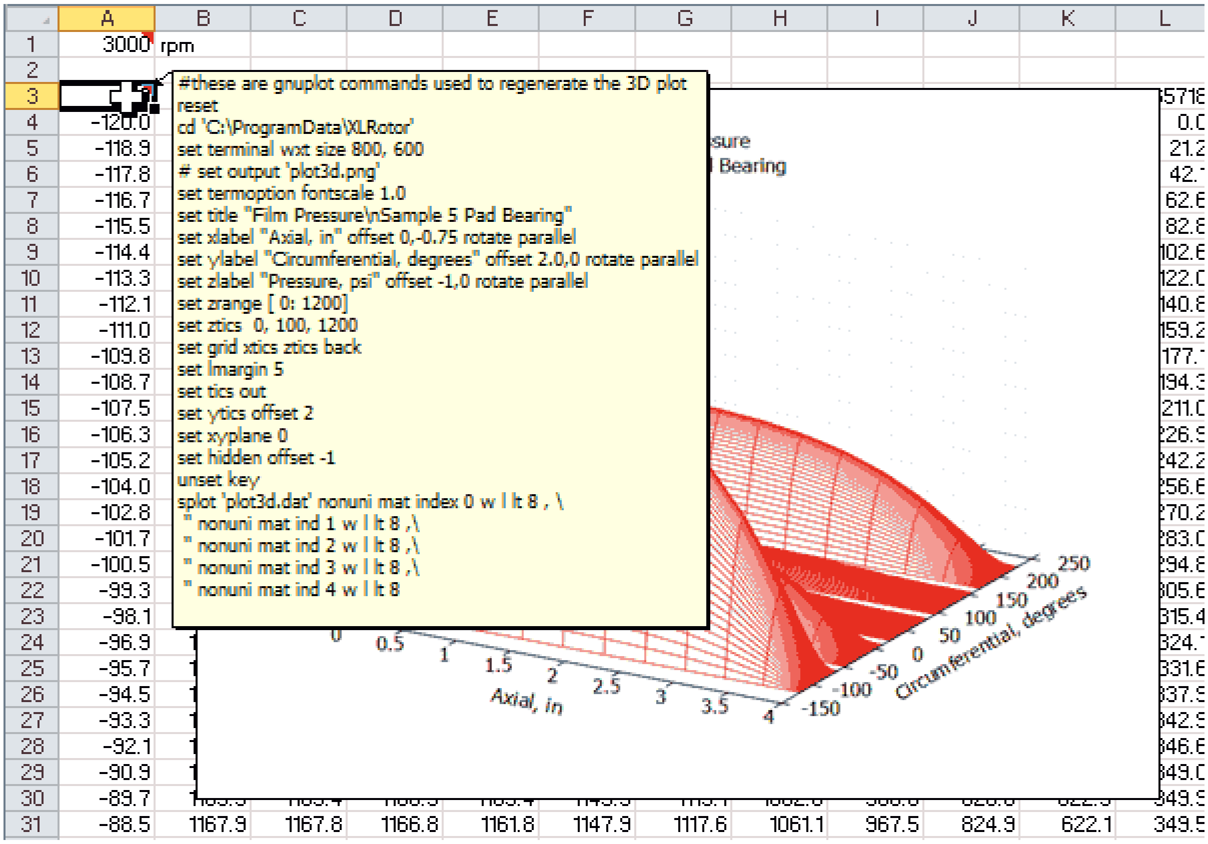
The Gnuplot plotting application is not installed when XLRotor is installed. The first time it is used, you will be prompted to download and install the following patch.



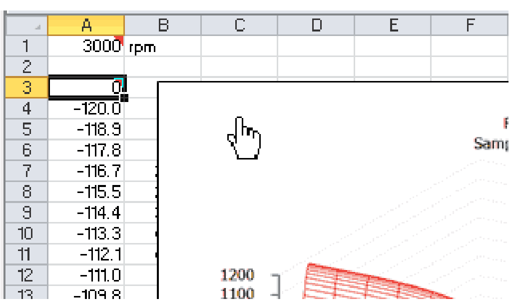
Or it can be downloaded by clicking the following link, or by copying this link to the address field of a web browser.

http://www.xlrotor.com/xlrotor_gnuplot_patch.exe

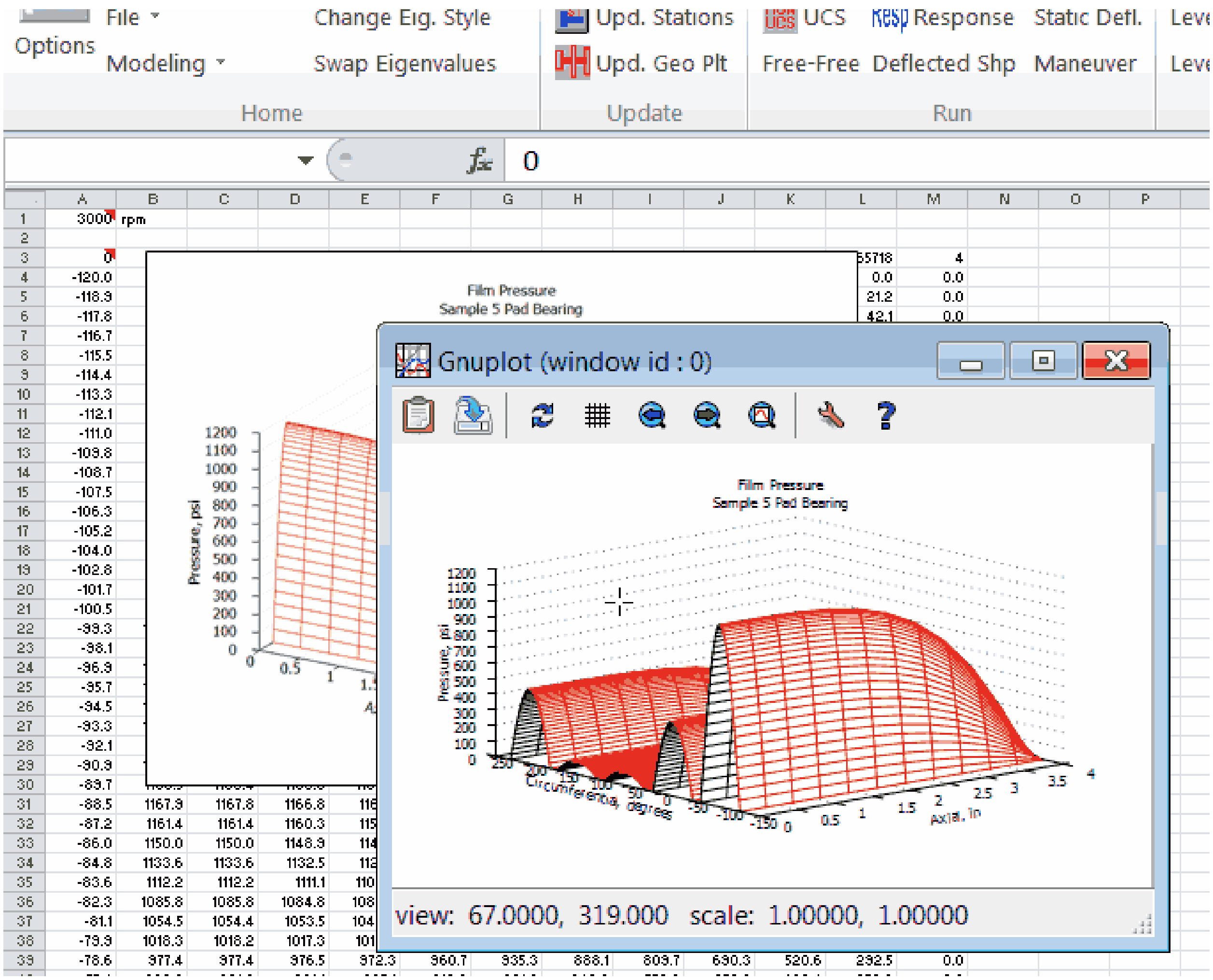
The data to be plotted is placed in a table on the worksheet. XLRotor generates a 3D plot in a png graphics file by sending gnuplot commands to the gnuplot application. A copy of the png file is placed on the worksheet as an image, but is not linked to the data. The images above are examples. The image could, for instance, be copy and pasted to a Word document. A copy of the gnuplot commands which generate the image is placed in a cell comment on the first cell of the data table. The reason for this is explained below.

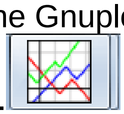


The image on the worksheet has been configured such that clicking on it will run a visual basic routine. This is indicated by the mouse cursor looking like a hand. 



The visual basic routine uses the table of data plus the gnuplot commands from the cell comment to generate an interactive graphics window hosted by the gnuplot application. The graphics window should initially look nearly identical to the image on the worksheet. The visual basic routine is actually still running and waiting for you to finish working with the gnuplot application (more on this below).



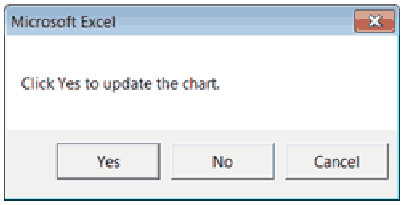
While the Gnuplot application is running, there will be an icon for it on the Windows taskbar.

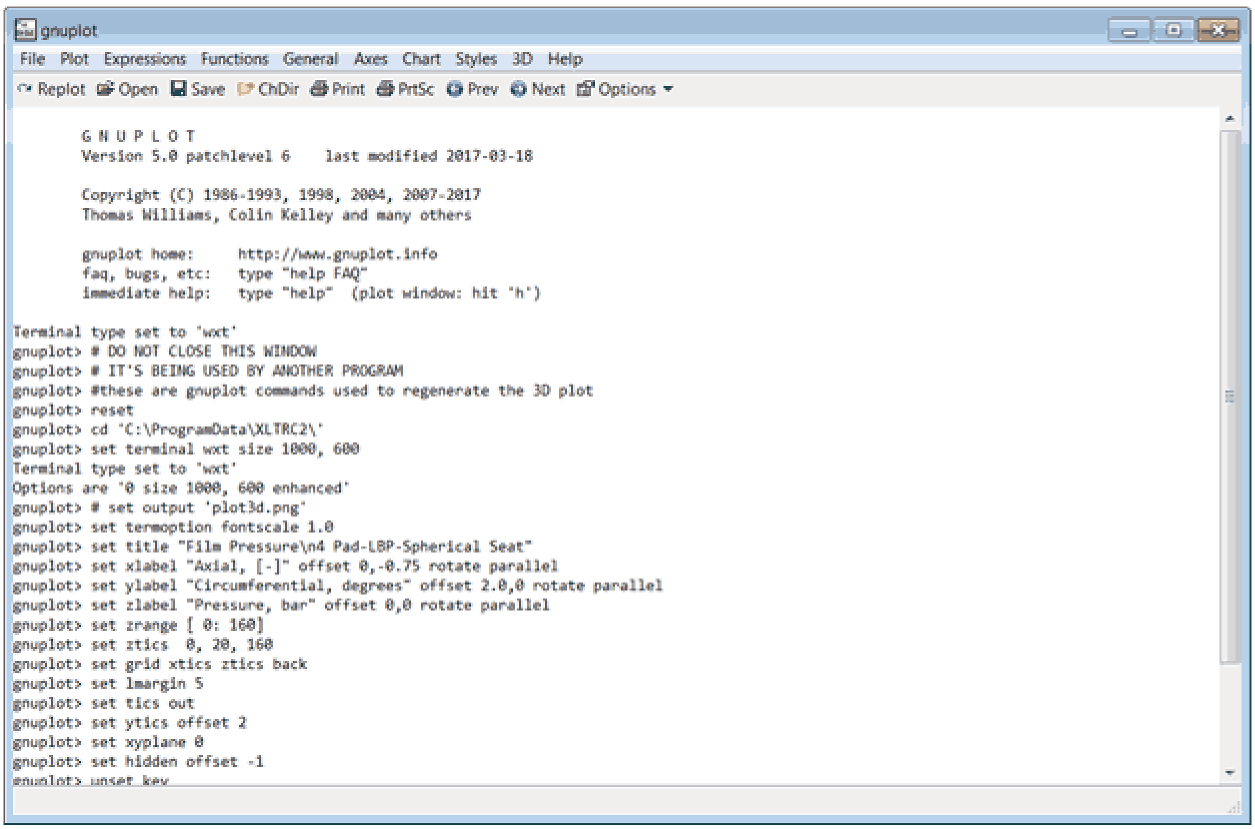
All gnuplot features and capabilities can be used to manipulate the image.

- Click and drag with the left mouse button to rotate the image.
- The mouse wheel, and the mouse wheel combined with the Shift key pans the plot.
- The mouse wheel combined with the Control key zooms the plot.
- There are more commands available by clicking on buttons in the menu bar.
- The gnuplot window can be moved and resized using the mouse.
- Pressing the spacebar will bring to the forefront a gnuplot command window. See the image below. This window shows the commands used to generate the currently displayed plot.
- Additional commands can be entered in this window.

- Pressing ***h*** in the graphics window will display mouse-related help in the gnuplot command window.
- In the command window, enter ***help*** and press enter to display the complete gnuplot help file.

When you have finished working with gnuplot, click on the Excel worksheet anyplace outside the gnuplot application window. This essentially leaves gnuplot and returns to Excel, and the visual basic macro that was waiting will then continue. The routine will display a prompt asking if you want to replace the plot image on the worksheet with a new one based on the interactive graphics window. After selecting Yes or No, the Gnuplot application will be closed.





Technical Support

See also

Options|Other

If you have a question for which you cannot find an answer in this help file - or if you have any comments or suggestions concerning the ***XLRotor*** software or this help file - we want to hear from you. You can contact us in several ways. The best way would generally be via email at support@xlrotor.com

When you first purchase ***XLRotor***, you automatically receive technical support for 1 year (help and software upgrades). After the first year, there is a technical support fee of 15% of ***XLRotor's*** price at the time of annual renewal.

You can reach us by:

Internet email: support@xlrotor.com

For phone, fax or regular mail, use the following:

RMA

ROTATING MACHINERY ANALYSIS, INC.

66 Quanv Ct, Brevard, NC 28712

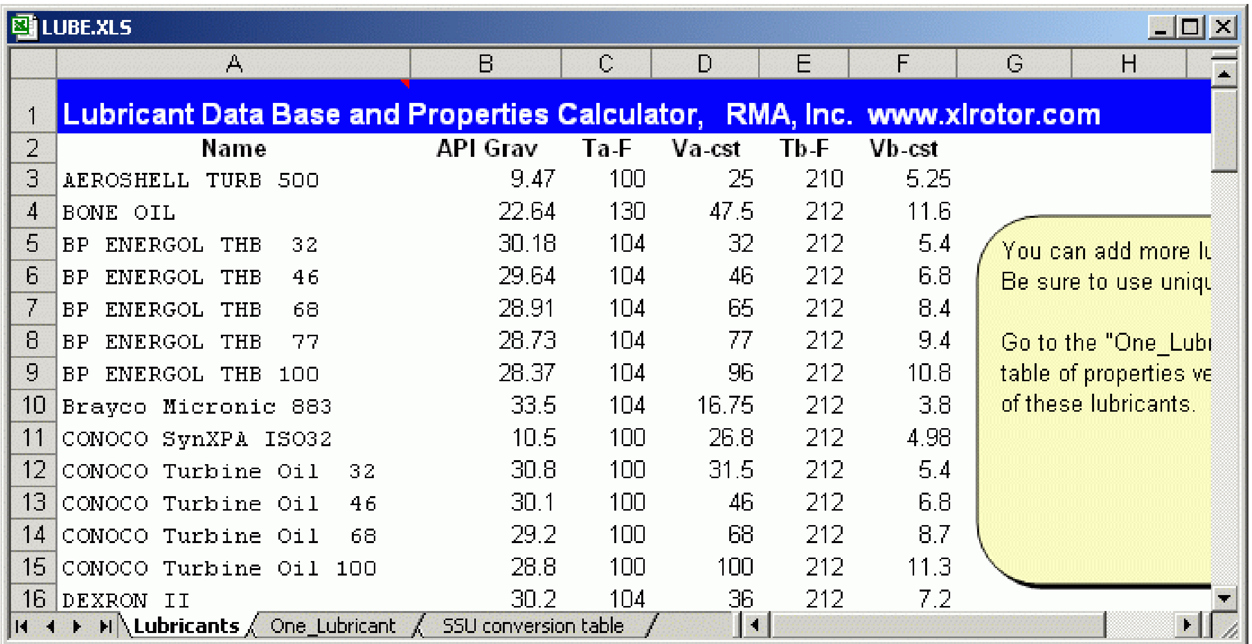
Ph. 512.592.7606 & Fax 512.918.9140

www.xlrotor.com

LUBE.XLS Lubricant Database

See also

XLSFD.XLS Squeeze Film Damper Template File



Name	API Grav	Ta-F	Va-cst	Tb-F	Vb-cst
AEROSHELL TURB 500	9.47	100	25	210	5.25
BONE OIL	22.64	130	47.5	212	11.6
BP ENERGOL THB 32	30.18	104	32	212	5.4
BP ENERGOL THB 46	29.64	104	46	212	6.8
BP ENERGOL THB 68	28.91	104	65	212	8.4
BP ENERGOL THB 77	28.73	104	77	212	9.4
BP ENERGOL THB 100	28.37	104	96	212	10.8
Brayco Micronic 883	33.5	104	16.75	212	3.8
CONOCO SynXPA ISO32	10.5	100	26.8	212	4.98
CONOCO Turbine Oil 32	30.8	100	31.5	212	5.4
CONOCO Turbine Oil 46	30.1	100	46	212	6.8
CONOCO Turbine Oil 68	29.2	100	68	212	8.7
CONOCO Turbine Oil 100	28.8	100	100	212	11.3
DEXRON II	30.2	104	36	212	7.2

This file contains a database of lubricants and their fluid properties. The file should be located in; for Windows Vista and later **C:\ProgramData\XLRotor**, or for Windows XP **C:\Documents and Settings\All Users\Application Data\XLRotor.** There is also a backup copy in the XLRotor installation folder. You can edit this file to add or delete lubricants, and change their properties. This file is accessed by some of XLRotor's bearing templates like XLJRNL that allow you to select a lubricant from a drop down list. The worksheet that contains the list of lubricants must be named "Lubricants", and the list of lubricant names must be in the first column, followed by 5 columns of properties as shown in the above figure. The program will read lubricants from the worksheet down to the first blank row.

XLRotor Menu Commands

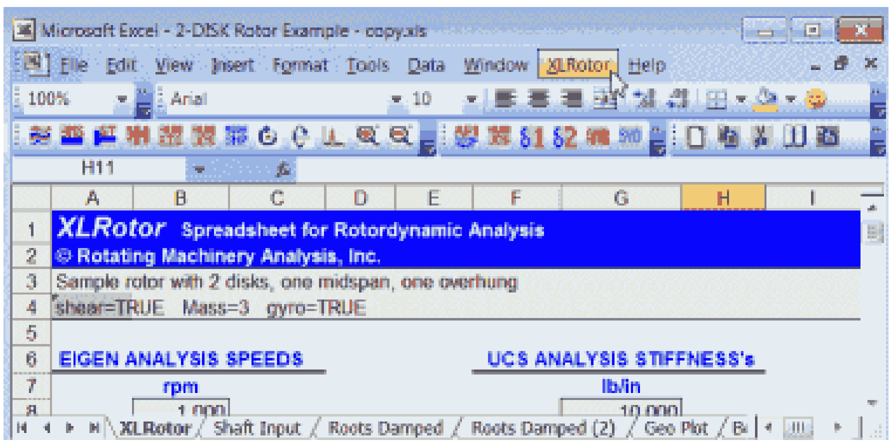
See also

XLRotor Toolbar
Modeling Menu Commands

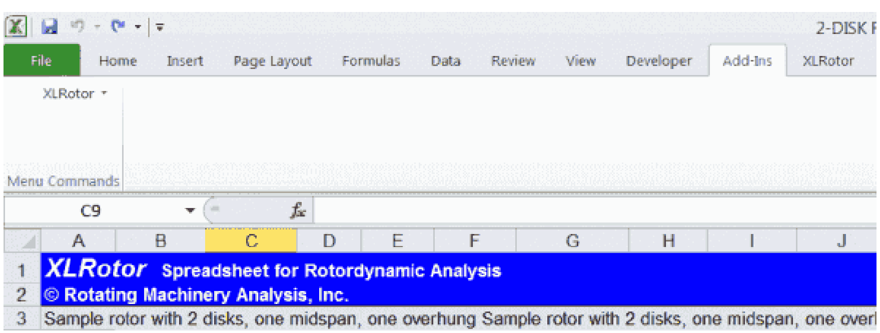
The XLRotor pull down menu is available in all versions of Excel. In Excel 2003 and earlier, the XLRotor menu appears on the Excel menu bar just to the left of the Help menu. In Excel 2007 and later, it appears on the Add-Ins tab of the Excel Ribbon. The items on the menu are exactly the same in all Excel versions. The items run macros which change options, run analyses, and work with the results.

Note that in Excel 2007 and later, all XLRotor commands are also on the XLRotor ribbon tab.

Excel 2003 Pull Down Menu



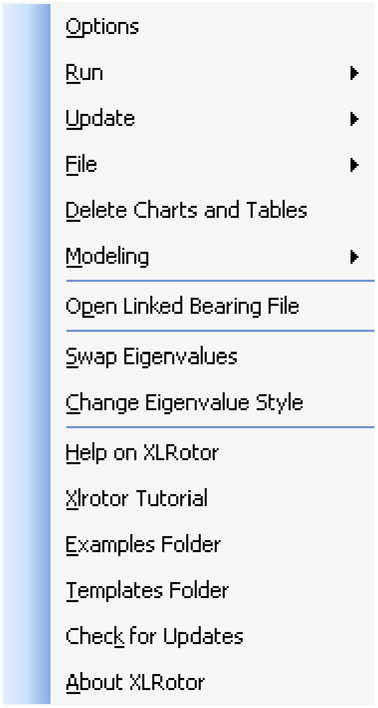
Excel 2010 Pull Down Menu

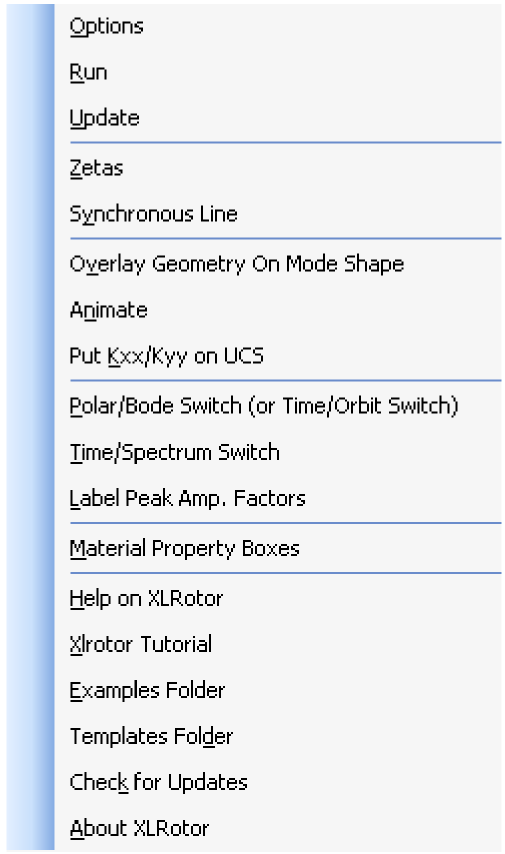


The contents of the XLRotor pull down menu are different for worksheets and charts. This is similar to Excel 2003's own Format menu, which contains different items for worksheets and charts.

Click on any of the commands below to jump to the page about that command.

Worksheet Menu **Chart Editing Menu**


Options
Run
Update
File
Delete Charts and Tables
Modeling
Open Linked Bearing File
Swap Eigenvalues
Change Eigenvalue Style
Help on XLRotor
Xlrotor Tutorial
Examples Folder
Templates Folder
Check for Updates
About XLRotor

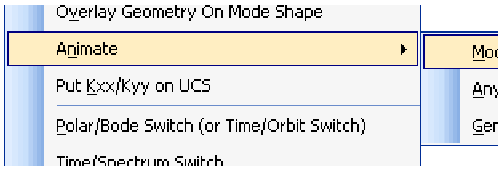

Options
Run
Update
Zetas
Synchronous Line
Overlay Geometry On Mode Shape
Animate
Put Kxx/Kyy on UCS
Polar/Bode Switch (or Time/Orbit Switch)
Time/Spectrum Switch
Label Peak Amp. Factors
Material Property Boxes
Help on XLRotor
Xlrotor Tutorial
Examples Folder
Templates Folder
Check for Updates
About XLRotor

Animate Mode Shape

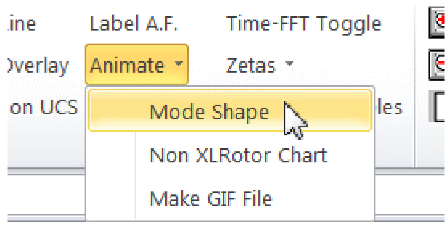
See also

XLRotor Menu Commands

Pull Down Menu



Ribbon



On the XLRotor pull down menu, the Animate menu appears only when a chart selected. XLRotor can animate mode shapes, or other Excel charts, right in the Excel window. Animated GIF files can also be created.

Animate|Mode Shape

This menu command animates a mode shape for both lateral and torsional models.

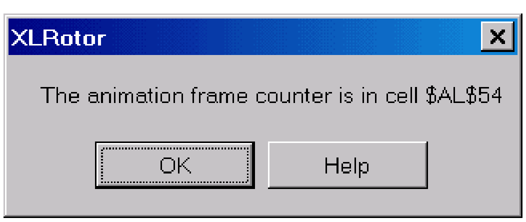
For lateral models XLRotor can generate 2D and 3D mode shapes (see Run|Mode Shapes). Both of these chart types can be animated. Click on the chart to edit it. Then from the XLRotor pull down menu select the Animate|Mode Shape command. After a few seconds the mode shape chart will begin to animate in the Excel window.

You can control the animation by moving your mouse to the left or right. Mouse motion to the right animates the mode shape forward in time. Left motion animates backward in time. This does ***not*** refer to the direction of whirl. In XLRotor "forward" whirl is always counterclockwise in a 3D mode shape chart.

You can also press the **Left Arrow** and **Right Arrow** keys to play the animation one frame at a time. Pressing the **Escape** key stops the animation.

The animation is generated by replacing the mode shape data on the worksheet with formulas that depend on a Frame Counter. When you stop the animation by pressing **Escape**, these formulas are removed and the original data is put back. Another way to stop the animation is to press **Control-Q**, in which case the formulas are left on the worksheet, and a message is displayed telling you which worksheet cell was used for the Frame Counter. If you wish, you can use your mouse to drag this cell to a new location.

Message displayed when **Control-Q** is used to halt an animation.



Animate|Any Excel Chart

This menu command can ***animate any Excel chart in any workbook file***, not just XLRotor files. To do this;

1. Select the worksheet cell that contains the frame counter for your chart.
2. Enter in that cell the total number of frames to be animated.
3. With this cell still selected, click on the chart to be animated and run the command.

Note that the data plotted in the chart needs to automatically change as the frame counter changes. This would be accomplished by using cell formulas in the cells of the data plotted in the chart. In addition, Excel's global setting for Recalculation should be set to Automatic (i.e. not Manual).

To animate a region of a worksheet instead of a single chart, do this;

1. Select the worksheet cell that contains the frame counter.
2. Enter in that cell the total number of frames to be animated.
3. Hold down Control, and use the mouse to select the cells to animate. If desired, this range can include the frame counter cell.

Animate|Generate Animated GIF File

This command will generate an animated GIF file named **"XLRotor chart animation.gif"**, and will overwrite any existing file with the same name. The file will be saved in the same folder where the current workbook is saved. This feature requires that the Microsoft Office GIF export filter was installed when Office was installed.

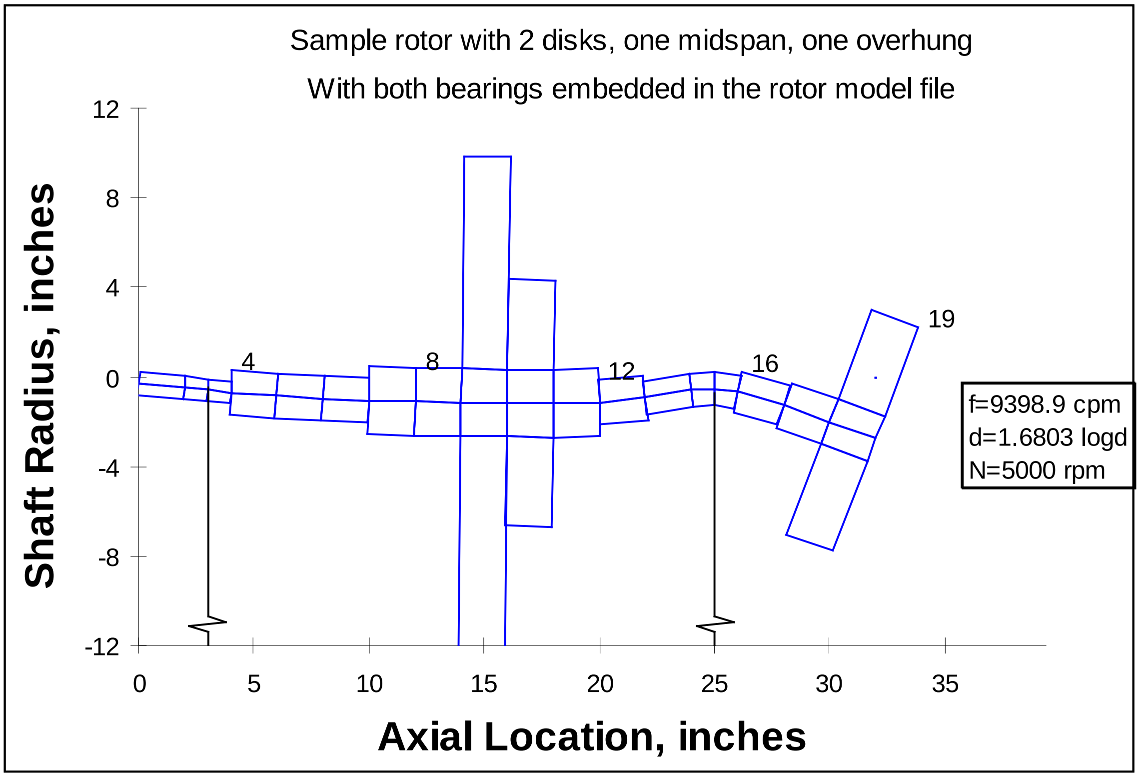
The resulting GIF files are often quite small. They can be placed onto a PowerPoint slide by drag and drop from Windows Explorer directly into PowerPoint. The animation will play when in slide show mode.

Other Notes

In the case of a 2D mode shape animation, the X axis and Y axis mode shape components are animated simultaneously. During the animation you can press the "**x**" and/or "**y**" keys on the keyboard to toggle the display of these components.

If you have created a geometry overlay chart of the mode shape, animating the <u>original</u> 2D mode shape chart will <u>also</u> animate the mode shape displayed in the overlay chart.

In addition, using the animate command on a geometry overlay chart of a mode shape will animate the entire model geometry as illustrated in the following example. This is for lateral models only.

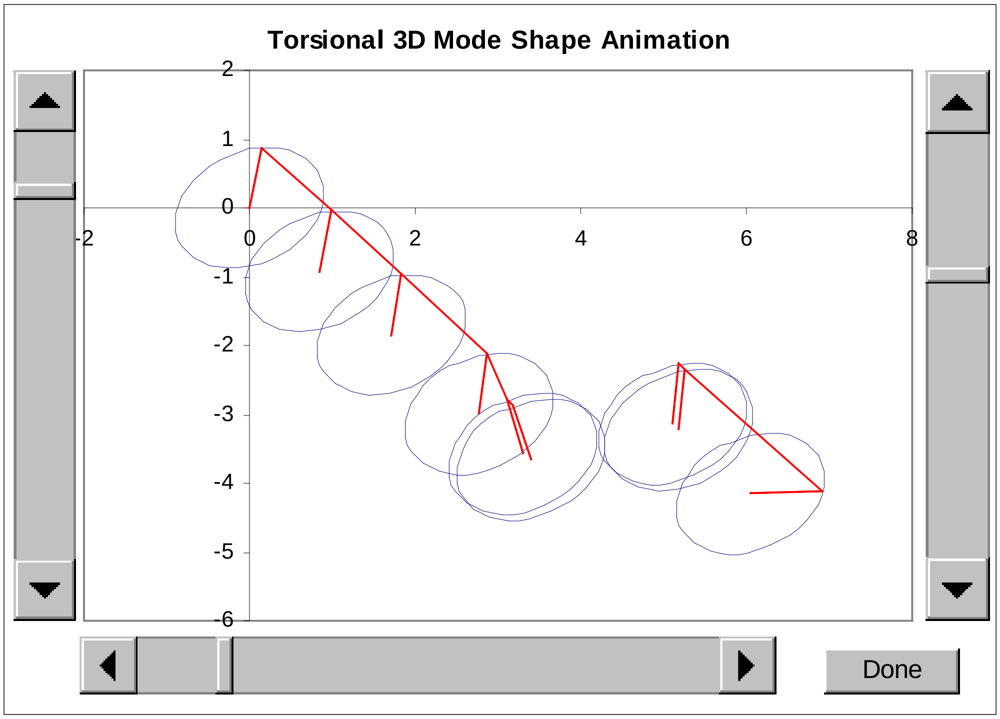


For torsional models mode shape charts are always 2D, and they can show one mode or multiple modes on one chart. The animate command will animate simultaneously all mode shapes displayed in the selected chart. However, if a **single** mode shape is selected in the chart by clicking on the data series with the mouse, the Animate command will animate that single mode shape in a special 3D torsional mode shape chart (sample shown below).

The 3D torsional mode shape chart is not a "live" animation. It instead contains 3 scrollbars and one button which perform the following actions:

- The **left scrollbar** controls the animation.
- The **bottom scrollbar** changes the orientation angle about the y axis.
- The **right scrollbar** changes the orientation angle about the x axis.
- The **Done** button will delete the chart, and delete temporary data that was placed on the worksheet to display in the chart.

The frames of the 3D chart can be exported to GIF files by clicking on the 3D chart and then executing the Animate|Generate Animated GIF File command.

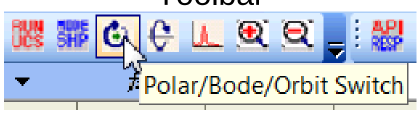

Torsional 3D Mode Shape Animation
2
1
0
-1
-2
-3
-4
-5
-6
-2
0
2
4
6
8
Done

Bode/Polar/Orbit Switch
(or Time/Orbit Switch)

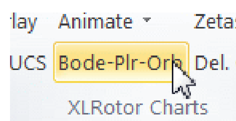
See also

[XLRotor Menu Commands](#)
[Transient Resp Worksheet](#)

Toolbar

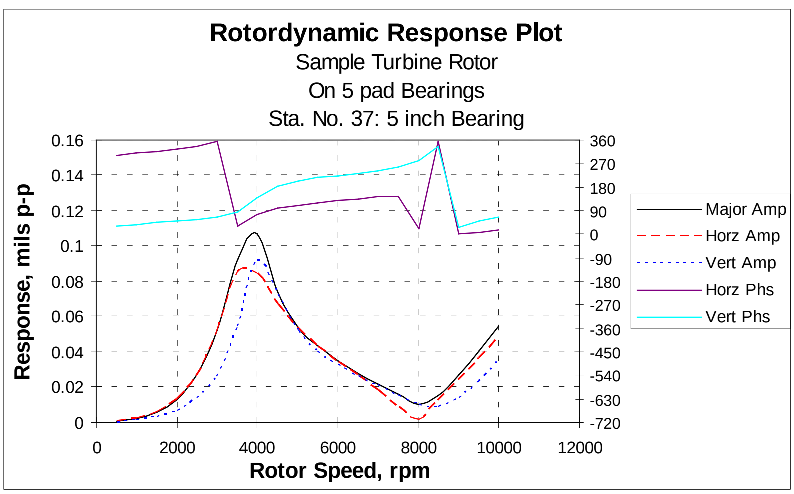


Ribbon

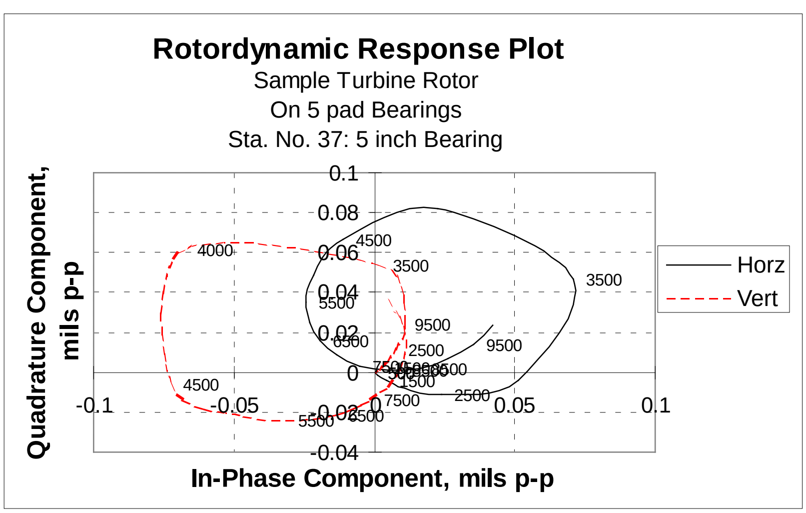


This command is for changing the format of response plots for lateral analysis models. Select one or more charts, then click the button in the XLRotor pull down menu, XLRotor toolbar, or on the XLRotor ribbon tab.

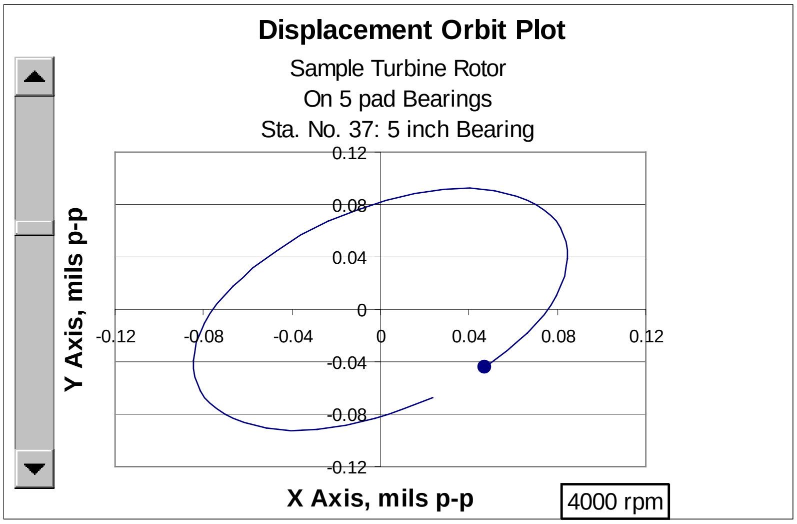
Bode formatted response plot.



Polar formatted response plot.



Orbit formatted response plot (orbit for one speed at a time).



This command can be used on a Resp Worksheet where charts of response versus rotor speed (Bode format) can be converted to Polar or Orbit format. This command cycles the format from Bode to Polar to Orbit, and then back to Bode. Polar charts can have some or all of the points labeled with rpm values (see Options|Response).

This command can also be used on a Transient Resp Worksheet. When a chart displays both x and y response values versus time, this command will convert the chart to an orbit chart, and back again.

Note:
Your input for units for response (see Options|Response) are invoked during a Bode/Polar switch. XLRotor will not let you execute the switch if the current option setting for units does not match what is already on the chart. Only the units are checked, not the factor.

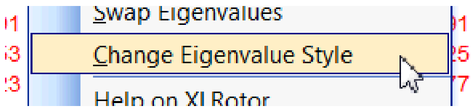
Note:
By holding down the Shift key, the mouse can be used to select more than one chart before executing this command. The command will operate on all selected charts.

Change Eigenvalue Style

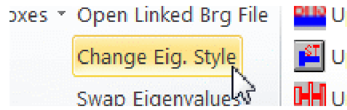
See also

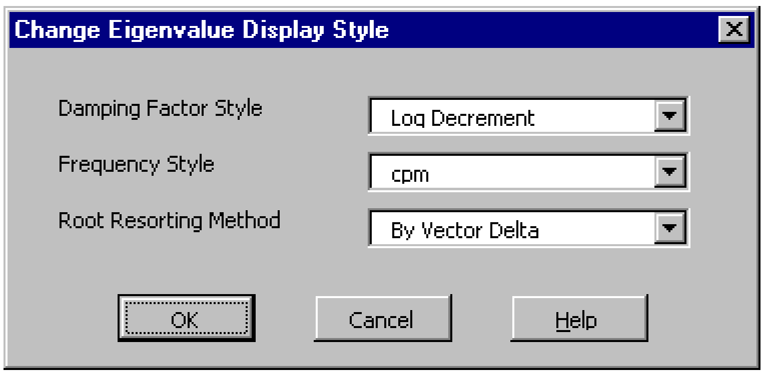
XLRotor Menu Commands
Options|Eigenanalysis

Pull Down Menu



Ribbon





This command can be used only on a worksheet of damped eigenvalues (see Roots Damped Worksheet).

This command displays the above dialog box in which you select what display styles you want for the real and imaginary parts of damped eigenvalues (i.e. damping factor and frequency). Whenever you compute damped eigenvalues, the roots are displayed according to what styles you have selected in the Options|Eigenanalysis dialog box. This dialog box is used for changing the output style of damped eigenvalues which have already been computed.

This command will not work on worksheets showing free-free modes or undamped critical speeds as they have no damping.

Note:
Zeta is the damping ratio expressed as a fraction of critical damping. The zeta values fall in the range of -1 to +1, where +1 indicates a mode is critically damped and stable, and negative values mean a mode is unstable.

Dexp is the damping exponent which is the unmodified real part of the eigenvalue. Dexp numbers can take on any value, where positive values indicate a mode is unstable.

Log Dec is the logarithmic decrement. It can fall anywhere in the range of minus infinity to plus infinity. An infinite magnitude means the mode is critically damped (i.e. the mode frequency is zero). A negative log dec means the mode is unstable.

A.F. is the amplification factor (sometimes called Q, or Quality Factor). Its value can be anywhere from 0.5 to infinity. Infinity corresponds to undamped modes, and 0.5 corresponds to critically damped modes (see details below).

A complex eigenvalue is defined by its real and imaginary parts as:

$$\lambda + i\omega \qquad i = \sqrt{-1}$$

λ is the **damping exponent** version of the real part in units of 1/seconds. Normally this is negative. Positive means the mode is unstable.

ω is the damped natural frequency in units of radians per second (rads)

Zeta is the damping factor expressed as a fraction of critical damping, and is computed as:

$$\zeta = \frac{-\lambda}{\sqrt{\lambda^2 + \omega^2}}$$

The **logarithmic decrement** is computed as

$$\delta = \frac{-2\pi\lambda}{\omega}$$

The **Amplification Factor** can be computed with either an exact or approximate relationship as shown below. XLRotor uses the approximate relationship. The approximate one is used because with the exact one the minimum possible A.F. is 1 which happens when the damping ratio is equal to the square root of 1/2 (i.e. 0.707). For a damping ratio greater than 0.707 the "exact" A.F. is greater than 1, which is really not valid because the resonant response curve for a mode with zeta>0.707 has no peak for which an A.F. can be defined (for critically damped modes the "exact" A.F. would be infinity!). By using the approximate relationship the minimum A.F. is then 0.5 which corresponds to critically damped modes. An approximate A.F. displayed by XLRotor of 0.707 corresponds to a zeta of 0.707. So a displayed A.F. less than or equal to 0.707 means the mode is so heavily damped it would not exhibit a peak in its resonant response curve. A.F. of 0.5 means the mode is critically damped which also means its frequency is zero.

$$A.F. = \frac{1}{2\zeta}\frac{1}{\sqrt{1-\zeta^2}} \approx \frac{1}{2\zeta}$$

The reciprocal of the log dec is the number of cycles of vibration in one time constant. When performing a ring down rap test, an estimate of the number of cycles of vibration (usually about 3 to 5 time constants) can yield an estimate of the log dec.

A problem with log dec is that it is undefined if the frequency is zero. Critically damped modes have zero frequency, and these are quite common in rotor models employing fluid film bearings. Thus XLRotor limits the displayed values of log dec to 999.

Both the log dec and zeta ratio provide a general purpose way of quantifying the relative stability of a mode. Quite often a log dec of greater than about 0.3 is taken to mean that a mode is "adequately" stable. This would be equivalent to a zeta ratio of about 5% (zeta=0.05).

Root Sorting

The option for root sorting does just what it implies - the set of eigenvalues computed for each speed are sorted according to the selected method. Any change in the frequency or damping style is implemented first, then the resorting is carried out. When the damped roots are first computed they are sorted according to your selection in the Options|Eigenanalysis dialog.

The available options are:

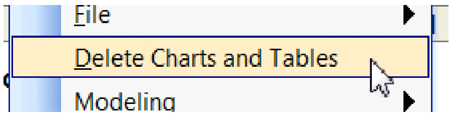
- Do not resort
- Sort by frequency. When this method is selected and there are transfer functions in the model, the list of roots will be partitioned into three groups; 1) complex roots with damping ratios less than 0.707, 2) complex roots with damping ratio greater than 0.707 and 3) real roots.
- Sort by real part (this could be zeta, log dec, or lambda)
- Sort by complex magnitude (this will use whatever styles are set for damping and frequency)
- Sort by vector delta - the first two speeds are sorted by complex magnitude, the rest are sorted by graphically extrapolating in the complex plane. The result you get from this method will depend on which damping style is selected.

Delete Charts and Tables

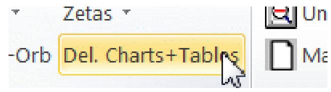
See also

XLRotor Menu Commands

Pull Down Menu



Ribbon



This pull down menu command is intended for use on worksheets that show results for mode shapes and responses (Shapes Worksheet, Resp Worksheet or Transient Resp Worksheet). Charts and tables are appended to these worksheets, and there may be times when you want to delete some of these charts (and their corresponding tables).

You can manually perform the actions carried out by this command, but this is tedious, so a macro has been created to automate the process.

To use this command select one or more of the *embedded charts* to be deleted. Then execute this command. Each chart you selected will be deleted, along with all the worksheet columns behind the charts. Also, any other charts whose left edges lie within the range of deleted columns will be deleted. To completely delete a mode shape, you need only select one of the *embedded charts* (2D or 3D chart, or both). The other unselected chart will be automatically deleted.

Be aware that the mode shape charts and response charts are generated from templates stored in XLRGRPH.XLS. These templates are just wide enough to span the width of columns which comprises the tables. Currently, mode shapes are 10 columns wide, and response tables are 8 columns wide.

Note:
If you alter the templates for these charts, make sure they still span the proper number of columns. You may also want to verify the proper numbers of columns if you change Excel's default column width.

Note:
If you manually delete all the worksheet columns behind an *embedded chart*, the chart is no longer visible but it has not been deleted. Since those columns contained the data for the chart, Excel then reports an "Invalid External Reference" error for the chart whose data has been deleted. To avoid this, always delete the chart before deleting the columns.

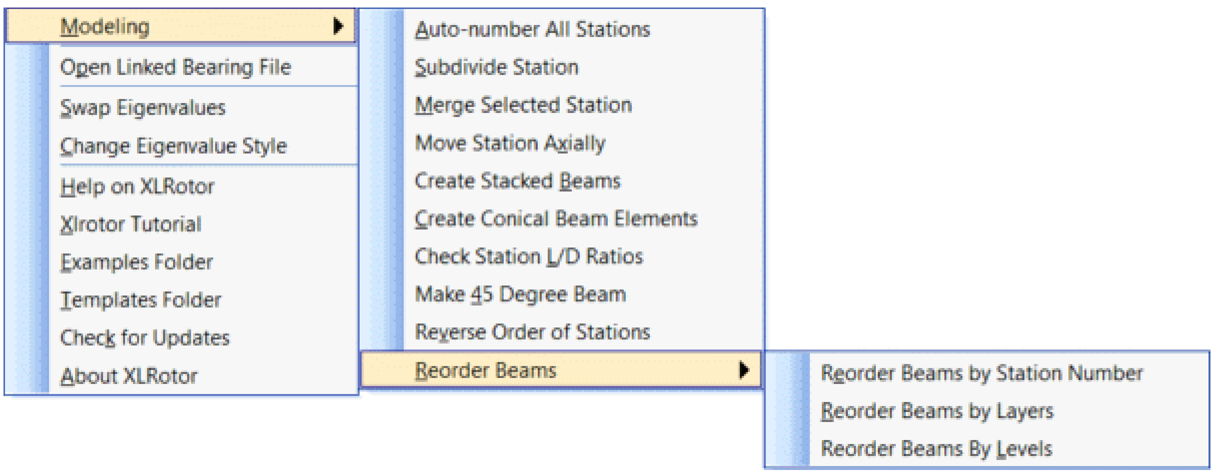
Modeling Menu Commands

See also

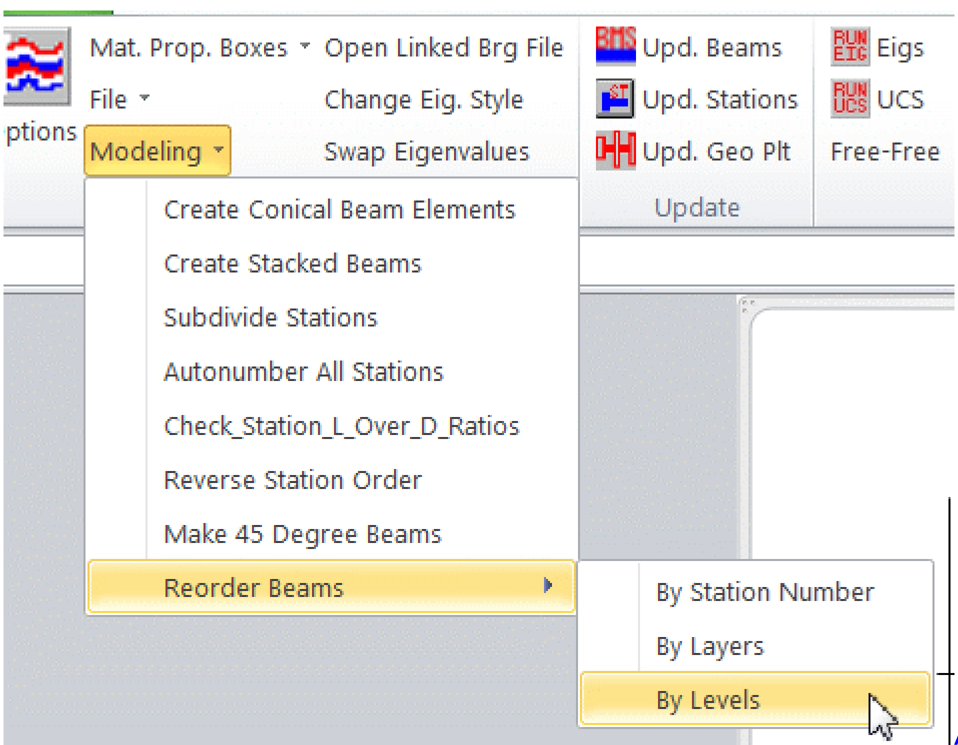
- XLRotor Menu Commands
- Options|General
- Shaft Input Worksheet

The Modeling commands are accelerators to help you create models more quickly.

XLRotor Pull Down Menu



XLRotor Ribbon



Auto-number All Stations

Auto-number All Stations

See also

- XLRotor Menu Commands
- Modeling Menu Commands
- Shaft Input Worksheet

Access this command from the XLRotor/Modeling pull down menu, or on the XLRotor ribbon.

Important: Save your file before using this command. The only way to undo the operation is to close and reopen the file.

This command will auto-number all station numbers on the Shaft Input Worksheet. This is done by placing cell formulas in the ***Station #*** column. Also, when there is more than one beam at the same station, cell formulas are put in the ***Length*** column so all beams lengths will equal the length of the first beam.

In addition, on the Brg's sheet of lateral models and Cplg's sheet of torsional models, this command will replace station numbers which have been entered as constant values, with cell formulas that refer to the corresponding station numbers on the Shaft Input sheet.

Subdivide Station

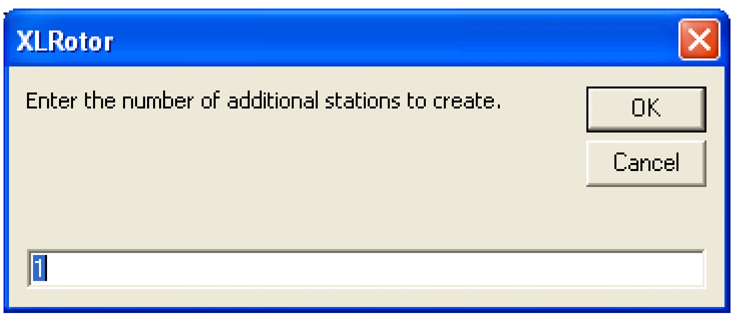
See also

- XLRotor Menu Commands
- Modeling Menu Commands
- Shaft Input Worksheet
- Create Conical Beam Elements
- Create Stacked Beams
- Auto-number All Stations
- Check Station L/D Ratios
- Reverse Order of Stations
- Make 45 Degree Beam
- Reorder Beams by Station Number, by Layers, or by Levels

Access this command from the XLRotor/Modeling pull down menu, or on the XLRotor ribbon.

Important: Save your file before using this command.

This command is used to subdivide selected stations into multiple stations of equal length. The following prompt will be displayed asking for the number of stations to create. This command operates on one station at a time. If you have selected more than one station, each station will be subdivided as a separate operation.



This command performs row operations on the Shaft Input sheet much like those you could do manually to achieve the same result. If on the Brg's Worksheet or Imb's Worksheet you have referred to stations of the model without using cell formulas linking back to the Shaft Input sheet, then you may need to adjust those station numbers on those sheets after the subdivide is finished.

Note: After having the program subdivide stations, execute an Update|Geometry Chart command to verify the changes made to the model are satisfactory. They only way to undo the changes is to close and reopen the file without saving it.

Merge Selected Stations

See also

- XLRotor Menu Commands
- Modeling Menu Commands
- Shaft Input Worksheet

Access this command from the XLRotor/Modeling pull down menu, or on the XLRotor ribbon.

Important: Save your file before using this command. The only way to undo the operation is to close and reopen the file.

To use this command, on the Shaft Input worksheet select a series of contiguous stations in the ***Station #*** column, then execute this command. The selected stations will be merged into a single station with the same total axial length. The diameters and material properties of the first beam will be assigned to the merged beam, or if the model uses conical beams the right end diameters of the merged beam will be the right end diameters of the last selected beam.

If the stations selected to be merged have multiple layers of beam elements and each station has the same layers, each layer is merged separately so that the final merged beam has the same number layers. However, if the selected stations do *not* all have the same number of beam layers, some layers may be lost in the merge.

Move Station Axially

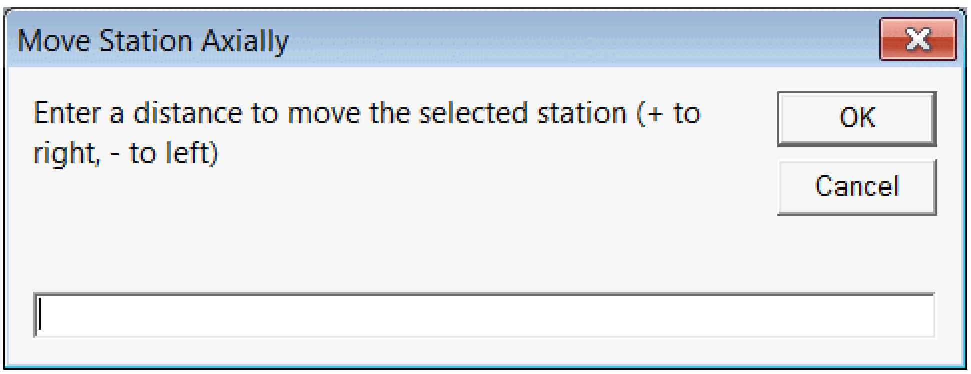
See also

- XLRotor Menu Commands
- Modeling Menu Commands
- Shaft Input Worksheet

Access this command from the XLRotor/Modeling pull down menu, or on the XLRotor ribbon.

Important: Save your file before using this command.   The only way to undo the operation is to close and reopen the file.

To use this command, on the Shaft Input worksheet select one station in the ***Station #*** column, then execute this command.   The following prompt will appear to ask for the distance to move the station.   The distance must not result in the station moving past the adjacent station.



The first and last stations of a model level cannot be moved with this command.

Create Stacked Beams

See also

XLRotor Menu Commands
Modeling Menu Commands
Shaft Input Worksheet
Create Conical Beam Elements
Subdivide Station
Auto-number All Stations
Check Station L/D Ratios
Reverse Order of Stations
Make 45 Degree Beam
Reorder Beams by Station Number, by Layers, or by Levels

Access this command from the XLRotor/Modeling pull down menu, or on the XLRotor ribbon.

Important: Save your file before using this command.   The only way to undo the operation is to close and reopen the file.

This command creates new beams on top of existing beams.   On the Shaft Input Worksheet select a range of stations in the **Station #** column, then execute this command from the pull down menu or ribbon.   New beams will be appended to the end of the Shaft Input table with the same station numbers as those selected, and with inside diameters set equal to the outside diameters of the selected beams.

Create Conical Beam Elements

See also

- XLRotor Menu Commands
- Modeling Menu Commands
- Options|General
- Shaft Input Worksheet
- Create Stacked Beams
- Subdivide Station
- Auto-number All Stations
- Check Station L/D Ratios
- Reverse Order of Stations
- Make 45 Degree Beam
- Reorder Beams by Station Number, by Layers, or by Levels

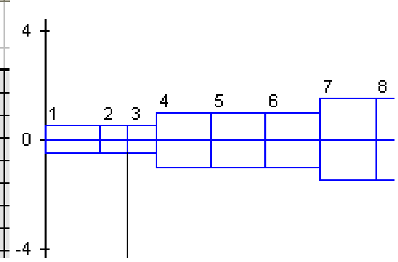
Access this command from the XLRotor/Modeling pull down menu, or on the XLRotor ribbon.

Important: Save your file before using this command. The only way to undo the operation is to close and reopen the file.

This pull down menu command is used on the Shaft Input Worksheet to automatically fill in cell formulas to create a linearly tapered set of beam elements spanning a range of stations. In order to use this command, the option for ***Conical Beam Elements*** must be turned **ON** in the Options|General dialog box.

First select two worksheet cells that span the range of stations over which to create the series of conical beams, then execute the command from the menu or ribbon. Here is an example. The following cells on the Shaft Input worksheet define the rotor cross section shown in the figure.

	A	B	C	D	E	F
2	Station	Length	OD Left	ID Left	OD Right	ID Right
3	#	in	in	in	in	in
6	1	2	1	0	1	0
7	2	1	1	0	1	0
8	3	1	1	0	1	0
9	4	2	2	0	2	0
10	5	2	2	0	2	0
11	6	2	2	0	2	0
12	7	2	3	0	3	0
13	8	2	3	0	3	0

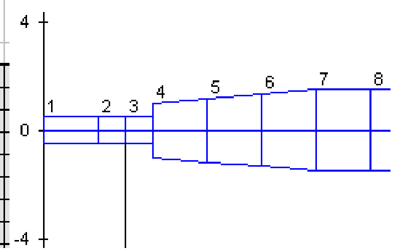


In order to change the outer diameters of stations 4, 5 and 6 to follow a linear taper up to the diameter of station 7, an outer diameter of 3 inches would first be entered in cell E11 of the OD Right column for station number 6. Then select the cell in the OD Left column for station 4 (cell C9), and then while holding down the Control key on the keyboard, use the mouse to click on cell E11. Your screen should look similar to the following which shows that the two cells have been selected.

	A	B	C	D	E	F
2	Station	Length	OD Left	ID Left	OD Right	ID Right
3	#	in	in	in	in	in
6	1	2	1	0	1	0
7	2	1	1	0	1	0
8	3	1	1	0	1	0
9	4	2	2	0	2	0
10	5	2	2	0	2	0
11	6	2	2	0	3	0
12	7	2	3	0	3	0
13	8	2	3	0	3	0

With these two cells selected, executing the **Create Conical Beam Elements** command will then fill in cells C10:C11 and E9:E10 with formulas that compute diameters of a linear taper. The cells which contain these formulas are selected in the following figure.

	A	B	C	D	E	F
2	Station	Length	OD Left	ID Left	OD Right	ID Right
3	#	in	in	in	in	in
6	1	2	1	0	1	0
7	2	1	1	0	1	0
8	3	1	1	0	1	0
9	4	2	2	0	2.333333	0
10	5	2	2.333333	0	2.666667	0
11	6	2	2.666667	0	3	0
12	7	2	3	0	3	0
13	8	2	3	0	3	0



You could enter the cell formulas yourself, but this command makes it easy. After executing this command, it might be necessary to execute an Update|Geometry Chart command so that the geometry plot will show the newly created conical form of the beams. This command can also be used in an analogous fashion with inside diameters. Any number of stations (2 or more) can be operated on with this command. The station numbers in the **Station #** column must be a continuous sequence of station numbers. You can click on the cells to see the cell formulas which have been created. Because cell formulas have been used instead of constant numerical values, if you change the length of any of the stations 4, 5 or 6, or change the two end point diameters (in cells C9 and E11), the model geometry will update automatically.

Check Station L/D Ratios

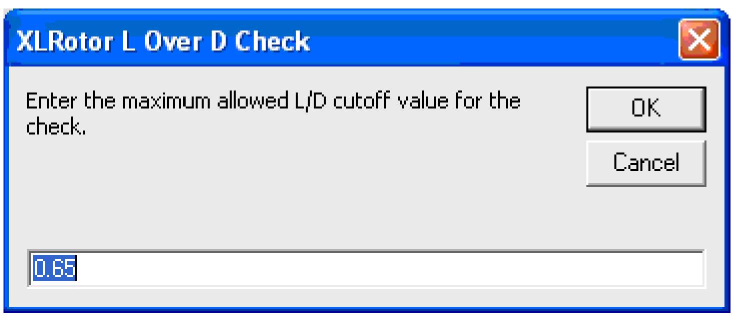
See also

- XLRotor Menu Commands
- Modeling Menu Commands
- Shaft Input Worksheet
- Create Conical Beam Elements
- Create Stacked Beams
- Subdivide Station
- Auto-number All Stations
- Reverse Order of Stations
- Make 45 Degree Beam
- Reorder Beams by Station Number, by Layers, or by Levels

Access this command from the XLRotor/Modeling pull down menu, or on the XLRotor ribbon.

Important: Save your file before using this command. The only way to undo the operation is to close and reopen the file.

This command will check the L/D ratios of either some or all stations on the Shaft Input Worksheet. The command will prompt you for a maximum limiting value for L/D with the following dialog:



When you select OK, all stations which are longer than this will be highlighted, and you will be prompted if you want the program to automatically subdivide each of these so that its L/D will then be equal to or less than the cutoff value. If no stations are highlighted, then no stations longer than the cutoff were found.

All stations in the model will be checked unless you select a subset of stations in the **Station #** column of the Shaft Input sheet, in which case only those will be checked.

When multiple beams are defined for a station, only the beam with the largest diameter is checked (and only this one will be highlighted). But all will be subdivided if you choose to do the subdivide.

Note: After having the program automatically subdivide stations, execute an Update|Geometry Chart command to verify the changes made to the model are satisfactory. They only way to undo the changes is to close and reopen the file without saving it.

The following paragraph is from the book *Machinery Vibration and Rotordynamics*, by JM Vance, FY Zeidan and BT Murphy, John Wiley & Sons, 2010.

A question often asked is; how many shaft modeling stations are needed for accurate results? There is no single answer to this question. It depends on the rotor, and also on the computer program used to the model the rotor. One general statement which can be made is that the more flexing taking place in the rotor, the more stations it will take to model it accurately. Another statement which ought to be true in general is that simple element formulations will require more elements than a more sophisticated element formulation (for example, a simple 2 node lumped mass beam element versus a 3 node iso-parametric beam element with consistent mass). When relatively simple 2 node lumped mass elements are employed, at least about 8 shaft modeling stations should be used for every half sine wave in a mode shape. For example, if the first mode has the shape of the jump rope (i.e. one half sine wave), then about 8 or more stations should be sufficient for good accuracy in predicting the frequency of that mode. If the second mode looks like a full sine wave (i.e. two half sine waves), then about 16 or more stations should be sufficient. Shaft modeling programs which employ a more sophisticated element than a 2 node lumped mass element should be able to deliver comparable accuracy with fewer stations. Experience has shown that for many industrial rotors, creating a model which endeavors to reproduce the rotor’s actual cross section geometry will likely end up with more than enough stations to accurately predict the lowest 2 or 3 flexible modes, regardless of the program being used. Another “rule of thumb” often followed is to have the length to diameter ratio (L/D) for all shaft modeling elements not exceed 1. In most situations station L/D does not need to be less than about 0.5 strictly for the purpose of modeling accuracy. Employing a large number of very short elements could be done in order to follow a very intricate rotor cross section, but this probably will not significantly affect the accuracy of predicting the first few rotor modes.

In addition to the above, another aspect of station L/D ratio arises when the Transfer Matrix method is used. If the L/D ratio exceeds about 0.65 then the transfer matrix algorithm could encounter numerical difficulties. This only applies to the Transfer Matrix method as the Finite Element method has no such restriction. Usually, however, this problem is rarely encountered in typical XLRotor models. It is certainly acceptable to have some elements with L/D greater than 0.65, or even greater than 1. However, if a model of a long flexible shaft has a large number of elements with L/D>0.65, then the problem would reveal itself as erratic eigenvalue results on a damped natural frequency map or undamped critical speed map. In XLRotor, only single level models can use the Transfer Matrix method. Multi-level models always will use the Finite Element method.

Make 45 Degree Beam

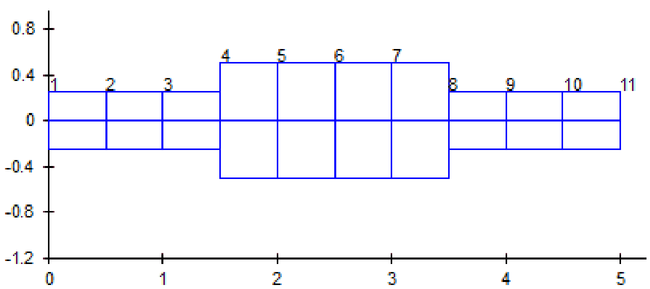
also

XLRotor Menu Commands
Modeling Menu Commands
Shaft Input Worksheet
Create Conical Beam Elements
Create Stacked Beams
Subdivide Station
Auto-number All Stations
Check Station L/D Ratios
Reverse Order of Stations
Reorder Beams by Station Number, by Layers, or by Levels

Access this command from the XLRotor/Modeling pull down menu, or on the XLRotor ribbon.

Important: Save your file before using this command. The only way to undo the operation is to close and reopen the file.

This command is used to split a beam into a pair of stacked conical beams. The option for conical beams must be turned on to use this command. As an example we will use this command on the beam at station 4 of the following model.



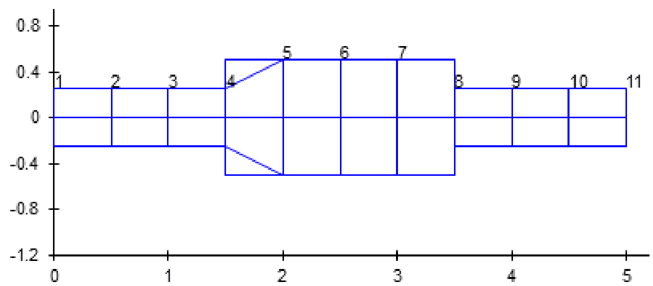
On the Shaft Input Worksheet the cell in the Station # column for station 4 is selected.

	Station	Length	ID Left	OD Left	ID Right	OD Right	Weig Densi
3	#	in	in	in	in	in	lb/in
6	1	0.5		0.5		0.5	0.
7	2	0.5		0.5		0.5	0.
8	3	0.5		0.5		0.5	0.
9	4	0.5		1		1	0.
10	5	0.5		1		1	0.
11	6	0.5		1		1	0.
12	7	0.5		1		1	0

Then the menu command is executed, which produces the following:

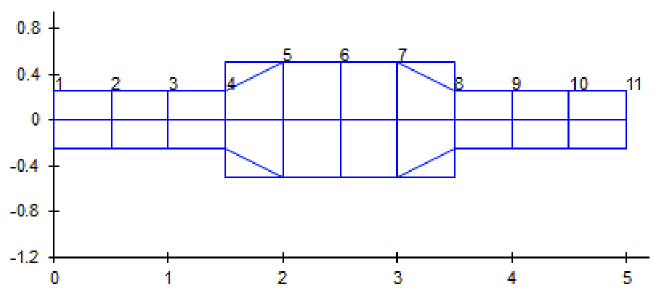
2	Station	Length	ID Left	OD Left	ID Right	OD Right	Weight Density	Elastic Modulus	Shear Modulus
3	#	in	in	in	in	in	lb/in^3	psi	psi
6	1	0.5		0.5		0.5	0.283	30.0E+6	12.0E+6
7	2	0.5		0.5		0.5	0.283	30.0E+6	12.0E+6
8	3	0.5		0.5		0.5	0.283	30.0E+6	12.0E+6
9	4	0.5		0.5		1	0.283	30.0E+6	12.0E+6
10	5	0.5		1		1	0.283	30.0E+6	12.0E+6
11	6	0.5		1		1	0.283	30.0E+6	12.0E+6
12	7	0.5		1		1	0.283	30.0E+6	12.0E+6
13	8	0.5		0.5		0.5	0.283	30.0E+6	12.0E+6
14	9	0.5		0.5		0.5	0.283	30.0E+6	12.0E+6
15	10	0.5		0.5		0.5	0.283	30.0E+6	12.0E+6
16	11								
17	4	0.5	0.5	1	1	1	0.283		

Then, after updating the model geometry, the model looks as follows:

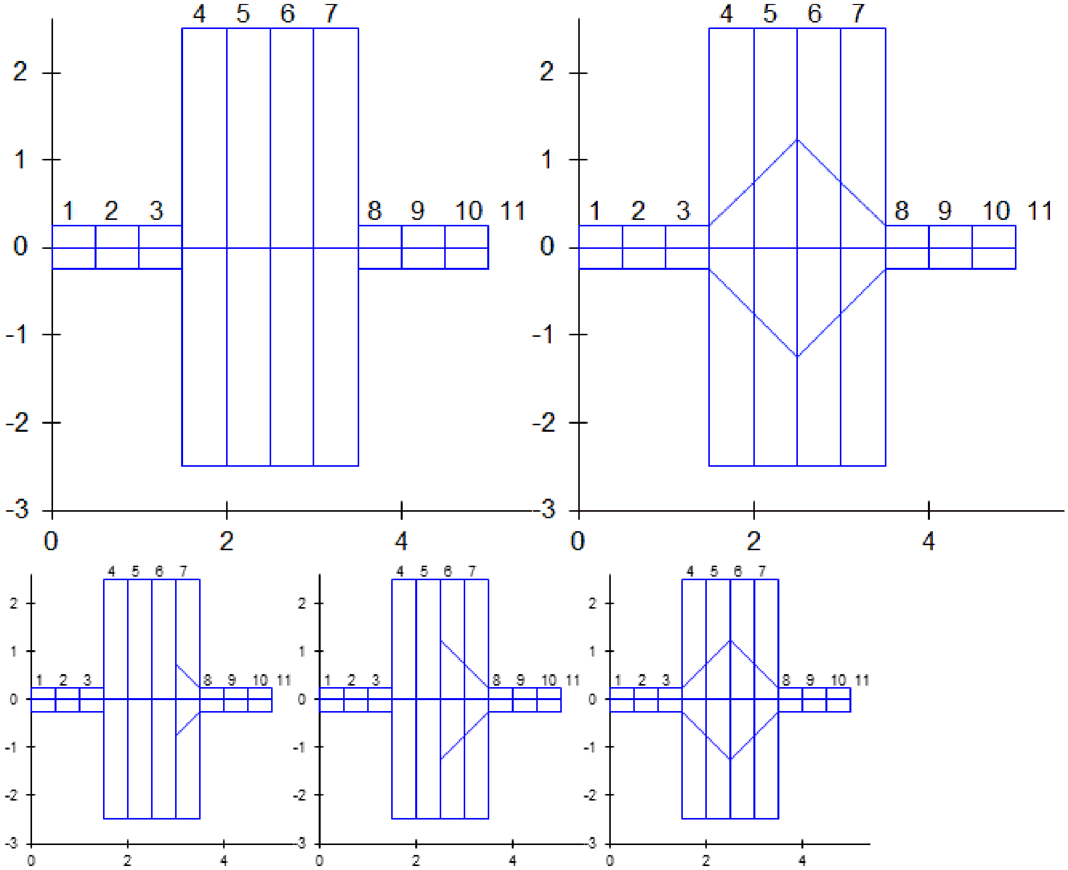


A typical reason for doing this is so the stiffness contribution of the outer beam can be zero by inputting the Elastic and Shear Modulus as zero for the outer beam (see the above image where the moduli cells are left empty).

When this command is used on station 7, the following model is produced.



The algorithm uses a left-to-right progression to determine if the diameter is stepping up or down. The following two images show an original and modified shaft model. This result can be achieve in three steps of using the menu command. 1) Station 7 is selected and the menu command is executed. 2) Station 6 selected. 3) Both stations 4 and 5 are selected. The three smaller images show this progression. The same result can be achieved in a single operation by holding down the control key and on the Shaft Input sheet selecting station numbers 7, 6, 4, 5 in that order.


1
2
3
4
5
6
7
8
9
10
11
2
1
0
-1
-2
-3
0
2
4

Reverse Order of Stations

See also

- XLRotor Menu Commands
- Modeling Menu Commands
- Shaft Input Worksheet
- Create Conical Beam Elements
- Create Stacked Beams
- Subdivide Station
- Auto-number All Stations
- Check Station L/D Ratios
- Make 45 Degree Beam
- Reorder Beams by Station Number, by Layers, or by Levels

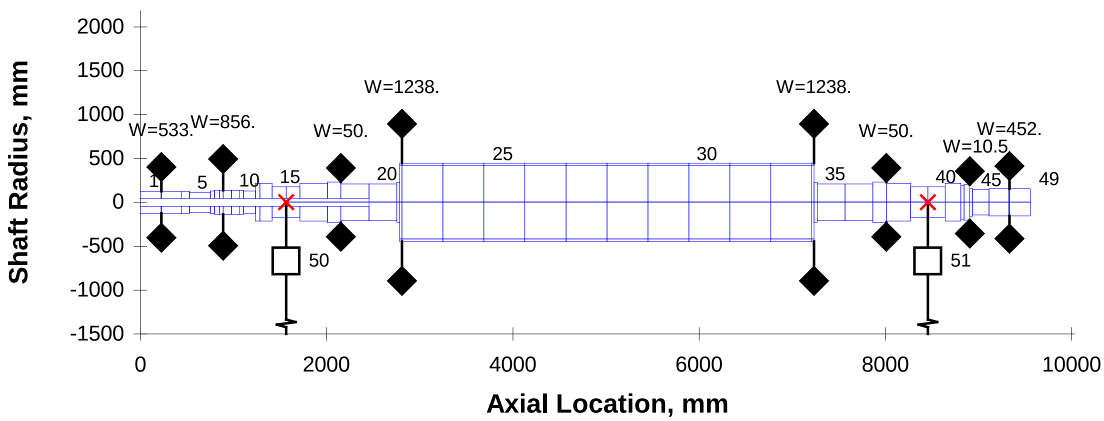
Access this command from the XLRotor/Modeling pull down menu, or on the XLRotor ribbon.

Important: Save your file before using this command. The only way to undo the operation is to close and reopen the file.

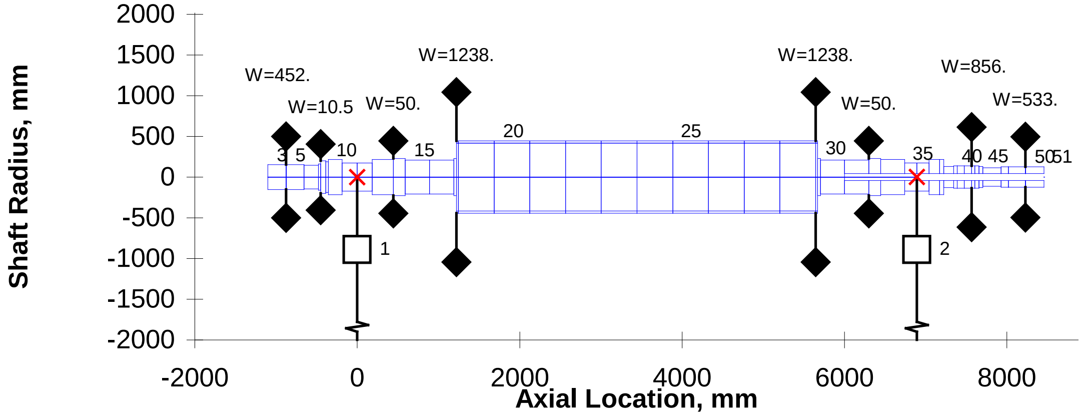
This command is used to reverse the order of all or part of a model. For instance, if you import a generator model from a Dyrobes or ARMD file, and need to reverse it prior to connecting it to a gearbox, use this command.

To reverse the entire model, go to the Shaft Input Worksheet, ensure that no more than one worksheet cell is selected, and execute the command from the pull down menu. The following images show an example.

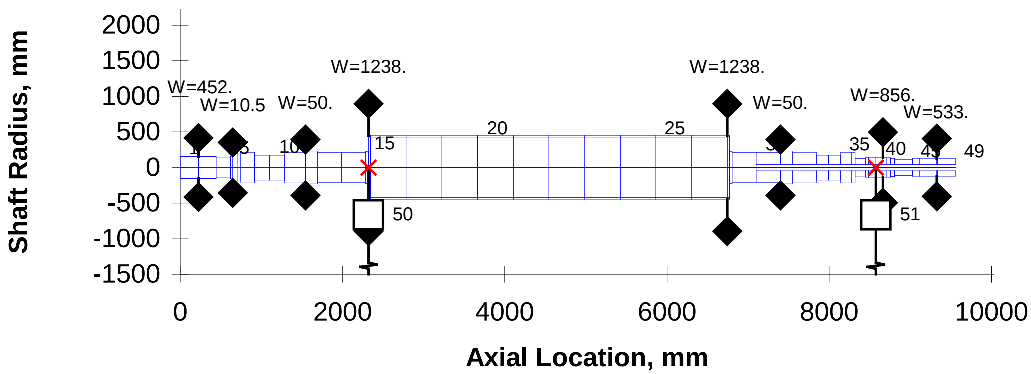
Before reversing



After reversing



In the above images the two stations 50 and 51 are bearing supports, and these become stations 1 and 2 after the reversal operation. Instead of reversing the entire model, you could instead reverse just the generator shaft. This would be done by selecting the station numbers for the shaft (1 to 49) in the **Station #** column on the **Shaft Input** sheet. Then execute the command. All beams in the model for these stations must be selected, and the selected cells must be a single contiguous group of cells. This may require running the command Reorder Beams by Station Number to enable selecting all the necessary cells in a single group. Reversing the generator rotor this way results in the following model. The bearing supports remain stations 50 and 51, however they are still located at the original stations 16 and 40 of the unreversed model. So in this case it becomes necessary to manually correct the locations of the bearings on the Brg's Worksheet.



Note: Whenever possible it is recommend to confirm that reversing a model does not change calculation results. For example, re-perform an eigenvalue analysis with the reversed model and confirm that the eigenvalues are unchanged. Also, performing the same reversing operation twice in succession should result in the original model

Reorder Beams by Station Number, by Layers, or by Levels

See also

- XLRotor Menu Commands
- Modeling Menu Commands
- Shaft Input Worksheet
- Create Conical Beam Elements
- Create Stacked Beams
- Subdivide Station
- Auto-number All Stations
- Check Station L/D Ratios
- Reverse Order of Stations
- Make 45 Degree Beam

Access these three commands from the XLRotor/Modeling pull down menu, or on the XLRotor ribbon.

These commands reorder the beams on the Shaft Input Worksheet. The actions performed cannot be undone, so it is recommended that you first save your file before using these commands.

These commands are for convenience only since you could reorder them yourself using the mouse or Excel's built-in sorting commands on the Data pull down menu.. XLRotor allows the beams to be in any desired order. The order has no affect on analysis results. Recall that the model is always "terminated" by the first empty row in the table. For instance, if a model has a rotor and a housing, and the rotor stations are listed first followed by the housing stations, you can remove the housing from the model by simply inserting a blank row between the rotor and housing portions of the input.

Any model can be considered to be made up of layers of beams, possibly multiple layers stacked on top of one another (e.g. laminations on a solid shaft), and also to consist of possibly more than one modeling level. A "Level" is any group of stations terminated by a zero length station. Any level can contain more than one layer of beams.

Note: Each of these commands works by moving entire rows of the Shaft Input worksheet exactly as if you moved them yourself using the mouse. So any other data and cell formulas on the sheet in addition to the input table will be affected by the reordering operation. Any cell formulas that refer to cells being moved will automatically be adjusted by Excel.

Note: Sometimes, but not always, after reordering the beams the geometry chart will need updating in order to display the model correctly.

By Station Number

This command will reorder all beams numerically by their corresponding station number. If there is more than one beam defined for a station, these are ordered by increasing diameter.

By Layers

This command will reorder the model so that all beams making up the first entire layer come first followed by successive layers in order of increasing diameter. For instance, if there are multiple levels in the model, the smallest diameter beam for each station will be listed first, for all stations for all levels. Then after this, successively larger diameter layers of beams are listed.

By Levels

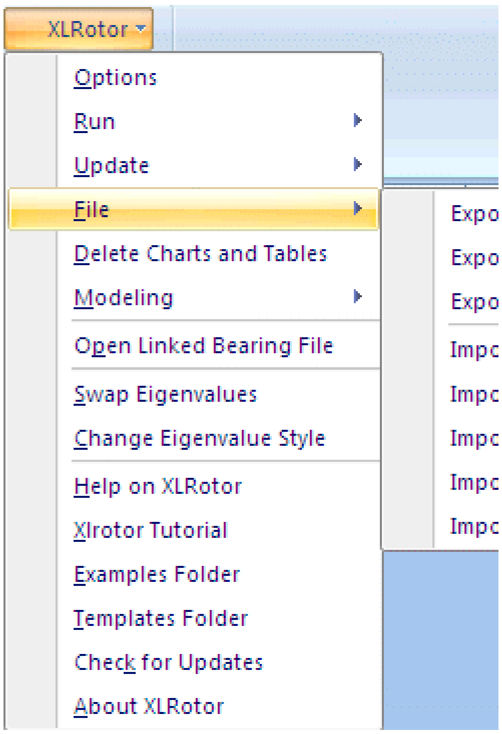
This command will group together the beams belonging to each level. For each level the beams are ordered in a "by layer" fashion.

File|Export Menu Command

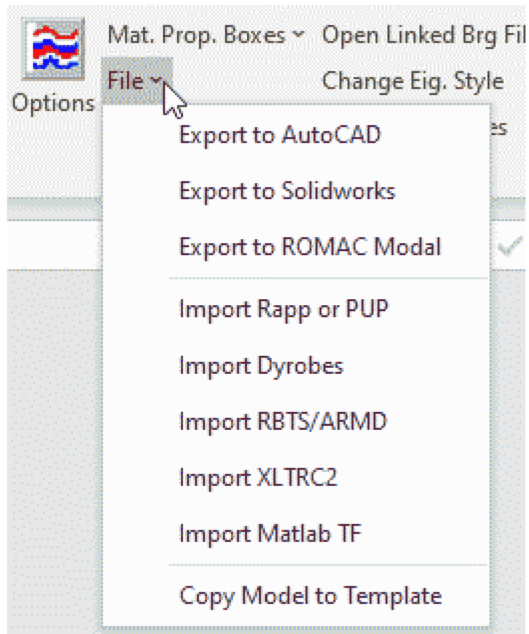
See also

XLRotor Menu Commands

Pull Down Menu



Ribbon



The three export commands are used to export either all or part of the rotor model geometry. To export a subset of the model, go to the Shaft Input Worksheet in the **Station #** column, and use your mouse to select the station numbers you wish to export. Otherwise the entire model geometry will be exported.

These commands export only geometry information. Material property data and bearing parameters are not exported (except the ROMAC option which does include material property data).

Export to Autocad

You can export to either a Visual Basic macro or to a DXF file. The visual basic macro is written to a file called *XLRotor_to_Autocad.bas*, and running this file in Autocad causes the model geometry to be drawn into the current layer. The dxf file is called *XLRotor_to_Autocad.dxf*, and this file can be opened in Autocad or many other applications that can read the dxf file format.

Export to SolidWorks

A Visual Basic macro is written to a file with a default name of *NameofyourXLRotorfile.swb* in the same folder as your XLRotor file, but a Save As dialog box will be displayed enabling you to change the name and folder. This file should be executed within SolidWorks to draw the model geometry. When this macro is run in Solidworks, it will create a sketch in the currently active part or assembly file. One sketch is created for each level of the XLRotor model.

Export to ROMAC Modal

An input file is created in that program's input format. The Modal program only accommodates elements consisting of single beams. If your model contains multiple beams defined for any of the stations, only the first beam is exported. A warning is displayed about this whenever your model contains multiple beams. A standard **Save As** dialog box is displayed so you can enter the name and location of the file to be saved.

Import RAPP File

Allows you to import most of the model data from an input file for the rotordynamic analysis program called RAPP.

Import DYROBES File

Allows you to import most of the model data from an ***output*** file for the rotordynamic analysis program called DYROBES. This command does not work on DYROBES input files, only the text based output files which show the summary data for the model (mainly material properties, elements and bearings).

For torsional models only, a DYROBES output file does not list the selected material property for each element. The importer tries to determine which material property goes with each element from the element stiffness values printed in the file. This works most of the time, but if two material properties differ by only their density value, there is no way to know for sure which one of these an element might be using. As long as you avoid using two materials with exactly (or almost exactly) the same modulus but different densities, the importer should interpret the model correctly.

The torsional importer imports only the model and boundary conditions, not any excitation torques.

The importer tries to determine what system of units is in the DYROBES output file, and proceeds accordingly.

Import RBTS/ARMD File

Allows you to import most of the model data from an ***output*** file for the rotordynamic analysis program called ARMD. This command does not work on ARMD input files, only the text based output files which show the summary data for the model (mainly material properties, elements and bearings). Model data can be imported from ARMD output files with the following file extensions:

SYO = ROSYNC synchronous response output file

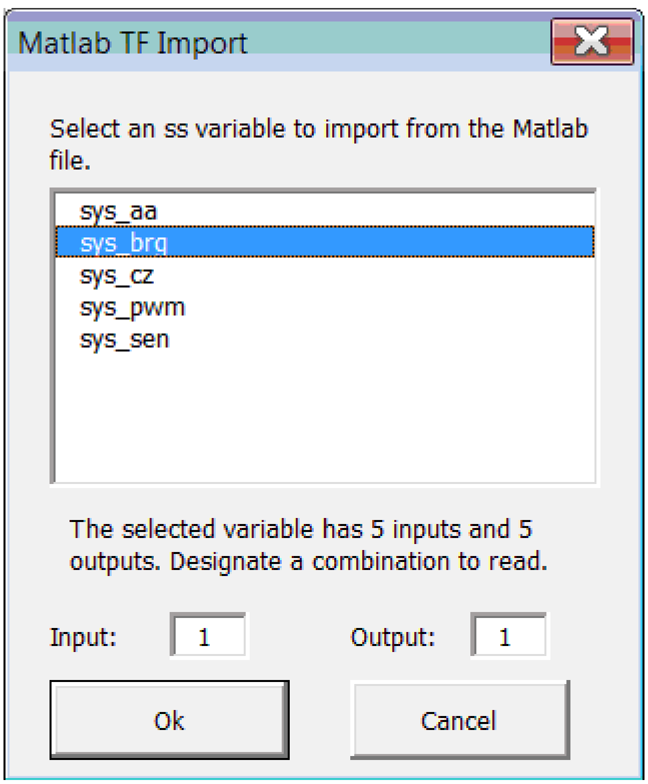
STO = ROSTAB damped eigenvalue output file

CMO = ROTORMAP undamped critical speeds output file.

Import Matlab TF

This command imports a transfer function from a Matlab binary data file onto an XLTransferFunction worksheet. This command requires an optional Matlab toolbox named Spreadsheet Link EX which is available from MathWorks. Compared to other Matlab toolboxes, this toolbox is very inexpensive. If you have Matlab, but are not sure if you have this toolbox, look for the following file in the Matlab program folder ***C:\Program Files\MATLAB\R2014a\toolbox\exlink\excllink.xlam***. The folder location may be different depending on your version of Matlab, but the file name ***excllink.xlam*** is the same for all Matlab versions since R2006. ***excllink.xlam*** is an Excel addin, and must be "installed" into Excel before it can be used. Instructions for installing it are in the same folder.

This command will first check that the toolbox is installed and ready for use. Then a File/Open dialog box will appear for you to select a Matlab binary data file. Normally these files have a ***.mat*** extension (although the extension may not be visible depending on your Windows settings). The file will be scanned for all the Matlab ***ss objects*** within it, and a dialog box similar to the following is displayed. It may take 10 or 20 seconds for this dialog to appear the first time the command is used in each Excel session (this is time to start a background instance of the Matlab application).



When an ***ss object*** variable is selected in the list, the number of inputs and outputs in that variable will be shown below the list These will both be 1 if it is a single input single output system (SISO). If the selected variable is MIMO, the ***Input*** field and ***Output*** field are for designating which transfer function to import.

Clicking OK will cause the ABC matrices to be extracted and output to the currently active XLTransferFunction worksheet.

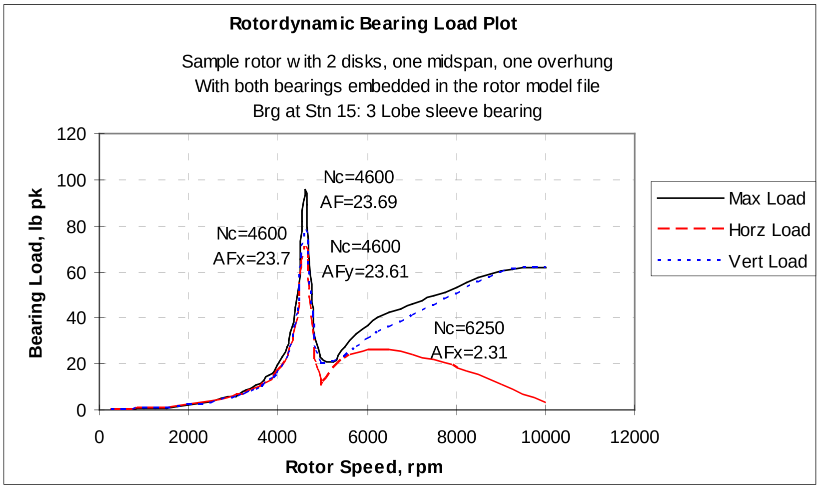
Copy To Template

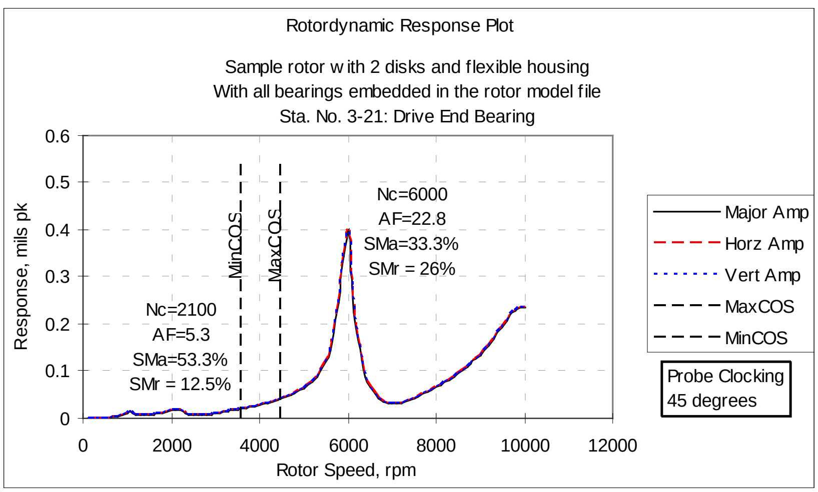
This command is intended for times when you suspect your file has become corrupt. Most of the contents of your file will be copied to an empty template. If your file contains embedded bearing or seal sheets, or API analysis sheets, those will copied as well.

Label Peak Amplification Factors

See also

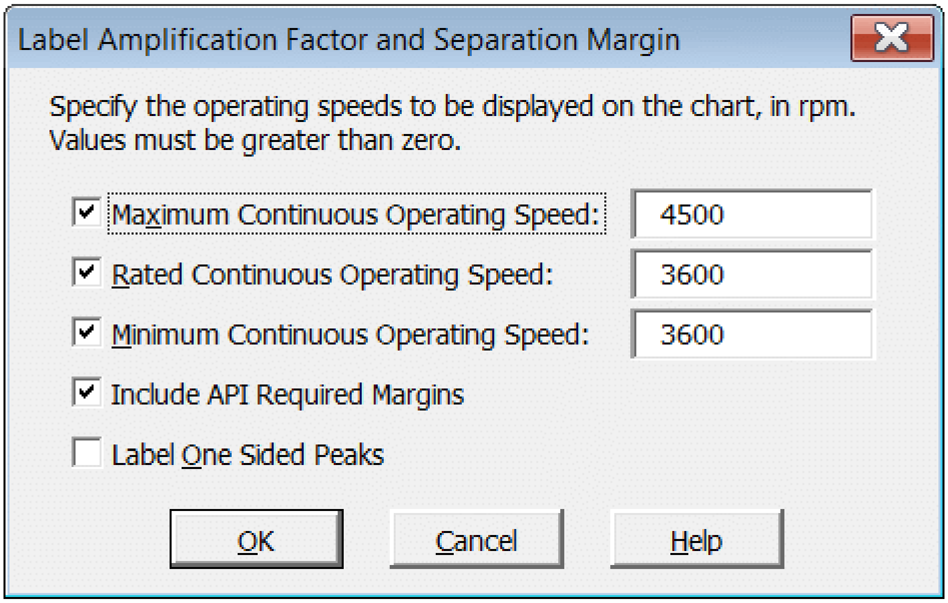
XLRotor Menu Commands





This pull down menu command should be used only on charts of response versus rotor speed.

This command displays the following dialog prompting you for operating speeds to display on the plot if the AF is labeled. These speeds are displayed on the chart, and are used to calculate critical speed separation margin.



You can use this command to label just one peak, or all the peaks on a plotted data series:

1. First click on a series to select it, then execute the command. This will label all peaks on the curve.
2. First click on a series, then click once slowly near a single peak, then execute the command. This will label just that peak.

Peaks are determined by looking for half power points where the amplitude is 0.707 times the amplitude at the peak. If a half power point cannot be found either to the left or right of the peak, then the peak is not labeled. However, see below for the option to label one sided peaks.

When selecting a single peak to be labeled, just picking a point close to the actual peak is usually sufficient.

No curve fitting is done to determine the peak amplitude, or speed at the peak. This means it is important to use a fine enough speed increment to adequately define the peak. Interpolation is used, however, to determine the speeds at the half power points (also see the option to Refine Response).

Amplification factor is defined in accordance with API (American Petroleum Institute) specifications as:

A.F. = Nc/(N2-N1)

where:

Nc = speed at the peak (i.e. the critical speed)

N1 = speed at the left half power point

N2 = speed at the right half power point

The Separation Margin is computed as:

if Nc<MinCOS then S.M. = [1-(Nc/MinCOS)] * 100

if Nc>MaxCOS then S.M. = [(Nc/MaxCOS)-1] * 100

The above separation margin is the "actual" separation margin, ***SMa***. The API specification also recommends a "required" separation margin, ***SMr***, which depends on the amplification factor as follows (see, for example, API 684 Rotordynamic Tutorial):

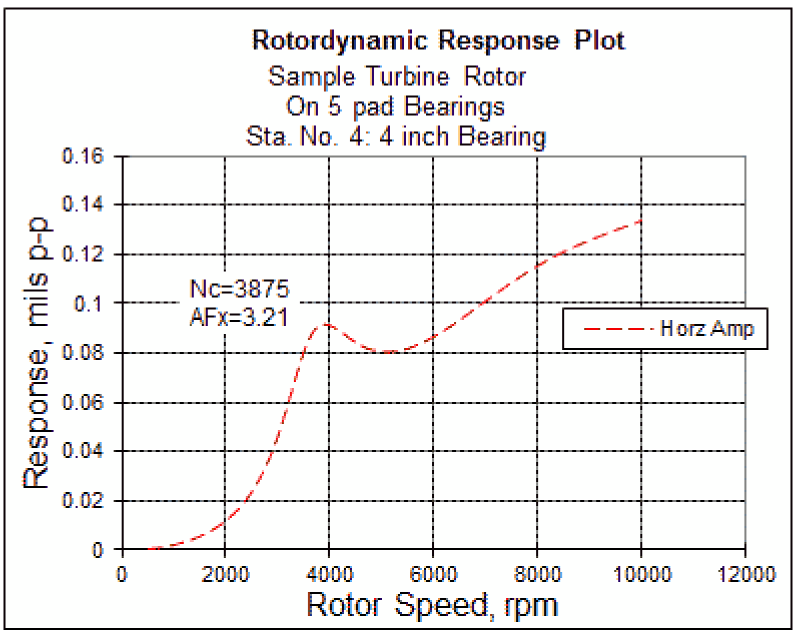
If AF<2.5 the mode is "overdamped," and no separation margin is required

If Nc<MinCOS then SMr=17*[1-1/(AF-1.5)] with a maximum of 16

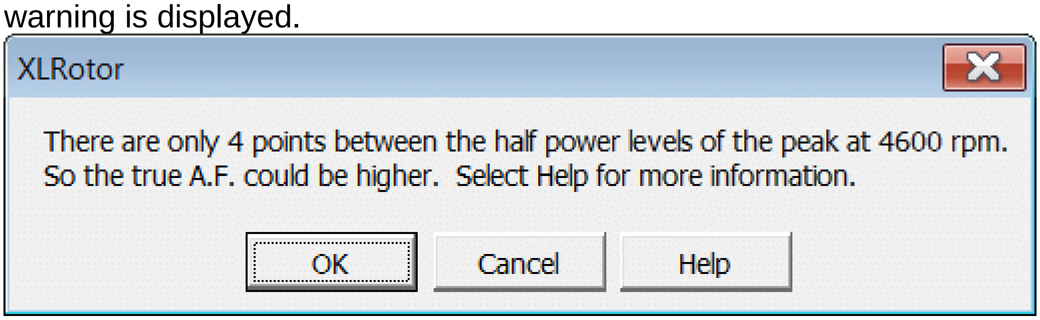
If Nc>MaxCOS then SMr=10 + 17*[1-1/(AF-1.5)] with a maximum of 26

Label One Sided Peaks

The API's expressions for calculating A.F. and S.M. require that there be a half power point on each side of the peak. Turning on this option will enable the labeling of peaks which have only a single half power point, as in the following example. The width of the peak is assumed equal to two times the width of the side with the half power point. Your selection for this option is saved with your file.



Note:
If there are fewer than 6 analysis points between the half power levels of a peak, a warning is displayed.



When this happens, insert some additional analysis speeds on the Imb's Worksheet right around the critical, and rerun the response analysis. You can also turn on the option to have Xlrotor automatically refine the peaks for you (see Options|Response).

Note:
Normally, the AF determined from a **synchronous** response peak will be very close to the AF obtained from the damping ratio of the peak's corresponding system eigenvalue. However, if the peak is of **asynchronous** response, the two amplification factors may not match because they are based on different frequency scales.

Note:
If you decide you do not want the labels or COS lines, simply select them with your mouse and press the DELETE key.

When called from a macro, this command takes optional arguments and returns an array of values. The macro's VBA declaration is as follows:

```
Function LabelAmplificationFactor(Optional arg_MaxCOS = -1, Optional arg_MinCOS
         = -1, Optional arg_RatedCOS = -1, Optional CreateLabels As Boolean = True,
         Optional SuppressWarning As Boolean = False) As Double()
```

When optional arguments are passed, the prompt described above for the operating speeds is not displayed. Display of the three speed arguments on the plot can be suppressed by either not passing them, or by passing -1 or an empty string. The last argument prevents display of the warning about insufficient points to adequately define a peak.

Here is an example.

```
Dim rtn As Variant

Dim MaxCOS As Double, MinCOS As Double, RatedCOS As Double

MaxCOS = 3600

MinCOS = 2400

RatedCOS = 3000

rtn = Application.Run("LabelAmplificationFactor", MaxCOS, MinCOS, RatedCOS,
         True, False)

'for the second to last argument, True means put the label on the peak.

If UBound(rtn) > 1 Then MsgBox "The A.F. is " & rtn(1) & " at a speed of " & rtn(3)
```

Note that either a chart series or a single point on a chart series must be selected when the macro command is executed. The returned array contains a single value if no peaks were found, or 6 values for each peak that is found.

rtn(1) = A.F.

rtn(2) = magnitude of the peak

rtn(3) = the speed at the peak

rtn(4) = actual separation margin

rtn(5) = API required separation margin

rtn(6) = the point number in the chart series at the peak

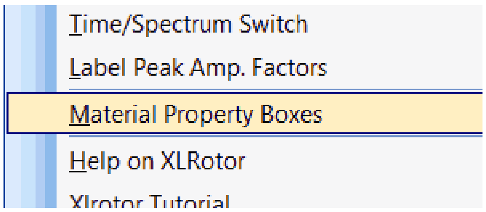
These 6 items are repeated when more than one peak is found (i.e. a vector array of length 6*number of peaks). The VBA function UBound() can be used to determine the number of peaks found.

Material Property Boxes

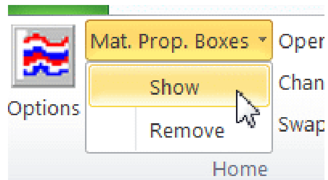
See also

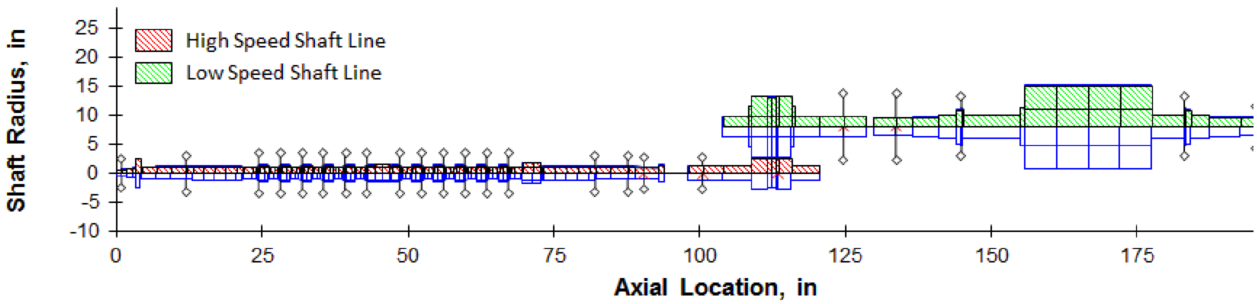
XLRotor Menu Commands

Pull Down Menu



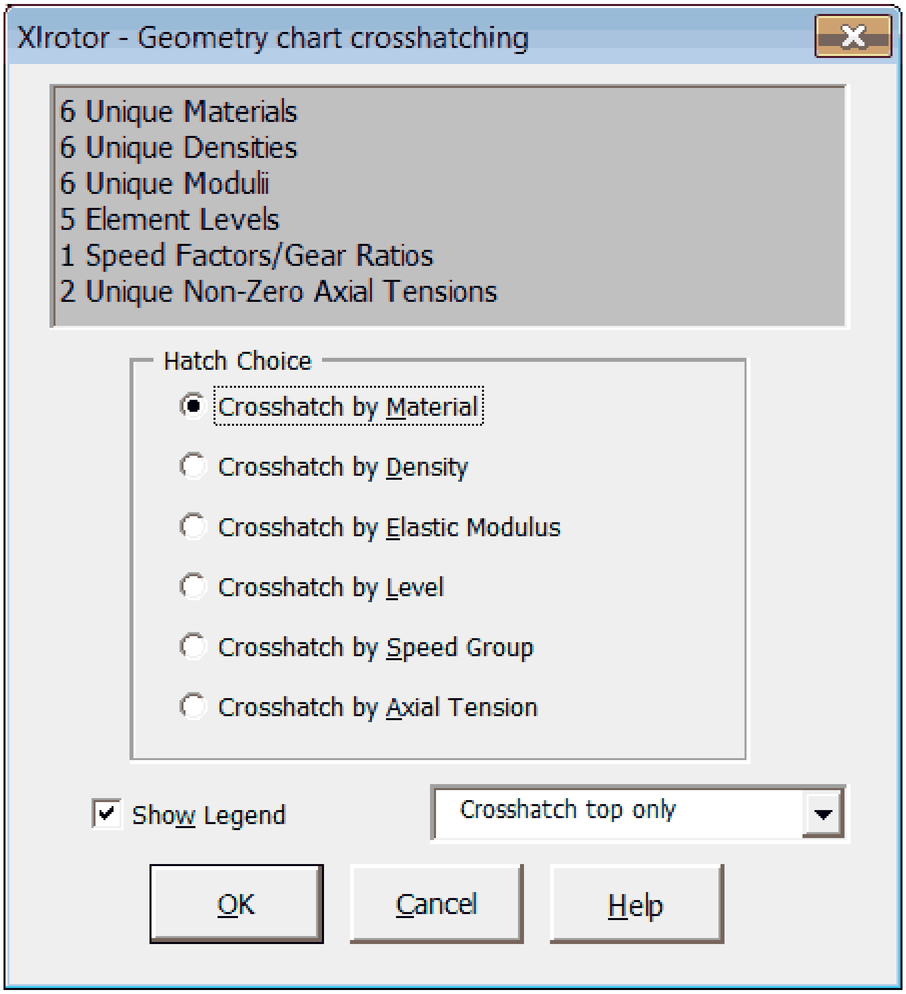
Ribbon



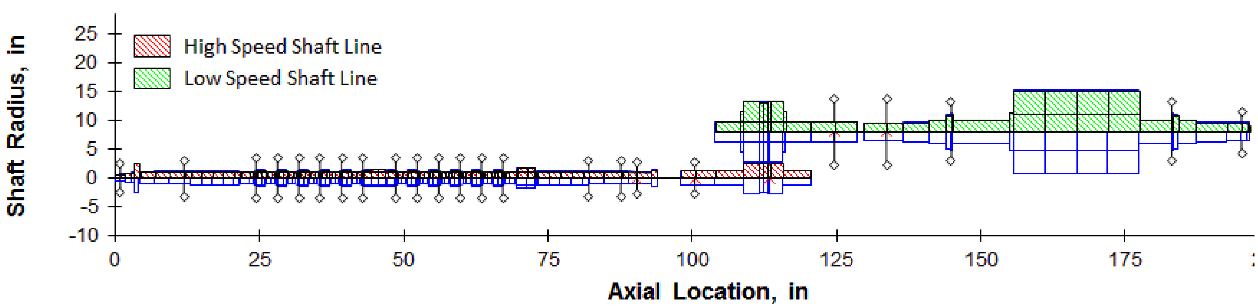


This pair of menu commands works only on a geometry plot chartsheet (Geo Plot Chartsheet). The **Show** command counts the number of unique material properties and element levels in the model, and draws a cross-hatched rectangle over each beam according to your selection in the dialog box shown below.

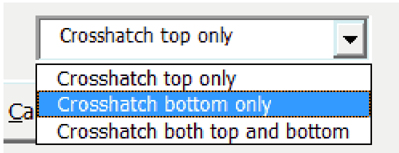
The **Remove** command deletes *all* rectangles from the chart.



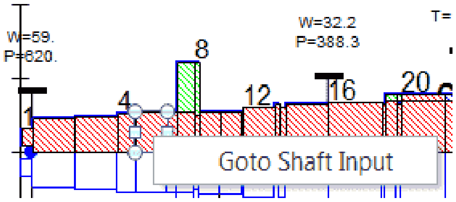
When using ***Crosshatch by Speed Group*** with ***Show Legend***, the names used for each group will either be generic text like "Speed group 1", or else whatever is on the Shaft Input sheet in the cell immediately to the right of the Speed Factor (or Gear Ratio) cell for the first beam in the group (also see GeoPlot Labels).   Here is an example from a torsional model:



The drop downlist enables crosshatching just the top, bottom or both parts of the model. Station number labels always appear in the top half, and some of these may be hidden when the top half is crosshatched.

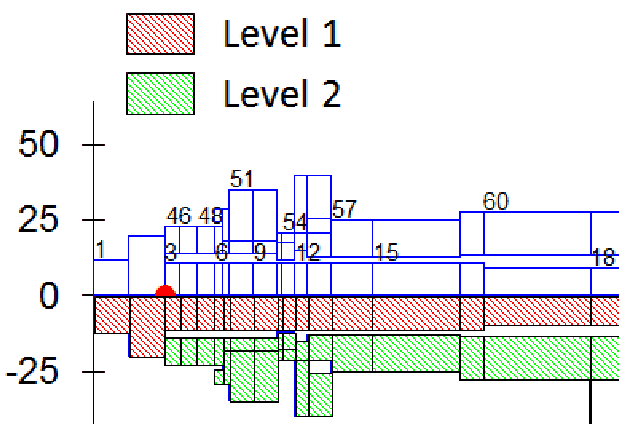


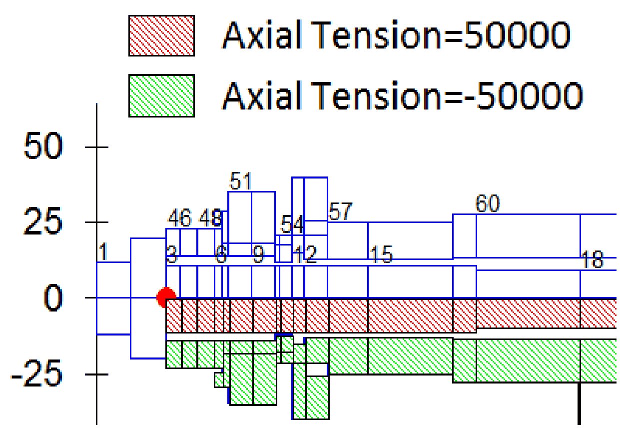
Clicking with the mouse on a cross hatch box displays a pop menu command to jump to the Shaft Input Worksheet at the row corresponding to the clicked element.



The Geo Plot can be cross hatched for just part of the model by first selecting a range of cells in the ***Station #*** column on the Shaft Input Worksheet.

When crosshatching by Axial Tension, only the portion of the model with *nonzero* tension will be crosshatched. Crosshatching by axial tension is an important step to visually confirm shaft spans have their intended tension values (see Shaft Input worksheet). When crosshatching by axial tension, when there are *multiple* beams at a station, *all* beams are crosshatched with the same value of tension. In the following pair of images, the first shows a drawbolt and stacked rotor which are modeled as separate levels. The second image shows how the drawbolt tension and rotor stack compression have been defined.





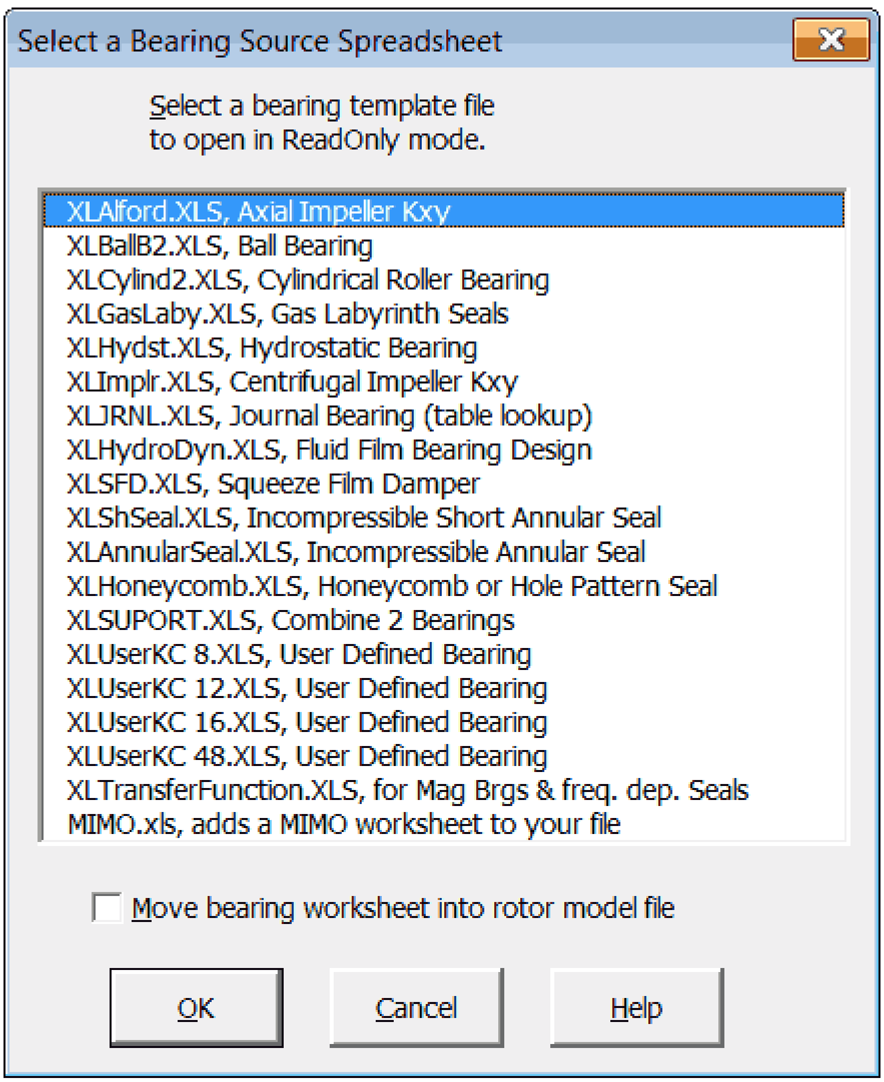
Open Linked Bearing File

See also

- XLRotor Menu Commands
- Bearing Template Files

This command is used to open workbook files for bearings which have already been linked to the rotor model file. You do this from a Brg's Worksheet by first selecting a cell in the "Link" column. Those cells display the Titles from the bearing files, but in actuality contain link references to the bearing files. If the file is already open, you are simply switched to it (it is not reopened).

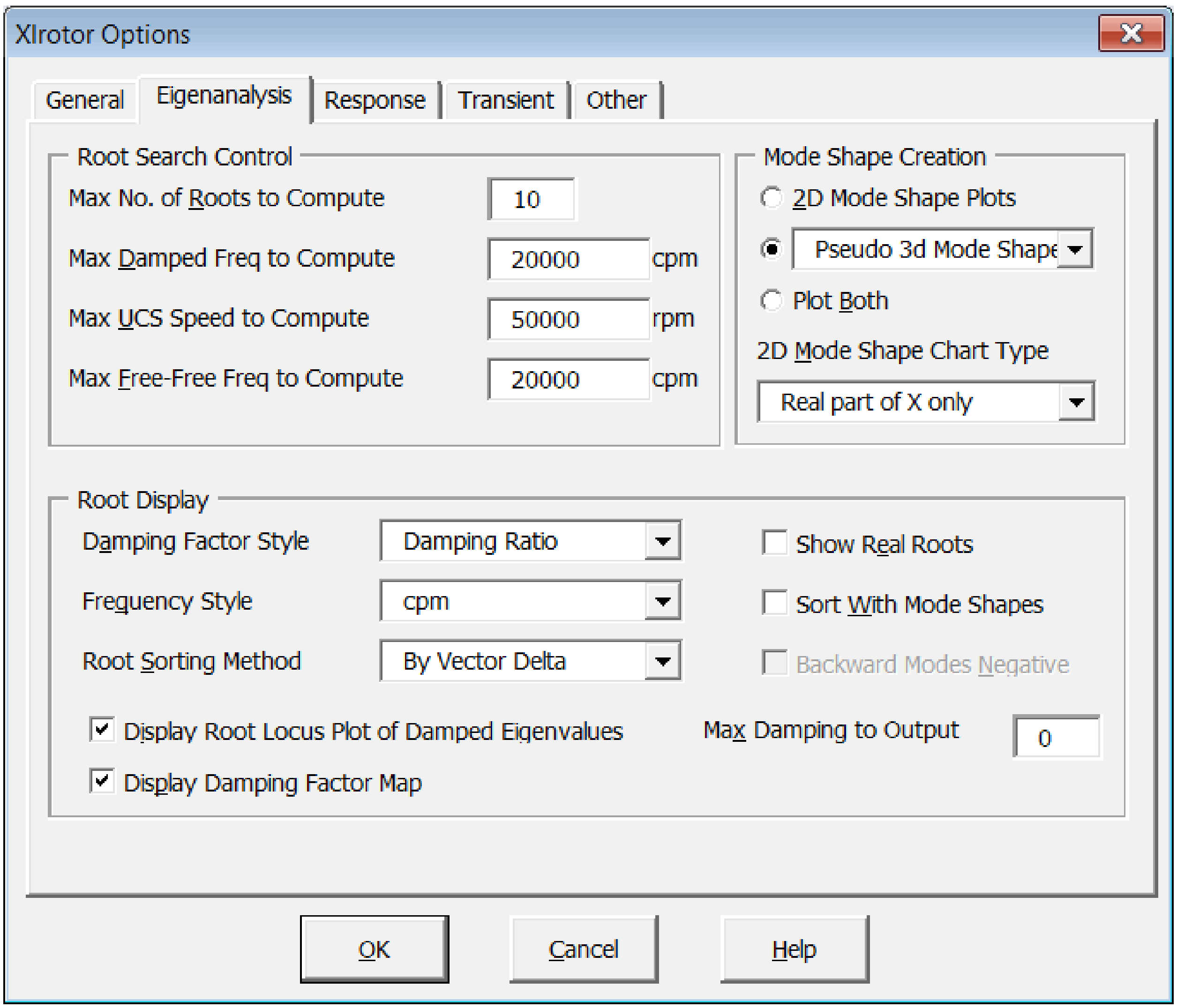
When you are in an empty cell in the "Link" column of the Brg's Worksheet, executing the Open Linked Bearing File command will display a dialog box presenting all the choices for bearing and seal templates. You can also use this dialog box to copy (which means embed) the template's worksheet directly in the rotor model file.



Options|Eigenanalysis

See also

- XLRotor Menu Commands
- Options|General
- Options|Response
- Options|Transient
- Options|Other
- Roots Damped Worksheet



This dialog is displayed by clicking the toolbar or ribbon button, or selecting XLRotor/Options from the pull down menu. This dialog contains a number of options which control certain actions of XLRotor. The settings for these options are stored in the rotor model file on a hidden worksheet. Any changes made to the options in the dialog box affect only the currently active file. If you want any changes to be retained for your next session, the file must be re-Saved.

The dialog box shown above appears when you are working with a ***<u>lateral</u>*** analysis rotor model file. When you are working in a ***<u>torsional</u>*** analysis file the there are some different options. Those are explained at the end of this section.

Maximum Number of Roots and Maximum Frequency or Critical Speed

These two inputs apply to lateral analysis files only. Together they control how many roots get computed, but this is done a little differently depending on whether the analysis uses the TM or FE solver (see Options|General).

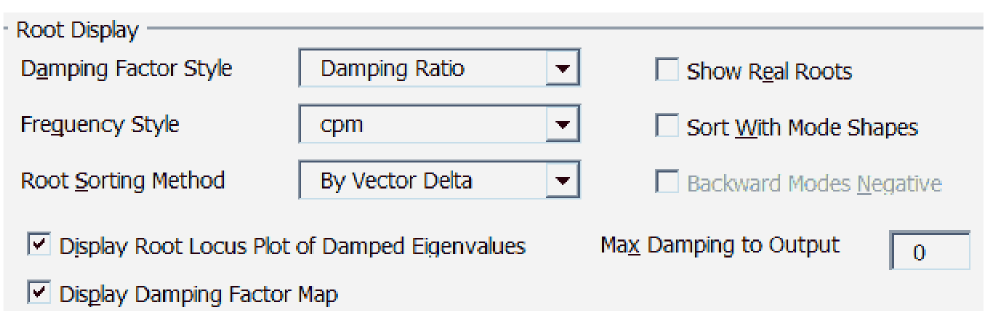
The TM solver computes all roots up to the maximum frequency (plus possibly a few more since the program will multiply your frequency value by 1.4). The program will output no more than the maximum number of roots specified. Your input value for maximum frequency can effect how long the TM solver takes to execute.

The FE solver computes the number of roots specified. Then it outputs all roots less than or equal to the specified maximum frequency. Your input value for the number of roots can effect how long the FE solver takes to execute.

Note:
Normally you would set the maximum frequency to about twice the maximum machine speed, and the maximum number of roots in the range of 12 to 18.

Be aware that when the TM solver is used, numerical accuracy begins to diminish for higher order rotor bending modes (generally around 5 to 6 inflection points on the rotor). Inaccurate roots will appear erratic on plots of natural frequency or critical speed. In addition, when computing the mode shape for an inaccurate eigenvalue, you will get a message that a boundary condition check failed (see Shapes Worksheet).

Root Display



Use the drop down lists to select how to display the real and imaginary parts of damped eigenvalues when performing a Run|Eigenvalues calculation to compute damped eigenvalues. You can also select a method for sorting the roots on a speed by speed basis For more information on the available selections see Change Eigenvalue Style.

Show Real Roots

When this box is checked, real roots will be included in the output (i.e. real roots are critically damped roots, with zero frequency). This option only applies to damped eigenvalue calculations (Run|Eigenvalues), and not on free-free or UCS calculations.

Sort With Mode Shapes

When this box is checked, mode shapes will be computed along with the damped eigenvalues so that the direction of whirl for each mode can be used as an aid in sorting the roots. In the resulting table of damped roots, all forward modes will be listed first, followed by all the backward modes. This option will slightly lengthen the amount of time required to compute damped eigenvalues. Note that the mode shapes themselves are not actually output. That is done with the Run|Mode Shapes command.

Backward Modes Negative

This option can be selected only when the ***Sort With Mode Shapes*** option is also selected. An individual mode shape can be all forward, all backward, or mixed. For mixed modes the direction is set according to the relative amount of volume swept by the forward and backward parts of the mode shape.

Max Damping to Output

This option will exclude heavily damped roots from the output. For example, if *damping ratio* has been selected for output, an input of 0.9 will exclude all roots with damping ratio greater than 0.9. If *log dec* has been selected for output, enter a high log dec value such as 5, 10 or 20. To output *all* roots, enter zero.

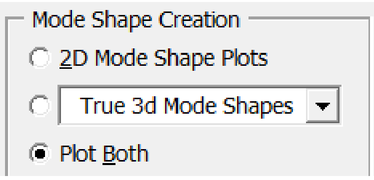
Display Root Locus Plot of Damped Eigenvalues

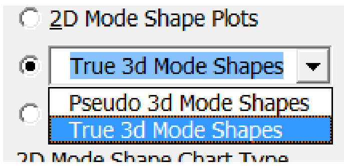
Check this box to have a Root Locus plot (damping constant vs damped natural frequency) created automatically when computing damped eigenvalues.

Display Damping Factor Map

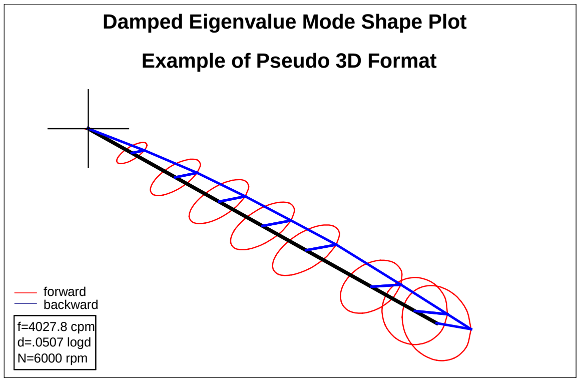
Check this box to have a plot of damping constant versus rotor speed created automatically when computing damped eigenvalues.

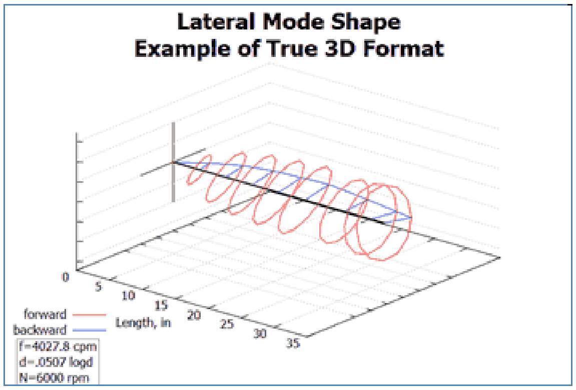
Mode Shape Creation





Check one of the three option buttons to control what kind of charts are created when computing mode shapes with the Run|Mode Shapes command. Be advised that 3D mode shapes require a lot of data in order to be displayed. This can lead to rather large workbook files (>1 megabyte). The amout of output can be reduced by using the Station Display feature on the Shaft Input worksheet. The two choices for 3D mode shapes are ***Pseudo 3D*** and ***True 3D***. In Pseudo 3D the orbits are in the plane of the paper even though the shaft centerline is not, such that circular orbits appear as circles. The following two plots are the same mode shape displayed in the two formats. The True 3D plot is generated using the Gnuplot Plotting Library.





2D Mode Shape Chart Type

The chart type options are as follows:

Real & Imaginary, max X at t=0 - The time base of the mode shape is adjusted so that at t=0, the imaginary part of X is zero at the station with maximum X axis deflection. The overall amplitude of the mode shape is adjusted so that the maximum component, real or imaginary, is 1.

Real & Imaginary, max Y at t=0 - The time base of the mode shape is adjusted so that at t=0, the imaginary part of Y is zero at the station with maximum Y axis deflection. The overall amplitude of the mode shape is adjusted so that the maximum component, real or imaginary, is 1.

Real & Imaginary, max radius at t=0 - The time base of the mode shape is adjusted so that at t=0, the rotor is at the precise instant of maximum radial deflection. The overall amplitude of the mode shape is adjusted so that the maximum component, real or imaginary, is 1.

A mode shape, or eigenvector, consists of real and imaginary components. The real valued vibration of the rotor, in terms of the real and imaginary components, is as follows:

$$x(t) = \mathrm{Re}(X)\cos(\omega t) - \mathrm{Im}(X)\sin(\omega t)$$

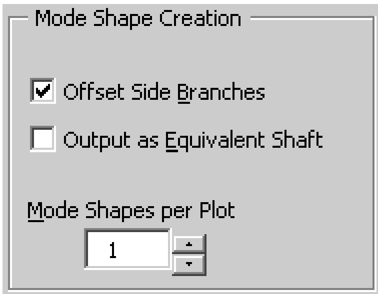
and similarly for y, about x rotation, and about y rotation

note that x is real, X is complex

Since eigenvectors have arbitrary overall magnitude, any eigenvector can be multiplied by a constant, real or complex. Thus, the amplitude and/or time base can be changed arbitrarily by multiplying the entire eigenvector by an appropriate constant.

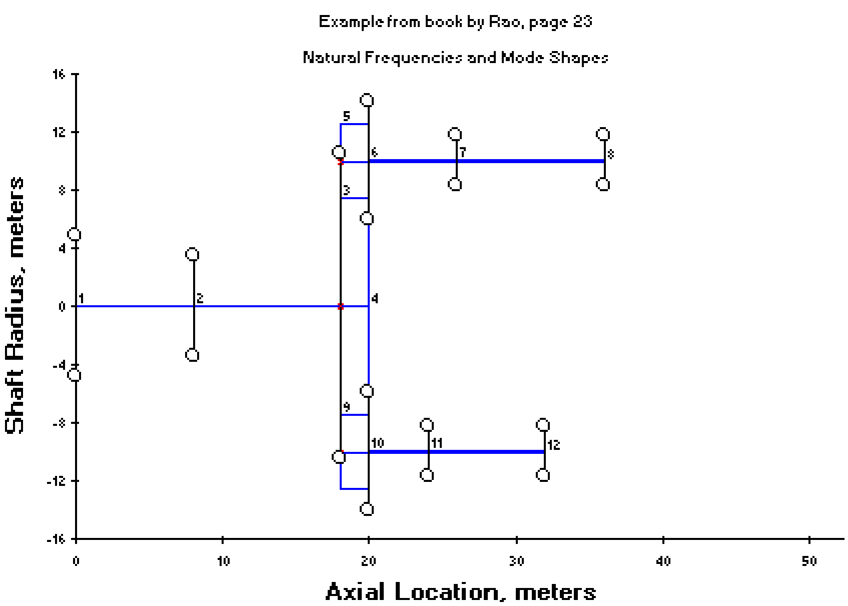
Torsional Models

The dialog box shown above appears when working with a lateral analysis rotor model file. When working in a ***torsional*** analysis rotor model file, the Mode Shape Creation section displays as follows:

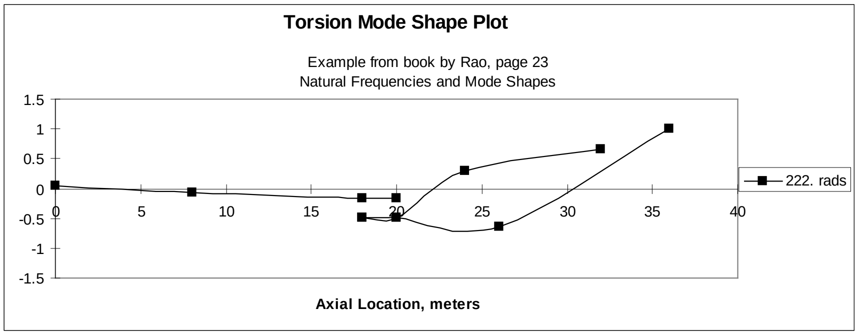


Offset Side Branches (torsional models only)

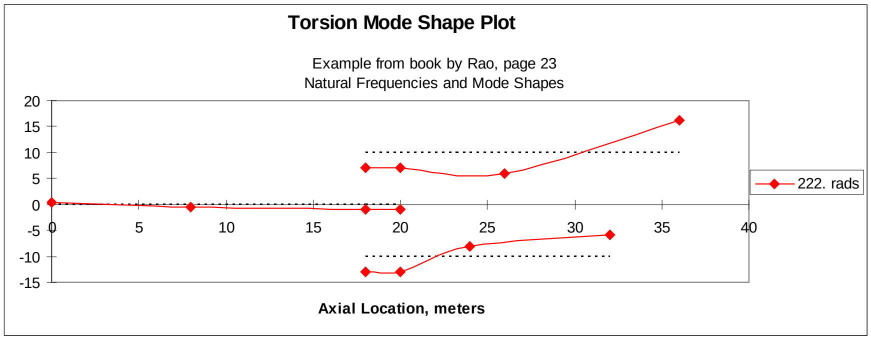
The option to offset side branches only has an affect on models that have side branches displayed in an offset fashion on the Geo Plot Chartsheet. The following model is an example which has two side branches displayed in offset fashion.



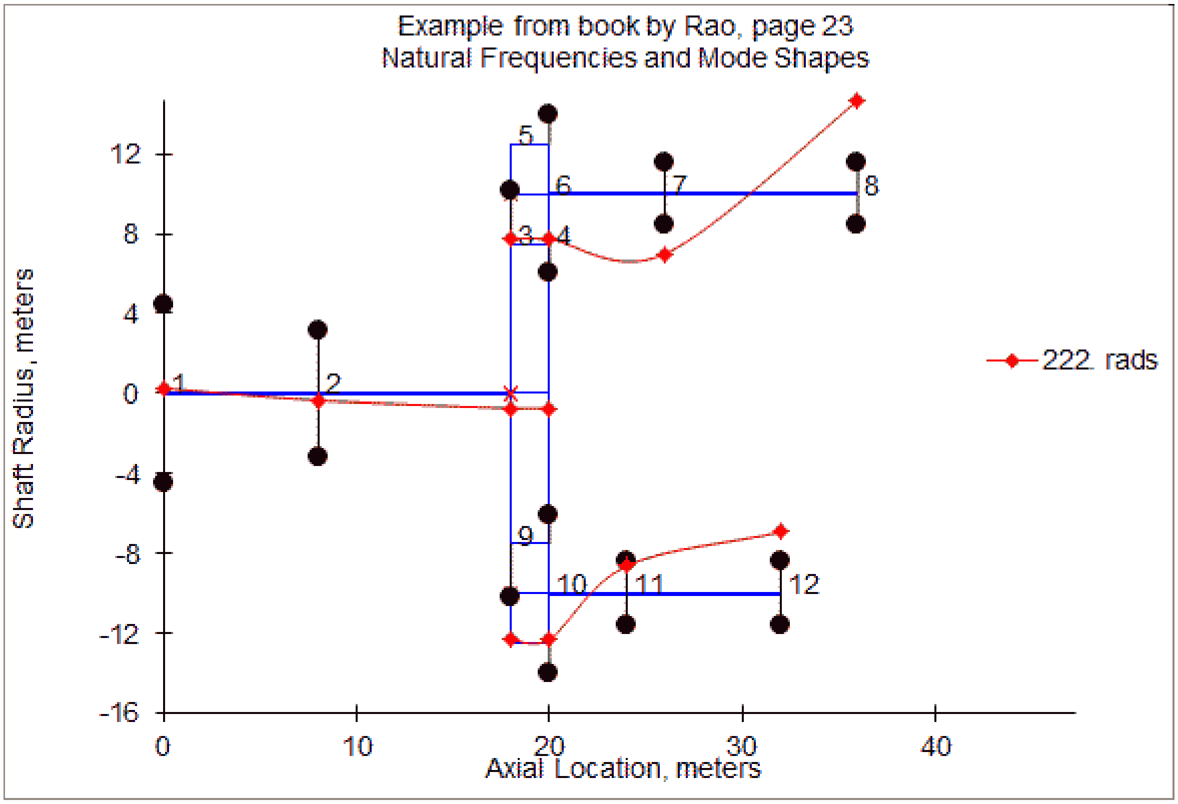
A mode shape that is generated without offsetting side branches looks like the following, where all the deflections are from the zero axis:



With offset side branches, the same mode shape looks as follows, where a dashed line is used to represent the undeformed shaft centerline:



The option to offset side branches will generally produce a mode shape that is easier to interpret, particularly when the model geometry is overlayed onto the mode shape plot with the Overlay Geometry on Mode Shape command.   For the above example mode shape this looks as follows:



Output as Equivalent Shaft (torsional models only)

This option only affects models with gears. When this option is NOT checked on, the mode shape amplitudes are output in terms of real physical degrees of twist in each shaft segment.

Turn this option ON to have mode shape amplitudes of the entire model output in terms of an *equivalent shaft,* which means all stations rotate at the same speed. For machines with gears, the mode shape amplitudes of the high speed shaft are in essence amplified by the gear ratio. This can sometimes obscure what is happening within the mode shape of the low speed part of the machine. Turning this option ON displays all portions of the model with equal emphasis.

Note:
It is important to be aware that in order to offset the side branches of the mode shape, the data for the mode shape is modified to incorporate the offsets. This means the mode shape data written to the worksheet cannot be used to diagonalize the system stiffness or inertia matrices without first removing the offsets.

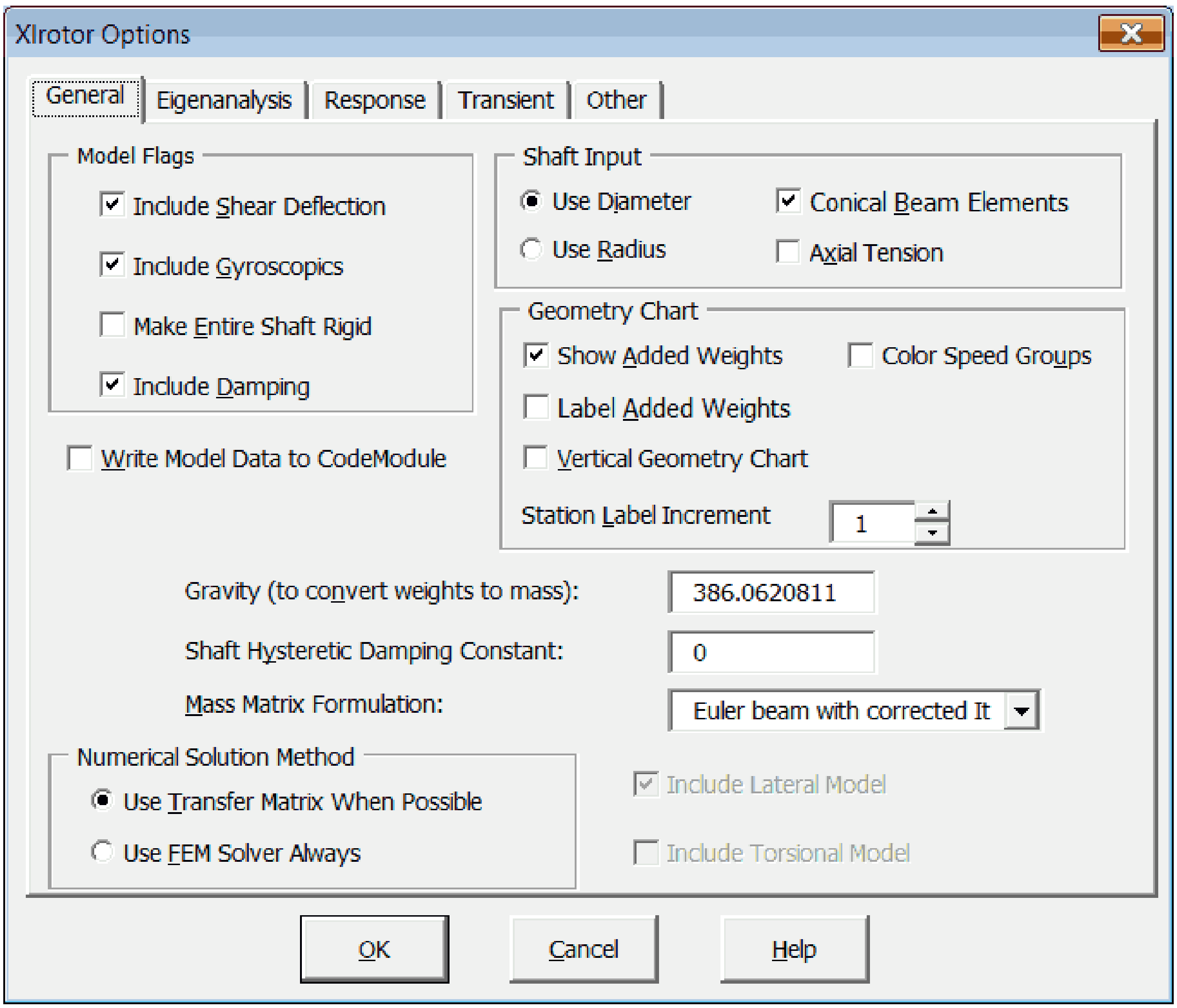
Mode Shapes per Plot (torsional models only)

This field controls how many torsional mode shapes are placed onto each of the mode shapes plots. This value must 3 or less in order to get normalized stress output for each mode shape (see Roots Tors Worksheet).

Options|General

See also

- XLRotor Menu Commands
- Options|Eigenanalysis
- Options|Response
- Options|Transient
- Options|Other
- Units in Xlrotor



This dialog is displayed by clicking the  toolbar or ribbon button, or selecting XLRotor/Options from the pull down menu. It contains a number of options which control certain actions of XLRotor. The settings for these options are stored in the rotor model file on a hidden worksheet. Any changes you make to the options in the dialog box affect only the currently active file. If you want any changes to be retained for your next session, you need to re-Save the file.

Note:
In future releases of XLRotor new options may be added to this dialog as well as others. When you open an old rotor model file with a new version of XLRotor, new options are automatically added to the rotor model file (see Adding Missing Options).

Include Shear Deformation

Put a check in this check box if you wish to include Timoshenko shear deformation in the elastic formulation for the shaft beam elements. This option would normally always be checked. However, should you ever wish to check the significance of shear deformation, or compare XLRotor results to another program without shear deformation, you can turn off this option.

Include Gyroscopics

Put a check in this check box to include gyroscopic effects during a rotor analysis. This includes all types of analysis performed by XLRotor (eigenvalues, mode shapes, and response). Normally this option would be turned on.

Make Entire Shaft Rigid

Put a check in this check box if you want to make the entire shaft perfectly rigid. Normally this option would not be turned on. Turn this option on only if you want to quickly compute results for the limiting case of a rigid rotor. This can be done in an exact fashion only when the TM solver is being used, the FEM solver cannot do this. So it is limited to use with single level rotor models, and you must have the ***Numerical Solution Method*** set to Use Transfer Matrix When Possible (see below).

Include Damping

Put a check in this check box to include damping due to bearings and seals for all rotor analyses performed by XLRotor. Normally this option would be turned on. When this option is off, the damping coefficients for the bearings and seals will be ignored for all rotordynamic calculations.

This option can be useful for heavily damped rotors when analysis results are difficult to interpret. For example, when one or more rotor modes are critically damped, it can be difficult to properly identify modes as being the "first" mode, "second" mode, etc.

Use Radius or Use Diameter

Select one of these two options according to how you want to input the shaft model geometry. The column headings on the Shaft Input Worksheet are set automatically according to your selection, and will appear either as:

	A	B	C	D	G
1	INPUT TABLE OF BEAM AND STATION DEFINIT				
2	Station	Length	ID	OD	Densit
3	#	mm	mm	mm	kg/m³
6	1	2	142	146	78

or as

	A	B	C	D	G
1	INPUT TABLE OF BEAM AND STATION DEFINIT				
2	Station	Length	IR	OR	Densit
3	#	mm	mm	mm	kg/m³
6	1	2	142	146	78

The values in the columns for shaft diameter or radius are not changed by the program, only the column headings are changed. The formulas on the Beams Worksheet that compute the inertia and stiffness properties of each beam will take into account your selection of diameter or radius for shaft input. This is done when you perform an Update|Beams command or an Update|Geometry Chart command.

It is ok to change the order of the columns. For example, the columns for inner and outer diameter can be reversed.

Conical Beam Elements

When this option is ***off***, shaft models are made up of cylindrical beams. Turn this option ***on*** to enable use of conical beam elements in the shaft model. When this option is ***on***, the two existing diameter columns on the Shaft Input Worksheet are assigned to the left end of the beam, and two new columns are added for the right end. The column headings are set to show that there are now inputs for both the left and right ends of every beam. Also, if the two columns for the right end diameters are either absent or empty when this option is turned ***on***, the program will automatically fill these two columns with cell formulas that set the right end diameters equal to their corresponding left end diameters.

	A	B	C	D	E	F	G
1	INPUT TABLE OF BEAM AND STATION DEFINITIONS, MORE THAN ONE						
2	Station	Length	ID Left	OD Left	ID Right	OD Right	Density
3	#	mm	mm	mm	mm	mm	kg/m³
6	1	2	142	146	142	146	7850

When this option is turned ***off***, the two right end columns are not actually deleted. They are hidden, which is done by setting their column widths to zero. When this is done the shaft input sheet will look as follows:

	A	B	C	D	G	H
1	INPUT TABLE OF BEAM AND STATION DEFINITIONS, MORE					
2	Station	Length	ID	OD	Density	Elastic Modulus
3	#	mm	mm	mm	kg/m^3	N/mm^2
6	1	2	142	146	7850	2.09E+0

The column letters in the figure indicate that columns E and F are still there, but are not visible. When the Conical option is turned ***on*** again, these columns will be made visible once again.

When the Conical option is turned ***on***, a column entitled **Beam CG** is added to the Beams Worksheet to display a dimensionless value between 0 and 1 for the center of gravity of the beam as a fraction of the beam length from the left end of the beam. Note that cylindrical beams will always have a value of 0.5 for their CG. This column is added because it will be needed by cell formulas on the Stations Worksheet.

LL BEAMS DEFINED IN MODEL						
xial cation	Beam Weight	Beam It	Beam Ip	Beam EI	Beam GA	Beam CG
mm	kg	kg-m^2	kg-m^2	N-m^2	N	
0	0.014205	3.68E-05	7.37E-05	490238.5	72730635	0.5
2	0.076288	0.000158	0.000316	3226089	6.01E+08	0.512931
3.3	0.21842	0.000421	0.00084	3702635	7.46E+08	0.521445

When the conical option is turned ***off***, the **Beam CG** column is hidden rather than deleted.

As expected, some of the cell formulas on both the Beams Worksheet and Stations Worksheet become more complex for conical beams as opposed to cylindrical beams. These formulas can be seen by clicking on the cells of these worksheets. The formulas for cylindrical beams are all exact expressions. For conical beams, some of the formulas on the Beams Worksheet are exact and some are approximate as follows:

Beam Weight	Exact
Beam It	Approximate, average of left end and right end cylindrical expressions, and is extremely close to a very complicated exact expression.
Beam Ip	Exact
Beam EI	Approximate, uses I that is average of left end and right end cylindrical expressions.
Beam GA	Approximate, uses A such that LA is the exact volume of beam.
Beam CG	Exact
Beam Stiffness	Exact. This is **for torsional models only**. This utilizes a very complicated expression, so a special function named Torsion_J is defined within Xlrotor which returns an exact value for J for use in a JG/L stiffness calculation.

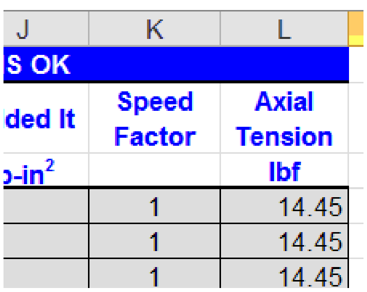
The formulas on the Stations Worksheet use the above values for individual beams along with the Beam CG value to apportion the beam values to opposing ends of each beam.

For rotordynamic calculations, the most important expression is that for Beam EI, which as stated above is approximate. Numerical tests have shown that this approximation is adequate as long as the basic assumptions of beam flexure are satisfied. This being that plane sections remain plane during deformation. If a beam element has a very steep cone angle, or a very thin wall thickness, out of plane warping may result which is not accounted for in beam flexure formulas. This means the true "bending" stiffness of the beam will be less than that calculated by Xlrotor.

Note:
The menu command Create Conical Beam Elements can be used to automatically create a series of stations with a linear taper.

Axial Tension

When this option is ***on***, the Shaft Input worksheet will be given an extra input column for specifying axial tension for each station. When this option is turned ***off***, the column is not actually deleted. It is hidden, which is done by setting its column width to zero. When multiple beams are input for the same station, axial tension is similar to axial length because it is a property of the station and therefore must be the same for each beam. However, unlike axial length, the axial tension can be input for the first beam, and left blank for the others.



J	K	L
S OK		
ded It	Speed Factor	Axial Tension
-in^2		lbf
	1	14.45
	1	14.45
	1	14.45

An example use of this option is for vertical pumps which have very long slender line shafts supported by very soft bushings. Gravity and impeller thrust would be the sources of axial tension. Another example is a long slender tiebolt (or drawbolt) used in construction of segmented rotor assemblies. Note that the input for tension would be positive in the bolt, and negative in the sections of the rotor compressed together by the bolt.

In built up rotors like the tiebolt example, a span in tension will have a parallel span in compression. These spans must be modeled as separate levels so the tension and compression can be specified separately for each span. It is also important that the two corresponding spans have the same total axial length (see Shaft Input).

The stiffness effect is linearly proportional to tension, and is related to the geometric properties of the beam, not its elastic properties. So the modulus values of a beam have very little influence on the effect of axial tension. In general, the effect is greater for slender beams (i.e. long length with small diameter).

Show Added Weights on Geometry Chart
Label Added Weights on Geometry Chart

Checks in these check boxes will cause any added concentrated weights to be displayed on the rotor model geometry chart. Changing the states of these options does not take effect until the next time you perform an Update|Geometry Chart command.

If you wish to remove added weights from an already existing geometry chart, you can turn off the option and Update the chart, or simply select the weights right on the chart, and press the Delete key on your keyboard.

Regular Excel chart data symbols are used to represent the weights, and regular Excel data labels are used to show the values. You can change the format of the chart symbol (type, size, color, etc.), and also the format of the data labels (font, size, position, orientation, etc.) using Excel's own formatting commands. Xlrotor will retain your changes on subsequent updates of the geometry chart.

In the added weight labels, only nonzero values are included. Also see GeoPlot Labels.

Station Label Increment

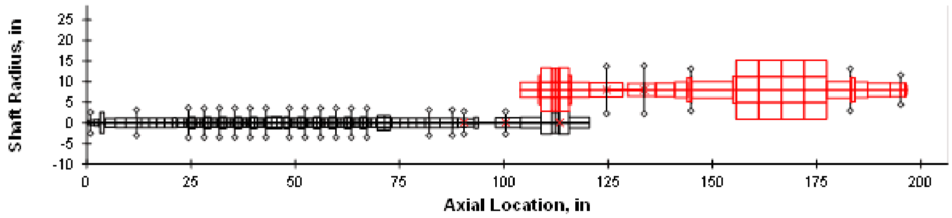
This value controls how many stations are labeled with their station number values. Use 1 to label every station, 2 to label every other station, and so on. The last station of each level is always numbered. A value of 0 suppresses all numbering. Using a large number, like 999, will cause only the first and last stations of each level to be numbered.

Vertical Geometry Chart

This option orients the geometry chart with a vertical centerline rather than the more typical horizontal centerline. This is a display property only, and has no affect on the way the model is analyzed, or the numerical results produced. For vertically oriented machines, the fact that they are vertical is generally accounted for only when selecting or computing the stiffness and damping coefficients for the bearings that support the rotor. Or for slender vertical rotors, shaft tension due to gravity may be included (see above).

Color Speed Groups

When this option is selected, each portion of the model with a distinct speed will be displayed with a different color. The following is an example of a torsional model where the Gear Ratio input distinguishes the high and low speed shaft lines. In a lateral model, the Speed Factor input will distinguish the various groups.



Write Model Data to CodeModule

When this option is selected, each time an analysis is executed the data from the model is written to the Code Module of the results worksheet. This is similar to what gets written to the XLROTOR.TXT Analysis Tracking File. This option is useful for documenting the exact state of the model when you do an analysis. In Excel, every worksheet has a Code Module. To see the contents of the code module right click on the sheet tab and select View Code. When this option is turned on, a macro with the name **Write_Model_Input_Data** will be present. To run this macro click on any line in the macro and press F5. This will create and open a text file in your default text editor.

Gravity

This input allows XLRotor to be used with any system of consistent units. Later, you will enter weights, weight density, and rotational inertia in units of weight-length^2. These inputs are called "weights" because they will be divided by Gravity before they are used to perform the rotordynamic analysis.

For models using SI units of (m-N-kg) or (mm-N-kg), this input should be 1 because density and added weights on the Shaft Input sheet use kg. So no conversion from weight to mass is necessary.

For models using *customary* US units of (in-lbf-lbm), this input should be 386.08858 (i.e. 9.80665/0.0254) because density and added weights on the Shaft Input sheet use lbm, and these must be divided by 386 to convert weight to mass.

For models using *consistent* US units of (in-lbf-sn), this input should be 1 because density and added weights on the Shaft Input sheet use snails (1 snail = 1 lbf-s^2/in, and no conversion from weight to mass is necessary.

Shaft Hysteretic Internal Damping Constant

This value specifies the hysteretic internal damping constant for the entire rotor. In general, a nonzero value like .01 to .05 can be used for rotors which are suspected to possess large amounts of internal damping. For example, built up rotors which have joints that are loose at high speed.

Be aware that hysteretic damping does not discriminate on frequency. **All** forward whirling modes, <u>*superscynchronous and subsynchronous*</u> alike, will have their damping factors reduced by hysteretic damping (i.e. less stable). By contrast, all backward modes will be more damped. Also, hysteretic damping will have very little, if any, influence on synchronous imbalance response.

Mass Matrix Formulation

Selections for formulating the system mass matrix are ***Standard Euler Beam***, ***Euler Beam with Corrected It***, and ***Consistent Mass***. The only difference between the first two options is the inclusion of the correction term (-0.25*bswt*slength^2) in the ***Beam It*** column on the Stations Worksheet. Where bswt is the weight of the beam, and slength is its axial length.

When using one of the two lumped mass options, half the weight of each beam is lumped at the stations at each end of the beam. Lumping the weight in this fashion creates a small additional amount of ***It*** for each element. When adding up all the ***It*** contributions for the entire rotor, this results in what is typically a small error in the ***It*** value for the entire rotor.

The correction term is used to eliminate this error. However, this term can result in the ***It*** value being negative for individual beams when the L/D ratio for the beam is more than about 0.6. In spite of this, using the corrected formulation generally improves the convergence qualities of the Euler beam element for rotordynamic shaft models.

Negative values for ***It*** can cause the model to have spurious eigenvalues associated with the negative ***It*** values. But these eigenvalues are normally very large in magnitude, and so normally do not appear in the output list of roots. Computing large numbers of roots in relation to the number of stations in the model can cause some of these spurious roots to appear in the output list. If you want to avoid having negative ***It*** values in your model, simply maintain all your element L/D ratios to be less than 0.6, or use the ***Standard Euler Beam*** option.

The ***Consistent Mass*** option was introduced in XLRotor 4.0. When this option is selected, the program does not use the values from the ***Beams*** and ***Stations*** worksheets. Instead, a more sophisticated finite element formulation for a conical element is employed. The element formulation is detailed in the following publications, as well as others.

G. Genta and A. Gugliotta, A Conical Element for Finite Element Rotor Dynamics, Journal of Sound and Vibration (1988) 120(1), 175-182.

M.A. Mohiuddin, Y.A. Khulief, Modal Characteristics of Rotors Using a Conical Shaft Finite Element, Computer Methods in Applied Mechanics and Engineering, 115 (1994) 125-144.

Erik Engdahl, Finite Element Modelling of Conical Sections in Rotordynamics, Chalmers University of Technology, MS Thesis, 1997.

Numerical Solution Method

Xlrotor has two built in solvers for eigenanalysis and linear response; a ***Transfer Matrix*** solver and an ***FEM*** (Finite Element Method) solver. The ***Transfer Matrix*** solver is extremely fast, but is limited to single level models, and is also sometimes limited in its ability to handle excessively flexible rotors and/or too many overly rigid bearings.

The ***FEM*** solver is automatically used on all multi level models regardless of the setting of this option. The ***FEM*** solver takes longer to execute than the ***Transfer Matrix*** solver, but it is not limited with regard to shaft flexibility or bearing stiffness.

In normal circumstances, results with the two methods are practically identical. See below.

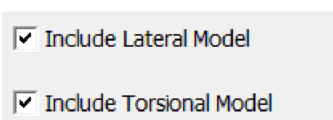
If the ***FEM*** option is selected in a rotor model file created with an older single level version of Xlrotor (i.e. XLRotor version 1.x), you may be prompted to automatically add some model input fields required to use this option.

The ***FEM*** solver is also used automatically whenever there are RIGID, PINNED or GUIDED connections in the model, or when performing a Run|Static Deflection command. It is also used when either the ***Consistent Mass*** element formulation or ***Axial Tension*** options have been selected (see above).

If the roots being plotted in a damped natural frequency map or undamped critical speed map appear erratic, this can be due to the numerical limitations of the ***TM*** solver. In addition, when computing mode shapes this can cause the program to display a warning that a boundary condition check has failed for the mode shape. If either of these symptoms occur, select the ***FEM*** solver option to force the program to use that method instead. These things can happen with the ***TM*** solver in rotor models that have extremely rigid bearings (compared to the shaft). Or when the model has more than two bearing locations such as when analyzing two or three coupled machines in a single model, or long vertical pumps with multiple line shaft bearings.

If the eigenvalue plots do not look erratic, and there are no warnings displayed during mode shape generation, then the ***TM*** solver is working satisfactorily.

Include Lateral / Include Torsional

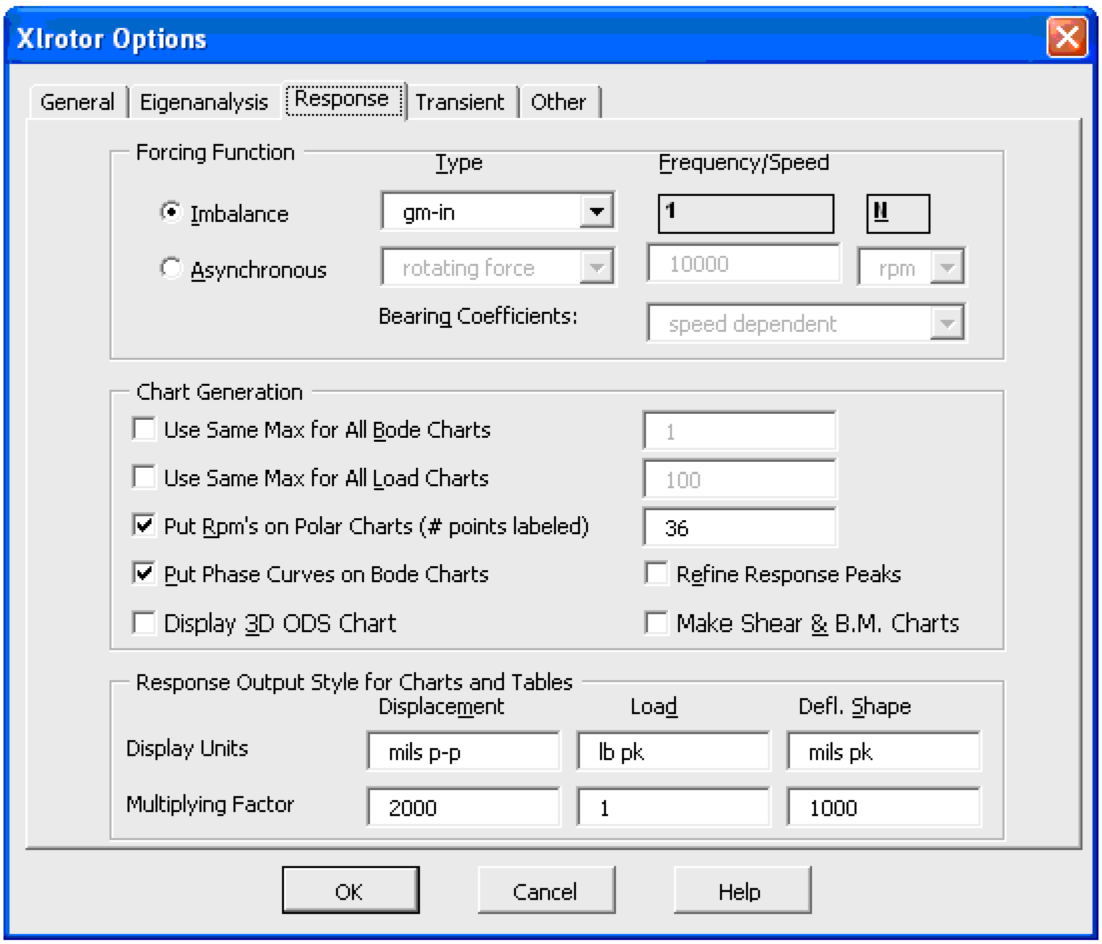


These two options are enabled only for lateral-torsional coupled analysis in an XLCoupled file. When both are selected, all analysis is performed with the full coupled system. To do an analysis with only the lateral part or torsional part, select just that part. At least one must be selected.

Options|Response

See also

- XLRotor Menu Commands
- Options|General
- Options|Eigenanalysis
- Options|Transient
- Options|Other
- Resp Worksheet



This dialog is displayed by clicking the  toolbar or ribbon button, or selecting XLRotor/Options from the pull down menu. This dialog box contains XLRotor options used in computing response to imbalance, or response to asynchronous forcing functions. The settings for these options are stored in the rotor model file on a hidden worksheet. Any changes made to the options in the dialog box affect only the currently active file. For changes to be retained between sessions, the file must re-Saved.

Forcing Function

Select between Imbalance and Asynchronous forcing functions by selecting the corresponding option button.

> **Imbalance** - Select this option to compute response to rotating mass imbalance. Most often this is the type of response analysis you will want to run. The forcing function will be defined by imbalances entered on the Imb's Worksheet. The resulting forces applied to the rotor will increase with the square of the rotor speed, and the frequency of the applied forces equals the rotor speed (i.e. synchronous). This option is just a special case of the asynchronous option discussed next. It could be duplicated by selecting Asynchronous Type=***imbalance*** with the excitation applied at ***1N*** frequency.
>
> **Asynchronous** - Select this option to compute response to forces which have frequencies different than the rotor speed. Examples would be blade or vane pass frequencies, or excitations coming from other nearby machines running at different speeds. When this option is selected, the columns of rotor speed and deflected shape speed on the Imb's Worksheet then specify excitation frequency in cycles per minute. The speed of the rotor is specified by the adjoining options (see below). Deflection due to static forces can be computed by using an excitation frequency equal to zero (the actual running speed of the rotor is specified separately).

Imbalance/Type

This is a drop down list of options for imbalance units. Currently there are 5 choices.

- gm-in
- oz-in
- W-L (input value will be divided grav and applied directly to the model)
- m-L (input value will be applied directly to the model)
  kg*meters for models in SI units
  (lbf-s^2/in)*inches for models in English units
- gm-mm

Note that the imbalance angles are always in degrees.

The units selected from the list are copied to the top of the column **Imbalance Amount** on the Imb's Worksheet.

Note:
Changing the units in the dialog box does not change the imbalance *values* on the Imb's Worksheet. When units are changed, the imbalance values must be changed to be in terms of the new units.

Asynchronous/Type

This is a drop down list of options for asynchronous forcing functions. There are 3 choices. The amounts entered on the Imb's Worksheet will take on units of either force or imbalance, depending on the asynchronous type which is selected. In the case of a force, the force units are consistent with the system of units of the rotor model (i.e. lbf or Newtons).

1. **rotating force** - The forces entered on the Imb's Worksheet will be applied to the rotor as rotating forces, constant in magnitude at all frequencies. The phase angle input has the same meaning as that for specifying imbalance.

3	Imbalance Station	Imbalance Amount	Imbalance Phase	Imbalance Type
4		rotating force	degrees	[F,M,X,Y]
5	1	1.3	180	Y
6	2	2.6	180	Y

2. **oscillating force** - The forces entered on the Imb's Worksheet specify stationary harmonic forces, constant in magnitude at all frequencies. For Imbalance Types of **F**orce or **M**oment, the input angle is used to specify the orientation of the force, and the temporal phase angle is zero. The phase angle input is lagging, so 0 degrees means the force is applied to the rotor in the +x direction, +90 degrees means -y direction. One use for this option is to compute response to static forces by setting the excitation frequency to zero on the Imb's Worksheet. For Imbalance Types of **X** or **Y**, the phase angle input is temporal and lagging.

3	Imbalance Station	Imbalance Amount	Imbalance Phase	Imbalance Type
4		oscillating force	degrees	[F,M,X,Y]
5	1	1.3	180	Y
6	2	2.6	180	Y

3. **imbalance** - The amount is an imbalance in whatever units are currently selected for specifying imbalances. The speed(s) used to compute the rotating imbalance force are the values in the "Response Speeds" column. This option is useful for multi-spool rotors when the rotating imbalance is on one of the rotors whose Speed Factor is not equal to one.

Asynchronous / Frequency/Speed

These two inputs allow you to specify how the rotor speed is related to the asynchronous excitation frequency. The rotor speed can either be a constant rpm value, or a multiple (or submultiple) of the excitation frequency.

For example, with an input value of **10000** and **rpm** selected from the drop down list, the rotor speed will be held constant at 10000 rpm while the excitation frequency varies. The rotor gyroscopic forces will correspond to the 10000 rpm rotor speed. The bearing coefficients will also correspond to 10000 rpm if you select **speed dependent** in the **Bearing Coefficients** drop down list (see below).

As another example, with an input value of **4** and **N** selected from the drop down list, the excitation will be 4N, and the rotor speed will be 1/4th of the excitation frequency.

Asynchronous / Bearing Coefficients

> **speed dependent -** Bearing coefficient values are usually *speed dependent,* and this is the normal selection for this option. This means that all bearing worksheets in the model describe how the bearing coefficients vary with rotor speed. When an asynchronous response analysis is performed, the bearing coefficients are determined from the current value of rotor speed, which is governed by the ***Frequency/Speed*** option described above.
>
> **frequency dependent** - This is an advanced analysis option. You can have the bearings be considered *frequency dependent* instead of speed dependent. Then, during the asynchronous response analysis, as the excitation frequency is varied, the bearing coefficients will also be varied, independent of the rotor speed.

When this option is set to **frequency dependent**, all bearings worksheets in the model are used to describe how the bearing coefficients vary with excitation frequency in cpm as opposed to rotor speed in rpm. The rpm values that appear on all bearing worksheets will then actually correspond to the asynchronous excitation frequency. This means that as the asynchronous excitation frequency is varied, the bearing coefficients will also vary.

Use Same Max for All Bode Charts

When this option is checked, all subsequent charts of displacement response vs. rotor speed will be created with the same maximum scale value on the y axis. Enter the desired max scale value in the input box to the right of the check box.

Note:
This option also affects deflected shape charts, in which case the y axis scale extends from -FSV to +FSV, where FSV is the full scale value entered in the dialog box. If you do not want the deflected shape charts scaled this way, you need to turn off the option prior to executing the Run|Deflected Shapes command.

Use Same Max for All Load Charts

When this option is checked, subsequent charts of bearing load versus rotor speed are created with the same maximum scale value on the y axis. Enter the desired max scale value in the input box to the right of the check box.

Put RPM's on Polar Charts

When this option is checked, polar charts of response will be created with rpm labeling applied to the data series. Using the pull down menu, toolbar or ribbon, you can switch a displacement response chart back and forth between bode and polar formats (see Bode/Polar/Orbit Switch).

The value in the input box to the right of the check box is for controlling how many of the points on the curve get labeled with rpm values. For example, if 15 is entered, the spacing between labeled points will be approximately 1/15th the size the chart. A value of 20 will result in more points being labeled. A value of 10 would be fewer points.

Put Phase Curves on Bode Charts

When this option is checked, bode charts of displacement response will be created including curves showing phase data. The horizontal and vertical phases are plotted using a secondary Y axis (i.e. right). The format of the right Y axis can be set to a fixed range of -720 to +360 degrees so that the phase curves are always at the top of the chart. If you wish, you can change this or any other format by editing the XLRGRPH.XLS chart template file (see XLRGRPH.XLS Chart Template File).

When you use the pull down menu command Bode/Polar/Orbit Switch to switch a polar chart back to bode form, phase curves will be included according to the current setting of this option.

Display 3D ODS Chart

As part of a Run|Deflected Shapes analysis, when this option is checked, a true 3D chart of the operating deflected shape is generated on the Resp Worksheet.

Refine Response Peaks

When this option is checked, all peaks in the displacement responses will be checked to make sure they have at least 6 points between the half power points of the peak. For any peak found lacking enough points, extra speeds will be automatically calculated so the peak will satisfy the 6 point requirement. To be considered a peak, a peak first must have a half power point to both the left and right of the peak. This means your list of response speeds (on either the **Imb's** or **Orders** worksheets) must have at least enough points for the peak to be detected.

Make Shear & Bending Moment Charts

As part of a Run|Deflected Shapes analysis, when this option is checked, shear and bending moment diagrams are generated on the Resp Worksheet.

Response Output Style for Charts and Tables

This series of input boxes allows you to control the style of response output XLRotor produces. The *Units* are strings which are copied to all subsequently created charts and tables of response. The *Factors* are multiplied by the raw response values. You can independently control the styles for bode, bearing load, and deflected shape responses.

This feature allows you to choose among styles such as: peak, peak-to-peak, rms, microinches, mils, etc. You can also execute a conversion of the reported output to another system of units (like SI).

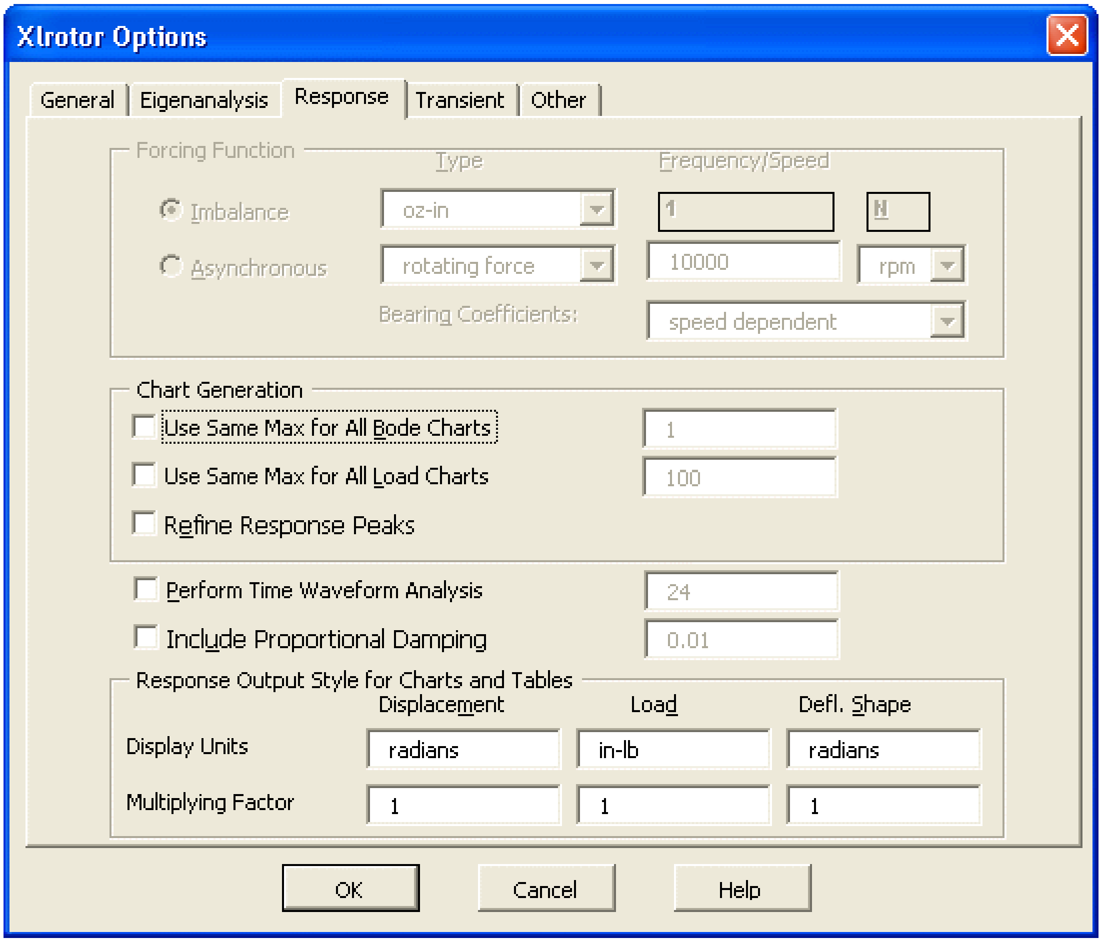
When your model is setup in English units using inches, response results are computed in inches. Models setup in SI units using meters yield response results in meters. Models setup in SI units using mm also yield response results in meters. Here are some example combinations that can be used for the ***display units*** and ***multiplying factor***:

"inches"	1.0
"mils"	1000
"mils pk"	1000
"mils pk-pk"	2000
"in rms"	0.7071
"mils rms"	707.1
"m pk-pk"	2.0
"mm pk"	1000
"um p-p"	2000000

Note:
The *Units* string for displacement are invoked during a Bode/Polar/Orbit Switch. XLRotor will not allow the switch if the option setting in the dialog box setting does not match what is on the chart. However, only the *Units* are checked - not the *Factor* (the *Factor* is not used during a Bode/Polar Switch).

Torsional Models

The dialog box shown at the beginning of this section appears when working with a lateral analysis rotor model file. When working in a ***torsional*** analysis rotor model file, it appears as follows. Options that do not apply are grayed out, and a few new options appear that are specific to torsional analysis.



Perform Time Waveform Analysis

As explained on the Orders Worksheet, the output of torsional responses is done by summing the absolute response value for each order. An alternative to this approach is to construct a composite time waveform by superimposing all harmonics, and output the maximum and minimum values determined from that waveform. Putting a check in the box will enable this option. This is a post-processing operation. When a Run|Response calculation has finished, and before output of results, the time waveforms are constructed and analyzed for max and min values. These max and min values are output to the Resp Worksheet as a function of operating speed. Data versus crank angle at individual operating speeds can also be output by using the Run|Deflected Shapes command.

The time waveform that is constructed will span a length of time equal to the period of the lowest input Order value which is greater than zero and less than 1. The time increment is equal to the period of the highest input Order value divided by the value input in the above dialog box. 24 is the recommended value since this provides a fine enough point spacing to determine the peak of a sine wave of the highest Order within 1% accuracy. For example, if 24 is the input value, and the highest order in the analysis is 6, then 24*6=144 will be the number of points per revolution with an angle increment of 2.5 degrees.

If exactly 360 is entered for the number of points, then a point increment of exactly 1 degree will be used for 1 revolution. If exactly 720 is entered, then a point increment of exactly 1 degree will be used for 2 revolutions.

Include Proportional Damping

This option applies **only** to the Run|Response and Run|Deflected Shapes types of analysis for torsional models. It does not apply to Run|Eigenanalysis or Run|Transient analyses, and it does not apply to lateral models.

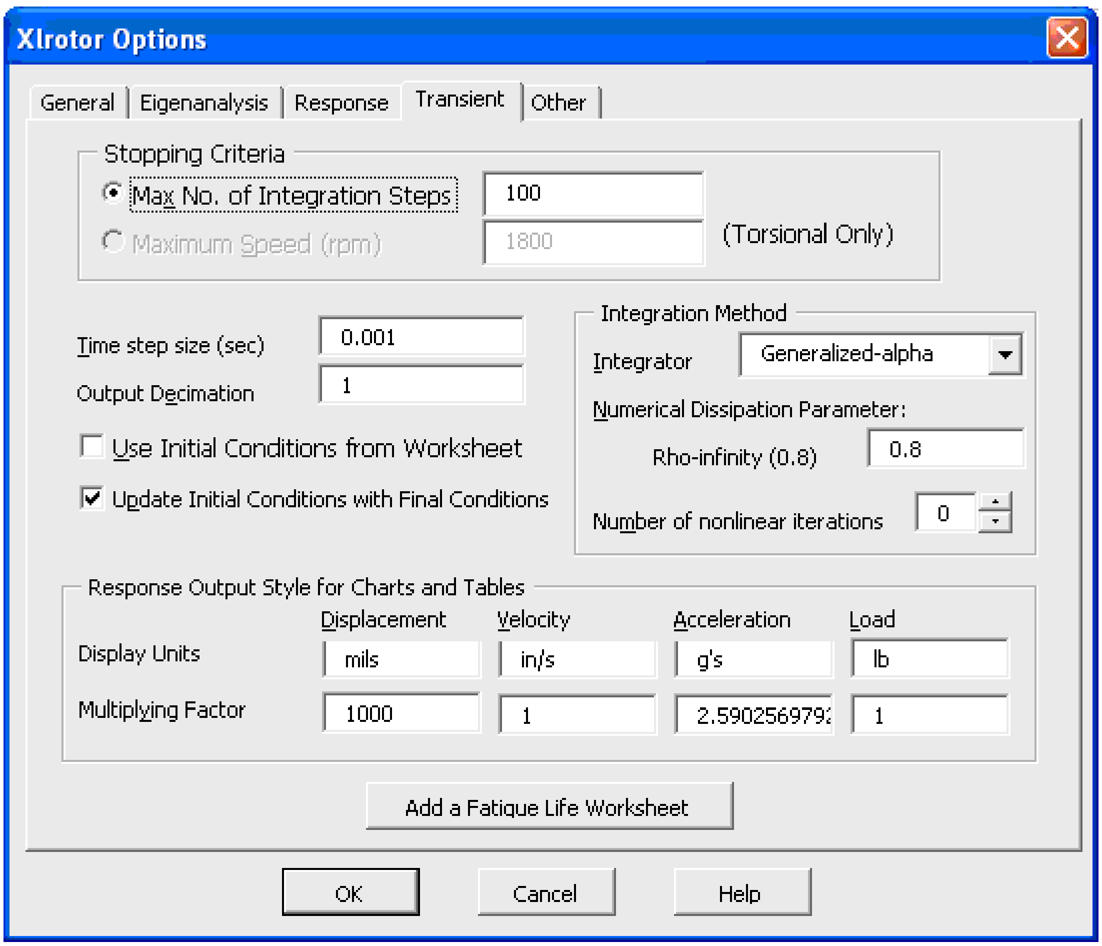
Viscous damping can be added to a torsional model by inputing damping constants on the Cplg's Worksheet. Note that viscous damping on the Cplg's sheet is constant and does not depend on the frequency of vibration.

In addition to Cplg's sheet damping, proportional damping can be defined as a damping ratio entered in the accompanying input field of the Options dialog box shown above. For example, if the option is turned on and 0.01 is entered, then 2*(0.01)*K/(omega) where K is the fully assembled system stiffness matrix, is added to the system damping matrix. Omega is the frequency of vibration. This type of damping is sometimes called "stiffness proportional damping" or "internal damping." If no additional damping is defined on the Cplg's Worksheet, then response peaks at all resonant frequencies will exhibit a damping ratio equal to the damping ratio value specified in the dialog box.

Options|Transient

See also

- XLRotor Menu Commands
- Options|General
- Options|Eigenanalysis
- Options|Response
- Options|Other
- Transient Worksheet
- Transient Resp Worksheet
- Fatigue Life Worksheet



This dialog box contains XLRotor options used in computing transient response to arbitrary forcing functions. The settings for these options are stored in the rotor model file on a hidden worksheet. Any changes made to the options in the dialog box affect only the currently active file. For changes to be retained between sessions, you need to re-Save the file.

Stopping Criteria

This option dictates how the integration will be halted.

> **Max no. of integration steps** - Select this option and enter the number of integration steps. This must be a positive number. Typical values might be several hundred to several thousand (see Note below). For lateral analysis rotor models, this is the only option available.
>
> **Maximum speed** - This option is available only for torsional analysis rotor model files. When selected, enter the maximum speed for station number 1. The integration will proceed until either this speed is reached, or the maximum number of integration steps is reached. This option is useful if you are integrating the start-up transient of a machine.

NOTE: Be aware that the computed results will be placed on a worksheet. Excel 2003 allows a maximum of 65536 rows on a worksheet, and a maximum of 32000 points in a chart series. Use the Output Decimation field to reduce the number of data points written to the worksheet. Excel 2007 and later greatly increases these limits, but the XLRotor file must be saved in the .xlsb format instead of the .xls format.

Time Step Size

This is the integration step size in seconds. The step size remains fixed for all available integration methods except Rosenbrock (see below). Generally, the step size dictates the frequency range of the analysis. Theoretically, all modes respond to the applied forcing functions. But response of higher modes are often not significant. For the response of a mode to be integrated accurately, the time step should be 1/10th to 1/20th of the period of the mode. The integration methods used by XLRotor tend to suppress (i.e. damp) the response of higher modes. First, decide how high a frequency you wish to go in capturing system response, then select the time step size accordingly. This approach to selecting the step size works well for linear models. For nonlinear models, numerical instabilities can sometimes occur if the step size is too large. Thus it is sometimes necessary to further reduce the step size to achieve a stable integration.

Output Decimation

Enter an integer value greater than or equal to 1. A value of 1 means every computed time step is output to the results worksheet. A value of 2 means every second time step is output, etc.

Use Initial Conditions from Worksheet

When this option is checked ON, the program will attempt to read initial conditions for displacement, velocity and acceleration for every station in the model from the Transient Worksheet.

When this option is not checked, which means it is OFF, the program will use zero for initial displacement and velocity, and it will compute the initial acceleration from the external forces present at t=0.

Update Initial Conditions with Final Conditions

When this option is checked ON, the program will, at the successful completion of the integration, write the final conditions of displacement, velocity, and acceleration to the Transient Worksheet. Any initial conditions that may already be there are overwritten.

Integration Method

Select one of the available integration methods. All of the methods used by XLRotor are implicit methods, and each allows you to specify one controlling integration parameter. All the methods are unconditionally stable for linear models.

Wilson-Theta, optimized - The numerical dissipation parameter is known as Theta for this family of methods, and should be in the range of 1 to 1.5. The default value is 1.4. When Theta is one, this method is equivalent to the undamped Newmark trapezoid method. This method has two other integration parameters. These are referred to as Alpha and Beta in many textbooks, and these are selected for you automatically from your input value of Theta in order to optimize the amount of high frequency numerical dissipation.

Newmark, undamped - The numerical dissipation parameter for this family of methods is called Beta. The default value is 1/4. When beta is input as 1/4 this method is also known as the average acceleration method, or trapezoidal method. When Beta is 1/6 this method is also known as the linear acceleration method. The other Newmark integration parameter is called Gamma, and is always set equal to 1/2. Whenever Beta is not equal to 1/4, this method becomes only conditionally stable.

Newmark, damped - The numerical dissipation parameter for this family of methods is called Gamma, and the default value is 0.6. For this method to be unconditionally stable, Gamma must be equal to or greater than 1/2. The greater the value of Gamma, the greater the numerical dissipation. The other Newmark integration parameter, Beta, is selected internally to optimize the amount of numerical dissipation.

Generalized Alpha - The numerical dissipation parameter for this family of methods is called Rho, and the default value is 0.8. Values smaller than 0.8 result in more numerical dissipation. The value entered must be greater than zero, and less than or equal to 1. When rho=1 the method is undamped, and is equivalent to the undamped Newmark trapezoid method.

Rosenbrock - This method is known as a "stiff"' integration method. This is the only method in XLRotor that offers automatic step size control. Here the controlling parameter is the absolute local error tolerance. A good choice for the error tolerance is that which results in the method eventually selecting a time step size that is about 1/10th of the period of the highest frequency mode you want to integrate accurately. This method takes the longest to execute for a given number of time steps. Try this method when your model is nonlinear, and the other methods are forcing you to use extremely small time steps to achieve a stable integration.

The time step size which you specify is used as the initial step size, and the method varies it up or down as needed. However, the most that the program will increase the step size is a factor of 1000.

When you enter a local error tolerance value of 1, the time step size is kept constant.

Number of Nonlinear Iterations

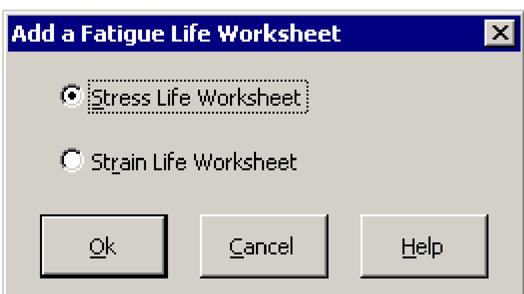
Because the methods used by XLRotor are implicit, models which are nonlinear usually benefit from some iteration on the calculation of the nonlinear forces within each time step. This input specifies the number of iterative refinements to perform during each time step. Typical values for this would be 0, 1 or 2.

Response Output Style for Charts and Tables

These inputs are similar to those found on the Options|Response dialog. They allow you to specify what units to use for output.

Add Fatigue Life Worksheet

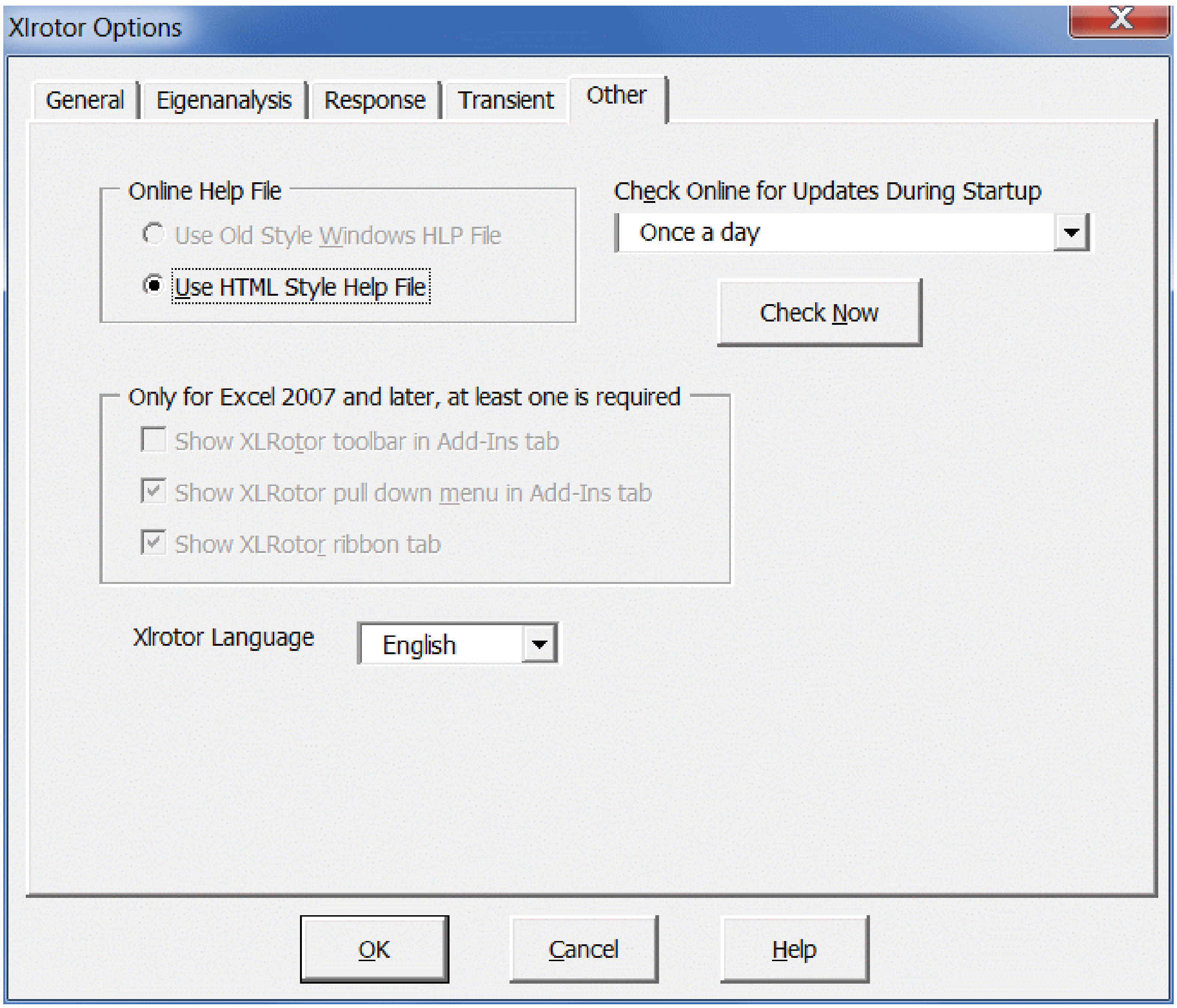
This button adds a fatigue life worksheet to your file. This feature is generally used only for torsional models. When the button is clicked, the following dialog is displayed. See Fatigue Life Worksheet for more information.



Options|Other

See also

- XLRotor Menu Commands
- Options|General
- Options|Eigenanalysis
- Options|Response
- Options|Transient
- Units in Xlrotor



This dialog is displayed by clicking the  toolbar button, or selecting XLRotor/Options from the pull down menu. The settings on this tab are system-wide settings which are saved in an XLROTOR.INI file located in the XLRotor Data folder. These settings are not saved with your individual XLRotor files.

Online Help File

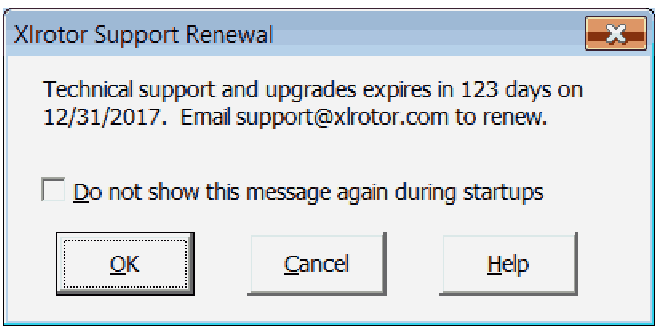
Old style Windows help files have an HLP file extension.   Starting with XLRotor 5.0 this format is no longer supported in XLRotor because of security concerns about this file format.

XLRotor's online help is in a compiled HTML help file named XLRotor.chm.   The entire help file is also available in a single pdf file at Start/All Programs/XLRotor/XLRotor Manual (pdf).

Check Online For Updates During Startup

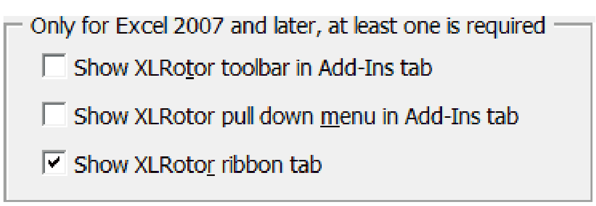
The program can check over the internet for new software versions automatically.   An internet connection is required.   If a newer version is detected, a message is displayed. Otherwise no message is displayed.   You can also manually check for new versions by clicking the button in this dialog, or by using the Check for Updates menu command.

Whenever an online check for updates is performed, the program also checks the current expiration date of your technical support contract, and when appropriate will display a reminder to renew.   These notices may appear in the last 30 days before expiration, and after it has expired.   The following example shows that the message can be disabled (the setting for this is saved in the Windows registry).



Only for Excel 2007 and Later

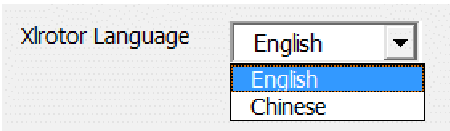
These option check boxes are enabled only for Excel versions Excel 2007 and later.   In versions earlier than Excel 2007, the XLRotor Toolbar and pull down menu always appear in the Excel workspace.   Excel 2007 and later uses a Ribbon interface.   In the ribbon interface the XLRotor toolbar and menu appear on the Add-Ins tab of the Excel Ribbon.



XLRotor also has its own ribbon tab that provides access to all features of the program. Most users will probably want to turn off the toolbar and menu, and use only the ribbon tab.   See XLRotor Toolbar for sample images of the XLRotor ribbon tab.

XLRotor Language

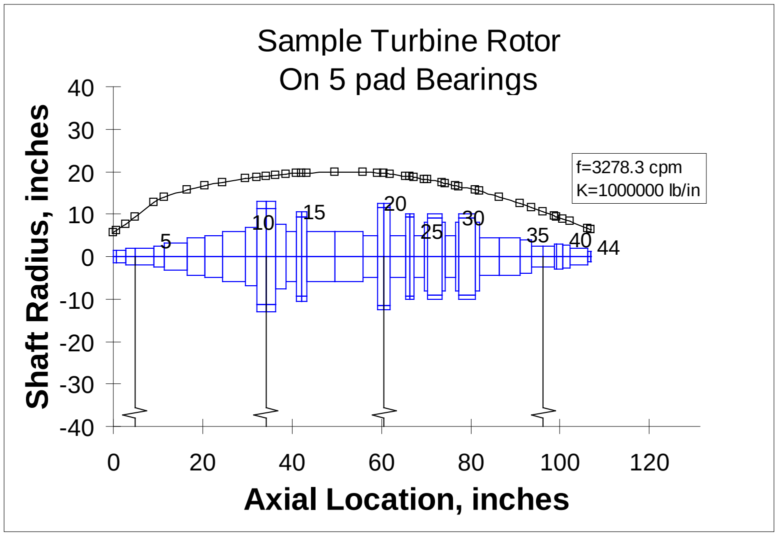
Two languages, English and Chinese, are available for display of many of the user interface elements. This includes the XLRotor custom ribbon tab, the XLRotor pull down menu on the Add-Ins ribbon tab, and many of the dialog boxes displayed by XLRotor. When the language is changed, the new language will be displayed the next time XLRotor is started.



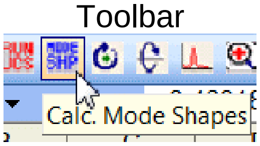
Overlay Geometry on Mode Shape

See also

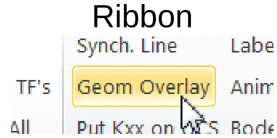
[XLRotor Menu Commands]



Toolbar



Ribbon

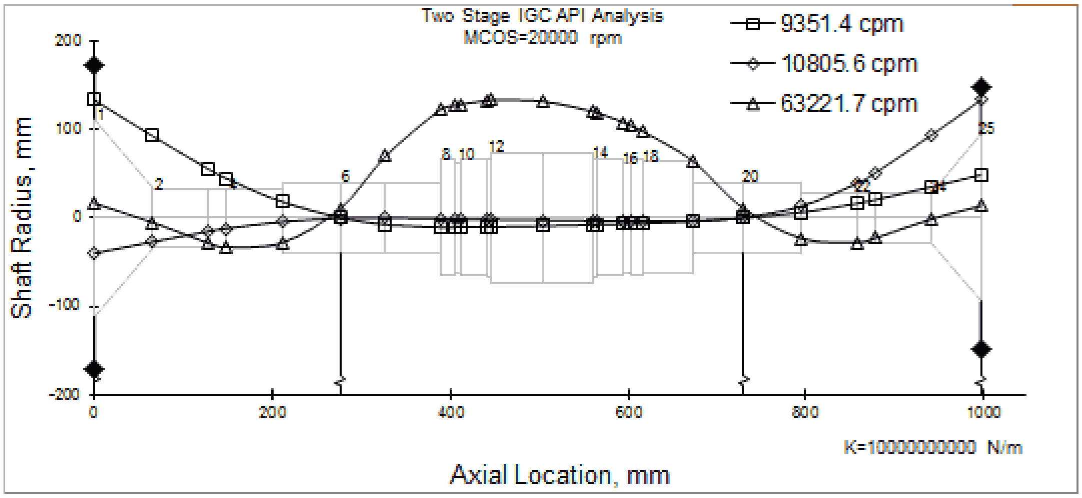


This command can be run from the XLRotor pull down menu for charts, or from the XLRotor toolbar, or XLRotor ribbon. It will create a new chart of the rotor geometry, overlaid with a selected mode shape. Start by clicking on the mode shape chart you wish to use for the overlay (either a 2D or 3D chart is okay, see Shapes Worksheet). Then run this command. XLRotor will place a copy of the Geo Plot Chartsheet in front of the selected mode shape chart, and add the dominant component of the complex mode shape to the chart on a secondary y axis.

After the overlay chart is created, additional mode shape data series can be added to the chart using standard Excel charting techniques. This makes it easy to show, for example, the first three mode shapes superimposed on the geometry chart.

The geometry can be overlaid on multiple mode shape charts in one operation. Click on one chart, then hold down the Shift key and click on additional charts. Then click on the XLRotor toolbar button . This method also works with imbalance response deflected shape charts.

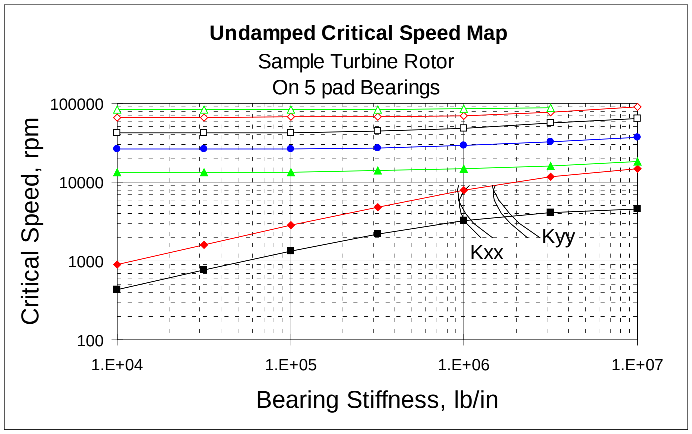
Multiple mode shapes can be plotted together in a single plot by holding down the shift key when clicking the  button.


Two Stage IGC API Analysis
MCOS=20000 rpm
9351.4 cpm
10805.6 cpm
63221.7 cpm
Shaft Radius, mm
200
100
0
-100
-200
0
200
400
600
800
1000
K=10000000000 N/m
Axial Location, mm

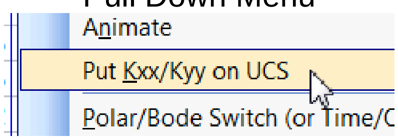
Put Kxx/Kyy on UCS

See also

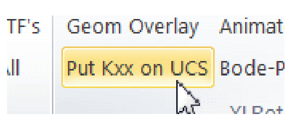
XLRotor Menu Commands
Run|Undamped Crit. Spds
Brg's Worksheet



Pull Down Menu



Ribbon



This command is used on Undamped Critical Speed charts only. It will add data series to the chart showing the bearing direct stiffness as a function of speed. The bearing stiffnesses are the x values, and the rotor speeds are the y values. Data series for both the Kxx and Kyy values will be added to the chart, and the first data point of each series will be labeled with either "Kxx" or "Kyy".

Referring to the Brg's Worksheet, any bearing which has a non zero value for ***UCSFactor*** will have its Kxx and Kyy data added to the UCS chart. Usually, only two bearings will have nonzero UCSFactors - for seals and impellers these will generally be zero.

Quick Bearings (see Brg's Worksheet) are not added to the UCS chart by this command.

If the model uses the same bearing worksheet for more than one bearing (a common situation when two journal bearings have the same geometry and static load), the program will only add one instance of the bearing data to the chart.

Once the bearing stiffnesses have been added to the chart, re-running the UCS analysis will cause the bearing stiffnesses to be updated. If you decide you no longer want them on the chart, you can either delete the data series from chart yourself, or simply delete the entire chart and re-run the UCS analysis which will make a new chart.

It is quite common, although not required, to use logarithmic scales for this plot. When the plot has log scales, take care to assure that all speed and stiffness values on the bearing worksheet are positive. Should you want to plot zero or negative values, use linear plot scales.

Note:
After running this command, you can delete any of the "Kxx" labels, or any of the series themselves, by merely selecting them with your mouse and pressing the Delete key. You can also change their display formats by double clicking them with the mouse, or reposition them by dragging them with the mouse.

Run|Eigenvalues

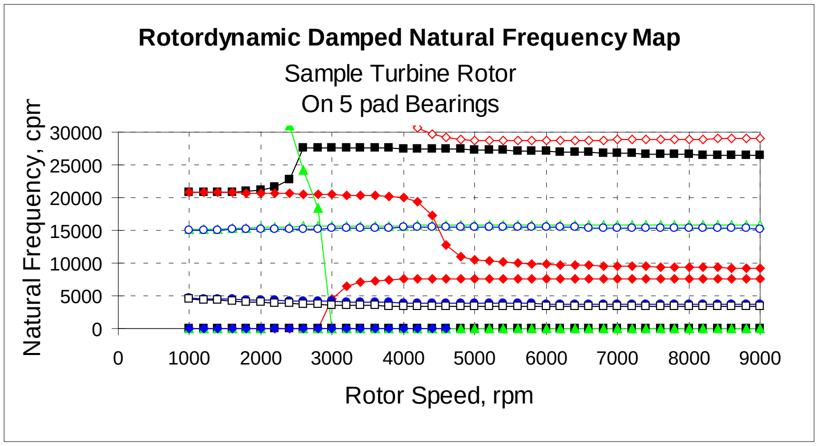
See also

Run|Undamped Crit. Spds
Run|Free Free Modes
Run|Mode Shapes

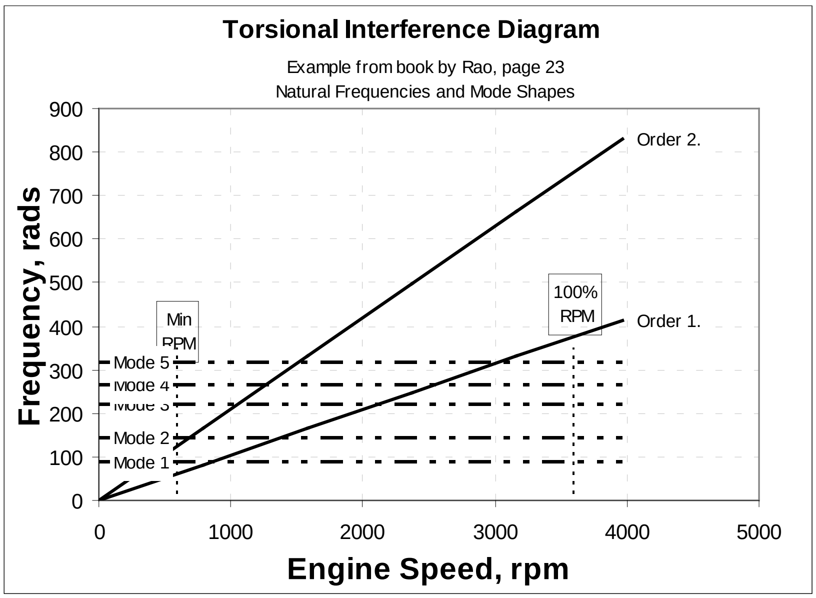
XLRGRPH.XLS Chart Template File

XLRotor Menu Commands
Options|Eigenanalysis
Torsional Analysis with XLRotor
Coupled Lateral-Torsional Analysis
Roots Damped Worksheet

Critical speed map for a lateral rotor model

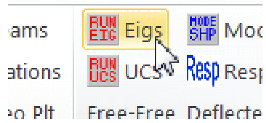


Torsional interference diagram for a torsional rotor model (see Roots Tors Worksheet)



Toolbar

Ribbon



This command starts a ***damped eigenvalue*** calculation. Damped eigenvalues will be computed for each rotor speed listed in the "EIGEN ANALYSIS SPEEDS" column on the XLRotor Worksheet. The current rotor model and bearing definitions are used for the analysis. If any of the bearings reference other files that are not open, XLRotor will open them.

The analysis results are a table of roots showing the real and imaginary parts, and one or more charts showing the roots. See Options|Eigenanalysis for your options on what charts are created. The table and chart(s) will be placed together on a worksheet named "Roots Damped" (see Roots Damped Worksheet).

This is a button on the XLRotor ToolBar. Clicking this button is equivalent to selecting the command from the pull down menu.

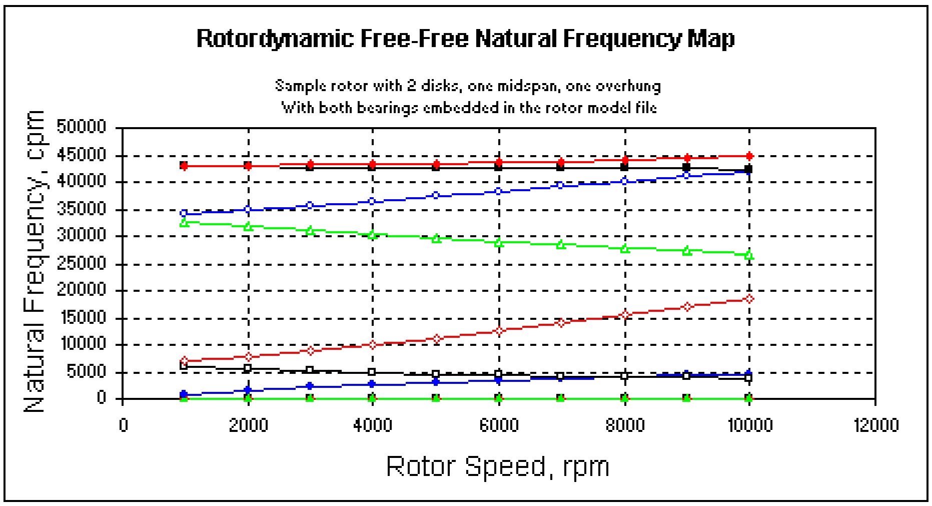
Very Important Note:
Multi level models always use the FEM solver for eigenanalysis. Whenever the FEM solver is used for eigenanalysis (see Options|General), the model must be fully grounded. This means there should be no zero frequency rigid body modes for any of the levels in the model.

Note: When the analysis is using the TM solver (for single level models this is the default), if there are more than two bearings in the model and the bearings are extremely stiff, the calculated eigenvalues and the accompanying plot of natural frequencies can become erratic. This is more likely to happen with very long rotor models employing many bearings, and is more likely to happen with high order modes. When this happens, either reduce the number of modes being calculated or select the FEM solver option. Erratic results should not happen with multi-level models because they always use the FEM solver.

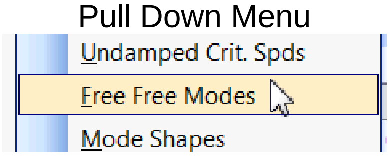
Run|Free Free Modes

See also

- XLRotor Menu Commands
- Roots FF Worksheet
- Run|Eigenvalues
- Run|Undamped Crit. Spds
- Run|Mode Shapes
- XLRGRPH.XLS Chart Template File



Pull Down Menu



Ribbon

This command will compute the free-free bending modes of the rotor as a function of rotor speed (the speeds in the "EIGEN ANALYSIS SPEEDS" column). Rotor gyroscopics are included in this analysis, but all bearings and seals are excluded. Because of gyroscopics, the free-free bending modes of the rotor will be functions of rotor speed.

The results of the analysis are displayed in a table of roots showing only the imaginary parts of the roots, and in a chart. The table and chart will be placed together on a worksheet named "Roots FF" (see Append or Overwrite Worksheet).

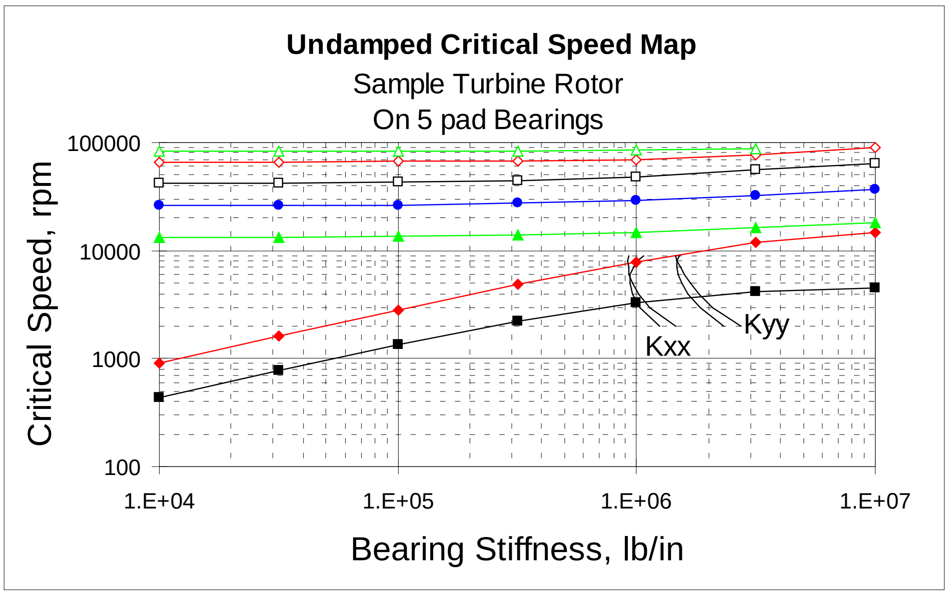
A free-free rotor will have either 3 or 4 rigid body modes with zero frequency. In the absence of any gyroscopic effects (i.e. the rotor speed is zero, or the Include Gyroscopics flag is turned off) there will be 4 zero frequency modes. When gyroscopics effects are present, one rigid body mode will have a nonzero frequency. This mode is often called a gyroscope mode. Its frequency is equal to the ratio of the total rotor polar inertia divided by the total transverse inertia (Ip/It) multiplied by the shaft speed. This gyroscopic mode is important for rigid rotors with extremely flexible supports (like spin pit arbors).

Note: If there are any RIGID, PINNED or GUIDED connections, these connections are retained for the free free analysis. For any or all of these to be left out of the free free analysis, you must delete or change the corresponding entry in the Link column.

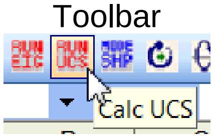
Run|Undamped Crit. Spds

See also

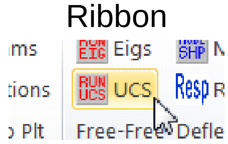
- XLRotor Menu Commands
- Run|Eigenvalues
- Run|Free Free Modes
- Run|Mode Shapes
- Options|Eigenanalysis
- XLRGRPH.XLS Chart Template File
- Roots UCS Worksheet
- Put Kxx/Kyy on UCS



Toolbar



Ribbon



This command starts an undamped critical speed calculation. Undamped critical speeds will be computed for each bearing stiffness listed in the "UCS ANALYSIS STIFFNESS" column on the XLRotor worksheet. The current rotor model and bearing definitions are used for the analysis.

The UCS ANALYSIS STIFFNESS values will be used at each bearing in the model, as governed by the values for UCS Factor and UCS Constant which have been entered on the Brg's Worksheet. Exceptions to this are RIGID, PINNED or GUIDED connections (see below).

The results of the analysis are produced in a table and chart of roots which show the undamped critical speeds versus bearing stiffness. This table and chart will be placed together on a separate worksheet named "Roots UCS" (see the Roots UCS Worksheet).

An **undamped critical speed** analysis is a special type of eigenvalue calculation. All bearings are reduced to simple undamped axisymmetric springs such that Kxx=Kyy and Kxy=Kyx=0 (see Brg's Worksheet). Also, the rotor transverse inertia, It, is replaced with the transverse minus the polar inertia (It-Ip). This last modification, in effect, *constrains* the rotor rotational speed to equal the eigenvalue frequency. This means that computed eigenvalues are automatically **synchronous** (i.e. whirl frequency = rotor speed). Recall that eigenvalue frequencies normally vary with rotor speed because of gyroscopics. At particular values of rotor speed where the frequency of a forward whirling eigenvalue matches exactly the speed, the eigenvalue is termed a **synchronous critical speed**. This special command computes those eigenvalues directly, without the need to iterate the rotor speed.

After the analysis is complete and the plot has been created, bearing stiffnesses can be added to the plot as illustrated in the above image by using the Put Kxx/Kyy on UCS menu command.

This is a button on the XLRotor ToolBar. Clicking this button is equivalent to selecting the command from the pull down menu.

Note: If there are any RIGID, PINNED or GUIDED bearing connections, these connections are retained for the UCS analysis, and the UCS Factor and UCS Constant are ignored for these bearings.

Note: When the analysis is using the TM solver (for single level models this is the default), if the bearing stiffnesses are given extremely high values the calculated critical speeds can become erratic. This is more likely to happen with high order modes. For most rotors, plotting 4 or 5 modes in the UCS plot is sufficient. The sample plot shown above contains 7 modes, which is more than adequate in most cases. Displaying a large number of modes and/or running the analysis up to extremely high values of bearing stiffness, will cause erratic results with the TM solver. When this happens either reduce the number of modes being displayed, reduce the maximum bearing stiffness, or select the FEM solver option. Erratic results should not happen with multi-level models because they always use the FEM solver.

Note: The following feature for retaining the "as defined" stiffness of a bearing connection while performing a UCS analysis only applies when using the Finite Element solver (see Options|General).

There may be times when doing a UCS analysis where you want one or more of your bearings to simply remain as you have defined them on their bearing worksheets, and not be governed by the ***UCS_Factor*** and ***UCS_Constant*** inputs. An example would be the lateral and rotational stiffness of a disk pack coupling element, or a trunnion stiffness in the shaft model. Bearings that satisfy the following conditions will be left "as is" for a USC analysis.

Both ***UCS_Constant*** and ***UCS_Factor*** cells are empty on the Brg's sheet.

The cell in the ***Link*** column on the Brg's sheet is not empty.

All stiffness coefficients are constant for all input speeds.

The number of coefficient columns on the bearing worksheet cannot be 8 or 12, must be 16, 24, 32, or 48.

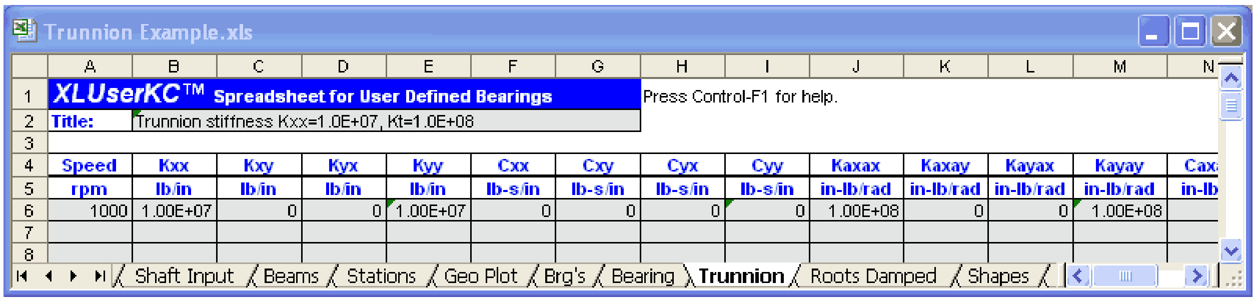
All 4 main diagonal stiffnesses must be nonzero.

The stiffnesses must be symmetric, which means Kxx=Kyy and Kaxax=Kayay

Off diagonal stiffnesses must conform to that of a beam element, which means only two can be nonzero and they must be equal.

All damping and inertia inputs must be zero.

Here is an example of a user defined bearing worksheet that XLRotor would retain in a UCS analysis (if the UCS Factor and UCS Constant cells were left empty on the Brg's worksheet).


Trunnion Example.xls

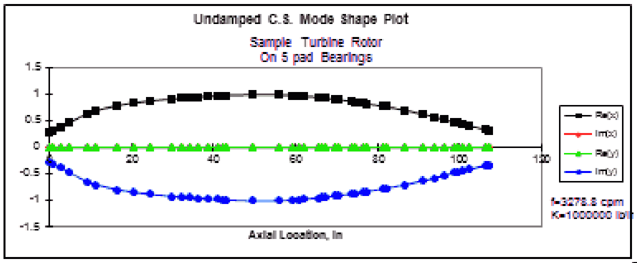
	A	B	C	D	E	F	G	H	I	J	K	L	M	N
1	XLUserKC™ Spreadsheet for User Defined Bearings							Press Control-F1 for help.						
2	Title:	Trunnion stiffness Kxx=1.0E+07, Kt=1.0E+08												
3														
4	Speed	Kxx	Kxy	Kyx	Kyy	Cxx	Cxy	Cyx	Cyy	Kaxax	Kaxay	Kayax	Kayay	Caxa
5	rpm	lb/in	lb/in	lb/in	lb/in	lb-s/in	lb-s/in	lb-s/in	lb-s/in	in-lb/rad	in-lb/rad	in-lb/rad	in-lb/rad	in-lb
6	1000	1.00E+07	0	0	1.00E+07	0	0	0	0	1.00E+08	0	0	1.00E+08	
7														
8														

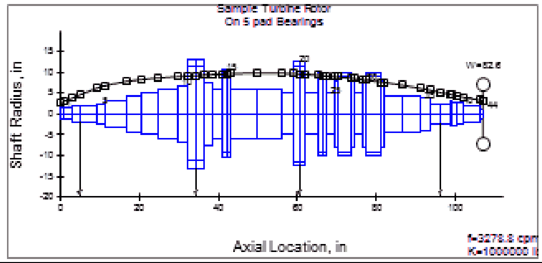
Shaft Input / Beams / Stations / Geo Plot / Brg's / Bearing / Trunnion / Roots Damped / Shapes

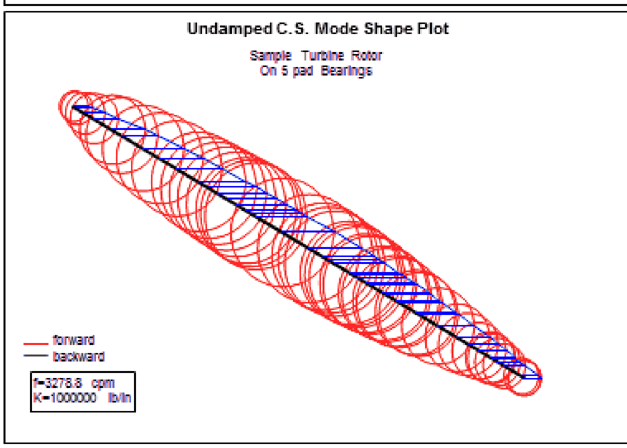
Run|Mode Shapes

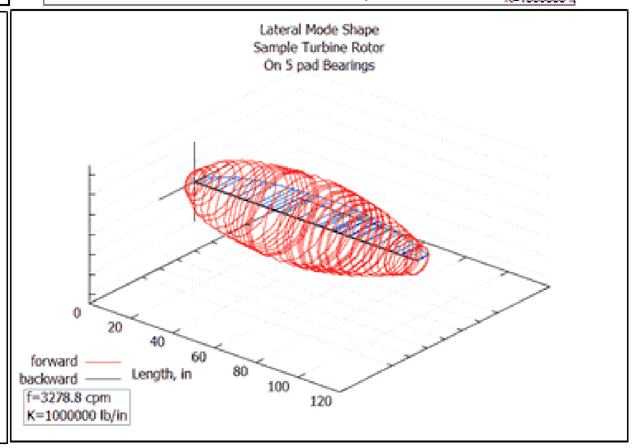
See also

- XLRotor Menu Commands
- Run|Eigenvalues
- Run|Undamped Crit. Spds
- Run|Free Free Modes
- Options|Eigenanalysis

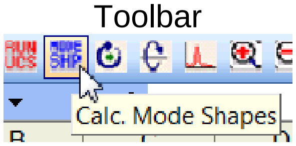




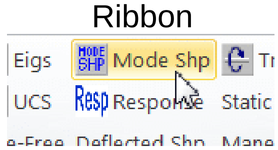




Toolbar



Ribbon



Use this command only with lateral models, to compute mode shapes for roots appearing on any of the 3 different kinds of "Roots" worksheets (see Roots Damped Worksheet). First, use your mouse to select the roots for which you want to generate mode shapes. Second, execute the Run|Mode Shape command. For more information on this procedure, see Shapes Worksheet. This command does not apply to torsional models because those mode shapes are generated at the same time the roots are calculated.

Mode shape output for Undamped Critical Speeds also includes strain energy distribution (see Shapes Worksheet).


This is a button on the XLRotor ToolBar. Clicking this button is equivalent to selecting the command from the pull down menu.

Note:
The worksheet with the selected roots must be the currently active worksheet for this command to work.

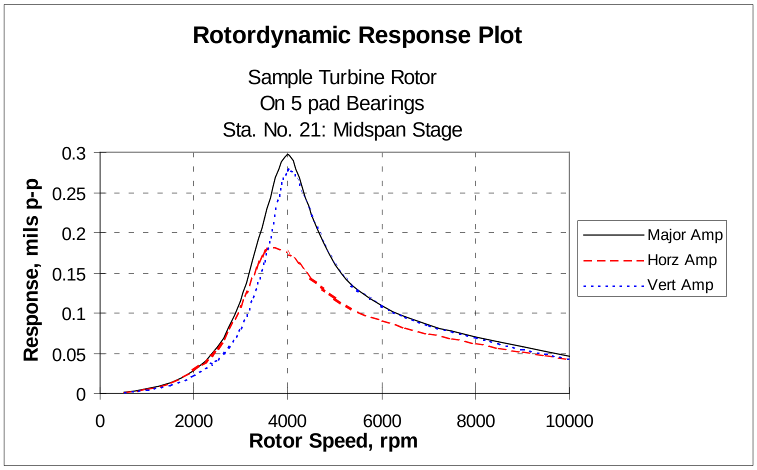
Note:
If the program displays a warning about failure of a bounday condition check, this means either that the model has been changed since the eigenvalue was calculated, or that the particular mode cannot be accurately calculated with TM solver numerical solution method. However, the mode shape will still be calculated and displayed

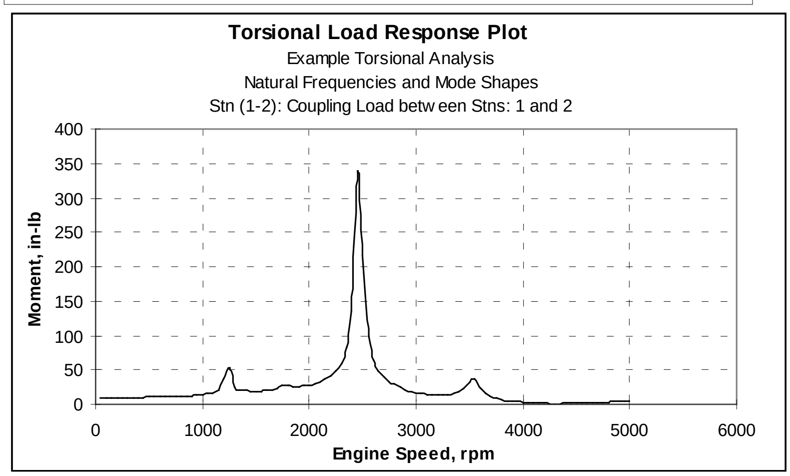
In the course of generating a mode shape, the program actually recalculates the complete eigensolution corresponding to the selected root. If the selected root is not in the eigensolution, the program will display a message that it could not find a root matching the frequency and damping of the one you have selected for mode shape calculation, and no mode is displayed.

Run|Response

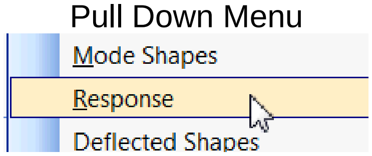
See also

XLRotor Menu Commands
Resp Worksheet
Label Peak Amplification Factors
Imb's Worksheet
Run|Deflected Shapes
Options|Response
Bode/Polar/Orbit Switch
Torsional Resp Worksheet

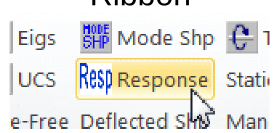




Pull Down Menu



Ribbon



This command is used to compute response to imbalance versus rotor speed using the currently defined rotor model and bearing and seal definitions. The imbalance distribution and calculation speeds are specified on the Imb's Worksheet along with the stations for which to output response charts. You can also get charts of bearing load by designating the bearing for load output on the Brg's Worksheet. These charts and accompanying tables are placed automatically on the Resp Worksheet. See Resp Worksheet for a more detailed description of the procedure. You can control some aspects of how the response results are displayed through settings in the Options|Response dialog box.

Lateral models must be fully grounded to calculate responses. This means there should be no zero frequency rigid body modes for any of the levels in the model. If there are, you may receive a message that calculation failed due to a singular matrix. A common cause for a singular matrix is a bearing support which has no restraint in the ax or ay rotational coordinates (pitch and yaw). To solve this problem either add moment springs or GUIDED constraints to ground.

For torsional models, this command computes response to engine orders (see Torsional Resp Worksheet)

New in Version 5.61: XLRotor will detect most instances where a GUIDED constraint is necessary to prevent a singular system stiffness matrix. If any GUIDED constraints are added, they will be listed in the Xlrotor.txt tracking file after the run.

Note:
XLRotor can also compute response to asynchronous forcing functions, either rotating or oscillating (see Options|Response).

Phase Angle Conventions

The phase angles output by XLRotor as part of a response analysis are "lagging" phase angles as evidenced by the angles progressing from 0 to +90 to +180 as a rotor traverses its critical speed. This means at a critical speed, the shaft center lags the mass center by 90 degrees. In polar plots, resonance loops sweep out counter clockwise circles as speed increases. The lagging convention was chosen as it is used in many textbooks on rotordynamics, and in many vibration measurement systems. Be aware, however, that some vibration measurement systems may use leading phase angle convention.

A useful way to think about this is when the rotor mass center is on the x axis, the shaft center is Beta degrees below the x axis (Beta is the lagging phase angle output by XLRotor). Or conversely, when the shaft center is on the x axis, the mass center is Beta degrees above the x axis.

In a simple rotor with one critical speed, the high spot and heavy spot line up at speeds well below the critical speed. At the critical speed the high spot lags the heavy spot by 90 degrees. At high speed the high spot lags the heavy spot by an angle approaching 180 degrees (this is called mass center inversion).

The applied forces, either imbalance or asynchronous forces, expressed as functions of time are applied as:

Fx(t) = F*cos(wt-alpha)

Fy(t) = F*sin(wt-alpha)

Where F is the amount of the force, and Alpha is the ***lagging*** phase angle input on the Imb's worksheet. These components define a force vector rotating counterclockwise in the xy plane (i.e. forward rotating). When Alpha is zero, the applied force vector at t=0 is on the +x axis. Specifying a positive value for Alpha rotates the applied force Alpha degrees ***clockwise***. This means it happens Alpha "degrees" later.

Expressions for the x and y components of shaft vibration computed by XLRotor, as functions of time, are expressed as follows:

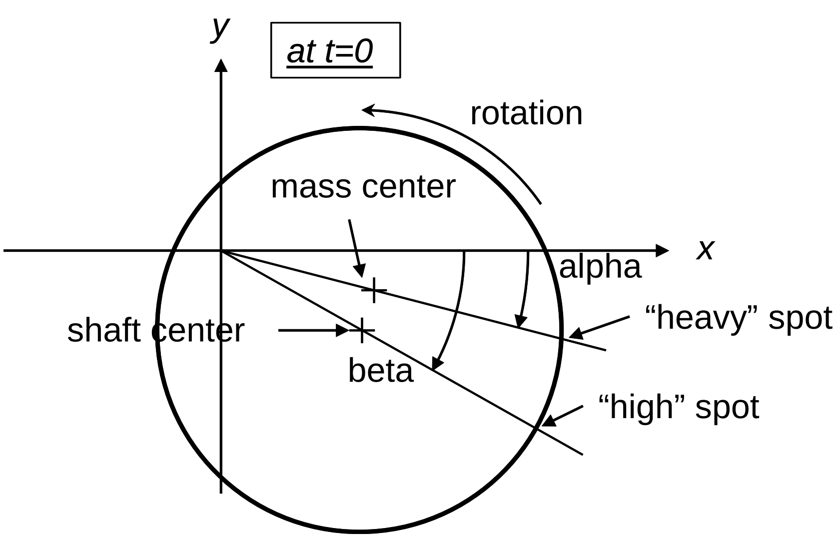
x(t) = X*cos(wt-Betax)

y(t) = Y*cos(wt-Betay)

These components locate the **shaft center**, not the mass center. X, Y, Betax and Betay are the values output by XLRotor (note, X=horizontal and Y=vertical on the Resp Worksheet. Betax and Betay are lagging phase angles.

When **zero** has been input for the imbalance angle Alpha, the mass center is on the x axis at t=0. The shaft center (high spot) will then pass through the x axis Beta degrees **after** the mass center, since the output angles are positive=lagging.

If alpha is +30 degrees, this moves the imbalance weight on the rotor +30 degrees in the direction **opposite** rotation (see the Imb's Worksheet). So at t=0 the mass center is now +30 degrees **below** the x axis. At any given response speed, the rotor's **shaft center** will still **lag** the **mass center** by the same amount regardless of Alpha. So Beta output by XLRotor will be 30 degrees more than with Alpha=0.



The "high" spot is the spot on the rotor surface farthest from the origin. The "high" spot would generally be the spot located by the phase angle output of a shaft displacement probe relative to a phase marker such as a keyway or similar notch (after subtracting slow roll runout). If the phase angle readout of your instrument increases as the machine traverses the first critical speed, your instrument reads out "lagging" phase angles. Otherwise it reads out a "leading" phase angle. Again, note that slow roll runout must be subtracted from all measurements for this statement to be correct.

Balancing

When performing single plane influence coefficient balancing, the following expression is generally used:

V=Au

where

V = the measured vibration ***vector***

u = the imbalance ***vector***

A = the influence coefficient, this is a ***vector***

Any phase angle convention (i.e. leading or lagging) can be used for the vibration and imbalance vectors in the above equation. But, the conventions ***must*** be consistent such that if the imbalance vector u is increased by 30 degrees, the response vector V will also increase 30 degrees (for a simple Jeffcott rotor). If a mix of leading and lagging is used, then use V=-1Au.

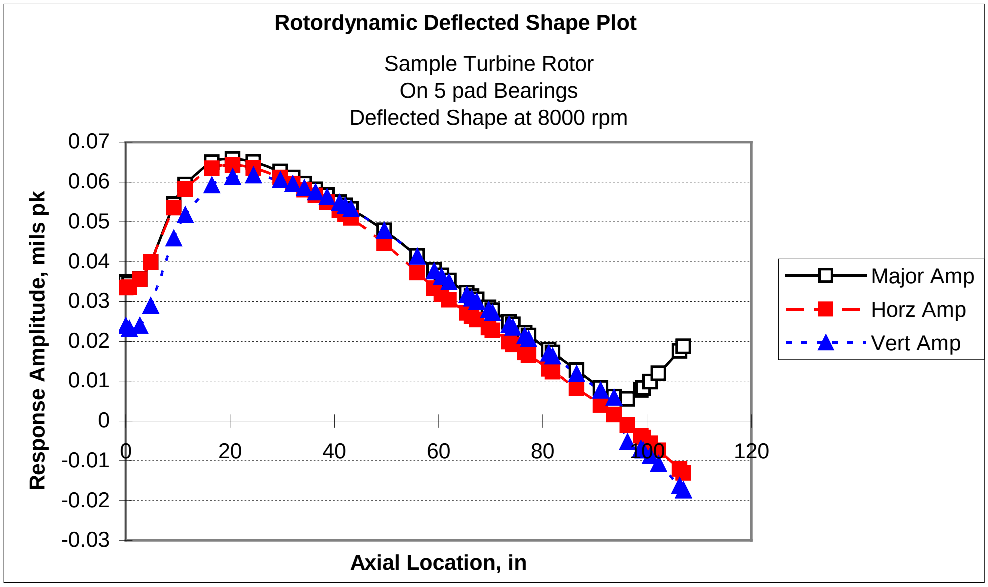
Note that in XLRotor an **increase** of 30 degrees in the imbalance angle will cause the response phases to **increase** by 30 degrees. This is because they use the same phase angle convention, which is lagging.

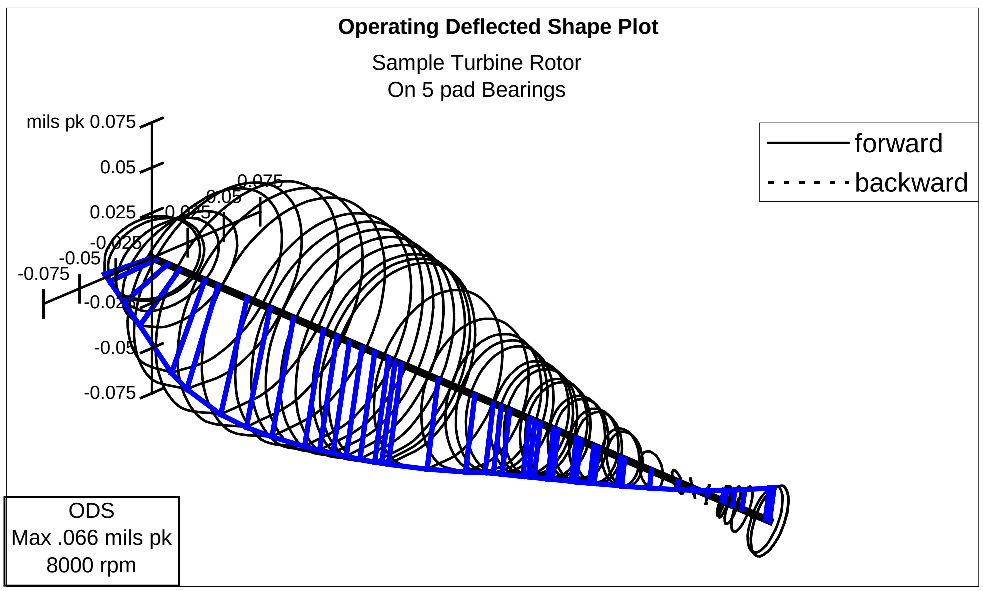
If an imbalance weight is placed on the rotor at the same angle as the phase marker, its phase angle is zero. If the weight is moved 30 degrees opposite rotation, its phase angle is now +30 degrees when using lagging phase angle convention.

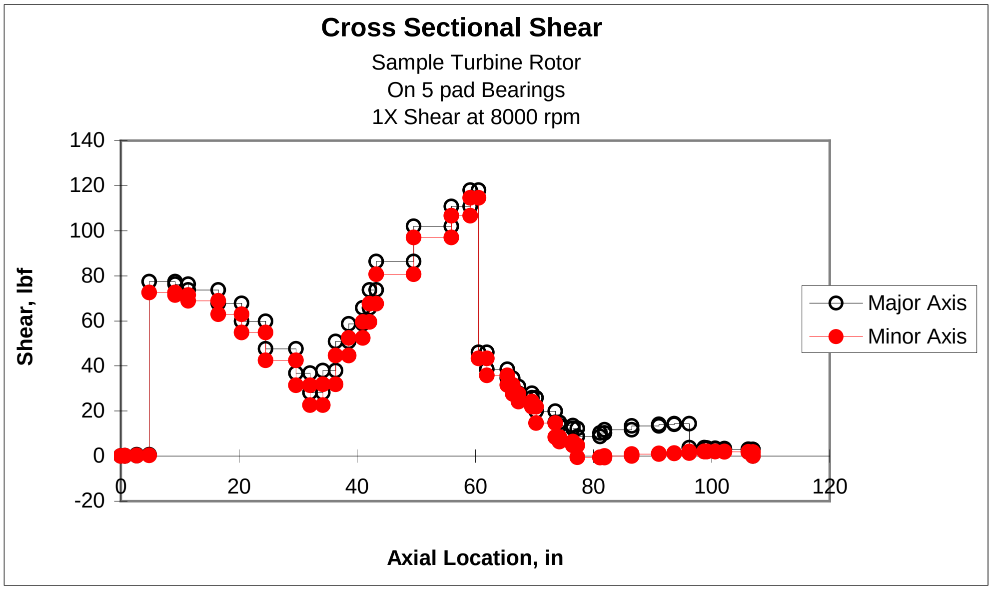
Run|Deflected Shapes

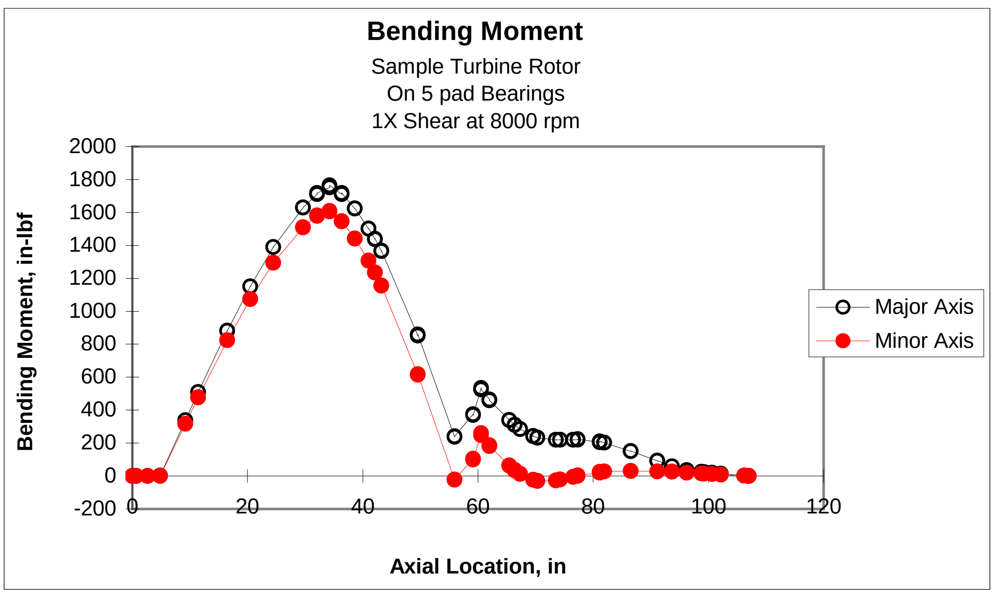
See also

XLRotor Menu Commands
Run|Response

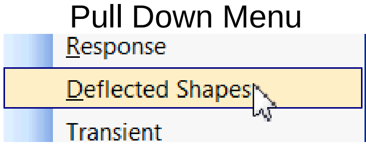




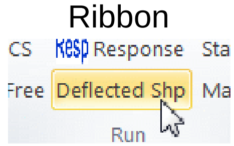




Pull Down Menu



Ribbon



This command computes complete rotor deflected shapes at a list of rotor speeds specified on the Imb's Worksheet. The results are tables and charts of deflected shapes. The charts and tables are appended to the Resp Worksheet. The deflected shapes can be either synchronous or asynchronous, depending on which analysis type you have selected in the Options|Response dialog.

The 3D version of the chart is an optional output feature. See the Display 3D ODS Chart option in the Options|Response dialog box. The default orientation of the 3D chart is shown above. You can specify a different orientation by creating 2 Excel

Defined Names called Alpha3D and Beta3D. These are angles of rotation, in degrees, about the Y axis and X axis, respectively. These defined names can either reference a worksheet cell or contain a value. The default values are Alpha3D=45 degrees, and Beta3D=25.7 degrees.

XLRotor will attempt to place the tables and charts on a worksheet named "Resp". If there is no worksheet by that exact name, then one will be created automatically. If there is a worksheet by that name you will be prompted if you want to Append the new data (see Append or Overwrite Worksheet).

The 2D deflected shape charts show three curves:

1. the major axis amplitude, which will always be positive at every station
2. the maximum x axis deflection at every station
3. the maximum y axis deflection at every station

The x axis and y axis deflections are plotted as positive or negative, depending on their phase angles. These curves can sometimes appear to be discontinuous. This can happen for two reasons; 1) the shape is corkscrewed, and corkscrewed rotors do not pass through the centerline, they wrap around it, and 2) the horizontal and vertical amplitude values which are plotted do not all occur at the same instant in time as the rotor whirls.

The shear and bending moment diagrams are another optional output feature. See the Make Shear & Bending Moment Charts option in the Options|Response dialog box. These charts display the major and minor axis amplitudes (0-peak) of an ellipse. When the shaft orbits are circular, the major and minor amplitudes are equal. If the minor axis amplitude is negative, the orbit is backward.

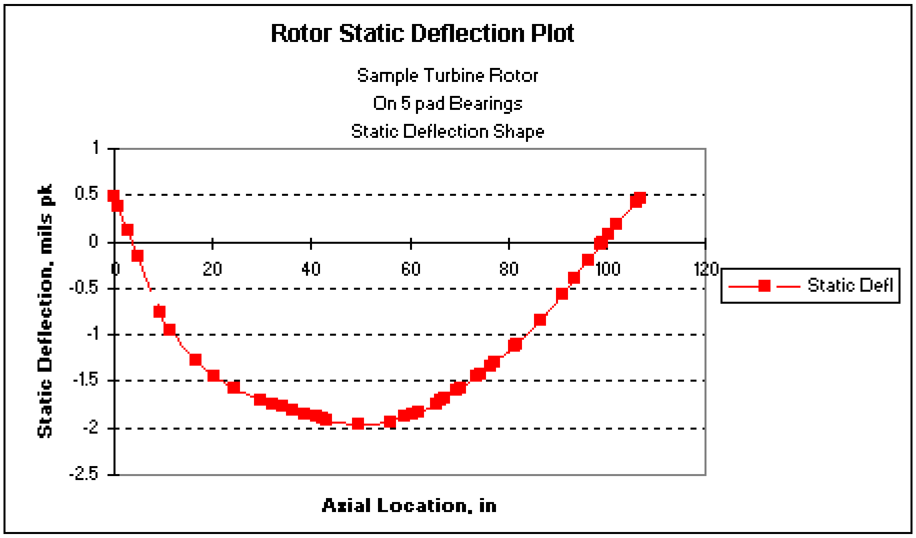
Be aware that all these plots come from templates stored in the XLRGRPH.XLS file. You can modify the formats of the templates to suit your needs. Changes will show up in any subsequent plots that are generated.

For torsional analysis, the output of this analysis will include plots of response versus crank angle when the ***Time Waveform*** analysis option is turned on (see Options|Response).

Run|Static Deflection

See also

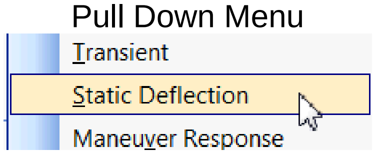
- XLRotor Menu Commands
- Run|Deflected Shapes



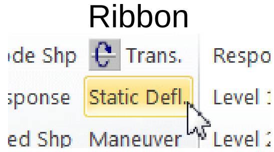
Rotor Static Deflection Shape

Stn. No.	Ax. Loc.	Static Defl	Brg F	Brg K	*	*	*
	in	mils pk					
1	0	0.47986	0	0			
2	0.6875	0.38764	0	0			
3	2.6875	0.11941	0	0			
4	4.8125	-0.16573	1657.28	1E+07			
5	9.1875	-0.75663	0	0			
6	11.4375	-0.9636	0	0			
7	16.5	-1.28479	0	0			

Pull Down Menu



Ribbon



This command is used to compute the static deflection of the rotor due to weight. The bearing stiffness values that are used to support the rotor are taken as the maximum values that would be used for an Undamped Critical Speed Analysis (see Run|Undamped Crit. Spds)

The result of this command is a table and chart placed on the Resp Worksheet. The table also shows the stiffness values used at each bearing, and the corresponding bearing reactions. An exception to this is that reactions are not output for any RIGID, PINNED or GUIDED connections.

It is also possible to compute static deflection due to weight, or any arbitrary static loading, by performing an asynchronous response analysis (see Options|Response) with an excitation frequency of zero cycles per minute.

Note:
You can use the Overlay Geometry on Mode Shape menu command on the static deflection chart.

Note:
This calculation always uses the FEM solver. If you run this command in a rotor model file created with an older single level version of XLRotor, you may be prompted to add some model input fields required to use this command.

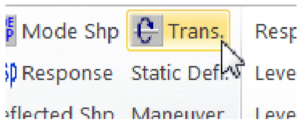
Run|Transient

See also

- XLRotor Menu Commands
- Options|Transient
- Transient Worksheet
- Transient Resp Worksheet

Toolbar

Ribbon



This command starts a transient analysis which uses direct numerical integration of the full equations of motion. The integration parameters are specified in the Options|Transient dialog. The external forcing functions and nonlinear elements are defined on the Transient worksheet. A list of which quantities are to be output is also specified on the Transient worksheet.

While the analysis is being carried out, the Excel statusbar should display a message about the progress of the integration.

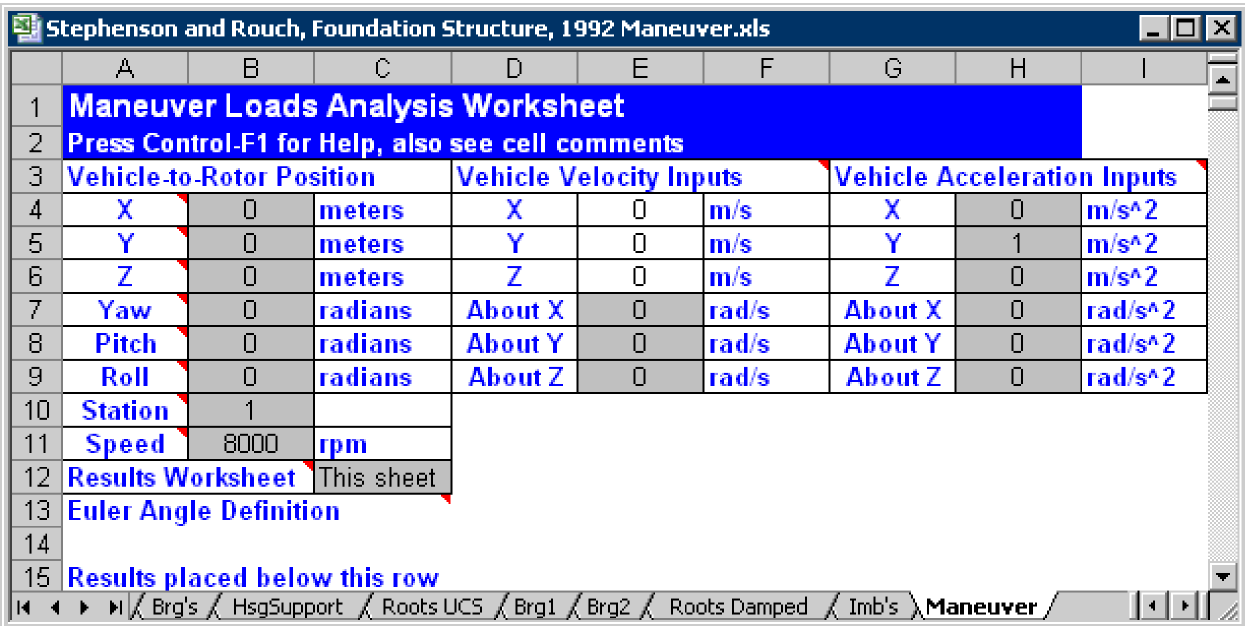
This command can be used in both lateral model and torsional model files.

This Run|Transient command is also on the XLRotor pull down menu.

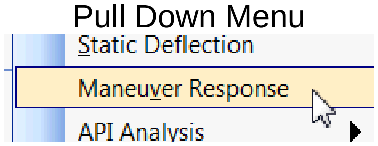
Run|Maneuver Response

See also

XLRotor Menu Commands



Pull Down Menu



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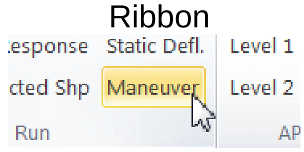


When a rotor is mounted in a vehicle such as an aircraft, ship or automobile, the rotor will experience inertial loading due to the motion of the vehicle. This command calculates the static deflection of the rotor system due to velocity and acceleration of the vehicle. Both translational and angular vehicle acceleration obviously creates inertial loads, and these loads cause reactions at the bearings and deflections of the rotor. However, if the rotor is spinning, then vehicle angular velocity creates gyroscopic moments as another form of inertial loading. In very high speed rotors, it would be typical for gyroscopics to be the dominant source of inertial loading. Gyroscopic moment is essentially equal to $Ip\Omega\omega$ where Ip is the rotor polar inertia, Ω is rotor speed, and ω is vehicle angular velocity (rads/s). This moment, divided by the bearing span, would be the reaction load on each radial bearing (when there are two bearings).

When the **Run|Maneuver Response** command is executed, one of the following three things will happen:

- If the currently active worksheet is a Maneuver input sheet, the analysis will be run for that sheet (regardless of the actual name of the worksheet).

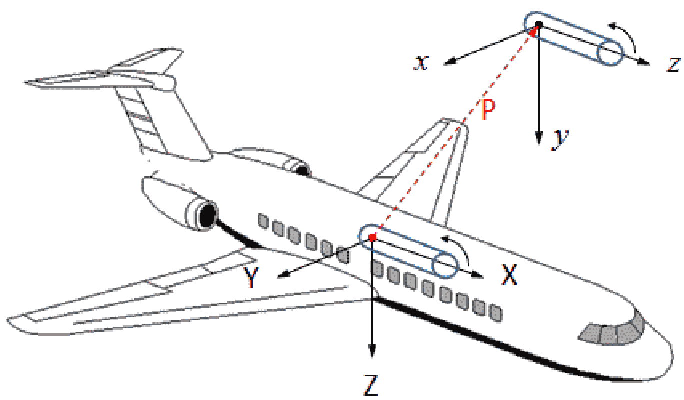
- If the currently active worksheet is not a Maneuver input sheet, but there is a sheet in the file with the exact name of "Maneuver", the analysis will be run for that sheet.
- If there is no "Maneuver" sheet in the file, a prompt is displayed offering to add one the file.

The inputs for this analysis are as follows:

Vehicle-to-Rotor Position

The XYZ inputs specify the position of one particular rotor station (see below) with respect to the center of rotation of the vehicle. For an aircraft, the center of rotation would usually be its center of mass. The XYZ coordinate system is fixed to the vehicle. The XYZ coordinate system is defined as follows:

- X: points out the front of the vehicle
- Y: points out the right of the vehicle (pilot's right)
- Z: points out the bottom



The coordinate system of the rotor is xyz.

Rotor +x lines up with vehicle +Y.

Rotor +y lines up with vehicle +Z.

Rotor +z lines up with vehicle +X (i.e. rotor centerline).

The orientation of the rotor centerline with respect to the XYZ coordinate system is specified using Euler angles Yaw, Pitch and Roll, which are defined as follows (the order is important):

- Yaw: 1st Euler angle, right hand rule rotation about Z, + = a turn to the right
- Pitch: 2nd Euler angle, rotation about new Y, + = nose up
- Roll: 3rd Euler angle, rotation about new X, + = roll right

In the above image of an aircraft, the rotor xyz axes are shown displaced from the vehicle cg, with Euler angles equal to zero.

The first two Euler angles essentially orient the shaft centerline. The last angle (roll) orients the rotor xy axes about the shaft centerline.

For the two engines appearing in the above image, all three Euler angles could be entered as zero. The speed of each engine would then be specified as either a positive or negative rpm value so as to model its true direction of rotation.

A Yaw angle of +pi/2 (90 degrees) would point the rotor centerline sideways out the right side of the vehicle.

A Pitch angle of +pi/2 (90 degrees) would point the rotor centerline up out the top of the vehicle.

Station

The station in the model located by the XYZ input coordinates.

When zero is entered for all 6 inputs, the rotor centerline (+z axis) is along the vehicle +X axis pointing out the front of the vehicle, and station number ***Station*** is at the origin of the XYZ coordinate system.

Note: To place the rotor cg at the aircraft cg, either specify a station close to the rotorcg and input X=0, <u>or</u> enter Station=1 and X=-rotorcg.

Speed

This specifies the constant speed of the rotor. It is used to compute bearing coefficients, and to compute gyroscopic moments. This input can be positive or negative. A positive value means the rotor is turning in a positive direction (right hand rule) on the rotor +z axis.

Vehicle Velocity Inputs

Both the linear and rotational velocity vectors are defined in the vehicle's body fixed XYZ axes. Only the rotational velocity vector is used in this version of XLRotor.

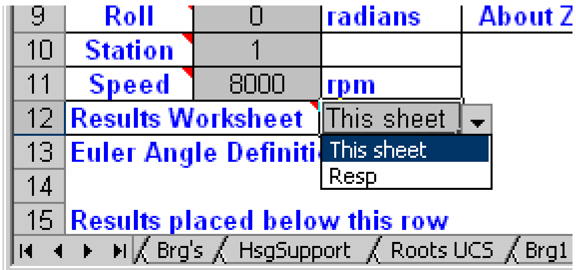
Vehicle Acceleration Inputs

Acceleration vectors are defined in the vehicle's body fixed XYZ axes.

Results Worksheet

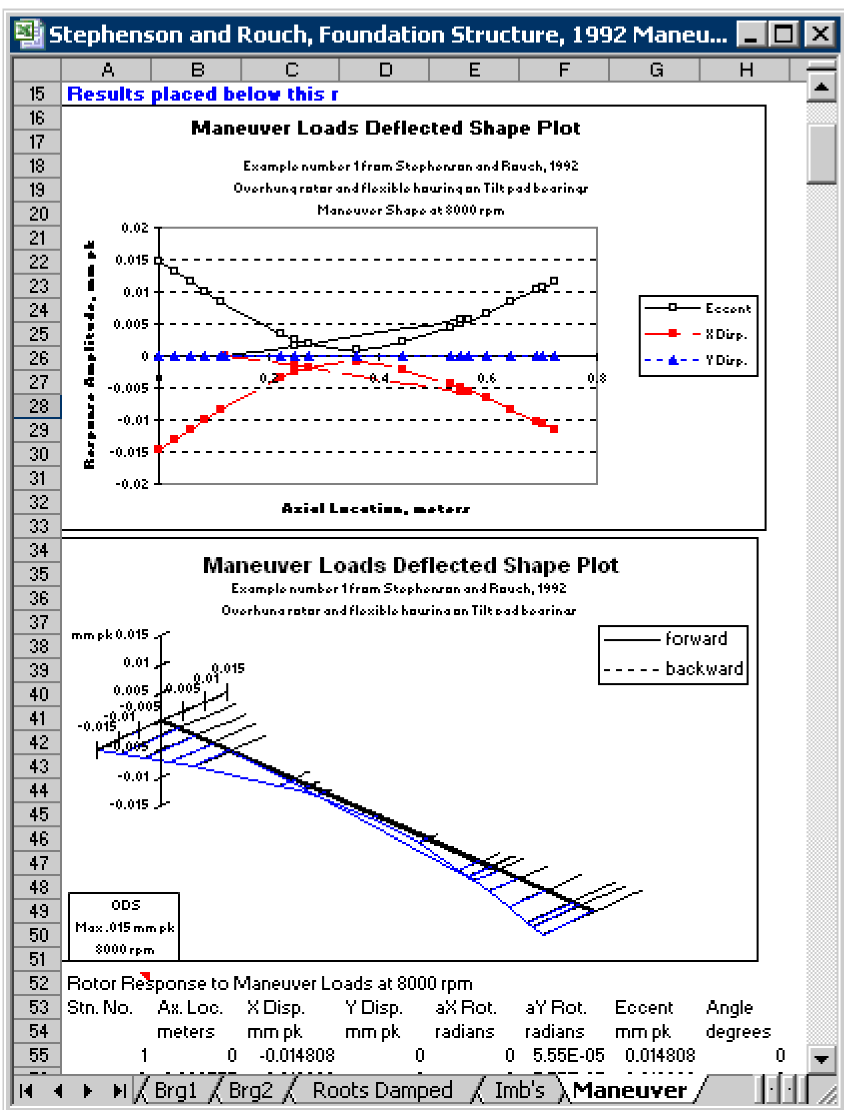
There are two choices for this input, and is selected from a drop down list.

- **This sheet** means the results will be placed on the Maneuver sheet below the row where you see "Results placed below this row".
- **Resp** means put the results on the Resp Worksheet, which is also where imbalance response results are placed.



In both cases you will be offered the choice of overwriting or appending newly computed results to any results already on the sheet.

The output of the analysis is similar to the output of a Run|Deflected Shapes command. It is the static deflection of the entire rotor system. This includes a table of all deflection values, and a two dimensional chart of the rotor's deflected shape. A three dimensional deflected shape chart is also produced if the option for this chart type is turned on (see Options|Response). A table of bearing loads appear just below the table of deflections.



Stephenson and Rouch, Foundation Structure, 1992 Maneuv...

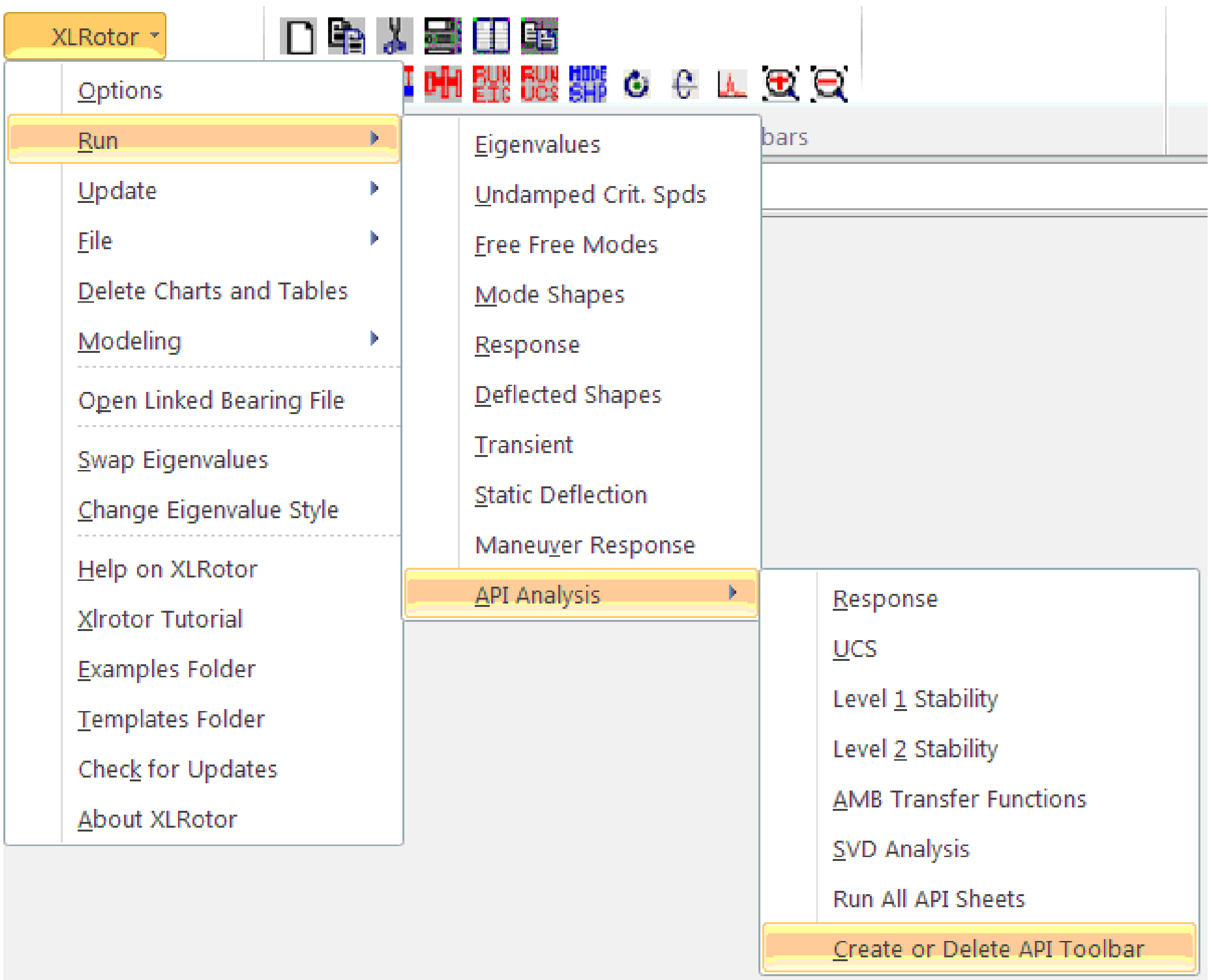
	A	B	C	D	E	F	G	H
52	Rotor Response to Maneuver Loads at 8000 rpm							
53	Stn. No.	Ax. Loc.	X Disp.	Y Disp.	aX Rot.	aY Rot.	Eccent	Angle
54		meters	mm pk	mm pk	radians	radians	mm pk	degrees
55	1	0	-0.014808	0	0	5.55E-05	0.014808	0
56	2	0.028575	-0.013222	0	0	5.55E-05	0.013222	0
57	3	0.05715	-0.011636	0	0	5.55E-05	0.011636	0
58	4	0.085725	-0.01005	0	0	5.55E-05	0.01005	0
59	5	0.1143	-0.008469	0	0	5.45E-05	0.008469	0
60	6	0.22225	-0.003316	0	0	3.75E-05	0.003316	0
61	7	0.24765	-0.002448	0	0	3E-05	0.002448	0
62	8	0.27305	-0.001792	0	0	2.22E-05	0.001792	0
63	9	0.359833	-0.001064	0	0	-3.5E-06	0.001064	0
64	10	0.446617	-0.002204	0	0	-2.1E-05	0.002204	0
65	11	0.5334	-0.004509	0	0	-3E-05	0.004509	0
66	12	0.55245	-0.005117	0	0	-3.3E-05	0.005117	0
67	13	0.59796	-0.006698	0	0	-3.6E-05	0.006698	0
68	14	0.64347	-0.008412	0	0	-3.9E-05	0.008412	0
69	15	0.68898	-0.010192	0	0	-3.9E-05	0.010192	0
70	16	0.70167	-0.010691	0	0	-3.9E-05	0.010691	0
71	17	0.7239	-0.011566	0	0	-3.9E-05	0.011566	0
72								
73	18	0.12065	-7.14E-08	0	0	-1.2E-05	7.14E-08	0
74	19	0.24765	-0.001597	0	0	-1.3E-05	0.001597	0
75	20	0.55245	-0.005516	0	0	-1.3E-05	0.005516	0
76	21	0.56515	-0.00568	0	0	-1.3E-05	0.00568	0
77								
78	Bearing Reactions							
79	Number	Station	Station	X Load	Y Load	X Momen	Y Moment	
80	1	18	0	-71.4095	0	0	-13.7617	
81	2	7	19	-28.0587	0	0	0	
82	3	12	20	5.390957	0	0	0	
83								

Brg1 / Brg2 / Roots Damped / Imb's / **Maneuver**

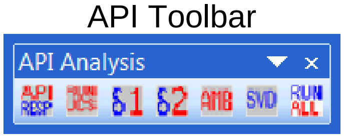
Run|API Analysis

See also

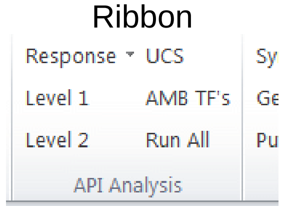
- XLRotor Menu Commands
- API Response Analysis
- API UCS Analysis
- API Level 1 Stability Analysis
- API Level 2 Stability Analysis
- API AMB Transfer Function Analysis
- API SVD Singular Value Decomposition Analysis



API Toolbar



Ribbon



These commands are for executing API style analyses. The first 6 items on the menu execute the indicated type of analysis on the currently active worksheet. The currently active worksheet must be the right type of worksheet. Otherwise, you will be prompted to add the corresponding type of worksheet to your file by copying a template stored within the program. The six types of worksheets are:

API Response Analysis

API UCS Analysis

API Level 1 Stability Analysis

API Level 2 Stability Analysis

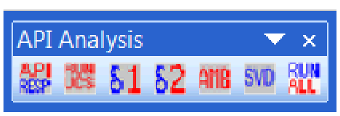
API AMB Transfer Function Analysis

API SVD Singular Value Decomposition Analysis

Click on the above links to see details about each type of worksheet. The best source of information with complete details about the different analysis types are the various API documents. Among these are: API 610 for pumps, API 612 for steam turbines, API 617 for compressors/expanders, and API 684 Rotordynamics Tutorial. Note that SVD is a new type of analysis, and is not presently discussed in any API document.

Also look in the XLRotor/Examples folder for files with "API" in their name.

The command **Run All API Sheets** will run the corresponding type of API analysis on all worksheets you have selected with your mouse (use the Shift or Control keys to select multiple worksheet tabs). Or, if only one worksheet is selected, it will run all worksheets starting with the current worksheet, to the last worksheet in the file at the right end of the worksheets tabs. In both situations any non-API worksheet will be bypassed.



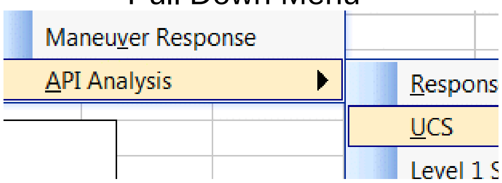
The menu command **Create or Delete API Toolbar** will create or delete the custom toolbar that contains buttons for executing the commands on the API analysis menu. In Excel version 2007 and later, this toolbar will appear on the Add-Ins tab of the Excel Ribbon.

API UCS Analysis

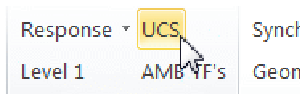
See also

- XLRotor Menu Commands
- Run|API Analysis
- API Response Analysis
- API Level 1 Stability Analysis
- API Level 2 Stability Analysis
- API AMB Transfer Function Analysis
- API SVD Singular Value Decomposition Analysis

Pull Down Menu



Ribbon



An API Undamped Critical Speed (UCS) analysis is almost identical to a normal UCS analysis that can be run using the Run|Undamped Crit. Spds command.

In an API UCS analysis, additional annotations are applied to the UCS chart automatically so that the plot conforms to presentation requirements described in API specification documents.

Inputs:

- Operating speeds.
- A list of chart series labels for the individual critical speeds.

Outputs:

- A table of undamped critical speeds which is identical to what would be computed with a Run|Undamped Crit. Spds command.
- The normal UCS chart with the operating speeds shown and labeled, and the critical speed curves labeled with your list of labels.

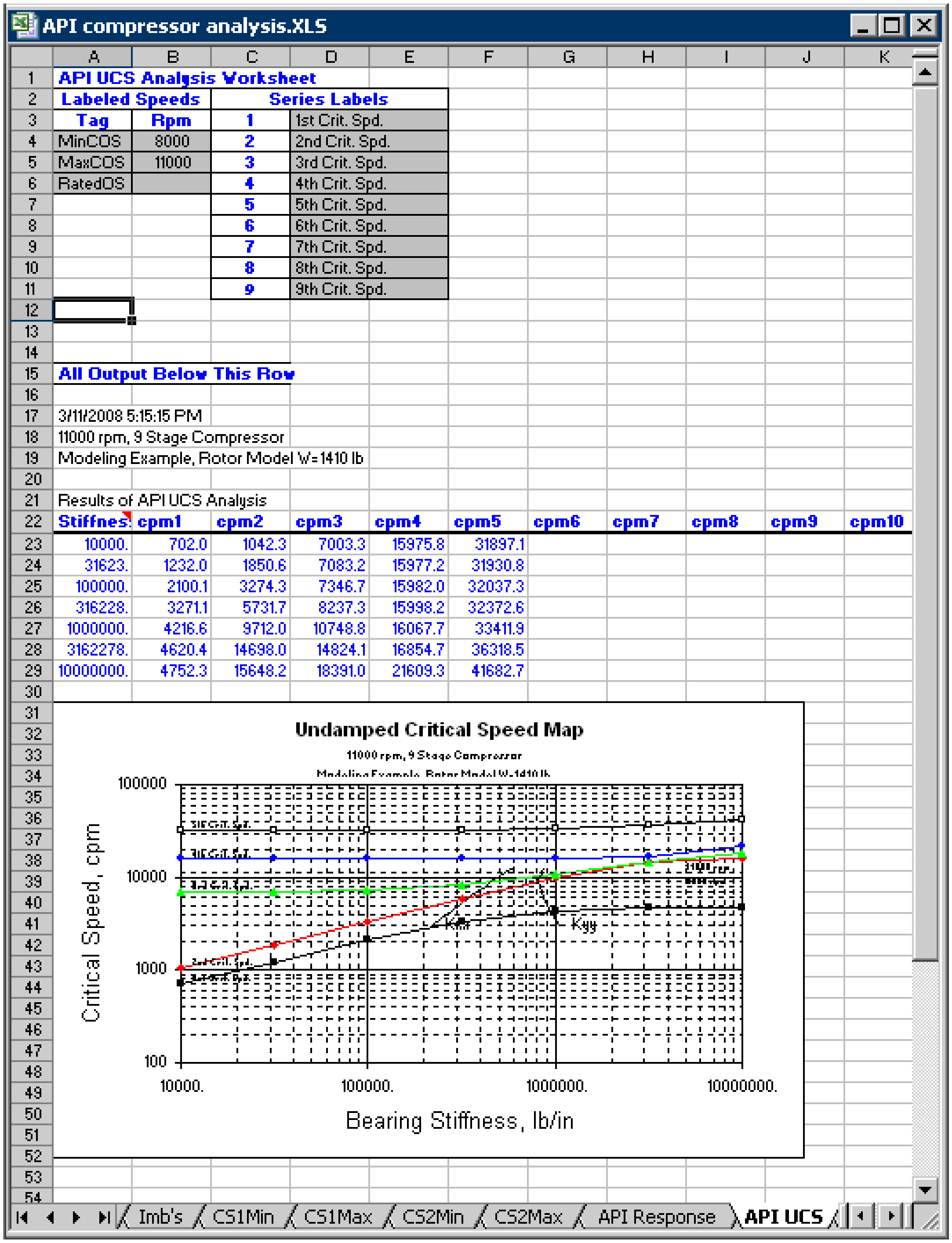
What Actions Are Taken:

1. A UCS analysis is run which is exactly analogous to what would be run with a Run|Undamped Crit. Spds command. This generates a Roots UCS worksheet. If a Roots UCS sheet already exists, it is overwritten.

1. The table of undamped critical speeds and the UCS chart are moved from the Roots UCS worksheet to the API UCS worksheet.

2. The Roots UCS sheet is deleted.

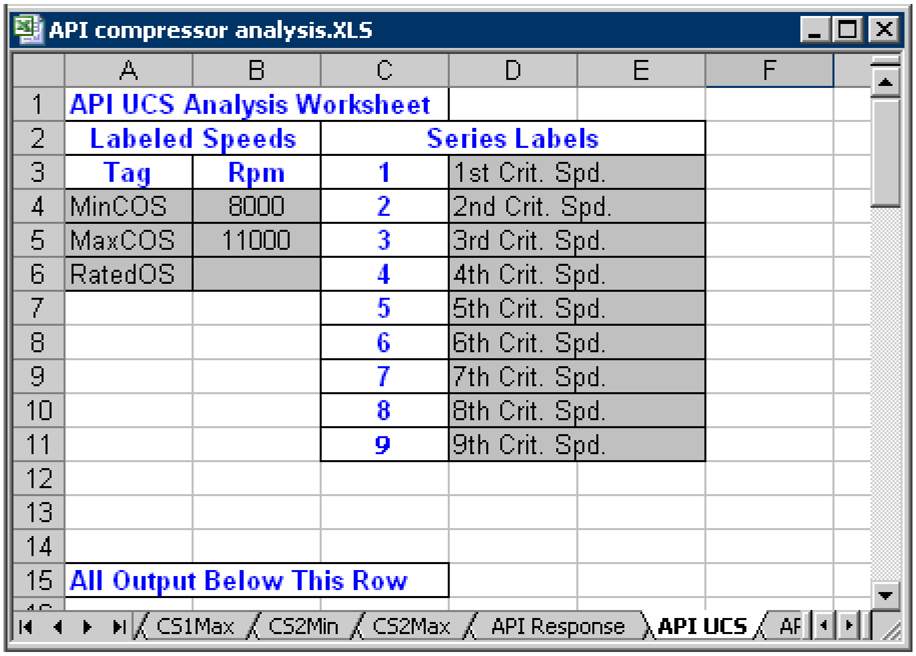
3. The Put Kxx/Kyy on UCS menu command is executed on the UCS chart to overlay the bearing data onto the chart.
4. The operating speeds you supply are added to the UCS chart and labeled.
5. The individual critical speed curves on the UCS chart are annotated with labels you provide on the API UCS worksheet.



Labeled Speeds		Series Labels	
Tag	Rpm		
MinCOS	8000	1	1st Crit. Spd.
MaxCOS	11000	2	2nd Crit. Spd.
RatedOS		3	3rd Crit. Spd.
		4	4th Crit. Spd.
		5	5th Crit. Spd.
		6	6th Crit. Spd.
		7	7th Crit. Spd.
		8	8th Crit. Spd.
		9	9th Crit. Spd.

Stiffnes	cpm1	cpm2	cpm3	cpm4	cpm5	cpm6	cpm7	cpm8	cpm9	cpm10
10000.	702.0	1042.3	7003.3	15975.8	31897.1					
31623.	1232.0	1850.6	7083.2	15977.2	31930.8					
100000.	2100.1	3274.3	7346.7	15982.0	32037.3					
316228.	3271.1	5731.7	8237.3	15998.2	32372.6					
1000000.	4216.6	9712.0	10748.8	16067.7	33411.9					
3162278.	4620.4	14698.0	14824.1	16854.7	36318.5					
10000000.	4752.3	15648.2	18391.0	21609.3	41682.7					

Getting Started & Setting Up Inputs:


API compressor analysis.XLS

	A	B	C	D	E	F
1	API UCS Analysis Worksheet					
2	Labeled Speeds		Series Labels			
3	Tag	Rpm	1	1st Crit. Spd.		
4	MinCOS	8000	2	2nd Crit. Spd.		
5	MaxCOS	11000	3	3rd Crit. Spd.		
6	RatedOS		4	4th Crit. Spd.		
7			5	5th Crit. Spd.		
8			6	6th Crit. Spd.		
9			7	7th Crit. Spd.		
10			8	8th Crit. Spd.		
11			9	9th Crit. Spd.		
12						
13						
14						
15	All Output Below This Row					

CS1Max / CS2Min / CS2Max / API Response / API UCS / AF

If there is not already an API UCS worksheet in your file, execute the Run|API Analysis|UCS command and you will be prompted for permission to have one added. Then after filling in your inputs (described next), run the same menu command again, and you will be prompted for permission to run the UCS analysis.

Labeled Speeds

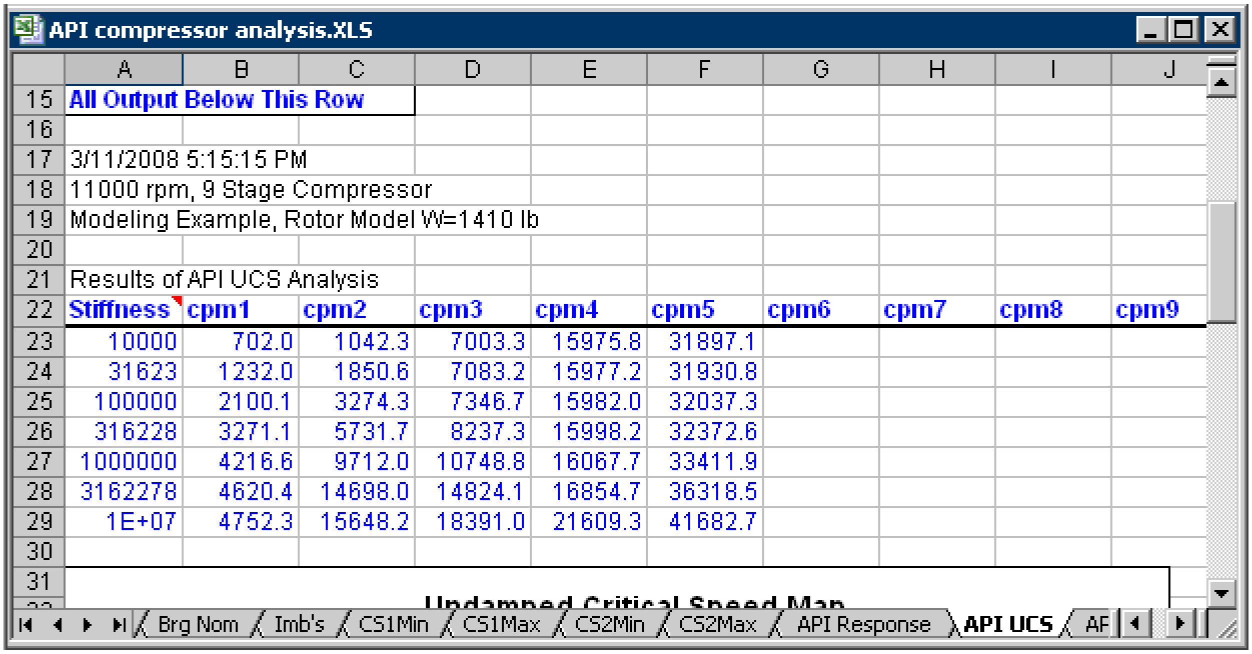
These three operating speeds will be displayed and labeled on the UCS chart. Leave the cell empty to suppress the display of the corresponding speed.

Series Labels

These are labels that will be added to the critical speed curves in the UCS chart. Only cells that contain something are used for the labels.

API UCS Results

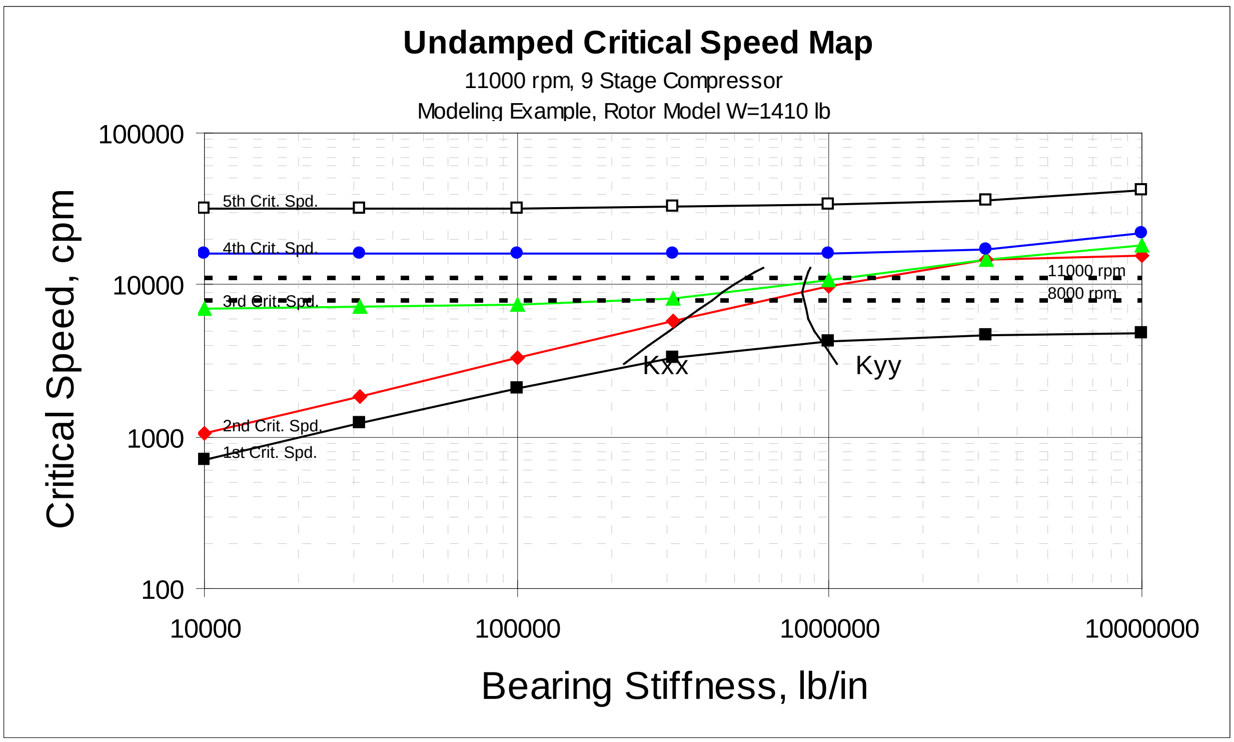
The table and chart are taken from the Roots UCS worksheet, and the annotations are added automatically. As the images below show, outputs are placed below the row where you see **All Output Below This Row**.



API compressor analysis.XLS

	A	B	C	D	E	F	G	H	I	J
15	**All Output Below This Row**									
16										
17	3/11/2008 5:15:15 PM									
18	11000 rpm, 9 Stage Compressor									
19	Modeling Example, Rotor Model W=1410 lb									
20										
21	Results of API UCS Analysis									
22	**Stiffness**	**cpm1**	**cpm2**	**cpm3**	**cpm4**	**cpm5**	**cpm6**	**cpm7**	**cpm8**	**cpm9**
23	10000	702.0	1042.3	7003.3	15975.8	31897.1				
24	31623	1232.0	1850.6	7083.2	15977.2	31930.8				
25	100000	2100.1	3274.3	7346.7	15982.0	32037.3				
26	316228	3271.1	5731.7	8237.3	15998.2	32372.6				
27	1000000	4216.6	9712.0	10748.8	16067.7	33411.9				
28	3162278	4620.4	14698.0	14824.1	16854.7	36318.5				
29	1E+07	4752.3	15648.2	18391.0	21609.3	41682.7				
30										
31										

Brg Nom / Imb's / CS1Min / CS1Max / CS2Min / CS2Max / API Response / **API UCS** / AF

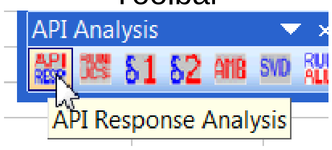


API Response Analysis

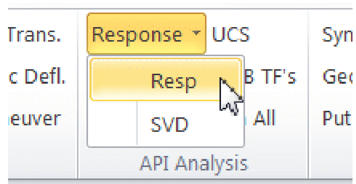
See also

- XLRotor Menu Commands
- Run|API Analysis
- API UCS Analysis
- API Level 1 Stability Analysis
- API Level 2 Stability Analysis
- API AMB Transfer Function Analysis
- API SVD Singular Value Decomposition Analysis

Toolbar



Ribbon



An ***API Response*** analysis requires performing multiple imbalance response runs with different sets of bearing coefficients and different distributions of imbalance. It also requires extracting much information from the results of those runs, and verifying that API requirements have been met.

Although this feature was created for doing an API Response analysis, it can be used in any situation to run multiple imbalance response cases where the differences between the cases is in the bearings and/or the imbalances.

Inputs:

- Operating speeds.
- Clearances to check for rubbing.
- Bearing probe locations.
- Multiple sets of bearing coefficients.
- Multiple sets of imbalances.

Outputs:

- Bode charts at all bearing probe locations, with critical speeds labeled.
- Operating Deflected Shapes for each critical speed.
- Table of critical speeds with their amplification factors and separation margins.
- Table summarizing any bearing probe displacements in the operating speed range that exceed the API recommended limit.
- Table summarizing displacements at all close clearances, when traversing critical speeds.

What Actions Are Taken:

An imbalance response analysis is run with each set of bearing coefficients combined with each set of imbalances.   For example, suppose there are two sets of bearing coefficients (e.g., for max and min bearing clearances) and there are two sets of imbalances (e.g., the rotor has two critical speeds to be analyzed per API guidelines). This means a total 4 cases will be run.   For each of these 4 cases the program will perform the following actions:

1. Create a Resp output worksheet for the case, or overwrite one already created from a previous run.
2. The bearing coefficient specifications for the case being run are copied to the Brg's sheet (originals are restored after completion of the run).
3. The imbalance specifications for the case being run are copied to the Imb's sheet (originals are restored after completion of the run).
4. Compute Bode charts for all bearing probe locations, and scan them for critical speeds, and label the critical speeds and operating speeds.   The list of response speeds on the Imb's Worksheet are used for the response calculation.
5. Check all bearing probe displacements throughout the operating speed range against the API recommended vibration limit.
6. Generate operating deflected shape (ODS) charts for each critical speed.
7. For a separate list of stations, compare shaft deflections in each ODS computed in step 3 against available clearances.
8. Generate ODS charts for an optional list of extra speeds.

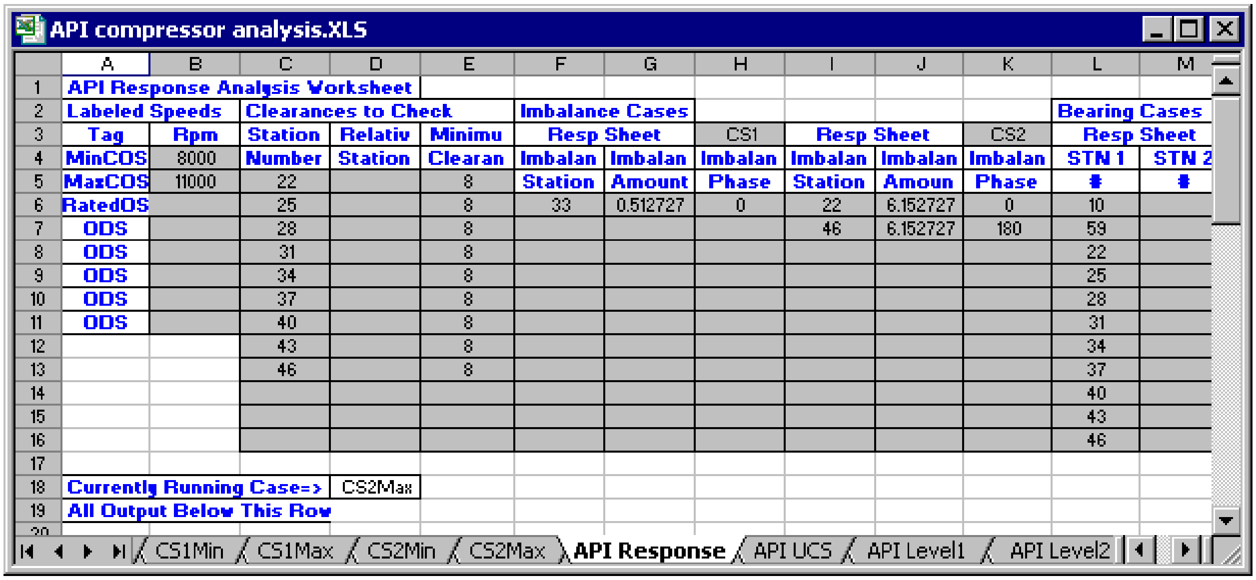
The above steps are repeated for each set of bearing coefficients and imbalance specifications.   When the analysis is complete, there will be tables on the API Response sheet summarizing results of the run (discussed below).

Getting Started & Setting Up Inputs:

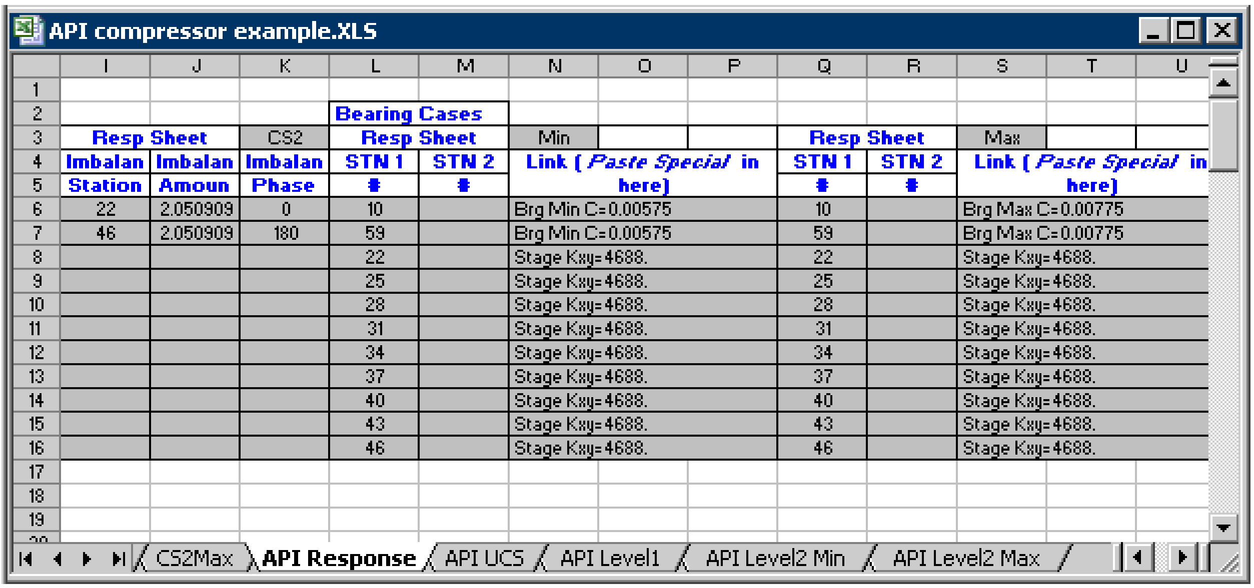
With XLRotor you could do all this yourself manually, one case at a time, and assemble all the necessary results.   But if anything in the model changed, like a coupling weight, you would have to do it all again.   In XLRotor a special worksheet can be used to set up the inputs for all required runs (named API Response, but you can rename it).   Then a single command runs all the analyses in one operation, and assembles the results into a set of tables.

To add an API Response worksheet to your rotor model file, execute the menu command **XLRotor/Run/API Analysis/Response** or click the button on the toolbar or ribbon.   The program will either prompt you for permission to add a sheet to your file, or if you are on an API Response sheet it will offer to run the analysis set up on that sheet.

As the images below show, your inputs go at the top of the sheet.   Outputs are placed below the row where you see **"All Output Below This Row"**.



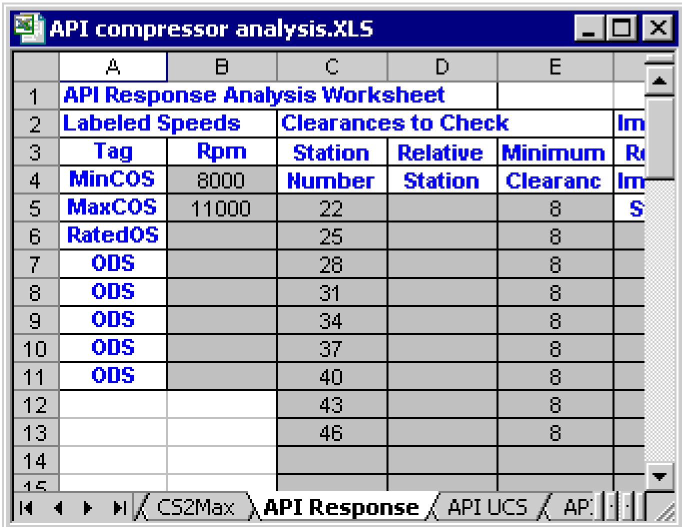
	A	B	C	D	E	F	G	H	I	J	K	L	M
1	API Response Analysis Worksheet												
2	Labeled Speeds		Clearances to Check			Imbalance Cases						Bearing Cases	
3	Tag	Rpm	Station	Relativ	Minimu	Resp Sheet		CS1	Resp Sheet		CS2	Resp Sheet	
4	MinCOS	8000	Number	Station	Clearan	Imbalan	Imbalan	Imbalan	Imbalan	Imbalan	Imbalan	STN 1	STN 2
5	MaxCOS	11000	22		8	Station	Amount	Phase	Station	Amoun	Phase	#	#
6	RatedOS		25		8	33	0.512727	0	22	6.152727	0	10	
7	ODS		28		8				46	6.152727	180	59	
8	ODS		31		8							22	
9	ODS		34		8							25	
10	ODS		37		8							28	
11	ODS		40		8							31	
12			43		8							34	
13			46		8							37	
14												40	
15												43	
16												46	
17													
18	Currently Running Case=>			CS2Max									
19	All Output Below This Row												



	I	J	K	L	M	N	O	P	Q	R	S	T	U
1													
2				Bearing Cases									
3	Resp Sheet		CS2	Resp Sheet		Min			Resp Sheet		Max		
4	Imbalan	Imbalan	Imbalan	STN 1	STN 2	Link (*Paste Special* in			STN 1	STN 2	Link (*Paste Special* in		
5	Station	Amoun	Phase	#	#	here)			#	#	here)		
6	22	2.050909	0	10		Brg Min C=0.00575			10		Brg Max C=0.00775		
7	46	2.050909	180	59		Brg Min C=0.00575			59		Brg Max C=0.00775		
8				22		Stage Kxy=4688.			22		Stage Kxy=4688.		
9				25		Stage Kxy=4688.			25		Stage Kxy=4688.		
10				28		Stage Kxy=4688.			28		Stage Kxy=4688.		
11				31		Stage Kxy=4688.			31		Stage Kxy=4688.		
12				34		Stage Kxy=4688.			34		Stage Kxy=4688.		
13				37		Stage Kxy=4688.			37		Stage Kxy=4688.		
14				40		Stage Kxy=4688.			40		Stage Kxy=4688.		
15				43		Stage Kxy=4688.			43		Stage Kxy=4688.		
16				46		Stage Kxy=4688.			46		Stage Kxy=4688.		
17													
18													
19													

Labeled Speeds

This is first of 5 parts to the inputs. The speeds entered here will be displayed on Bode charts which are created during the analysis. The speeds are also used to determine critical speed separation margins.



	A	B	C	D	E	
1	API Response Analysis Worksheet					
2	Labeled Speeds		Clearances to Check			Im
3	Tag	Rpm	Station	Relative	Minimum	R
4	MinCOS	8000	Number	Station	Clearanc	Im
5	MaxCOS	11000	22		8	S
6	RatedOS		25		8	
7	ODS		28		8	
8	ODS		31		8	
9	ODS		34		8	
10	ODS		37		8	
11	ODS		40		8	
12			43		8	
13			46		8	
14						

ODS

This is a list of extra speeds for which you want operating deflected shapes (ODS) to always be computed, for all cases. Be aware that the program will automatically run an ODS analysis for each critical speed that is found. The speeds you list here will be in addition to these. Normally these cells will be left empty, and the only ODS that will be computed will be those for the critical speeds.

Clearances to Check

This is a list of stations and clearances. When the program computes an ODS for a critical speed, the amplitude of the entire ODS will be scaled up or down so that the bearing probe which sees maximum response will have a response equal to the API vibration limit. If the major axis response at any station in the list exceeds 75% of its clearance, it is listed in an output table described later.

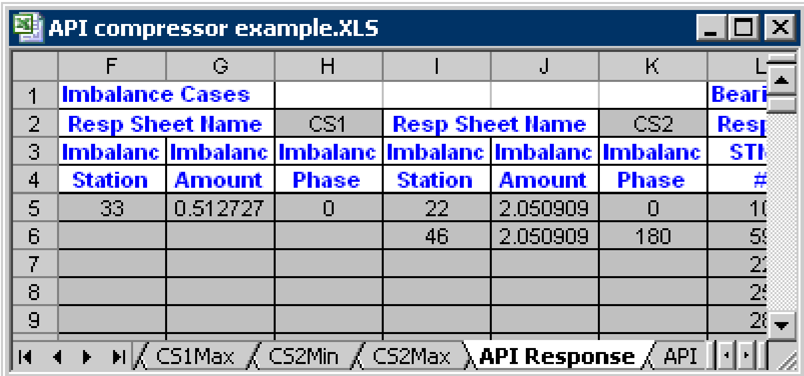
$$\text{API Recommended Limit} = \sqrt{\frac{12000}{N}}\, mils\ pk - pk$$

The API limit is converted to the same units that you have in the Options/Response dialog for displacement output. Be aware of this when entering the clearances. For example, a model set to output displacements in "mils pk-pk" should have clearances entered as diametral clearance in mils. If the option is set to output displacement in "microns 0-p", then clearances should be entered as radial in units of microns.

Imbalance Cases

Here you specify the different cases of imbalance distributions to be run. There must be at least one case, but you can specify as many as you need. Specify the stations and their imbalances for each case. You also must give each case a unique name. In the example shown below the first imbalance set excites the first critical speed which is a bounce mode. The name for this case is CS1. The second imbalance set excites the second critical speed which is a conical mode. Its name is CS2.

The imbalance stations, amounts and phases for each case will each in turn be Copied and Pasted to the corresponding cells on the Imb's Worksheet. *Values* are pasted, not *formulas*, so you do not have to worry about cell references going astray when pasted.


API compressor example.XLS

	F	G	H	I	J	K	L
1	Imbalance Cases						Beari
2	Resp Sheet Name		CS1	Resp Sheet Name		CS2	Resp
3	Imbalanc	Imbalanc	Imbalanc	Imbalanc	Imbalanc	Imbalanc	STI
4	Station	Amount	Phase	Station	Amount	Phase	#
5	33	0.512727	0	22	2.050909	0	1(
6				46	2.050909	180	5!
7							2:
8							2!
9							2!

Bearing Cases

Here you specify the different sets of bearing coefficients to be run. There must be at least one set, but you can specify as many as you need. Specify the stations and their links, and you must give each set a unique name. In the example shown below the first set has bearing coefficients calculated with minimum bearing clearances. There is also aerodynamic cross coupling applied at each impeller of this 9 stage centrifugal compressor. The name for this set is Min. The second set of bearing coefficients is designated Max, and these bearing coefficients have been calculated with maximum bearing clearances.

For each set in turn, the bearing stations will be Copied and Pasted to the Brg's Worksheet as *values*. But the Links must be pasted as formulas because formulas are required in the Links column on the Brg's sheet. So make sure that Link formulas always use absolute cell references (as in $B$2 as opposed to B2).

API compressor example.XLS

	L	M	N	O	P	Q	R	S	T	U
1	Bearing Cases									
2	Resp Sheet Name		Min			Resp Sheet Name		Max		
3	STN 1	STN 2	Link (*Paste Special* in here)			STN 1	STN 2	Link (*Paste Special* in here)		
4	#	#				#	#			
5	10		Brg Min C=0.00575			10		Brg Max C=0.00775		
6	59		Brg Min C=0.00575			59		Brg Max C=0.00775		
7	22		Stage Kxy=4688.			22		Stage Kxy=4688.		
8	25		Stage Kxy=4688.			25		Stage Kxy=4688.		
9	28		Stage Kxy=4688.			28		Stage Kxy=4688.		
10	31		Stage Kxy=4688.			31		Stage Kxy=4688.		
11	34		Stage Kxy=4688.			34		Stage Kxy=4688.		
12	37		Stage Kxy=4688.			37		Stage Kxy=4688.		
13	40		Stage Kxy=4688.			40		Stage Kxy=4688.		
14	43		Stage Kxy=4688.			43		Stage Kxy=4688.		
15	46		Stage Kxy=4688.			46		Stage Kxy=4688.		
16										

CS1Max / CS2Min / CS2Max / **API Response** / API UCS / API Level1 / API Level2 Min

Note: In the example, the imbalance cases appear on the worksheet first, followed by the bearing cases. This means all bearing cases are run for the first imbalance case, before moving on to the second imbalance case. If you reposition the cases so the bearing cases come first, the program runs all imbalance cases for the first bearing case, before moving on to the second bearing case.

Bearing Probe Locations

The locations of the bearing probes are specified on the Imb's Worksheet. This is done in the table where output stations are listed. Whenever an imbalance response analysis is run, XLRotor produces Bode charts for all the stations in this list. Bearing probe locations are those having any value (even zero) entered in the Probe Clocking column. If the Probe Clocking cell empty for a station, then that station is not a bearing probe location.

In the example below, stations 9 and 60 are where the probes are located just outboard of the bearings. When the API Response analysis is done, only the Bode charts for stations 9 and 60 will be scanned for critical speeds, and labeled accordingly.

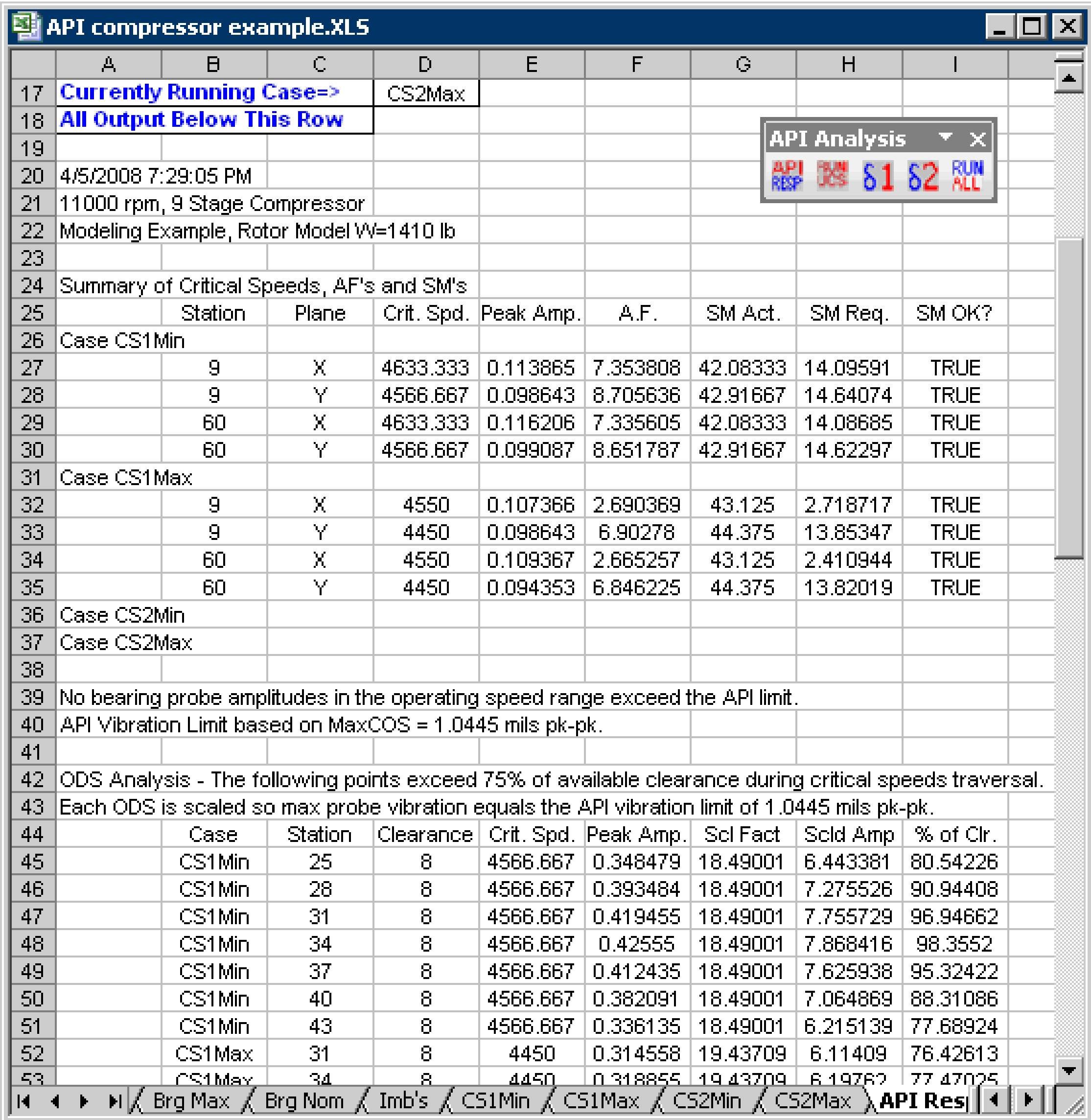
API compressor example.XLS

	H	I	J	K
2	Output Stations	Relative Stations	Probe Clocking	Titles to be Placed on Plots
3	9		0	Brg Max C=0.00775
4	60		0	Brg Max C=0.00775
5	33			Rotor Midspan
6				
7				

Brg Max / Brg Nom / **Imb's** / CS1Min / CS1Max / CS2Min

API Response Analysis Results

The results of the API Response analysis appear on a set of Resp Worksheets, and in three summary tables on the API Response sheet as illustrated in the following figure.



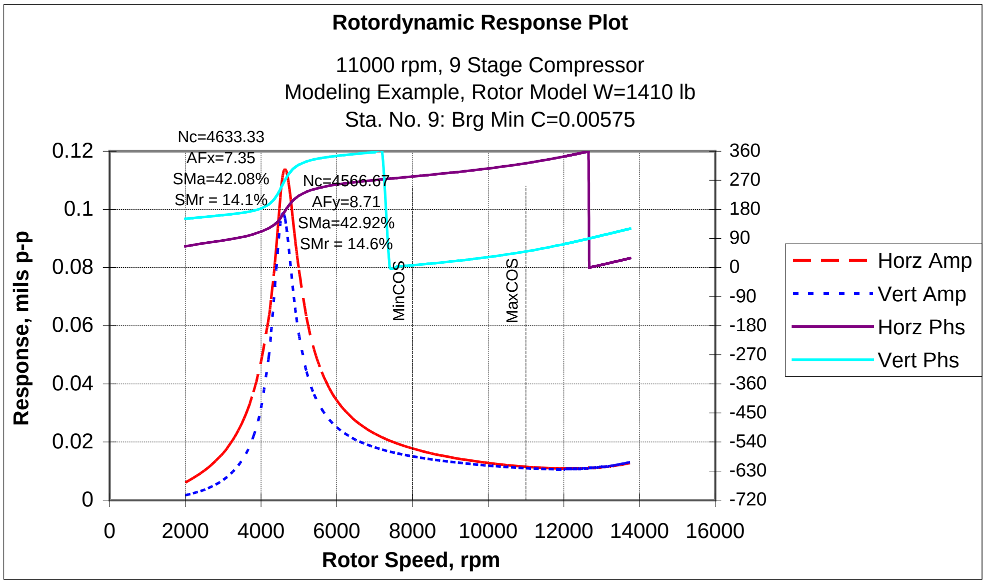
	A	B	C	D	E	F	G	H	I
17	Currently Running Case=>			CS2Max					
18	All Output Below This Row								
19									
20	4/5/2008 7:29:05 PM								
21	11000 rpm, 9 Stage Compressor								
22	Modeling Example, Rotor Model W=1410 lb								
23									
24	Summary of Critical Speeds, AF's and SM's								
25		Station	Plane	Crit. Spd.	Peak Amp.	A.F.	SM Act.	SM Req.	SM OK?
26	Case CS1Min								
27		9	X	4633.333	0.113865	7.353808	42.08333	14.09591	TRUE
28		9	Y	4566.667	0.098643	8.705636	42.91667	14.64074	TRUE
29		60	X	4633.333	0.116206	7.335605	42.08333	14.08685	TRUE
30		60	Y	4566.667	0.099087	8.651787	42.91667	14.62297	TRUE
31	Case CS1Max								
32		9	X	4550	0.107366	2.690369	43.125	2.718717	TRUE
33		9	Y	4450	0.098643	6.90278	44.375	13.85347	TRUE
34		60	X	4550	0.109367	2.665257	43.125	2.410944	TRUE
35		60	Y	4450	0.094353	6.846225	44.375	13.82019	TRUE
36	Case CS2Min								
37	Case CS2Max								
38									
39	No bearing probe amplitudes in the operating speed range exceed the API limit.								
40	API Vibration Limit based on MaxCOS = 1.0445 mils pk-pk.								
41									
42	ODS Analysis - The following points exceed 75% of available clearance during critical speeds traversal.								
43	Each ODS is scaled so max probe vibration equals the API vibration limit of 1.0445 mils pk-pk.								
44		Case	Station	Clearance	Crit. Spd.	Peak Amp.	Scl Fact	Scld Amp	% of Clr.
45		CS1Min	25	8	4566.667	0.348479	18.49001	6.443381	80.54226
46		CS1Min	28	8	4566.667	0.393484	18.49001	7.275526	90.94408
47		CS1Min	31	8	4566.667	0.419455	18.49001	7.755729	96.94662
48		CS1Min	34	8	4566.667	0.42555	18.49001	7.868416	98.3552
49		CS1Min	37	8	4566.667	0.412435	18.49001	7.625938	95.32422
50		CS1Min	40	8	4566.667	0.382091	18.49001	7.064869	88.31086
51		CS1Min	43	8	4566.667	0.336135	18.49001	6.215139	77.68924
52		CS1Max	31	8	4450	0.314558	19.43709	6.11409	76.42613
53		CS1Max	34	8	4450	0.318855	19.43709	6.19762	77.47025

Individual Resp Output Worksheets

When you run the XLRotor/Run/API Analysis/Response command, all the cases are run in succession. Referring to the examples given above, the first case will pair the CS1 imbalance with the Min bearing coefficients. This case will take the name CS1Min. The Resp Worksheet generated for this run will be renamed "CS1Min". The Resp sheet for each case is renamed in a similar fashion.

The Bode charts for the bearing probes are scanned for peaks to identify the critical speeds. These peaks are labeled with a) the critical speed in rpm, b) the amplification factor, c) the actual separation margin (SMa) from the closest operating speed, and d) the required separation margin (SMr) per API requirements as calculated from the amplification factor (see Label Peak Amplification Factors for details about the label).

The example Bode chart below illustrates the critical speed labels, and also that the operating speeds are added to the chart as well.



First Summary Table

The first summary table on the API Response sheet lists all critical speeds identified in all cases. In the example table appearing below, two distinct critical speeds were found for both the CS1Min and CS1Max cases. The x and y axis critical speeds are predicted to occur at slightly different speeds. Both cases employing the CS2 imbalance failed to produce a critical speed in this example. For this example that is because the second mode is very heavily damped.

API compressor example.XLS

	A	B	C	D	E	F	G	H	I
18	All Output Below This Row								
19									
20	4/5/2008 7:29:05 PM								
21	11000 rpm, 9 Stage Compressor								
22	Modeling Example, Rotor Model W=1410 lb								
23									
24	Summary of Critical Speeds, AF's and SM's								
25		Station	Plane	Crit. Spd.	Peak Amp.	A.F.	SM Act.	SM Req.	SM OK?
26	Case CS1Min								
27		9	X	4633.333	0.113865	7.353808	42.08333	14.09591	TRUE
28		9	Y	4566.667	0.098643	8.705636	42.91667	14.64074	TRUE
29		60	X	4633.333	0.116206	7.335605	42.08333	14.08685	TRUE
30		60	Y	4566.667	0.099087	8.651787	42.91667	14.62297	TRUE
31	Case CS1Max								
32		9	X	4550	0.107366	2.690369	43.125	2.718717	TRUE
33		9	Y	4450	0.098643	6.90278	44.375	13.85347	TRUE
34		60	X	4550	0.109367	2.665257	43.125	2.410944	TRUE
35		60	Y	4450	0.094353	6.846225	44.375	13.82019	TRUE
36	Case CS2Min								
37	Case CS2Max								
38									
39	No bearing probe amplitudes in the operating speed range exceed the API limit								

Imb's / CS1Min / CS1Max / CS2Min / CS2Max / **API Response** / API UCS

Second Summary Table

The second summary table lists the results of comparing all bearing probe vibration amplitudes within the operating speed range against the API recommended vibration limit.

$$\text{API Recommended Limit} = \sqrt{\frac{12000}{N}} mils\ pk - pk$$

If vibration exceeds this limit anywhere within the operating speed range, the speeds with maximum vibration are listed in the table.

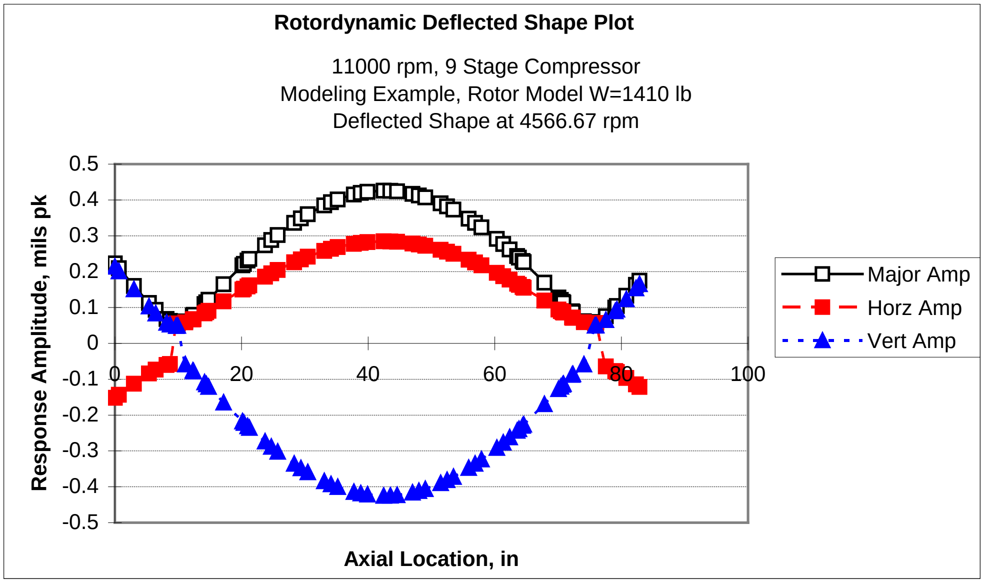
The API limit is converted to the same units that you have in the Options/Response dialog for displacement output.

API compressor analysis.XLS

	A	B	C	D	E	F	G	H
40	Speeds in the operating speed range with probe vibration exceeding the API limit.							
41	API Vibration Limit based on MaxCOS = 1.0445 mils pk-pk.							
42		Case	Station	Axis	Speed	Amp.		
43		CS2Max	9	X	11000	1.3914		
44		CS2Max	9	Y	11000	1.4138		
45		CS2Max	60	X	11000	1.6141		
46		CS2Max	60	Y	11000	1.6727		
47								
48	ODS Analysis - The following points exceed 75% of available clearance during critic							

XLRotor / Shaft Input / Beams / Stations / Geo Plot / Brg's / Stage Kxy

For each critical speed appearing in the first summary table, an ODS (Run|Deflected Shapes) is calculated and appended to the corresponding Resp worksheet. If two critical speeds are with 2.5% of each other, the ODS for just one is calculated.



Third Summary Table

The third summary table lists the stations in the scaled ODS (scaling was described earlier) whose major axis amplitude exceeds 75% of the clearance you specify in the "Clearances to Check" table.

Recall that the API limit is converted to the same units that you have in the Options/Response dialog for displacement output.

The units specified in the Options/Response dialog for deflected shape output do not matter because the ODS is scaled for comparison to the API limit.

API compressor analysis.XLS

	A	B	C	D	E	F	G	H	I
48	ODS Analysis - The following points exceed 75% of available clearance during critical speeds traversal.								
49	Each ODS is scaled so max probe vibration equals the API vibration limit of 1.0445 mils p-p								
50		Case	Station	Clearance	Crit. Spd.	Peak Amp.	Scl Fact	Scld Amp	% of Clr.
51		CS1Min	25	8.0000	4567	0.3485	18.4900	6.4434	80.5423
52		CS1Min	28	8.0000	4567	0.3935	18.4900	7.2755	90.9441
53		CS1Min	31	8	4567	0.4195	18.4900	7.7557	96.9466
54		CS1Min	34	8	4567	0.4255	18.4900	7.8684	98.3552
55		CS1Min	37	8	4567	0.4124	18.4900	7.6259	95.3242
56		CS1Min	40	8	4567	0.3821	18.4900	7.0649	88.3109
57		CS1Min	43	8	4567	0.3361	18.4900	6.2151	77.6892
58		CS1Max	31	8	4450	0.3146	19.4371	6.1141	76.4261
59		CS1Max	34	8.0000	4450	0.3189	19.4371	6.1976	77.4703
60		CS1Max	37	8.0000	4450	0.3097	19.4371	6.0200	75.2500
61									

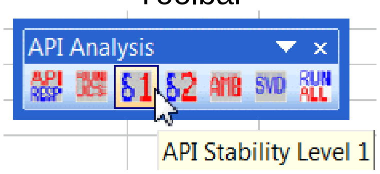
Imb's / CS1Min / CS1Max / CS2Min / CS2Max / **API Response** / API UCS / AP

API Level 1 Stability Analysis

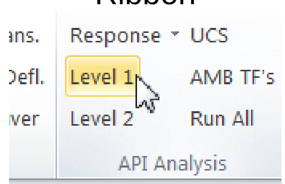
See also

XLRotor Menu Commands
Run|API Analysis
API Response Analysis
API UCS Analysis
API Level 2 Stability Analysis
API AMB Transfer Function Analysis
API SVD Singular Value Decomposition Analysis

Toolbar



Ribbon



A Level 1 Stability Analysis is a screening tool to identify machines that require a more comprehensive and detailed Level 2 Stability Analysis.

A Level 1 Stability Analysis requires performing multiple damped eigenvalue calculations with different sets of bearing coefficients, for a range of cross coupled stiffness values, Q, at one of the bearings. It also requires extracting the stability information (i.e. log dec) of the first rotor critical speed.

Inputs:

- Operating speed.
- Approximate frequency of the first rotor critical speed (i.e. critical speed ratio).
- A range of Q values, and which bearing to apply these to.
- One or more sets of bearing coefficients.

Outputs:

- A table of log decs for the first rotor mode versus Q for each set of bearing coefficients.
- Qo, which is the value of Q where the log dec equals zero, for each set of bearing coefficients.
- A chart of log dec versus Q annotated in a way recommended by the API.

What Actions Are Taken:

In the examples presented below, there are three sets of bearing coefficients; one for minimum bearing clearance, one for maximum bearing clearance, and one for nominal bearing clearance. For each of these cases the program will perform the following actions:

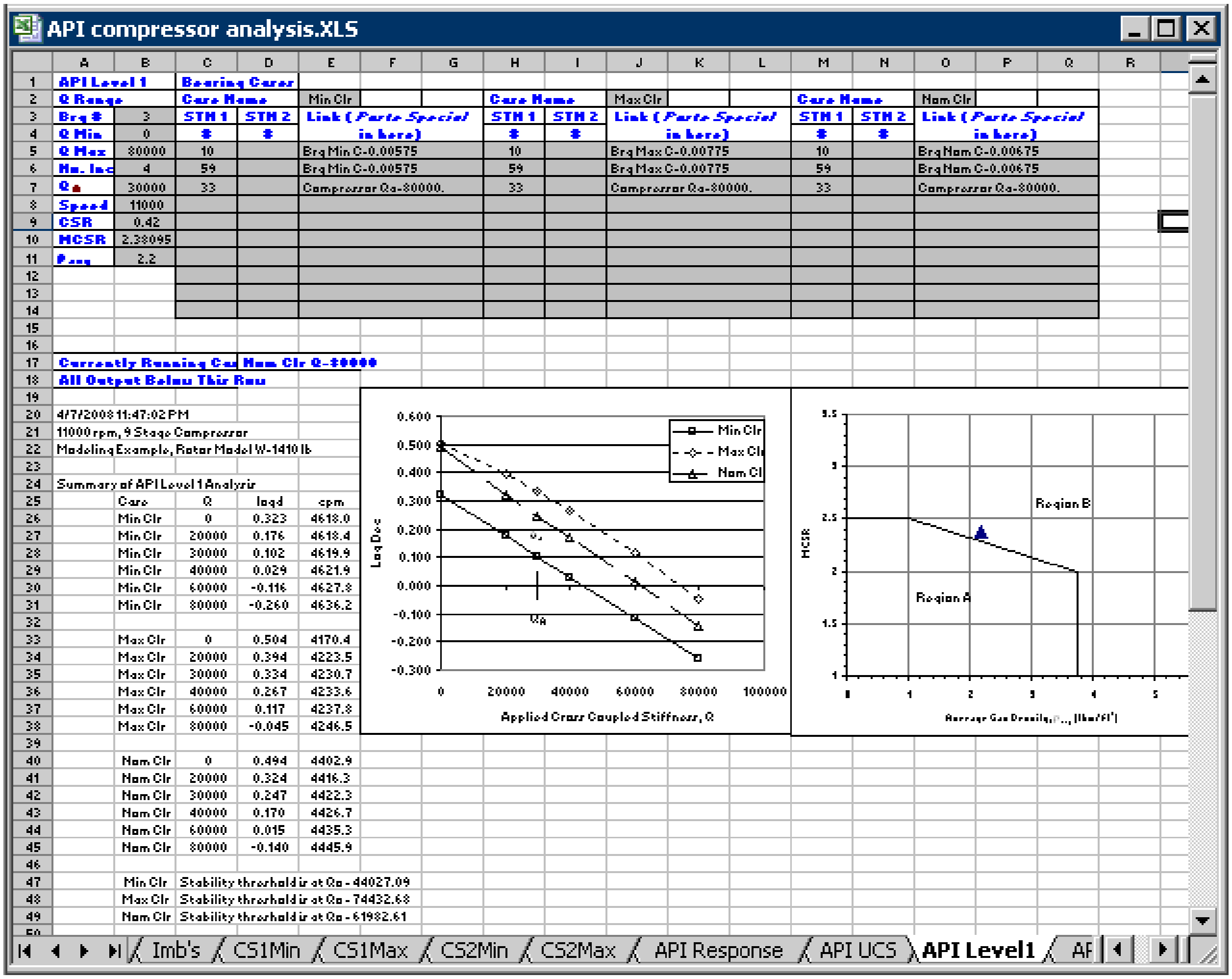
1. An operating speed which you specify is placed in the EIGEN ANALYSIS SPEEDS column on the XLRotor Worksheet (original values are restored after completion of the run).
2. The bearing coefficient specifications for the case being run are copied to the Brg's sheet (originals are restored after completion of the run).
3. Run a series of damped eigenvalue calculations where the Kxy & -Kyx values for one designated bearing are assigned the value of Q. Q is varied over a range you specify.
4. The log dec of the first rotor mode is extracted from the damped eigenvalue results calculated for each value of Q.

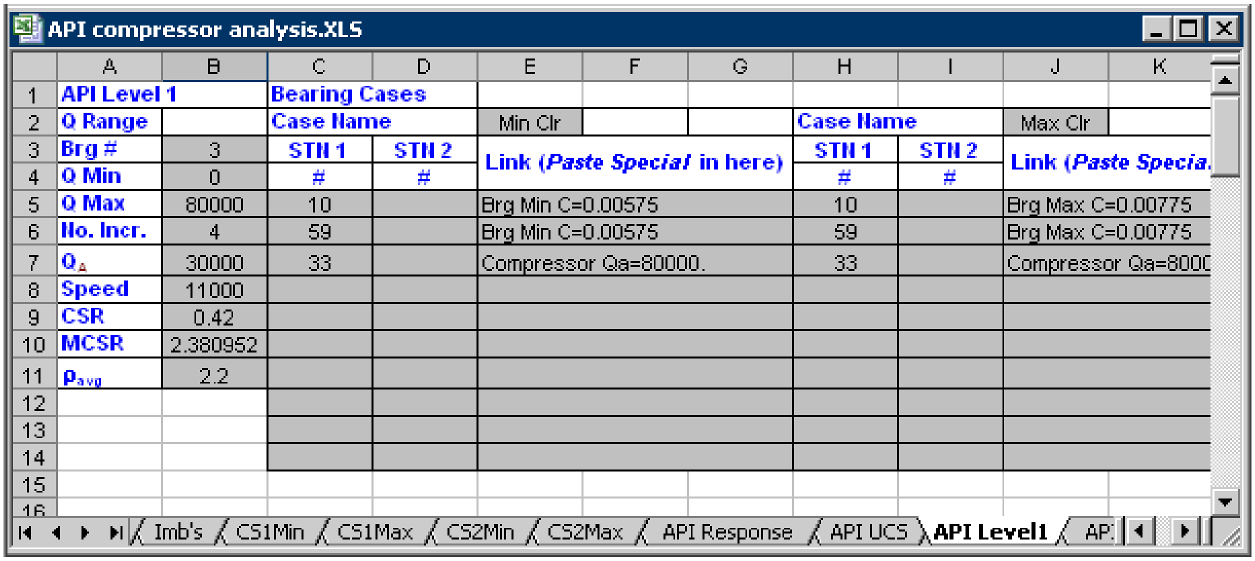
When the analysis is complete, there will be a summary table and a chart showing the log dec versus Q for each bearing case.

Getting Started & Setting Up Inputs:

To add an API Level1 worksheet to your rotor model file, execute the command **XLRotor/Run/API Analysis/Level 1 Stability** from the menu, toolbar or ribbon. The program will either prompt you for permission to add a sheet to your file, or if you are on an API Level 1 sheet, it will offer to run the analysis set up on that sheet.

As the images below show, your inputs go at the top of the sheet. Outputs are placed below the row where you see **"All Output Below This Row"**.

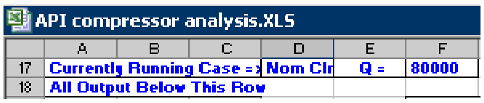

API compressor analysis.XLS
API Level 1
Q Range
Brg # 3
Q Min 0
Q Max 80000
No. Incr. 4
Qa 30000
Speed 11000
CSR 0.42
MCSR 2.38095
ρavg 2.2
Bearing Cases
Case Name | Min Clr
STN 1 # | STN 2 # | Link (Paste Special in here)
10 | Brg Min C=0.00575
59 | Brg Min C=0.00575
33 | Compressor Qa=80000.
Case Name | Max Clr
STN 1 # | STN 2 # | Link (Paste Special in here)
10 | Brg Max C=0.00775
59 | Brg Max C=0.00775
33 | Compressor Qa=80000.
Case Name | Nom Clr
STN 1 # | STN 2 # | Link (Paste Special in here)
10 | Brg Nom C=0.00675
59 | Brg Nom C=0.00675
33 | Compressor Qa=80000.
Currently Running Cas | Nom Clr Q=#####
All Output Below This Row
4/7/2008 11:47:02 PM
11000 rpm, 9 Stage Compressor
Modeling Example, Rotor Model W=1410 lb
Summary of API Level 1 Analysis
Case | Q | logd | cpm
Min Clr | 0 | 0.323 | 4618.0
Min Clr | 20000 | 0.176 | 4618.4
Min Clr | 30000 | 0.102 | 4619.9
Min Clr | 40000 | 0.029 | 4621.9
Min Clr | 60000 | -0.116 | 4627.8
Min Clr | 80000 | -0.260 | 4636.2
Max Clr | 0 | 0.504 | 4170.4
Max Clr | 20000 | 0.394 | 4223.5
Max Clr | 30000 | 0.334 | 4230.7
Max Clr | 40000 | 0.267 | 4233.6
Max Clr | 60000 | 0.117 | 4237.8
Max Clr | 80000 | -0.045 | 4246.5
Nom Clr | 0 | 0.494 | 4402.9
Nom Clr | 20000 | 0.324 | 4416.3
Nom Clr | 30000 | 0.247 | 4422.3
Nom Clr | 40000 | 0.170 | 4426.7
Nom Clr | 60000 | 0.015 | 4435.3
Nom Clr | 80000 | -0.140 | 4445.9
Min Clr | Stability threshold is at Qa = 44027.09
Max Clr | Stability threshold is at Qa = 74432.68
Nom Clr | Stability threshold is at Qa = 61982.61
Log Dec
Min Clr
Max Clr
Nom Cl
QA
Applied Cross Coupled Stiffness, Q
MCSR
Region B
Region A
Average Gas Density
Imb's
CS1Min
CS1Max
CS2Min
CS2Max
API Response
API UCS
API Level1


API compressor analysis.XLS
API Level 1
Q Range
Brg # 3
Q Min 0
Q Max 80000
No. Incr. 4
QA 30000
Speed 11000
CSR 0.42
MCSR 2.380952
ρavg 2.2
Bearing Cases
Case Name | Min Clr
STN 1 # | STN 2 # | Link (Paste Special in here)
10 | Brg Min C=0.00575
59 | Brg Min C=0.00575
33 | Compressor Qa=80000.
Case Name | Max Clr
STN 1 # | STN 2 # | Link (Paste Specia
10 | Brg Max C=0.00775
59 | Brg Max C=0.00775
33 | Compressor Qa=800
Imb's
CS1Min
CS1Max
CS2Min
CS2Max
API Response
API UCS
API Level1

Brg #

In the list of bearings for each bearing set, this is the number of the bearing where the Q value will be placed. The ***Brg #*** input has to be the same for each bearing set. In the example above Q will be assigned to the 3rd bearing in the list, so the Brg # is 3.

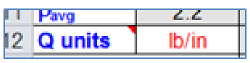
This input can be left blank. When it is blank, the Q values will *not* be placed directly onto any worksheet. Instead, bearing worksheets can use the currently running Q value which is written to the Level 1 worksheet during the run (cell F17 in the following image). This allows Q to be varied on multiple worksheets such as for compressor impellers which have different Q values.



Q Min, Q Max & No. Incr.

These inputs specify a range of Q values.

The units for Q are the same as the units for Kxy on the worksheet referenced by ***Brg #***. When a run has finished, the units for Q are documented below the input for average density.



Note: This is <u>not</u> an input. It is updated each time the sheet is run.

Q_A

This a special value of Q for the machine (compressor) being analyzed. Refer to various API documents for recommendations about determining its value (particularly API 684 and 617). Also, the XLIMPLR.XLS Impeller Cross Coupling Template File could be used to compute the value of Q_A.

If it is not already in the list, Q_A will be added to the list of Q values generated by the Q Min and Q Max inputs described above.

Speed

This is the speed value, in rpm, for which the damped eigenvalues will be computed. This value will be copied to the EIGEN ANALYSIS SPEEDS column on the XLRotor worksheet at the beginning of the analysis. Normally the value for speed would be the machine's maximum continuous operating speed.

CSR

This is the approximate ratio of first mode frequency to the operating speed. Typical values would be in the range 0.4 to 0.5. The ***CSR*** is only used to help the program select the correct eigenvalue from among all the damped eigenvalues which are computed. The program will select the eigenvalue whose frequency is closest to ***CSR*** multiplied by the operating speed.

If you enter a whole number like 2 or 3 for the ***CSR***, then the program will select that exact root number from the list of calculated roots for each bearing case. The value must be a whole number (an integer) to use this method.

You can enter a single value in the worksheet cell, or you can enter a series of values separated by semicolons. The following is an example:

0.42 ; 3 ; 0.37

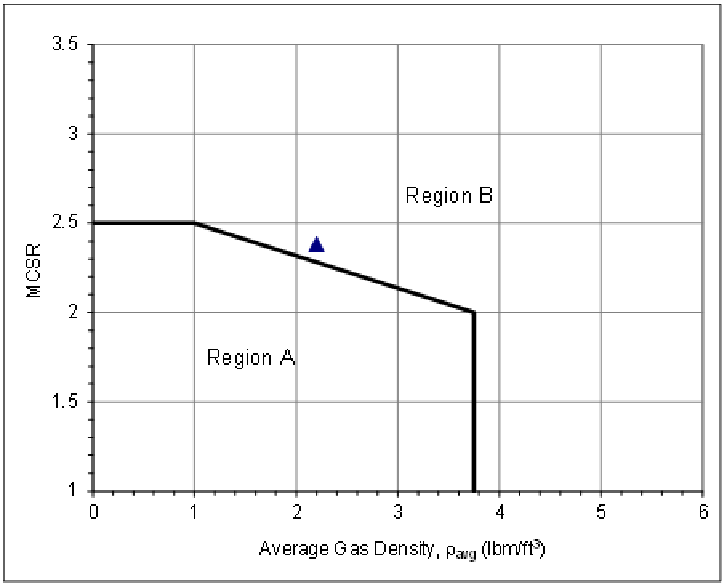
In this example 0.42 will be used for the first bearing case, then 3 for the second and 0.37 for the third bearing case. The number of values must match the number of bearing cases to be run.

A value of -1 for ***CSR*** will cause the program to select whichever root has the lowest damping. This can be useful with machines like double overhung integrally geared compressors because they sometimes have two different modes which could have the lowest damping.

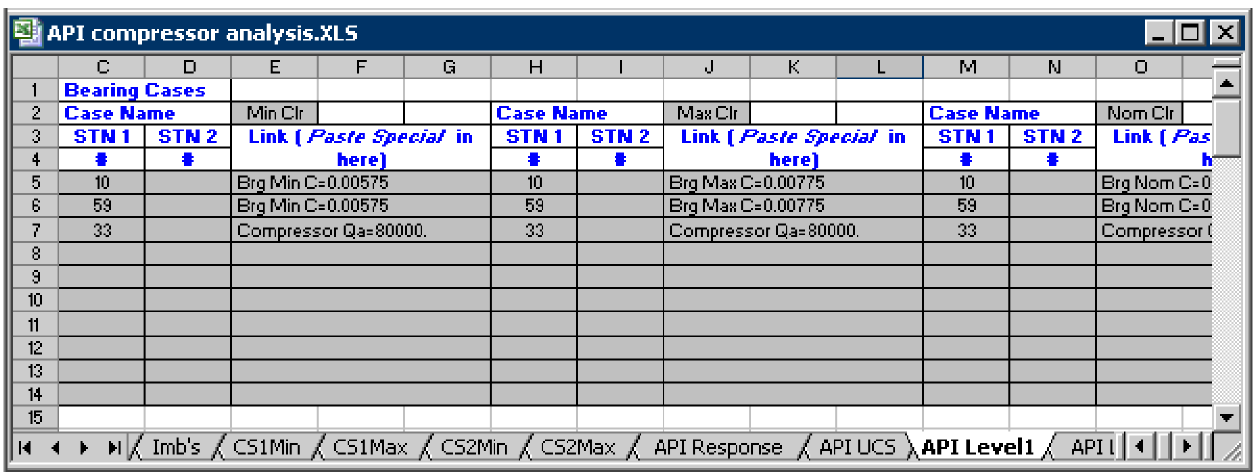
MCSR & RHO$_{avg}$

The ***MCSR*** is another number for the critical speed ratio. It is the reciprocal of the CSR described above, so typical values would be around 2 to 2.5. The ***MCSR*** is used along with the average gas density, ***RHO$_{avg}$,*** to plot a point on an API stability diagram. In the following diagram for our example, this point is the solid triangle. The API recommends that if the point lies in Region B, a Level 2 Stability Analysis be performed. These two values are used only for plotting the point in the chart (i.e. they are not inputs to the Level 1 analysis). The units for ***RHO$_{avg}$*** are indicated in the x axis title of the plot. lbm/ft^3 or kg/m^3, in files using US or SI units, respectively.

Rotordynamic terminology for "critical speed ratio" is not standardized. "Critical speed ratio" can mean either first mode frequency over operating speed, or operating speed over first mode frequency. Fortunately, in nearly any practical stability investigation the first mode frequency will be subsynchronous. Thus, values like 0.4 and 2.5 are understood to have the same basic meaning.



Bearing Case Inputs



The inputs for each bearing case are exactly analogous to the inputs you would enter on the Brg's Worksheet. As each case is run, the bearing station numbers and Link specifications are copied to the Brg's worksheet. The station numbers are copied and pasted to the Brg's sheet as "values", and the link cells are copied and pasted as formulas.

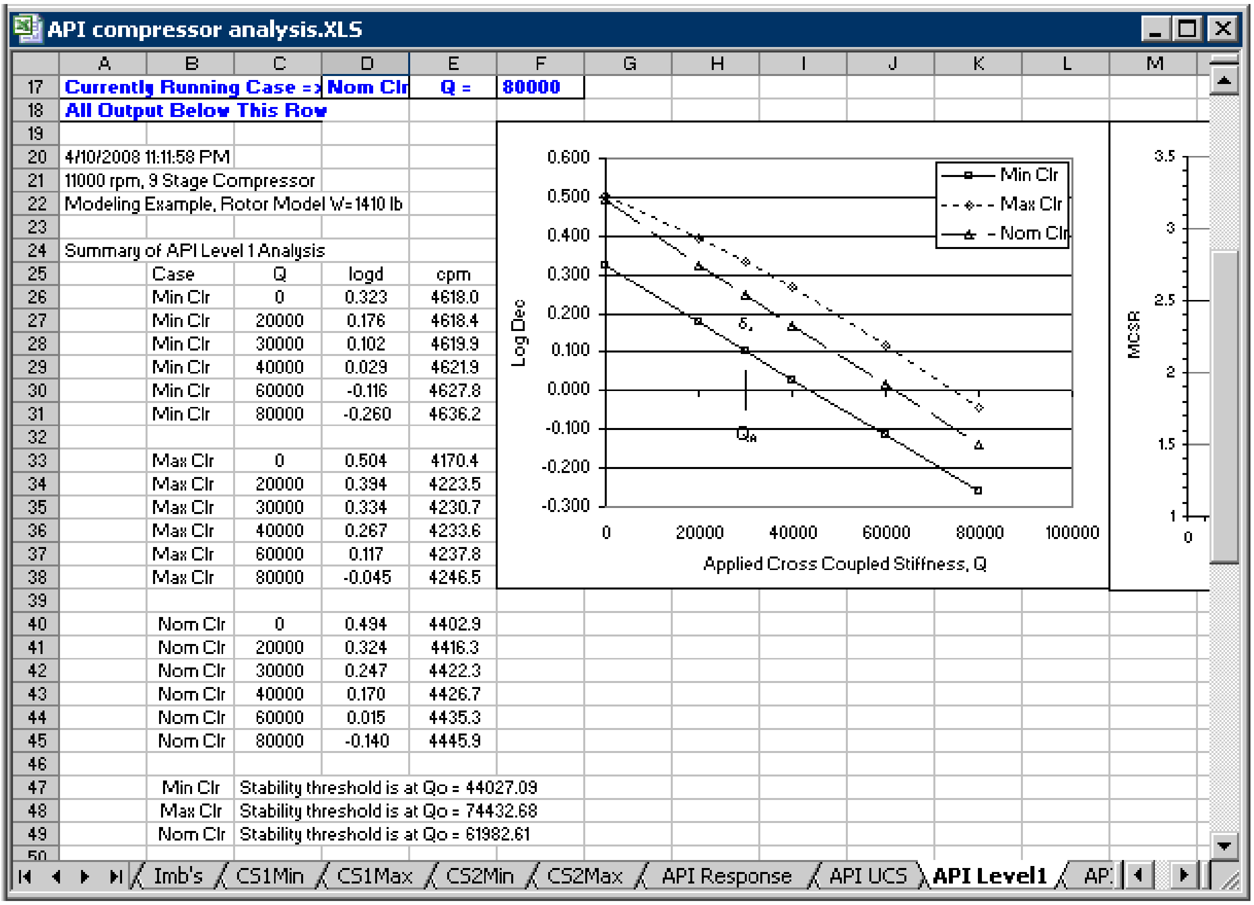
Case Name

The case names must be unique for each case. These names are used to annotate the results table as well as the data series in the log dec stability chart.

As each case is run, the case name and Q value is copied to the cell next to where you see "Currently Running Case=>." The value in this cell can be referred to elsewhere in the file. By using cell formulas, this can be used to change other aspects of the model. This makes it possible to change more than just the bearing coefficients as each case is run. The currently running value of Q is also written to a cell two cells to the right of the case name.

API Level 1 Stability Analysis Results

When the analysis has been completed, the summary table and log dec stability chart would appear similar to the following:



Case	Q	logd	cpm
Min Clr	0	0.323	4618.0
Min Clr	20000	0.176	4618.4
Min Clr	30000	0.102	4619.9
Min Clr	40000	0.029	4621.9
Min Clr	60000	-0.116	4627.8
Min Clr	80000	-0.260	4636.2
Max Clr	0	0.504	4170.4
Max Clr	20000	0.394	4223.5
Max Clr	30000	0.334	4230.7
Max Clr	40000	0.267	4233.6
Max Clr	60000	0.117	4237.8
Max Clr	80000	-0.045	4246.5
Nom Clr	0	0.494	4402.9
Nom Clr	20000	0.324	4416.3
Nom Clr	30000	0.247	4422.3
Nom Clr	40000	0.170	4426.7
Nom Clr	60000	0.015	4435.3
Nom Clr	80000	-0.140	4445.9

Min Clr Stability threshold is at Qo = 44027.09
Max Clr Stability threshold is at Qo = 74432.68
Nom Clr Stability threshold is at Qo = 61982.61

The table and chart are fairly self explanatory. The Q value, first mode log dec and whirl frequency are listed in the table for each bearing case. The log dec chart displays this data. As the above example shows, a marker is placed at the $Q=Q_A$ value. The log dec at $Q=Q_A$ is also annotated on the chart.

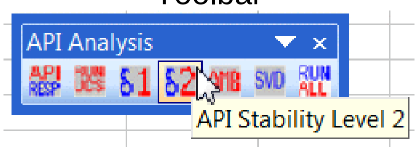
At the bottom of the summary table are values of Qo for each bearing case. These Qo values establish where the log dec transitions from positive to negative (i.e. stable to unstable). In our example, the machine has better stability with maximum bearing clearance than it does with minimum bearing clearance.

API Level 2 Stability Analysis

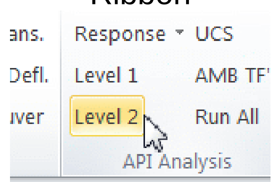
See also

- XLRotor Menu Commands
- Run|API Analysis
- API Response Analysis
- API UCS Analysis
- API Level 1 Stability Analysis
- API AMB Transfer Function Analysis
- API SVD Singular Value Decomposition Analysis

Toolbar



Ribbon



A Level 2 Stability Analysis requires a fully detailed model, with all anticipated instability mechanisms accounted for. Most of the work is in setting up the model. The relevant API document should be consulted for specific modeling requirements. The analysis step itself is relatively straightforward.

The API recommendations for a Level 2 stability analysis appear in various API documents. These essentially say that the log dec of the first rotor mode should be calculated for the following conditions:

1. Rotor and support system only (basic log dec).
2. For the addition of each group of destabilizing effects utilized in the analysis.
3. Complete model including all destabilizing forces (final log dec).

The above may need to be done for different operating conditions such as minimum and maximum bearing and/or seal clearances, and extremes of lubricating oil temperature.

It is advisable to always refer to the most current API documents (eg. API 610 for pumps, API 612 for steam turbines, API 617 for compressors/expanders, API 684 Rotordynamics Tutorial).

The API Level 2 worksheet is very similar to a Level 1 worksheet, and is actually simpler as it has fewer inputs.

Inputs:

- Operating speed (this can be left blank, see below).
- Approximate frequency of the first rotor critical speed (i.e. critical speed ratio).
- Multiple sets of bearing coefficients.

Outputs:

- A table showing the log dec for each set of bearing coefficients.
- A chart of log dec versus the series of bearing coefficients sets.

What Actions Are Taken:

1. An operating speed which you specify is placed in the EIGEN ANALYSIS SPEEDS column on the XLRotor Worksheet (original values are restored after completion of the run).
2. Create a Roots Damped output worksheet for the case, or overwrite one already created from a previous run.
3. The bearing coefficient specifications for the case being run are copied to the Brg's sheet (originals are restored after completion of the run).
4. A damped eigenvalue calculation is performed.
5. The log dec of the first rotor mode is extracted from the damped eigenvalue results.

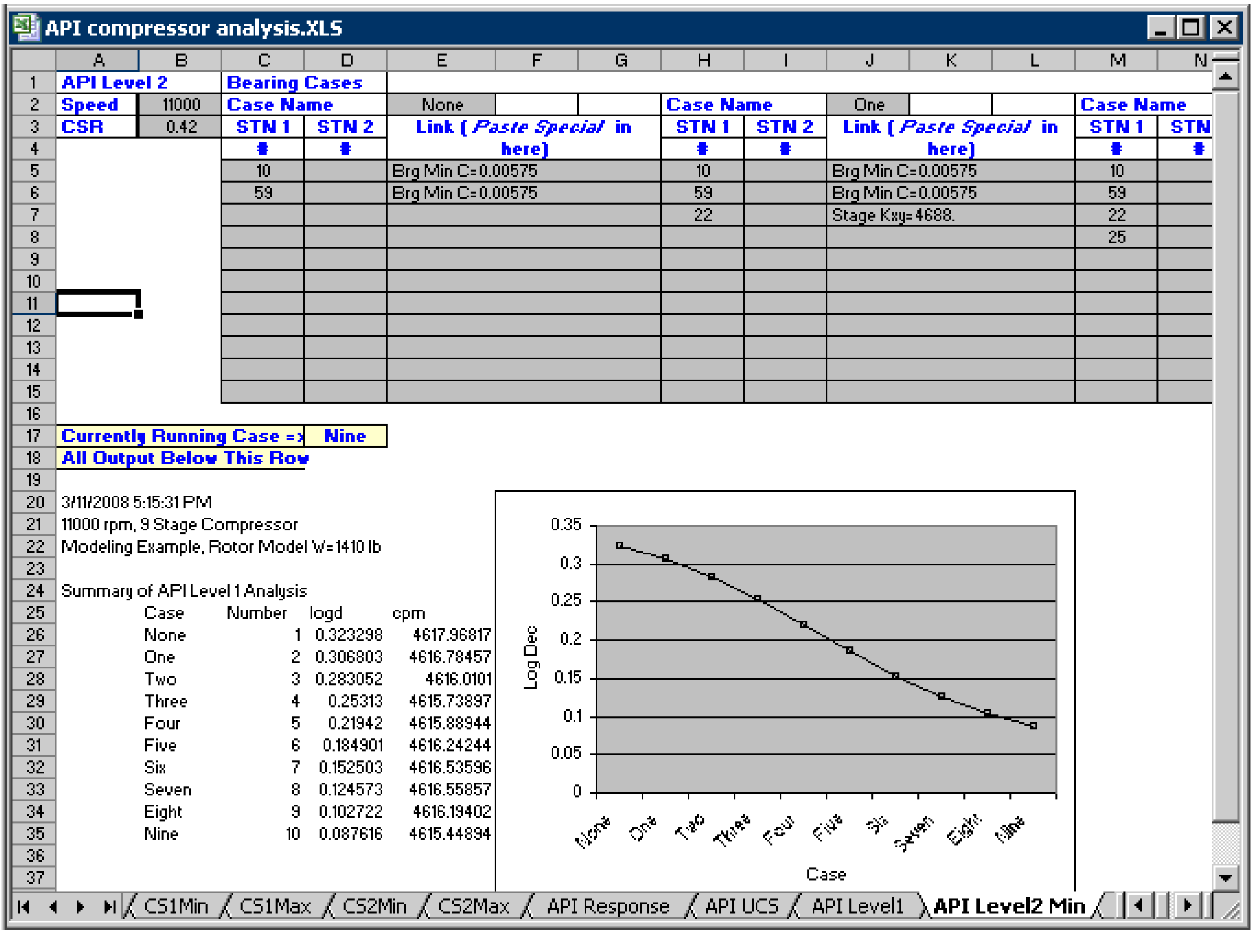
The above steps are repeated for each set of bearing coefficients. When the analysis is complete, there will be a summary table and a chart showing the log dec versus the series of bearing coefficient cases.

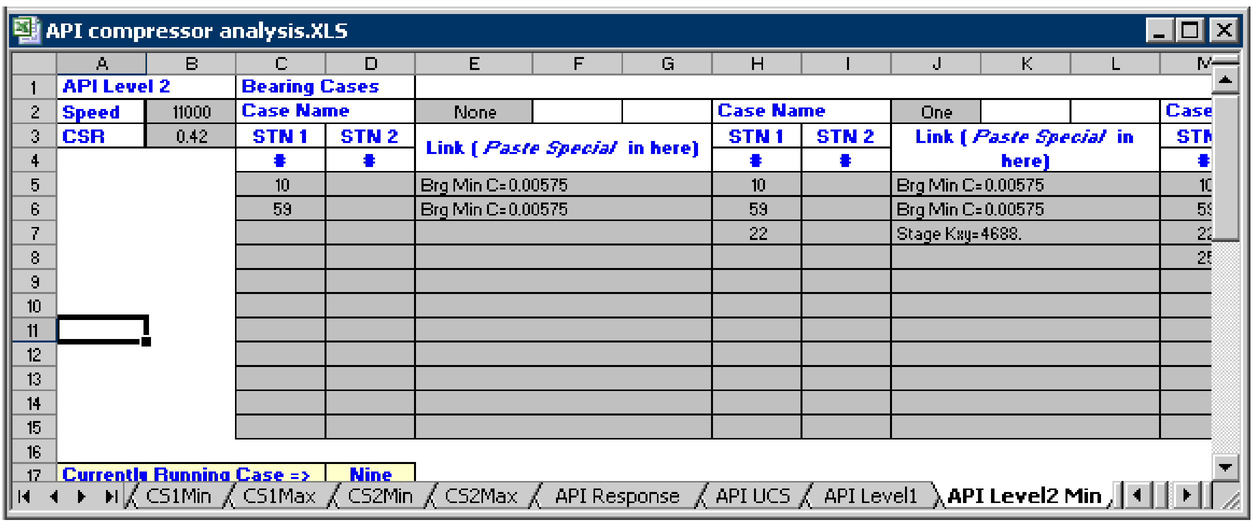
In the example images presented below, there are 10 sets of bearing coefficients. The first set has just the bearings and no other instability influences. The second bearing coefficient set has aerodynamic cross coupling added at the first stage impeller (the example rotor is a 9 stage compressor). Each subsequent bearing coefficient set has aerodynamic cross coupling added at one more stage. Although not done for this simple example, in a more detailed model the stiffness and damping coefficients of the impellers and seals may sometimes be modeled separately.

Getting Started & Setting Up Inputs:

To add an API Level2 worksheet to your rotor model file, execute the menu command **XLRotor/Run/API Analysis/Level 2 Stability**. The program will either prompt you for permission to add a sheet to your file, or if you are on an API Level 2 sheet, it will offer to run the analysis set up on that sheet.

As the images below show, your inputs go at the top of the sheet. Outputs are placed below the row where you see **"All Output Below This Row"**.





Speed

This is the speed value, in rpm, for which the damped eigenvalues will be computed. This value will be copied to the EIGEN ANALYSIS SPEEDS column on the XLRotor worksheet at the beginning of the analysis. Normally the value for speed would be the machine's maximum continuous operating speed.

Note: If you leave this cell empty, then each bearing case will be run with the full list of EIGEN ANALYSIS SPEEDS entered on the XLRotor sheet, and each resulting Roots Damped sheet will be renamed with the ***Case Name***. Use this option when you just want to run a bunch of cases and get the entire Roots Damped sheet for each case. The ***CSR*** input will be ignored, and the log dec table for the mode nearest the ***CSR*** will not be filled out.

CSR

This is the approximate ratio of first mode frequency to the operating speed. Typical values would be in the range 0.4 to 0.5. The CSR is only used to help the program select the correct eigenvalue from among all the damped eigenvalues which are computed. The program will select the eigenvalue whose frequency is closest to CSR multiplied by the operating speed.

If you enter a whole number like 2 or 3 for the CSR, then the program will select that exact root number from the list of calculated roots for each bearing case. The value must be a whole number (an integer) to use this method.

You can enter a single value in the worksheet cell, or you can enter a series of values separated by semicolons. The following is an example:

0.42 ; 3 ; 0.37

In this example 0.42 will be used for the first bearing case, then 3 for the second and 0.37 for the third bearing case. The number of values must match the number of bearing cases to be run.Bearing Case Inputs

The inputs for each bearing case are exactly analogous to the inputs you would enter on the Brg's Worksheet. As each case is run, the bearing station numbers and Link specifications are copied to the Brg's worksheet. The station numbers are copied and pasted to the Brg's sheet as "values", and the Link cells are copied and pasted as formulas.

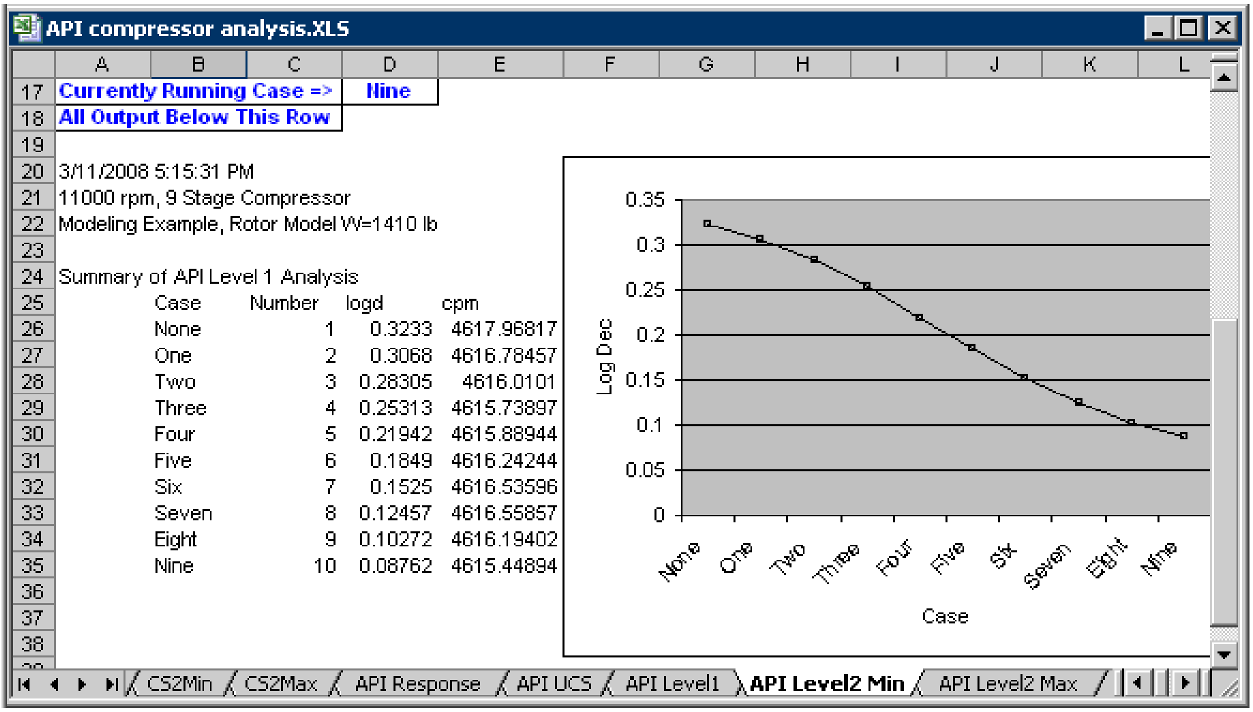
Case Name

The case names must be unique for each case. These names are used to annotate the results table, and to annotate the horizontal axis of the log dec stability chart.

As each case is run, the case name is copied to the cell next to where you see "Currently Running Case=>." The value in this cell can be referred to elsewhere in the file. By using cell formulas, this can be used to change other aspects of the model. This makes it possible to change more than just the bearing coefficients as each case is run.

API Level 2 Stability Analysis Results

When the analysis is complete, the summary table and log dec stability chart would appear similar to the following:



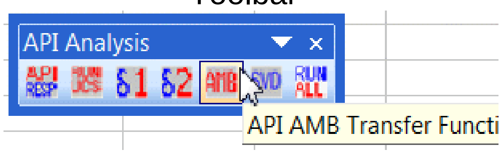
Case	Number	logd	cpm
None	1	0.3233	4617.96817
One	2	0.3068	4616.78457
Two	3	0.28305	4616.0101
Three	4	0.25313	4615.73897
Four	5	0.21942	4615.88944
Five	6	0.1849	4616.24244
Six	7	0.1525	4616.53596
Seven	8	0.12457	4616.55857
Eight	9	0.10272	4616.19402
Nine	10	0.08762	4615.44894

API AMB Transfer Function Analysis

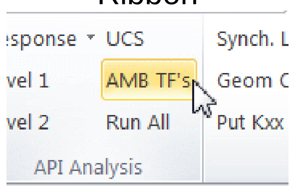
See also

XLRotor Menu Commands
Run|API Analysis
API Response Analysis
API UCS Analysis
API Level 1 Stability Analysis
API Level 2 Stability Analysis
API SVD Singular Value Decomposition Analysis

Toolbar



Ribbon



A ***API Transfer Functions*** analysis is intended for use with rotors supported by actively controlled magnetic bearings (AMB's). This analysis computes any or all of the following three different basic types of transfer functions.

1. Closed Loop Transfer Function (CLTF)
2. Open Loop Transfer Function (OLTF)
3. Sensitivity Transfer Function (SNTF)

AMB controller transfer functions are defined as part of a rotor model using an XLTransferFunction worksheet. When controller transfer functions are merged with a rotor-bearing model to form a complete system model, several other useful transfer functions can be calculated corresponding to each of the controller transfer functions, and thereby include the dynamics of the plant (i.e. rotor and housing).

The input for the transfer function analysis is essentially a unit amplitude sinusoidal sensor displacement input directly to the controller. This will be called f. From that input, the controller generates a force that excites the entire system, and the resulting displacement at the same sensor location is the output of the calculation. This will be called x. This is a linear forced response calculation which is done for a range of frequencies. The above three transfer functions are then computed using the following expressions:

CLTF = -x/f

OLTF = x/(f+x)

SNTF = (f+x)/f

Each of these quantities provides useful insight into the performance of the controller with the given plant. These three TF's can be calculated separately for each axis of control.

Note: The excitation force generated by the unit amplitude sensor displacement is equal to (1+i*0) times the transfer function for the controller which is a complex value evaluated at the frequency of excitation (having units of force/length).

Inputs:

- List of operating speed(s).
- Which of the three TF's to calculate.
- One or more sets of bearing specifications.

Outputs:

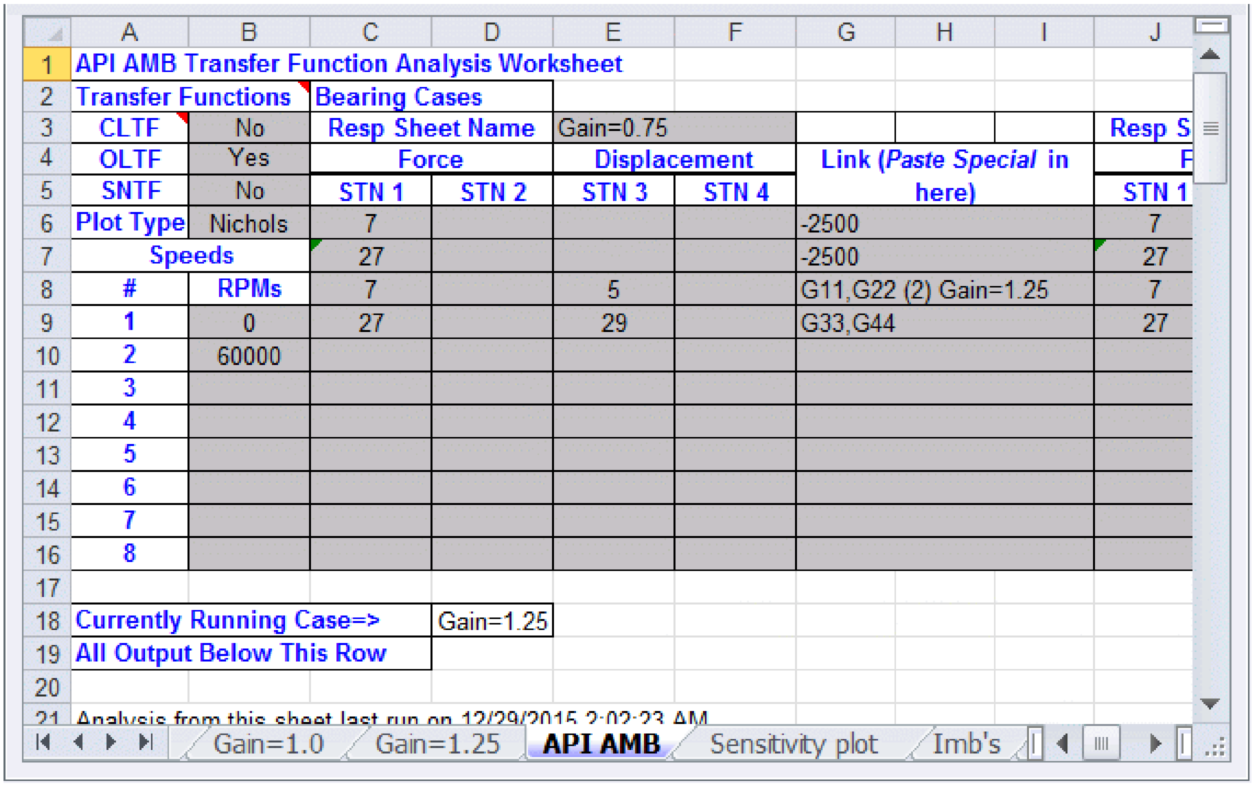
- A set of Resp Worksheets that show the calculated TF's. Each set of bearing specifications will generate one Resp worksheet. Each Resp worksheet will contain all the TF's, calculated for each operating speed.

What Actions Are Taken:

1. Copy the first set of bearing specifications from the API AMB worksheet to the Brg's worksheet (originals are restored after completion of the run).
2. Create a Resp output worksheet for the case, or overwrite one already created from a previous run.
3. Starting with the first transfer function in the list of bearing specifications, and with the first operating speed, and run a linear forced response calculation. The list of excitation frequencies used for the calculation is taken from the XLTransferFunction worksheet in the ***Freq*** column (see the XLTransferFunction sheet).
4. Output the requested CLTF, OLTF and SNTF plots to a Resp worksheet.
5. Repeat steps 2 and 3 for all transfer functions in the bearing specification, and for all operating speeds on the API AMB sheet.
6. After all transfer functions for every operating speed have been output, change the name of the Resp worksheet to the name provided for this case.
7. Repeat steps 1 to 6 for the second set of bearing specifications, and so on.

Getting Started & Setting Up Inputs:

To add an API AMB worksheet to your rotor model file (see sample below), execute the menu command ***XLRotor/Run/API Analysis/AMB Transfer Functions*** (or click its button on the XLRotor toolbar or ribbon). The program will either prompt you for permission to add a sheet to your file, or if you are on an API AMB sheet it will offer to run the analysis set up on that sheet.

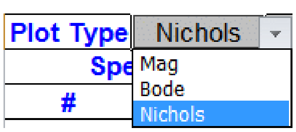


Transfer Functions

Transfer Functions	
CLTF	Yes
OLTF	No
SNTF	No

Enter Yes or No for outputting each type of transfer function.

Plot Type



Select one of three plot types. Selecting ***Mag*** will produce only a plot of magnitude. Selecting ***Bode*** will produce plots of magnitude and phase. Selecting ***Nichols*** will produce a plot of gain on the y axis, and phase angle on the x axis. The default formats for these plots can be customized by editing the templates located in the XLRGRPH.XLS file.

Mag/phase data values are always output to the worksheet.

Speeds (RPMs)

Speeds	
#	RPMs
1	0
2	60000
3	
4	

Enter the list of operating speeds for which to compute transfer functions. Any number of speeds can be listed.

Bearing Cases

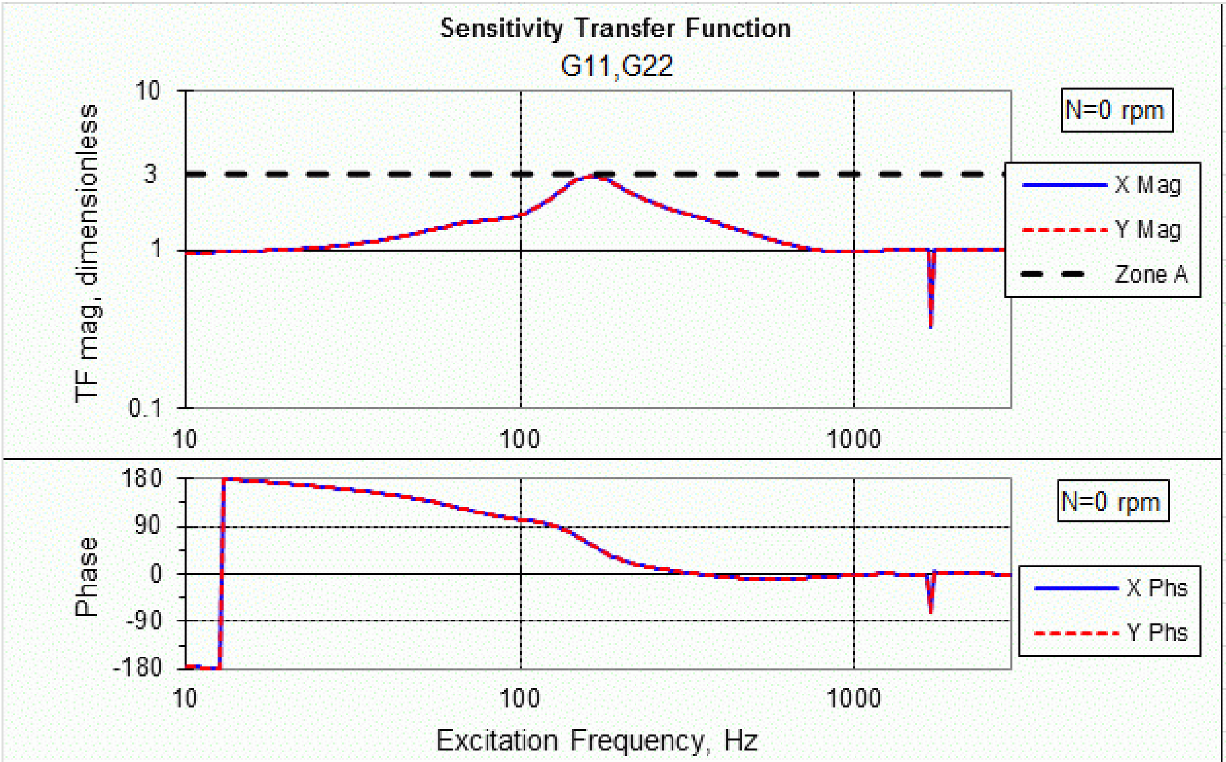
Bearing Cases									
Resp Sheet Name		Comp 1			Resp Sheet Name				
Force		Displacement		Link (*Paste Special* in here)	Force		Displacement		Link (*Paste Special* in here)
STN 1	STN 2	STN 3	STN 4		STN 1	STN 2	STN 3	STN 4	
7				-2500					
27				-2500					
7		5		G11,G22					
27		29		G33,G44					

Here the different sets of bearing specifications to be run are listed. There must be at least one set, and you can specify as many as you need. Specify the stations numbers and their associated Links exactly as done on the Brg's Worksheet, and each set must have a unique name. In the example shown above the first set of bearing specifications is named Comp 1. The Resp worksheet for this case will be renamed "Comp 1".

Individual Resp Output Worksheets

When running the ***XLRotor/Run/API Analysis/API AMB Transfer Functions*** from either its menu command or Ribbon button, all cases are run in succession. Each Resp Worksheet generated will contain tables and plots for each transfer function.

SNTF plots will include a horizontal line at a magnitude of 3 which in API 617 8th Edition is the maximum recommended value for this quantity. If this line is not wanted, it can be deleted from the chart by selecting it and pressing Delete on the keyboard.



Sensitivity Transfer Function							
Rotor Speed = 0							
G11,G22							
Exc. Freq.	X Mag	X Phs	Y Mag	Y Phs	-	-	-
Hz	--	degrees	--	degrees			
10	0.944534	-175.218	0.944534	-175.218			
10.23293	0.946164	-175.681	0.946164	-175.681			
10.47129	0.947779	-176.143	0.947779	-176.143			
10.71519	0.949384	-176.604	0.949384	-176.604			

Singular Value Analysis in XLRotor

See also

API SVD Singular Value Decomposition Analysis

The following are excellent references on singular value decomposition.

1. *Computer Methods for Mathematical Computations,* George· E. Forsythe, Michael A. Malcolm, and Cleve B. Moler, Prentice-Hall, 1977.

2. "Practical Applications of Singular Value Decomposition in Rotordynamics", C. Hunter Cloud, William C. Foiles, Guoxin Lia, Eric H. Maslen and Lloyd E. Barrett, IFToMM Sixth International Conference on Rotor Dynamics, Sydney, Australia, 2002.

SVD Problem Definition

$r = Ax$

x = input vector of forces or unbalances in n input planes.

r = output vector of vibration responses in m response planes.

A = synchronous response matrix of influence coefficients, typically calculated with a rotordynamic model. This matrix will vary with speed. It is also possible to determine this matrix experimentally. The values in this matrix are influence coefficients with units such as mils pk-pk per oz-in. Typical rotor balancing by the method of influence coefficients utilizes this equation.

SVD Basics

Matrix A can be decomposed using a standard SVD subroutine as follows.

$A=U\Sigma V^H$ (H indicates Hermitian transpose).

$\Sigma = m$ x n rectangular matrix of singular values with diagonal elements σ_i. The number of diagonal elements is the smaller of m and n, all other elements are zero.

$V = n$ x n orthonormal matrix of right singular vectors (aka, input vectors). Each column is a unit length vector.

$U = m$ x m orthonormal matrix of left singular vectors (aka, output vectors). Each column is a unit length vector.

SVD and Rotordynamic Synchronous Response

Each column V_i defines a distinct unbalance distribution.

Each column U_i defines the response to corresponding column V_i.

The actual vibration response r_i to unbalance V_i can be calculated using $r_i= AV_i$ or $r_i= \sigma_i U_i$. By definition all the V_i and U_i have unit length (i.e. 2-norm=1). So the length of each r_i is σ_i, and the largest σ_i will cause the largest r_i. An important detail here is the precise meaning of "largest". The σ values are merely individual real numbers, so the largest σ is simply the biggest one. The r_i are vectors, and the "largest" one is the one with greatest Euclidean length (i.e. 2-norm).

The columns V_i are essentially modal unbalance distributions, and note that these vectors always have length=1. For any selected rotor speed, the column with the largest corresponding σ_i (designated $\overline{\sigma}$) is the unbalance distribution that generates the largest response at that speed. At speeds near a critical speed, the $\overline{V}$ that goes with $\overline{\sigma}$ will resemble the mode shape of that critical.

> Calculating $V^H x$ decomposes an arbitrary unbalance distribution x into n modal unbalance components (i.e. a vector with n elements).
>
> Multiplying that by Σ converts the modal unbalances to m modal responses (i.e. a vector with m elements).
>
> Multiplying that by U converts the modal responses to physical responses, resulting in a final r vector identical to Ax.

At every value of rotor speed the SVD analysis automatically determines the unbalance distribution $\overline{V}$ which generates the largest response, and that response can be compared to vibration limits.

Since the SVD calculation determines modal unbalance vectors, it can be used as an aid for rotor balancing in the field by inputting either a measured or calculated influence coefficient matrix. XLRotor makes it easy to do an SVD calculation with any matrix of elements entered on a spreadsheet.

Forming the A Matrix

Each element $A_{i,j}$ of the A matrix is the response at output i due to a force at input j. When generating the A matrix, the x and y force components at one input station can be treated in one of two ways:

> 1) Two independent inputs, x force and y force, allowing each to have its own magnitude and phase angle.
>
> 2) One input in the form of a forward rotating force with given magnitude and phase angle.

For 1), the SVD calculation will determine force components at each station, and allows forces to be forward rotating, backward rotating, circular or elliptic. When a backward rotor mode has a lower damping ratio than a forward mode, the SVD analysis may find $\overline{\sigma}$ (i.e. the largest σ) at a backward critical driven by backward rotating forces. That would usually not be what is wanted.

For 2), the forces can only be forward rotating and circular, as are normal unbalance forces. Backward rotor modes can still be excited if they have elliptic orbits, but not as strongly as forward modes. So $\overline{\sigma}$ should occur at a forward critical speed.

Scaling the A Matrix

A common case with rotating machines is each balance plane will have a maximum practical unbalance, for instance based on known balance and assembly tolerances. Those specified unbalance amounts can be used as the inputs to generate the $A_{i,j}$ elements. In which case each element of the input vector x will have been effectively "scaled" such that 1 corresponds to the maximum possible amount in any plane. The responses to these unbalances are typically on the order of mils at each output plane. So each $A_{i,j}$ would then have units such as mils per max unit of unbalance (mils at output i due to max unbalance at j).

Each output location i probably has a maximum allowable displacement, like the clearance at a seal or API recommended vibration limit at a bearing probe. If each $A_{i,j}$ is divided by the maximum allowable number of mils at location i, then the A matrix effectively becomes dimensionless. An input of 1 equates to an unbalance equal to the max allowable value, and an output of 1 equates to a response equal to the max clearance. Ideally all elements of A will be less than 1. Should an element $A_{i,j}$=1, this implies that max allowable unbalance in plane j causes max allowable response at i, without unbalance in any other planes!

When the A matrix is formed in this fashion, it is a "scaled response matrix". Each individual "scaled" input is bounded by 1. The goal of SVD analysis is to determine the worst case distribution of inputs, and whether or not this causes "scaled" outputs which exceed 1.

Physical Interpretation of $\bar{\sigma}$

The SVD of A determines the specific input distribution $\bar{V}$ that causes the maximum possible response, subject to the constraint that $\|\bar{V}\| = 1$. The output to this is $\bar{r} = \bar{\sigma}\bar{U}$. In this context "Maximum" response means that the 2-norm of $\|\bar{r}\|$ is the largest possible for any V with a 2-norm of 1. Since $\|\bar{U}\| = 1$, no element of $\bar{r}$ can exceed $\bar{\sigma}$. So $\bar{\sigma}$ is guaranteed to be a conservative estimate of the largest element of $\bar{r}$. This is true regardless of any scaling applied to the inputs or outputs when forming A.

As an example, consider A is unscaled such that in the expression $r=Ax$ the units of x are gm-mm, and r are microns zero to peak. The resulting value of $\bar{\sigma}$ would be a conservative estimate of the maximum element of $\bar{r}$, in units of microns 0-pk, caused by a worst case unbalance distribution which has a 2-norm magnitude of 1 gm-mm.

If A has been scaled as described earlier, $\bar{\sigma}$ is a conservative estimate for the maximum element of the scaled $\bar{r}$ vector such that if $\bar{\sigma}$<1 then no response can exceed its specified limit for any scaled forcing function with a 2-norm magnitude not exceeding 1.

Mathematical Representation of Vibration

$$x(t) = x_c * \cos(\omega t) + x_s * \sin(\omega t)$$

$$x(t) = \sqrt{x_c^2 + x_s^2}\cos\left(\omega t - tan^{-1}\frac{x_s}{x_c}\right) = A_x cos(\omega t - \phi_x)$$ lagging phase angle

$$x(t) = A_x\cos(\phi_x)\cos(\omega t) + A_x\sin(\phi_x)\sin(\omega t) = A_x\sin(\omega t - \phi_x + \tfrac{\pi}{2})$$

$$\hat{x} = x_c + i(-x_s) = x_r + ix_i \qquad x_r = x_c \text{ and } x_i = -x_s$$

$$x(t) = \frac{\hat{x}e^{i\omega t} + (\hat{x}e^{i\omega t})^*}{2} = \frac{\hat{x}e^{i\omega t} + \hat{x}^* e^{-i\omega t}}{2}$$ ( )*=complex conjugate

$$A_x = \sqrt{x_c^2 + x_s^2} = |\hat{x}| = \sqrt{x_r^2 + x_i^2} = \sqrt{\hat{x}\cdot\hat{x}^*} \qquad \phi_x = \tan^{-1}\left(\frac{-x_i}{x_r}\right) = \tan^{-1}\left(\frac{x_s}{x_c}\right)$$

And similarly for y.

Conversion of x & y to an Ellipse

$\hat{r}_f = \hat{x} + i\hat{y} = r_{f_r} + ir_{f_i}$ $\quad r_f = |\hat{r}_f|$ $\quad$ forward circular magnitude (≥0)

$\hat{r}_b = \hat{x}^* + i\hat{y}^* = r_{b_r} + ir_{b_i}$ $\quad r_b = |\hat{r}_b|$ $\quad$ backward circular magnitude (≥0)

$$\phi_f = \tan^{-1}\left(\frac{r_{f_i}}{r_{f_r}}\right) \qquad \phi_b = \tan^{-1}\left(\frac{r_{b_i}}{r_{b_r}}\right)$$

$a = r_f + r_b$ $\quad$ a=major axis amplitude (≥0)

$b = r_f - r_b$ $\quad$ b=minor axis amplitude (>0 = forward, <0 = backward)

$\psi = \frac{1}{2}(\phi_f + \phi_b)$ $\quad$ orientation of major axis measured ccw from x axis

2-norm Magnitude of an Ellipse

$A_2 = \sqrt{A_x^2 + A_y^2}$ 2-norm magnitude of an elliptic orbit

$A_2 \geq a$

$A_2 = a$ for orbits totally flat (i.e. when $b = 0$)

$A_2 = \sqrt{2} * a$ for circular orbits (i.e. when $a = \pm b$)

The ratio A_2/a ranges from 1 to $\sqrt{2}$ for all ellipses

A_2 may be considered a conservative estimate of a since it is $\geq a$. The degree of conservatism is limited to 41.4%.

Vector Norms

2-norm Magnitude of a Vector

For a vector X with m real or complex elements, its 2-norm magnitude is its ***Euclidean*** length $\|X\|$ =$(\Sigma X_i^2)^{0.5}$, and is always $\geq$0.

Infinity-norm Magnitude of a Vector

For the same vector X, its infinity norm magnitude $\|X\|_\infty$ is simply the absolute value of the largest element.

Note that $\|X\|_\infty \leq \|X\| \leq \sqrt{m} * \|X\|_\infty$.

> The 2-norm is always greater than the Inf-norm, but...
>
> not greater than $\sqrt{m}$ * Inf-norm.
>
> The 2-norm is a single number which reflects the sizes of <u>all</u> elements in a vector.
>
> The Inf-norm is the size of one element, i.e. the largest.

2-norm Magnitude of a Set of Ellipses

Consider a vector X of m stations in a rotor model, containing x and y complex magnitudes for each (i.e. for m stations, X contains $2m$ complex elements). The 2-norm magnitude is $\|X\|$ =$(\Sigma X_i^2)^{0.5}$. This 2-norm magnitude can be as much as $\sqrt{2m}$ times larger than the largest major axis in the vector.

Consider a vector M of m stations in a rotor model, containing major axis amplitudes for each (i.e. for m stations, M contains m real elements). As above, the 2-norm magnitude of this vector is $\|M\|$=$(\Sigma M_i^2)^{0.5}$. This 2-norm magnitude can be as much as $\sqrt{m}$ times larger than the largest major axis in the vector.

Note that $\|X\| \geq \|M\|$, i.e. $\|X\|$ is a conservative estimate of $\|M\|$ by up to 41.4%.

Vector Norms and Rotordynamics

In rotordynamics, most often we would prefer to specify the unbalances as a maximum allowable value separately for each plane. In addition, we would prefer to specify the maximum allowable response for each output plane. These types of specifications lend themselves to an infinity norm type of vector representation. However, a singular value decomposition calculation by definition is carried out using 2-norm vectors magnitudes. The Left and Right singular vectors of an SVD calculation must have 2-norm magnitudes equal to 1. In order to obtain SVD results with vectors more to our liking, i.e. with infinity norms, it is necessary to modify the SVD calculation.

How XLRotor Computes the SVD

The exact procedure used by XLRotor to compute the SVD depends on the selections for ***Input Norm*** and ***Output Norm***, and also on the selection for input ***Force Type***. The following table describes the calculations.

n = The number of input <u>stations</u>. However, the actual number of SVD inputs, which is the number elements in the Right singular vectors, is either n or $2n$ depending on the choice of input Force Type. Choosing a rotating force type reduces the number of independent inputs from $2n$ to n.

m = The number of output <u>stations</u>. However, the actual number of SVD outputs is $2m$ because both x and y components must be output independently for each station so that response orbits can be elliptic. Therefore $2m$ will always be the number of elements in the Left singular vectors.

	Input norm	Output norm	Force Type	Calculation procedure
1	2norm	2norm	osc	Compute [2m,2n] SVD, output $\bar{\sigma},\bar{U},\bar{V}$
2			rot	compute [2m,n] SVD, output $\bar{\sigma},\bar{U},\bar{V}$
3		Inf.	osc	Compute [2,2n] SVD separately for each *output station* and $\bar{\sigma}$=max major axis in $\bar{\sigma}\bar{U}$, output overall max $\bar{\sigma}$, $\bar{V}$ and $\bar{U}$
4			rot	Compute [2,n] SVD separately for each *output station* and $\bar{\sigma}$=max major axis in $\bar{\sigma}\bar{U}$, output overall max $\bar{\sigma}$, $\bar{V}$ and $\bar{U}$
5	Inf.	2norm	osc	Do 1 to get $\bar{V}$, then set magnitude of each element equal to 1‡, then $\bar{U} = A\bar{V}$ and $\bar{\sigma} = \lVert\bar{U}\rVert$, output $\bar{\sigma},\bar{U},\bar{V}$
6			rot	Same as 5 except start with 2
7		Inf.	osc	Do 5 separately for each *output station* i to get U and σ_i=major axis, then $\bar{\sigma} = \lVert\sigma_i\rVert_\infty$
8			rot	Do 6 separately for each *output station* i to get U and σ_i=major axis, then $\bar{\sigma} = \lVert\sigma_i\rVert_\infty$

‡In row 5, calculation of $\bar{V}$ provides phase angles for the worst case distribution.

osc = independent x and y oscillating forces at each input station.

rot = forward rotating input force at each input station.

A special case combining rotating force input with a rotordynamic model that is axisymmetric, will produce whirl orbits which are perfect forward circles (i.e. x and y outputs are not independent). In this case the SVD calculation could be with done with n inputs and m outputs, but this special case is not included in the above table.

Selecting ***2-norm*** for input means a "worst case" set of unbalances has a collective 2-norm magnitude of 1, and therefore none of the individual unbalance planes will equal its specified upper limit. In order for the "worst case" set of unbalances to equal the limit that was specified for <u>every</u> unbalance plane, select ***Infinity Norm*** for input.

Selecting ***2-norm*** for output means that the response to the "worst case" input is given as a 2-norm vector magnitude, which is a blend of the responses in all output planes. In order to get the true worst case response magnitude which will be at one particular output plane, select ***Infinity Norm*** for output, and along with the max singular value the program will also output which output plane had the maximum response.

The most common case is ***Infinity Norm*** for both input and output. The worst case unbalance set will have the full specified allowable value in every unbalance plane, and the max singular value will be the resulting response in whichever output plane has the largest major axis response relative to its clearance. In the above table, this is analysis type number 8. All the example XLRotor analysis files for SVD were done using type 8.

Analysis type number 1 in the above table is the most fundamental way to perform a singular value analysis. Sample SVD calculations presented in Reference number 2 cited near the beginning of this page were done in this fashion.

Rotor bearing system optimization studies can be done using results of SVD. Optimization studies generally work best if model results are continuous functions of model parameters. SVD calculation type 8 may be discontinuous since for example peak response can shift from one output plane to another as model parameters are adjusted by the optimizer. SVD analysis type 1 will generate continuous results, and so may be better suited for optimization work.

API SVD Singular Value Decomposition Analysis

See also

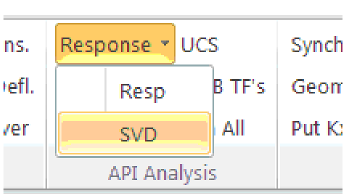
XLRotor Menu Commands
Run|API Analysis
API Response Analysis
API UCS Analysis
API Level 1 Stability Analysis
API Level 2 Stability Analysis
API AMB Transfer Function Analysis
Singular Value Analysis in XLRotor
Singular Value Analysis of a Cell Range

An ***SVD*** analysis is a special type of forced response analysis done using a Singular Value Decomposition algorithm. This type of analysis is not actually discussed in any current API documents or purchase specifications, although it may be at some point in the future. The SVD analysis is grouped with the API Analysis commands in XLRotor because of its similarity with the API Response command. In a typical API Response analysis, multiple sets of imbalances are input (magnitudes and phase angles), and it is up to the analyst to determine how many distinct phase angle distributions are required to excite all relevant critical speeds of the rotor, and what those phase distributions are. In an SVD analysis, the same set of imbalance magnitudes are input, but without phase angles. The SVD analysis automatically determines phase angles which generate worst case responses, and this is done for all critical speeds simultaneously.

An SVD analysis is similar to an API Response analysis. The main difference is an API Response analysis usually requires inputting multiple sets of imbalance weights and phase angles, whereas an SVD analysis usually requires inputting just one set of imbalance weights and no phase angles.

To run an SVD analysis, click the ***SVD*** button on the API Analysis toolbar

or on the XLRotor ribbon



.

Inputs:

- Operating speeds.
- Multiple sets of bearing coefficients.

- Clearances, i.e. maximum allowable response magnitudes.
- Multiple sets of imbalances, i.e. maximum allowable imbalances in each plane of imbalance.
- SVD analysis parameters.

Outputs:

- Table and corresponding plot of singular values versus running speed, for each combination of bearing coefficients and imbalances.
- Table of left and right singular vectors, i.e. imbalance magnitudes and phase angles determined by the SVD algorithm, and the response to those.
- Operating Deflected Shapes at selected speeds, using imbalances and phase angles determined by the SVD algorithm.

What Actions Are Taken:

A singular value analysis is run with each set of bearing coefficients combined with each set of imbalances. For example, suppose there are two sets of bearing coefficients (e.g., for max and min bearing clearances) and there are two sets of imbalances (although usually one is sufficient). Then a total 4 cases will be run, and 4 output worksheets will be generated. For each of these 4 cases the program performs the following actions:

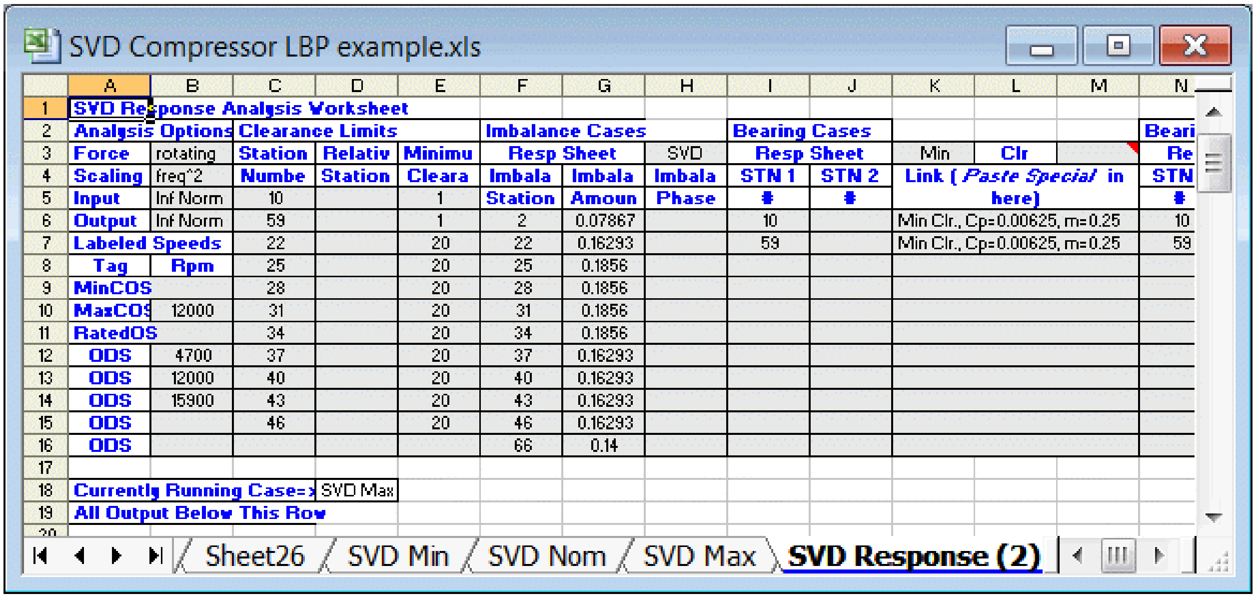
1. Create a Resp output worksheet for the case, or overwrite one already created from a previous run.
2. The bearing coefficient specifications for the case being run are copied to the Brg's sheet (originals are restored after completion of the run).
3. For each speed of rotation, compute singular values and output them to the Resp sheet. The list of response speeds on the Imb's Worksheet are used for the calculation.
4. For the overall maximum singular value, output its value, the speed, and Left and Right singular vectors. The Right vector is an imbalance distribution. The Left vector is the response to that distribution.
5. Generate an ODS chart for an optional list of speeds. The imbalance used is the Right singular vector for the maximum singular value at that speed.
6. Rename the Resp worksheet using the unique name supplied for each case.

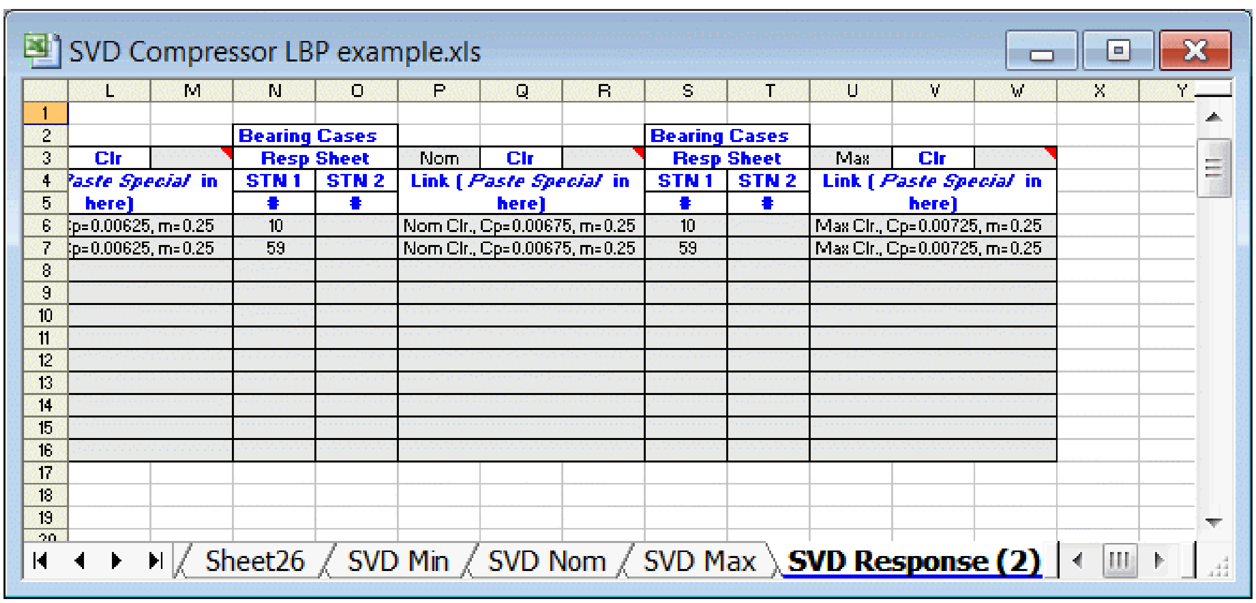
The above steps are repeated for each set of bearing coefficients and imbalance specifications. When the analysis is complete, there will be a table on the SVD Response worksheet summarizing results of the run.

Getting Started & Setting Up Inputs:

To add an **SVD Response** worksheet to your rotor model file, execute the menu command **XLRotor/Run/API Analysis/SVD Analysis**. The program will either prompt you for permission to add a sheet to your file, or if you are on an SVD Response sheet it will offer to run the analysis set up on that sheet.

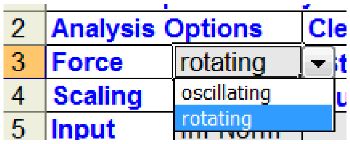
As the images below show, your inputs go at the top of the sheet. Outputs summarizing the run are placed below the row where you see **"All Output Below This Row"**.





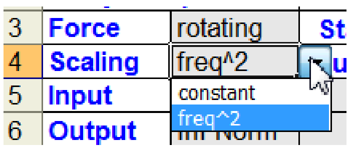
Force

This parameter selects whether to use a forward ***rotating*** force at each input plane, or to use ***oscillating*** force components which are independent in magnitude and phase in the x and y directions.   The normal input is ***rotating***.



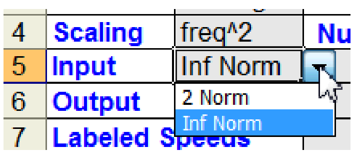
Scaling

This parameter selects whether the input force at each input plane is constant with frequency, or increases with the square of frequency.   Selecting ***constant*** means the values entered in the columns of ***Imbalance Amount*** will have units of force, in the same units as the model (i.e. lbf or Newtons).   Selecting ***freq^2*** means the values in the columns of ***Imbalance Amount*** will have units of imbalance (i.e. same units as on the Imb's Worksheet).   The normal input is ***freq^2***.



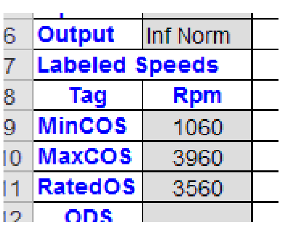
Input Norm & Output Norm

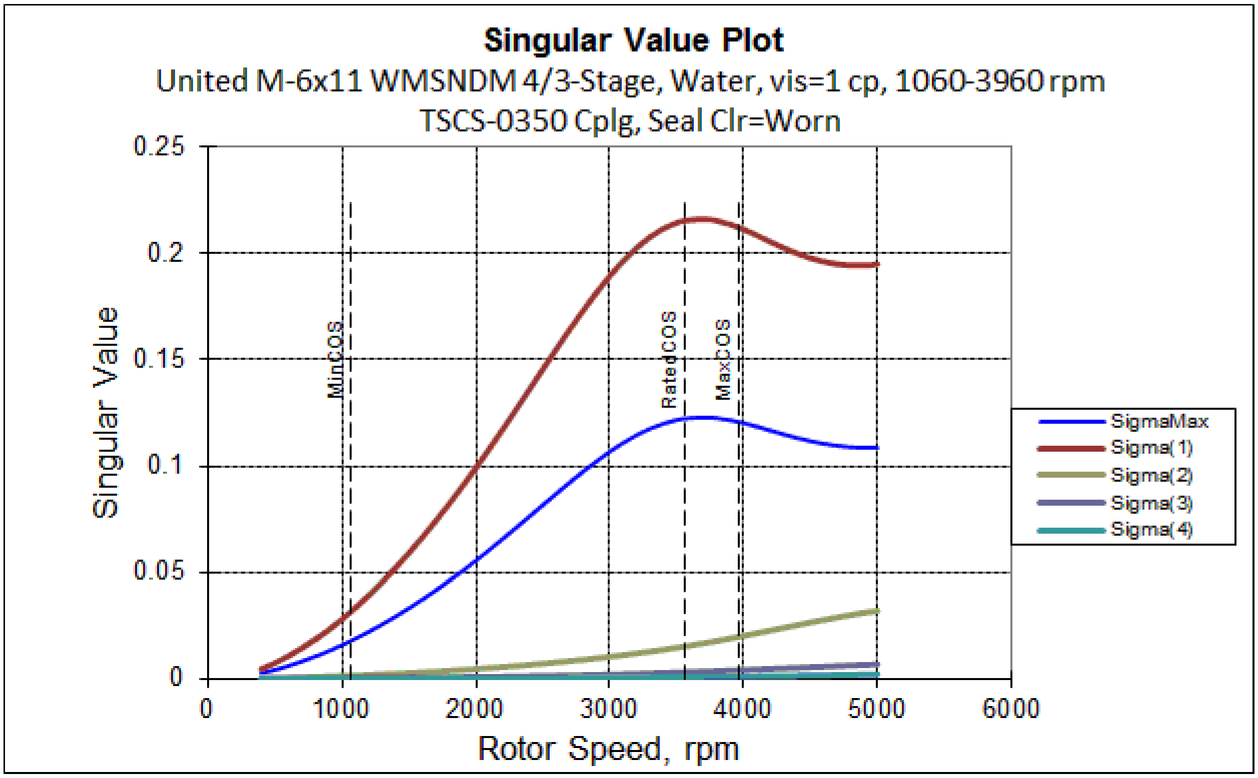
The type of vector norm for input and output can be either ***2 Norm*** or ***Infinity Norm***. For each, the normal input is ***Infinity Norm***.   Note that the choice of norms affects the precise meaning of the singular values.



Labeled Speeds

The speeds entered here will be displayed on the singular value chart created during the analysis.   A plot of singular values is also called a "sigma chart".

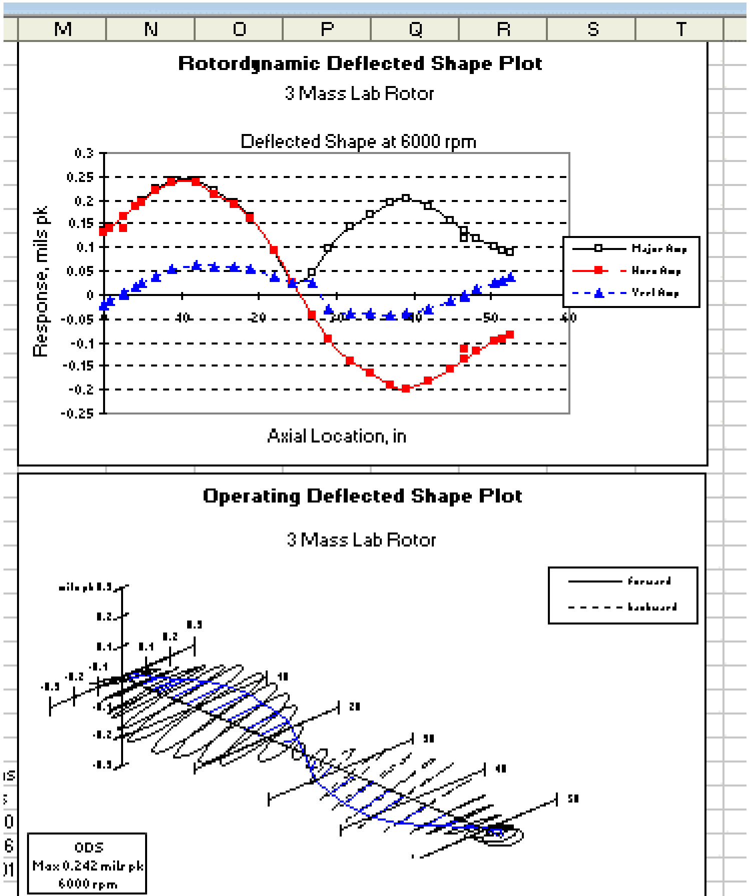




ODS

This is a list of speeds for which to generate operating deflected shapes (ODS). In addition to a 2D chart, the output will include a 3D ODS chart if the option to display them is turned on (see 3D ODS). The output will also include a table of imbalances and phase angles used, which correspond to the maximum singular value at that speed. Therefore, the ODS displays the maximum possible response due to the specified imbalances. If the exact ODS speed is not in the list of speeds used for the SVD analysis, the closest speed is used.

Output	Inf Norm
Labeled Speeds	
Tag	Rpm
MinCOS	3000
MaxCOS	7500
RatedOS	6000
ODS	6000
ODS	



Excitation Input			
Station	Amount	Phase	Type
9	0.1	0	F
13	0.1	-143.9	F
17	0.1	-179.996	F

Complete Rotor Deflected Shape at Speed = 6000 rpm

Stn. No.	Ax. Loc.	Horz Amp	Horz Phs	Vert Amp	Vert Phs	Major Am	Ell Ang
	in	mils pk	degrees	mils pk	degrees	mils pk	degrees
1	0	0.13214	67.0694	-0.01997	64.3837	0.13364	171.413
2	0.753	0.141	64.1039	-0.01372	58.4463	0.14166	174.467
3	2.505	0.16282	58.4975	0.00484	141.702	0.16282	0.20183
4	4.257	0.18615	54.2259	0.0178	91.2763	0.18669	4.37808
5	5.019	0.19621	52.7154	0.02412	87.5203	0.19721	5.79148

Clearances to Check

This is a list of stations and clearances. These stations become the "output" stations for the singular value analysis. The outputs specify the maximum allowable deflection at each station. In the example below there are 8 output stations with allowable deflections ranging from 15 to 18 mils pk-pk. The units are taken to be the same as the units specified for synchronous response output (see Options|Response). Only one such list of stations can be specified. However, a clearance multiplier described below offers a way to modify the clearance on a case by case basis.

Clearances to Check		
Station	Relative	Minimum
Number	Station	Clearance
15		18
21		18
25		19
37		19
29		16
33		16
31		15
44		15

Imbalance Cases

This is a list of stations and imbalances, and these become the "inputs" for the singular value analysis. In the example below there are 4 input stations with ***Amounts*** ranging from 0.36 oz-in to 1.96 oz-in. The units are determined by the ***Scaling*** selection, which in the example is ***freq^2***, and the units selected for imbalance for synchronous response (see Options|Response). The input column for ***Imbalance Phase*** is ignored for a SVD analysis because phase angles are determined automatically during the analysis.

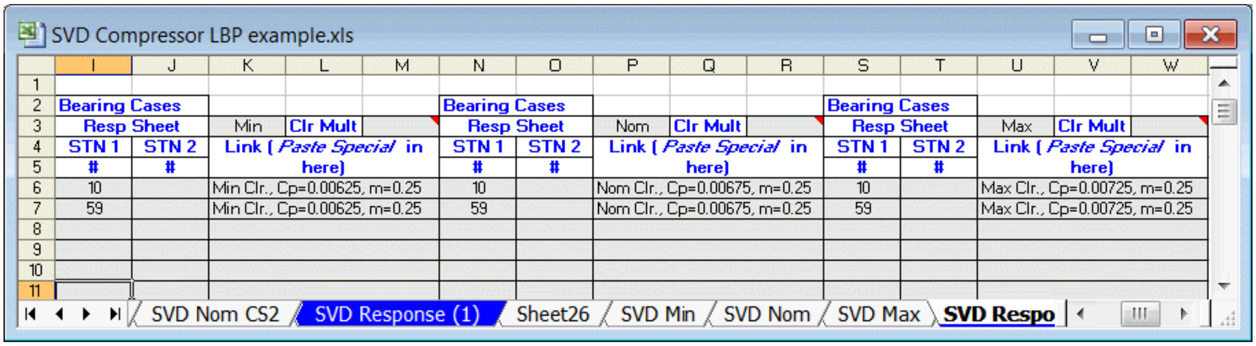
In addition to the ***Stations*** and ***Amounts***, a unique ***Resp Sheet Name*** must be given for each imbalance set. These names are paired with bearing case names (discussed next), to derive a unique name for each response worksheet.

SVD Response Analysis Worksheet										
Analysis Options		Clearances to Check			Imbalance Cases					
Force	rotating	Station	Relative	Minimum	Resp Sheet Name		SVD	Resp Sheet Name		
Scaling	freq^2	Number	Station	Clearance	Imbalanc	Imbalanc	Imbalanc	Imbalanc	Imbalanc	Imbalanc
Input	Inf Norm	15		18	Station	Amount	Phase	Station	Amount	Phase
Output	Inf Norm	21		18	18	1.96	0			
Labeled Speeds		25		19	28	1.88	0			
Tag	Rpm	37		19	34	1.88	0			
MinCOS	1060	29		16	51	0.36	0			
MaxCOS	3960	33		16						
RatedOS	3560	31		15						
ODS		44		15						

Bearing Cases

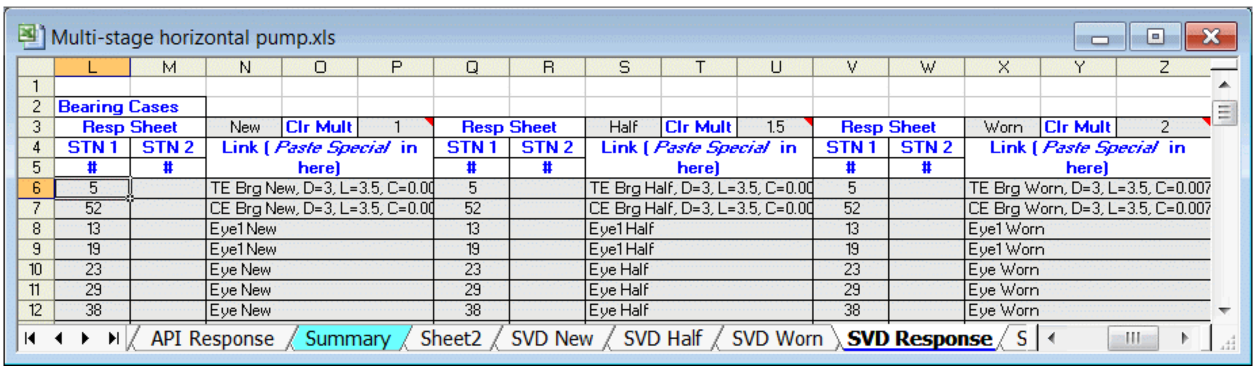
Here is specified different sets of bearing coefficients to be run. There must be at least one set, but any number can be input. Specify the stations and their links, and give each set a unique name. For each set in turn, the bearing stations will be Copied and Pasted to the Brg's Worksheet as *values*. The Links are pasted as formulas since formulas are required in the Links column on the Brg's sheet. So make sure that Link formulas always use absolute cell references (as in $B$2 as opposed to B2).

The following example is for a compressor. There are three sets of bearing coefficients for minimum, nominal and maximum bearing clearance. The sets have been given the names ***Min, Nom*** and ***Max***.



	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W
1															
2	Bearing Cases					Bearing Cases					Bearing Cases				
3	Resp Sheet		Min	Clr Mult		Resp Sheet		Nom	Clr Mult		Resp Sheet		Max	Clr Mult	
4	STN 1	STN 2	Link (*Paste Special* in			STN 1	STN 2	Link (*Paste Special* in			STN 1	STN 2	Link (*Paste Special* in		
5	#	#	here)			#	#	here)			#	#	here)		
6	10		Min Clr., Cp=0.00625, m=0.25			10		Nom Clr., Cp=0.00675, m=0.25			10		Max Clr., Cp=0.00725, m=0.25		
7	59		Min Clr., Cp=0.00625, m=0.25			59		Nom Clr., Cp=0.00675, m=0.25			59		Max Clr., Cp=0.00725, m=0.25		
8															
9															
10															
11															

The next example is for a multi-stage pump. Multi-stage pumps are often analyzed with the seal clearances ***New*** and ***Worn,*** where worn clearances are two times the new clearances. For the SVD analysis, the new seal clearances would be input in the ***Clearances to Check*** section discussed earlier. Then clearance multipliers are entered in cells P3, U3 and Z3 in this example. This example runs cases for new seal clearances, half worn clearances, and fully worn clearances.



	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y	Z
1															
2	Bearing Cases														
3	Resp Sheet		New	Clr Mult	1	Resp Sheet		Half	Clr Mult	1.5	Resp Sheet		Worn	Clr Mult	2
4	STN 1	STN 2	Link (*Paste Special* in			STN 1	STN 2	Link (*Paste Special* in			STN 1	STN 2	Link (*Paste Special* in		
5	#	#	here)			#	#	here)			#	#	here)		
6	5		TE Brg New, D=3, L=3.5, C=0.00			5		TE Brg Half, D=3, L=3.5, C=0.00			5		TE Brg Worn, D=3, L=3.5, C=0.007		
7	52		CE Brg New, D=3, L=3.5, C=0.00			52		CE Brg Half, D=3, L=3.5, C=0.00			52		CE Brg Worn, D=3, L=3.5, C=0.007		
8	13		Eye1 New			13		Eye1 Half			13		Eye1 Worn		
9	19		Eye1 New			19		Eye1 Half			19		Eye1 Worn		
10	23		Eye New			23		Eye Half			23		Eye Worn		
11	29		Eye New			29		Eye Half			29		Eye Worn		
12	38		Eye New			38		Eye Half			38		Eye Worn		

SVD Response Analysis Results

The results of the SVD Response analysis appear on a set of Resp Worksheets, and in a summary table on the SVD Response sheet.

The following is the summary table for the compressor example. For each case it lists the overall maximum singular value and the speed at which it occurs, plus the maximum singular value for each specified operating speed (i.e. min, max and rated speeds, if given). Also listed is the output # at which the maximum response occurs. So in this example, the maximum response is 1.677 and occured with Max bearing coefficients, at 15,900 rpm, at output #2. This means the largest response throughout the entire speed range analyzed happens at 15,900 rpm, with Max bearing coefficients, and the response magnitude is 1.677 times the specified clearance for output #2.

SVD Compressor LBP example.xls

	A	B	C	D	E	F	G
19	All Output Below This Row						
20							
21	11/7/2015 5:01:54 PM						
22	Refinery Comressor Example, 9 Stage, 12000 rpm						
23	Nom Clr., Cb=0.00675						
24	Force=rotating, Scaling=freq^2						
25	Input=Inf Norm, Output=Inf Norm						
26	Summary of Singular Values						
27	Case		Point#	Speed	Max Sigma		Output #
28	SVD Min		139	15800	1.342689	Ovl Peak	1
29				12000	0.089764	MaxCOS	2
30	SVD Nom		140	15900	1.502958	Ovl Peak	1
31				12000	0.110583	MaxCOS	2
32	SVD Max		140	15900	1.677471	Ovl Peak	1
33				12000	0.131547	MaxCOS	2

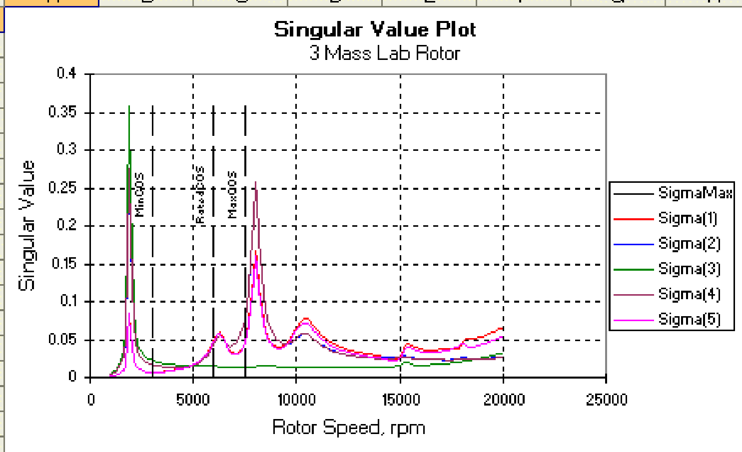
The next summary table is for the muti-stage pump. The largest singular value in the table is 0.1205, and is for fully worn seals, at 6000 rpm, at output #9. This means the largest response anywhere in the pump, at any speed, new or worn, is just 12.05% of the clearance at output #9.

Multi-stage horizontal pump.xls

	A	B	C	D	E	F	G
25	All Output Below This Row						
26							
27	11/6/2015 3:58:29 PM						
28	5-Stage, Crude, vis=1.75 cp, 1060-3960 rpm						
29	TSCS-0350 Cplg, Seal Clr=New						
30	Force=rotating, Scaling=freq^2						
31	Input=Inf Norm, Output=Inf Norm						
32	Summary of Singular Values						
33	Case		Point#	Speed	Max Sigma		Output #
34	SVD New		56	5900	0.101584	Ovl Peak	9
35				1060	0.043036	MinCOS	9
36				3960	0.080089	MaxCOS	9
37				3560	0.077692	RatedOS	9
38	SVD Half		57	6000	0.108435	Ovl Peak	9
39				1060	0.023733	MinCOS	9
40				3960	0.095361	MaxCOS	9
41				3560	0.090112	RatedOS	9
42	SVD Worn		57	6000	0.120521	Ovl Peak	9
43				1060	0.021836	MinCOS	9
44				3960	0.102409	MaxCOS	9
45				3560	0.097539	RatedOS	9

In addition to the summary table on the ***SVD Response*** sheet, each bearing/imbalance case generates an output sheet with a table and plot of all calculated singular values for that case. In the next example, the chart displays a curve for each singular value. In this case there are 5 singular values. The number of singular values is determined by the number inputs and outputs, and the choices for SVD analysis parameters. The chart also includes a curve for the overall maximum singular value. The SVD inputs, outputs and analysis parameters are documented just below the chart. Below that is a table of the singular values which appear in the chart. When the selected output norm is ***Infinity***, the maximum singular value at each speed (i.e. column labeled SigmaMax) will correspond to a particular output number, and that output number will be listed alongside the SigmaMax. To the right of the table of singular values will be Left and Right singular vectors corresponding to the overall maximum singular value. If any ODS output is generated, that will be appened to the right.

SVD Three Mass Lab Rotor, 8 ways.xls



	A	B	C	D	E	F	G	H	I	J	K	L
19	Singular Values											
20	3 Mass Lab Rotor											
21												
22	Force=rotating, Scaling=freq^2, Input=Inf Norm, Output=Inf Norm, Analysis Type=8											
23		Inputs		Outputs								
24	Number	Station	Amount	Station1	Station2	Clearance						
25	1	9	0.1	3	27	1						
26	2	13	0.1	9	0	10						
27	3	17	0.1	13	0	10						
28	4			17	0	10						
29	5			22	28	1						
30									Left & Right Singular Vectors at 1900 rpm			
31	Speed	SigmaMax	Output	Sigma(1)	Sigma(2)	Sigma(3)	Sigma(4)	Sigma(5)	Umax.mag	Umax.phs	Vmax.mag	Vmax.phs
32	rpm	--	#	--	--	--	--	--	--	degrees	--	degrees
33	1000	0.005099	3	0.001518	0.003957	0.005099	0.004011	0.001501	0.020347	151.6393	1	0
34	1100	0.006741	3	0.001995	0.005231	0.006741	0.005303	0.001972	0.082629	149.8609	1	0.277655
35	1200	0.008929	3	0.00262	0.006929	0.008929	0.007024	0.002591	0.096973	147.8357	1	0.022009
36	1300	0.011947	3	0.003468	0.009271	0.011947	0.009398	0.003429	0.258901	109.8275		
37	1400	0.016331	3	0.004671	0.012671	0.016331	0.012846	0.004619	0.126071	148.0193		
38	1500	0.023211	3	0.006506	0.018007	0.023211	0.018257	0.006434	0.343331	109.5041		
39	1600	0.035486	3	0.009656	0.027524	0.035486	0.027908	0.00955	0.098385	147.8361		
40	1700	0.063608	3	0.016511	0.049316	0.063608	0.050008	0.01633	0.263169	109.8024		
41	1800	0.201885	3	0.048358	0.156355	0.201885	0.158569	0.047844	0.020178	151.8147		
42	1900	0.357908	3	0.085098	0.270494	0.357908	0.274901	0.084268	0.081817	149.85		
43	2000	0.239026	3	0.059238	0.180425	0.239026	0.183421	0.058621	Umax at Output #3			
44	2100	0.094033	3	0.024469	0.070966	0.094033	0.072155	0.02421				
45	2200	0.060887	3	0.01627	0.045936	0.060887	0.046713	0.016098				
46	2300	0.046446	3	0.012594	0.035028	0.046446	0.035626	0.012461				
47	2400	0.038409	3	0.010497	0.028955	0.038409	0.029454	0.010387				

Resp SVD (3) | SVD (3) | Resp SVD (4) | SVD (4) | Resp SVD (5) | SVD

Singular Value Analysis of a Cell Range

See also

- XLRotor Menu Commands
- Run|API Analysis
- API SVD Singular Value Decomposition Analysis
- Singular Value Analysis in XLRotor

The singular value decomposition of any rectangular matrix can be calculated with XLRotor's SVD command. Enter the magnitudes and phase angles (lagging) of the matrix elements on a worksheet as in the following example for a 2x2 complex matrix:

SVD paper, balancing data analysis.xls

	A	B	C	D
9	mag	degrees	mag	degrees
10	11.3405	43	9.2189	223
11	7.8777	218	4.8643	58
12				

Sheet1 Sheet2

Then select all the cells of the matrix ***including the column headings*** (cells A9:D11). Then click the SVD button on the XLRotor toolbar or ribbon. The results of the SVD analysis will be written to the worksheet just to the right of the input matrix.

The column heading for phase angles can be either ***degrees*** or ***radians***. In addition, the column headings can be ***Real*** and ***Imag***.

SVD paper, balancing data analysis.xls

	F	G	H	I	J	K	L	M
9	sv(1)=	17.22377			sv(2)=	1.629866		
10	V.mag	V.phs	U.mag	U.phs	V.mag	V.phs	U.mag	U.phs
11	0.799676	0	0.847038	319.0187	0.600432	180	0.531532	9.190404
12	0.600432	185.3271	0.531532	137.3649	0.799676	185.3271	0.847038	7.536627
13								

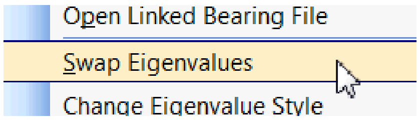
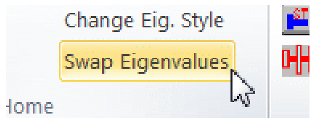
Sheet1 Sheet2

The results display the singular values in the first row, from largest to smallest. Below each singular value will the be its corresponding Input Vector (V.mag & V.phs) and Output Vector (U.mag & U.phs). The phase angle outputs are lagging. If the input matrix contains influence coefficients for rotor balancing, the V vectors will be modal balance distributions.

Swap Eigenvalues

See also

XLRotor Menu Commands

Pull Down Menu	Ribbon
	

This command should be used only on worksheets of damped eigenvalues (see Roots Damped Worksheet). This feature is handy when the roots of successive speeds do not appear in the same columns of a "Roots Damped" worksheet. When this occurs, the charted curves on the natural frequency map and root locus chart appear to be discontinuous.

For rotors supported on fluid film bearings, roots often cross each other in frequency and/or damping, as rotor speed varies. XLRotor attempts to sort the roots into proper order, but this is not always possible for the general case. The sorting algorithm will be skipped if any two successive Eigen Analysis Speeds are equal (see XLRotor Worksheet).

To use the Swap feature, first select all or part of one column of root pairs (damping and frequency columns). Then while holding down the control key, select an analogous set of roots in another column. With the two sets of roots selected, execute the Swap Eigenvalues command. The two sets are then interchanged.

You can also do this manually by moving one set temporarily out of the way, moving the other set to take its place, and finally placing the first set back in place of the second set. The Swap command runs a short macro that carries out these steps for you.

To help ensure proper root order, the first two or three Eigenanalysis Speed increments should be close together. For example, 1000 and 1100 rpm, followed by 2000, 3000, etc.

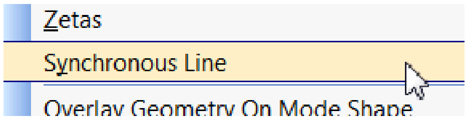
Note:
To update the result of one or more swaps on the affected charts, it may be necessary to press the *Recalc key* F9.

Synchronous Line

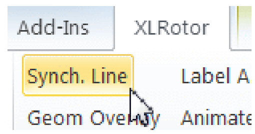
See also

XLRotor Menu Commands

Pull Down Menu



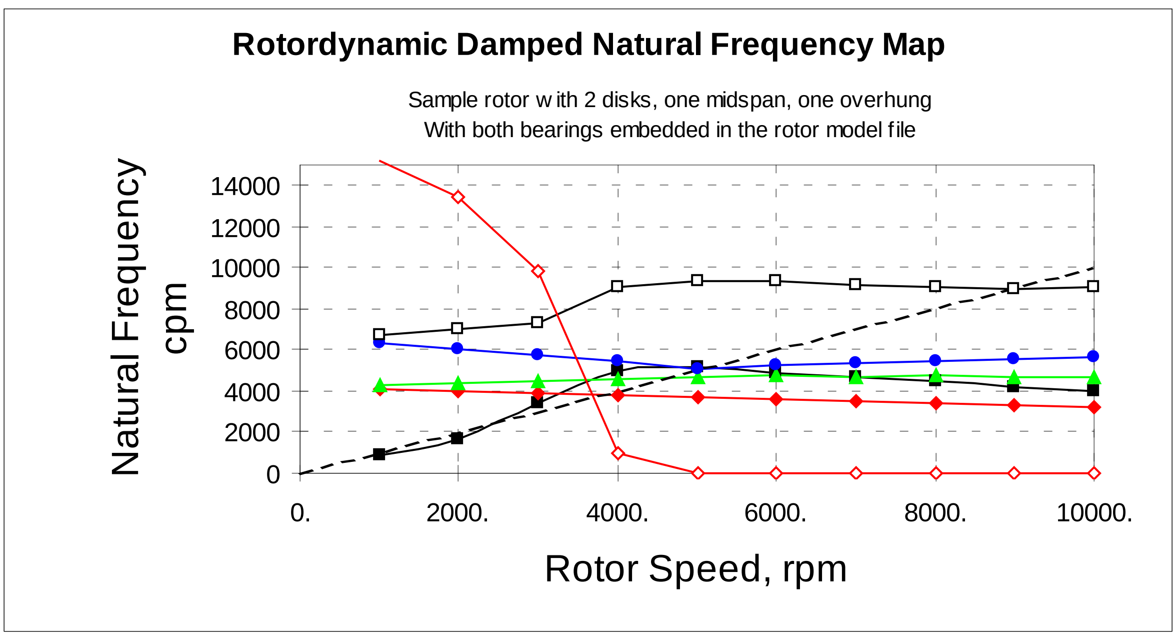
Ribbon



This command should be used only on damped natural frequency maps or free-free natural frequency maps (see Roots Damped Worksheet or Roots FF Worksheet). This will place what is often called a "45 degree synchronous line" on the chart. It is a line with a slope of 1 (i.e. natural frequency equals rotor speed).

The line is added as a new charted series comprised of constant values. You can change the appearance of the line by selecting it and pressing the Control-1 format hotkey. You can delete the line by selecting it and pressing either the Delete or Backspace keys (as you can with any charted series).

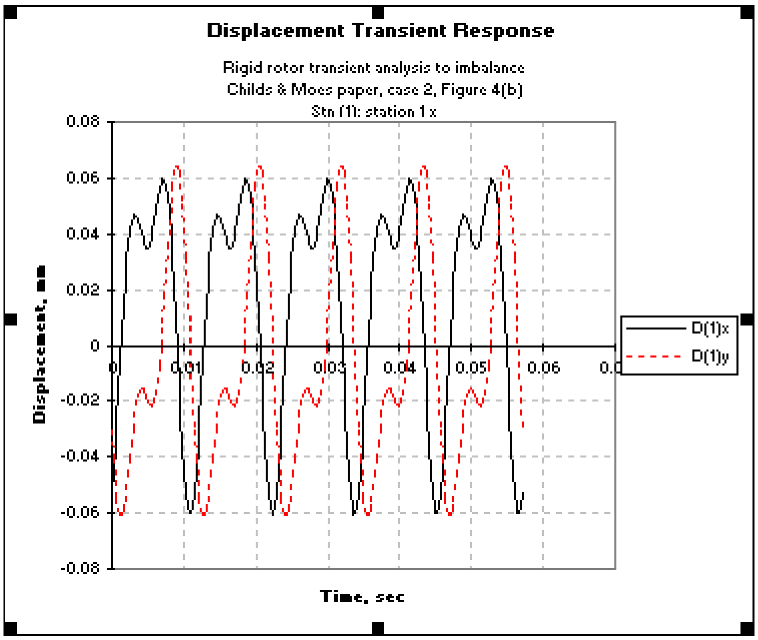
The synchronous line in this example is the dashed sloping line.

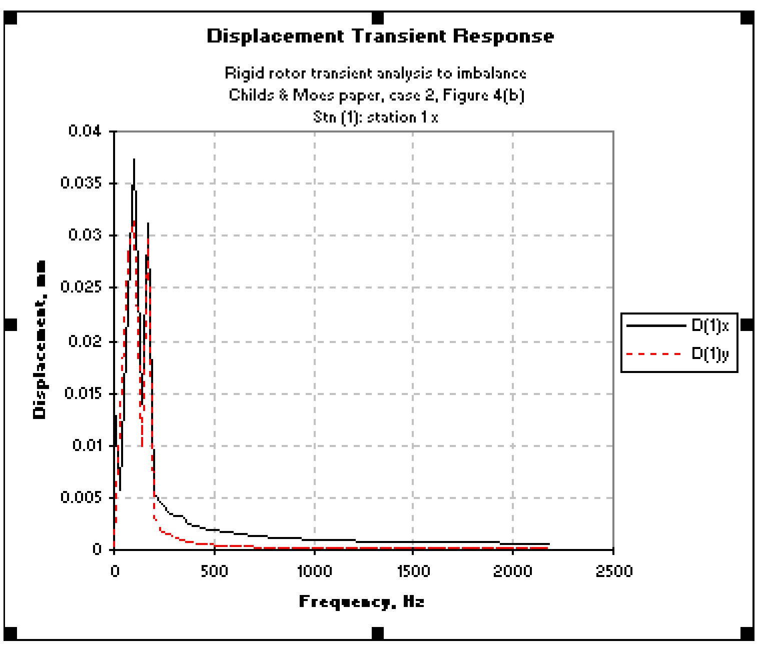


Time/Spectrum Switch

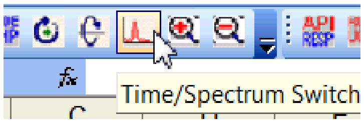
See also

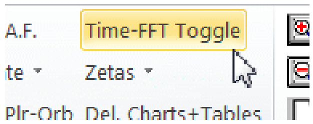
- XLRotor Menu Commands
- Transient Resp Worksheet
- Bode/Polar/Orbit Switch





Toolbar Ribbon





This command can be used on a Transient Resp Worksheet where charts of transient response versus time can be converted to frequency spectrums.   This command toggles the format back and forth between time and spectrum.

XLRotor uses an FFT style algorithm.   So the program will use as many time points as possible, with the constraint that the number of points be a whole power of 2.   For example, if the transient response table contains 1000 time points, the spectrum will be computed from the last 512 points.

The spectrum is computed without any tapering window (i.e., rectangular), and the results are scaled as a zero to peak magnitude.   The result of the FFT calculation is placed on the worksheet in the rows immediately below the time response table.   When you convert the spectrum plot back to a time plot, the FFT values will remain on the worksheet.

This command can be used on non-XLRotor charts as long as the X axis title contains the word "Time".   The program will assume that each data series on the chart plots a range of data values versus a common range of time values.

Note:
You cannot convert an orbit plot directly to a spectrum plot.   To do this, first convert the orbit plot back to a time plot (Bode/Polar/Orbit Switch)

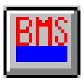
Note:
If you hold down the Shift key, you can use your mouse to select more than one chart before executing this command.   The command will operate on all the selected charts.

Update|Beams

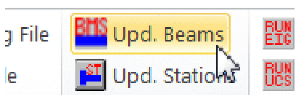
See also

- XLRotor Menu Commands
- Update|Stations
- Update|Geometry Chart

This command updates the Beams Worksheet. All cell formulas and values which appear on this worksheet are updated. These values are computed from your inputs on the Shaft Input Worksheet.
Usually you will not execute this command directly. This command is executed for you automatically when you perform an Update|Geometry Chart.



This is a button on the XLRotor ToolBar. Clicking this button is equivalent to selecting the command from the pull down menu.



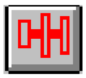
This is how the button appears on the XLRotor ribbon.

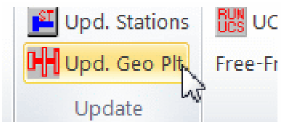
Update|Geometry Chart

See also

- XLRotor Menu Commands
- Update|Beams
- Update|Stations

This command updates the display of the "Geo Plot" chartsheet.   This sheet is an Excel chartsheet, as opposed to a worksheet.   For more information, see the Geo Plot Chartsheet.

 This is a button on the XLRotor ToolBar.   Clicking this button is equivalent to selecting the command from the pull down menu.



This is how the button appears on the XLRotor ribbon.

Note:
Executing the Update|Geometry Plot command will sometimes also trigger updates of the Beams Worksheet and Stations Worksheet.

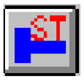
Update|Stations

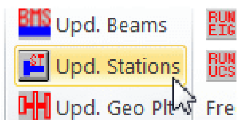
See also

- XLRotor Menu Commands
- Update|Beams
- Update|Geometry Chart

This pull down menu command updates the formulas and values on the Stations Worksheet. These are derived directly from the contents of the Beams Worksheet.

Usually you will not execute this command directly. This command is executed for you automatically when you update the Geometry Chart.


This is a button on the XLRotor ToolBar. Clicking this button is equivalent to selecting the command from the pull down menu.



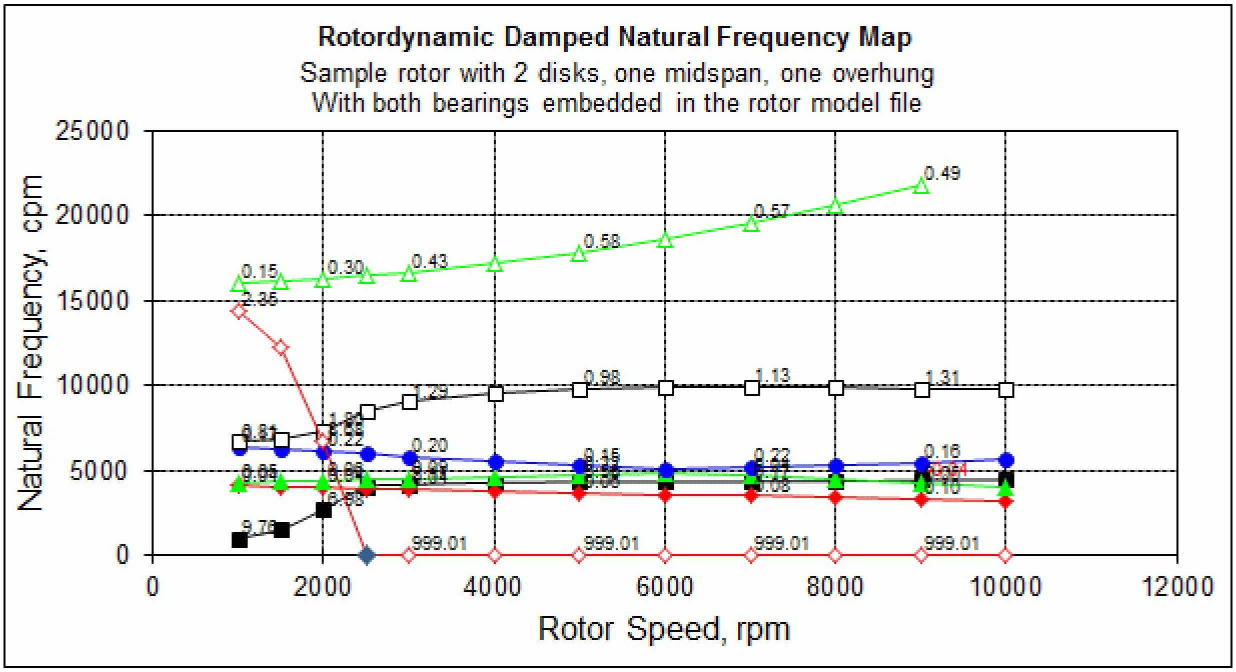
This is how the button appears on the XLRotor ribbon.

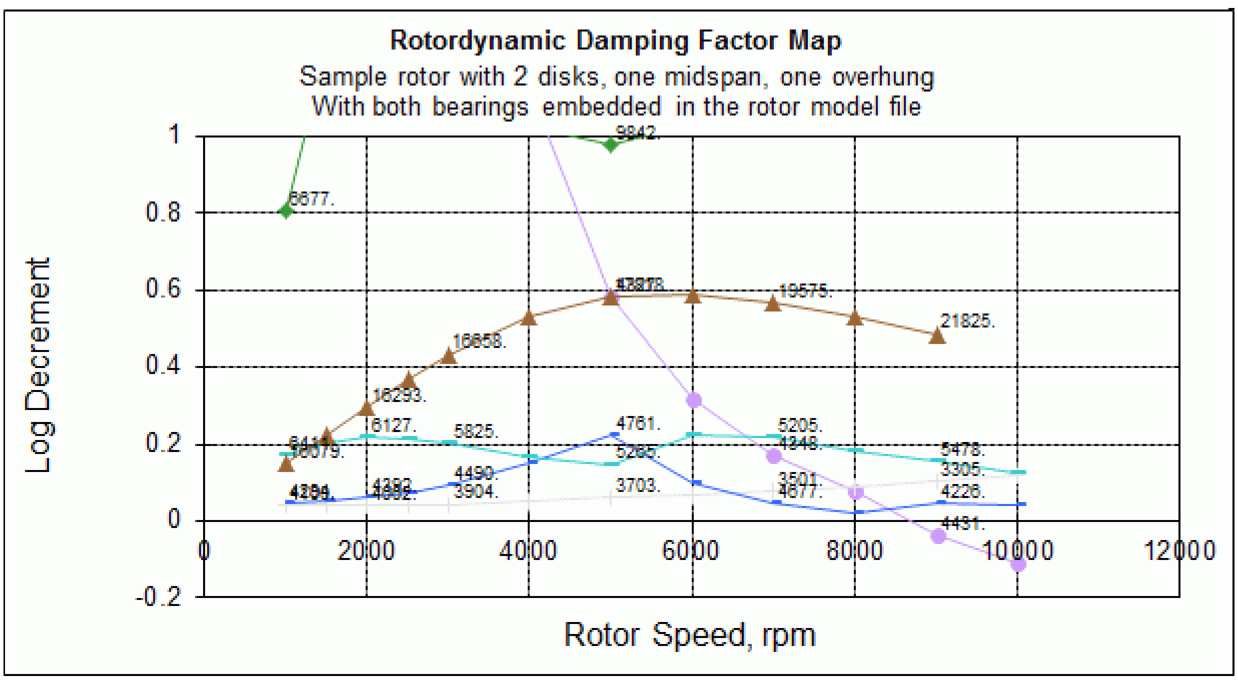
Zetas

Show/Hide Zetas

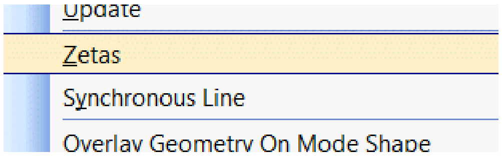
See also

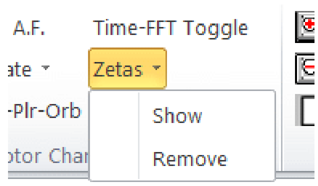
XLRotor Menu Commands





Pull Down Menu Ribbon





These two commands can be used on either a damped natural frequency map or damping factor map.

On a DNF map, "Show Zetas" will run a macro that labels the frequency points with their corresponding damping values.

On a Damping Factor plot, points are labeled with their corresponding frequencies.

"Hide Zetas" removes all labels from every data series on the chart. Note that this will remove any other data labels which may be present on the chart, in addition to the zetas.

Worksheets in an XLRotor File

Certain worksheets must be in every XLRotor file. The names of the worksheets identify them (displayed on the sheet tabs). If you rename or accidentally delete one of these worksheets, XLRotor may later tell you that a required worksheet is missing. You can either change its name back to its required name, or try *copying* the worksheet from another file.

Here is a list of the required worksheets:

Lateral analysis rotor model file:

- XLRotor
- Shaft Input
- Beams
- Stations
- Geo Plot
- Brg's
- Imb's
- Transient (not required, automatically added as needed)
- Maneuver (not required, automatically added as needed)
- API UCS (not required, automatically added as needed)
- API Response (not required, automatically added as needed)
- API Level 1 (not required, automatically added as needed)
- API Level 2 (not required, automatically added as needed)
- API AMB (not required, automatically added as needed)
- SVD Response (not required, automatically added as needed)

Torsional analysis rotor model file:

- XLTorsion
- Shaft Input
- Beams
- Stations
- Geo Plot
- Cplg's
- Orders
- Transient (not required, automatically added as needed)
- API Response (not required, automatically added as needed)

API Level 2 (not required, automatically added as needed)

The above sheets are always required. Computed results for the various analyses which you perform are displayed on additional sheets which are created when the analysis is done.

Lateral analysis results worksheet:

Roots Damped

Roots USC

Roots FF

Shapes

Resp

Transient Resp

Torsional analysis results worksheet:

Roots Tors

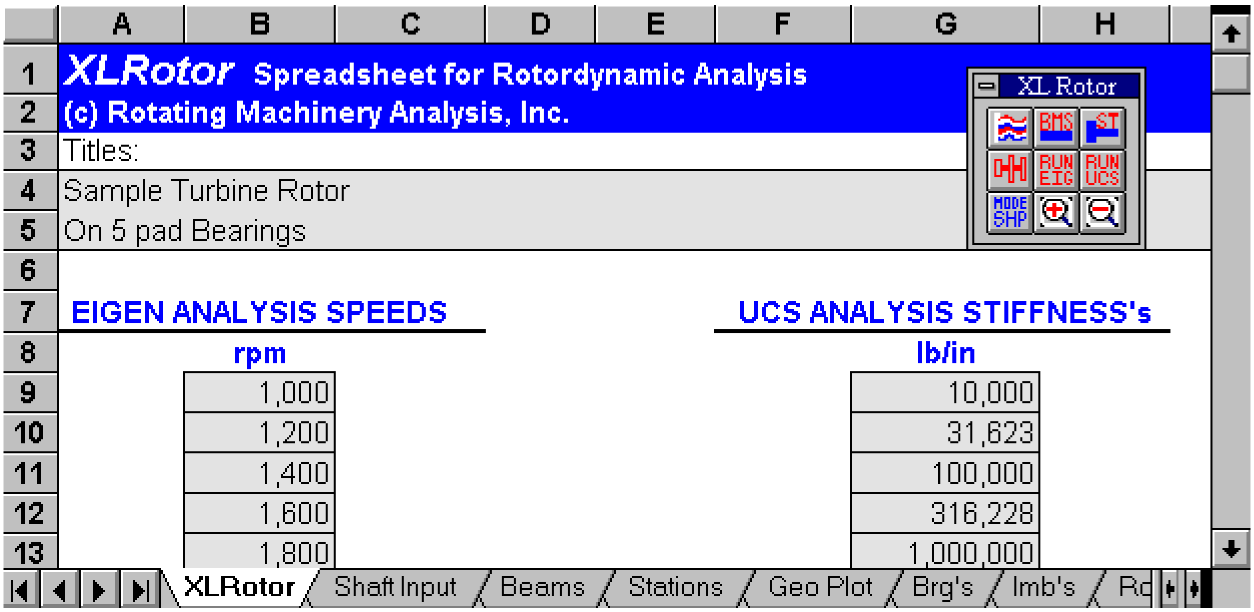
Resp

Transient Resp

XLRotor Worksheet

See also

- XLRotor Overview
- XLTorsion Worksheet
- XLCoupled Worksheet
- Running XLRotor
- Beams Worksheet



This worksheet is the starting point for creating your rotor model. Here you type in a descriptive title, and specify the extent of the eigenanalyses you will be performing.

Titles

Two cells are provided to enter titles that will be copied to charts created during analysis. The contents of these cells are **copied** to the charts, as opposed to being referenced. This means once a chart has been created, the titles appearing on the chart will not change.

Changes you make to the Title cells will **not** update automatically on **existing** charts (i.e. mode shapes, response, etc.). The geometry chart (Geo Plot Chartsheet), however, is an **exception.** Changes made to the Title cells **will** update automatically on the Geometry chart.

Eigen Analysis Speeds

The rotor speeds entered in this column are used for two types of eigenanalysis; 1) calculation of damped eigenvalues, and 2) free-free modes. When performing either of these types of analyses, the eigenvalues for the rotor will be computed for each value of rotor speed entered in this column.

Use Excel's Auto Fill features to easily enter a series of speed values. The list of speeds must start in the cell just below the column heading, and must run consecutively down the column. The first blank cell signifies the end of the list. The speed values in the list can appear in any order.

UCS Analysis Stiffness

The bearing stiffness values entered in this column are used to compute undamped critical speeds. You can use a simple formula to automatically generate a series of values. The sample file has the stiffness increasing by the same fraction for each increment. This makes the points on a log/log Undamped Critical Speed map equally spaced. If you prefer linear plot scales, use a constant stiffness increment instead of a constant multiplicative factor. The list of stiffnesses must start in the cell just below the column heading, and must run consecutively down the column. The first blank cell signifies the end of the list.

In nearly all cases you'll want the stiffness values to start out soft enough to produce pure rigid body modes - like the rotor is free-free. Then transition to high stiffness where the bearings are rigid - like pin joints. See Run|Undamped Crit. Spds for an example plot of an undamped critical speed analysis done this way.

Shaft Input Worksheet

	A	B	C	D	E	F	G	H	I	J	K
1	INPUT TABLE OF BEAM AND STATION DEFINITIONS, MORE THAN ONE BEAM PER STATION IS OK										
2	Station	Length	OD	ID	Weight Density	Elastic Modulus	Shear Modulus	Added Weight	Added Ip	Added It	Speed Factor
3	#	in	in	in	lb/in^3	psi	psi	lb	$lb\text{-}in^2$	$lb\text{-}in^2$	
6	1	0.565	0.75	0	0.283	28.5E+6	11.1E+6				1
7	2	0.565	0.75	0	0.283	28.5E+6	11.1E+6				1
8	3	0.375	0.90625	0	0.283	28.5E+6	11.1E+6				1
9	4	0.3125	0.984375	0	0.283	28.5E+6	11.1E+6				1
10	**5**	**0.34375**	**0.984375**	**0**	**0.283**	**28.5E+6**	**11.1E+6**				**1**
11	6	0.09375	1	0	0.283	28.5E+6	11.1E+6				1

XLRotor / **Shaft Input** / Geo Plot / Beams / Stations / Brg's / Roots FF / Roots Damped

See also

XLRotor Overview
Torsional Shaft Input Worksheet
XLCoupled Shaft Input Worksheet
Options|General
Units in XLRotor
Modeling Menu Commands

On this sheet you enter the geometry of the rotor model. Fill in the table with the values for your rotor. Each row of the table specifies one beam. Insert and delete rows to add and delete beams. Each beam is assigned to the station number which is entered in the first column.

The following rules apply for the stations and beams that make up the model. These rules apply for all models, single level and multi level.

1. The stations can be listed in any order.
2. The last (i.e. highest numbered) station in the model must have its **Length** = 0 (or left blank).
3. A **Station** number can be listed more than once. This allows creation of multiple beams per station. When doing this, the **Length** properties must match for each occurrence of the same **Station**. Multiple beams at the same station are referred to as "layers".

The following rules apply to multi level models.

1. More than one **Station** can have a **Length** of 0 (or blank). This divides the model into multiple *levels*. Each *level* is a consecutive string of stations terminated by a zero length station. This means each *level* has its own set of degrees of freedom, and can move independently of all other *levels*.
2. Each *level* must be connected to at least one other *level* by at least one bearing defined on the Brg's Worksheet. This is how XLRotor determines the relative axial position of levels.
3. A *level* can consist of as little as one station (for example, a bearing pedestal).

Following the above rules, beams will usually be input either consecutively by station number, or in contiguous sections that make up different parts of the rotor. For example, the following two tables show two ways to define the same 1 inch diameter steel shaft with an Aluminum sleeve covering its midsection. Both these examples are single level models, because there is exactly 1 zero length station. These two examples result in exactly the same shaft model.

Station	Length	OD	ID	Weight Density	Elastic Modulus	Shear Modulus
#	in	in	in	lb/in^3	psi	psi
1	0.875	1.000	0.000	0.283	30.0E+6	12.0E+6
2	0.900	1.000	0.000	0.283	30.0E+6	12.0E+6
3	0.800	1.000	0.000	0.283	30.0E+6	12.0E+6
4	0.850	1.000	0.000	0.283	30.0E+6	12.0E+6
4	0.850	2.000	1.000	0.1	10.0E+6	4.0E+6
5	0.880	1.000	0.000	0.283	30.0E+6	12.0E+6
5	0.880	2.000	1.000	0.1	10.0E+6	4.0E+6
6	0.920	1.000	0.000	0.283	30.0E+6	12.0E+6
6	0.920	2.000	1.000	0.1	10.0E+6	4.0E+6
7	0.900	1.000	0.000	0.283	30.0E+6	12.0E+6
7	0.900	2.000	1.000	0.1	10.0E+6	4.0E+6
8	0.930	1.000	0.000	0.283	30.0E+6	12.0E+6
8	0.930	2.000	1.000	0.1	10.0E+6	4.0E+6
9	1.000	1.000	0.000	0.283	30.0E+6	12.0E+6
10	0.990	1.000	0.000	0.283	30.0E+6	12.0E+6
11						

Station	Length	OD	ID	Weight Density	Elastic Modulus	Shear Modulus
#	in	in	in	lb/in^3	psi	psi
1	0.875	1.000	0.000	0.283	30.0E+6	12.0E+6
2	0.900	1.000	0.000	0.283	30.0E+6	12.0E+6
3	0.800	1.000	0.000	0.283	30.0E+6	12.0E+6
4	0.850	1.000	0.000	0.283	30.0E+6	12.0E+6
5	0.880	1.000	0.000	0.283	30.0E+6	12.0E+6
6	0.920	1.000	0.000	0.283	30.0E+6	12.0E+6
7	0.900	1.000	0.000	0.283	30.0E+6	12.0E+6
8	0.930	1.000	0.000	0.283	30.0E+6	12.0E+6
9	1.000	1.000	0.000	0.283	30.0E+6	12.0E+6
10	0.990	1.000	0.000	0.283	30.0E+6	12.0E+6
11						
4	0.850	2.000	1.000	0.1	10.0E+6	4.0E+6
5	0.880	2.000	1.000	0.1	10.0E+6	4.0E+6
6	0.920	2.000	1.000	0.1	10.0E+6	4.0E+6
7	0.900	2.000	1.000	0.1	10.0E+6	4.0E+6
8	0.930	2.000	1.000	0.1	10.0E+6	4.0E+6

Layers and Levels

In the above examples, the steel and aluminum portions are referred to as *layers*. During all eigenvalue or response calculations, XLRotor automatically merges layers, For example, the steel and aluminum beams at Station 4 will be combined as an equivalent beam (this is done by summing their respective stiffness and mass properties). XLRotor always combines beams which are at the same station. Both of the above examples have 11 stations, and so the model has 44 total dof. Note that each aluminum beam has the same ***Station #*** and ***Length*** as its corresponding steel beam. That is required for single level models.

In the following example, the steel and aluminum portions are input as separate *levels*. The aluminum sleeve is now stations 12 to 17, and so exists as a completely separate piece with its own dofs. This model has 68 total dof (4*17). The steel and aluminum levels must be connected to each other by defining connections on the Brg's Worksheet. An example of when the aluminum sleeve would be modeled this way is if its ***ID*** were 1.010" except at its ends. Then on the Brg's Worksheet, Station 12 would be connected to station 4, and station 17 would be connected to station 9.

Station	Length	OD	ID	Weight Density	Elastic Modulus	Shear Modulus
#	in	in	in	lb/in^3	psi	psi
1	0.875	1.000	0.000	0.283	30.0E+6	12.0E+6
2	0.900	1.000	0.000	0.283	30.0E+6	12.0E+6
3	0.800	1.000	0.000	0.283	30.0E+6	12.0E+6
4	0.850	1.000	0.000	0.283	30.0E+6	12.0E+6
5	0.880	1.000	0.000	0.283	30.0E+6	12.0E+6
6	0.920	1.000	0.000	0.283	30.0E+6	12.0E+6
7	0.900	1.000	0.000	0.283	30.0E+6	12.0E+6
8	0.930	1.000	0.000	0.283	30.0E+6	12.0E+6
9	1.000	1.000	0.000	0.283	30.0E+6	12.0E+6
10	0.990	1.000	0.000	0.283	30.0E+6	12.0E+6
11						
12	0.850	2.000	1.000	0.1	10.0E+6	4.0E+6
13	0.880	2.000	1.000	0.1	10.0E+6	4.0E+6
14	0.920	2.000	1.000	0.1	10.0E+6	4.0E+6
15	0.900	2.000	1.000	0.1	10.0E+6	4.0E+6
16	0.930	2.000	1.000	0.1	10.0E+6	4.0E+6
17						

XLRotor will catch most modeling errors when you click one of the Update buttons, and take you to the offending cell (e.g., see Update|Beams).

Note:
You are encouraged to use formulas in this table. This allows values in various cells to be computed from values in other cells. This makes changing a property of a group of beams as easy as changing a single number. See Excel's online documentation on "formulas, cell references" for more information.

After you complete this worksheet of Shaft Inputs, move on to the Beams Worksheet if you want to see intermediate values computed for the individual beams.

Your rotor model file can contain more than one "Shaft Input" worksheet. For example, you create an initial rotor model on the Shaft Input worksheet. Then you make a copy of this worksheet (click *here* to see how). This will create a worksheet with a name like "Shaft Input (2)" that is a duplicate of the original. You can rename this new worksheet to something like "Shaft Input initial". Then you can modify the contents of the original Shaft Input worksheet to create another version of your rotor model. At this point you have two worksheets that contain valid rotor models. XLRotor will utilize the contents of whichever worksheet has the exact name of "Shaft Input". This means you can change back to the "initial" model at any time by just renaming the worksheets.

Station Number

This column specifies the station number for each beam in the table. Each station has 4 distinct degrees of freedom associated with it. Each beam must have a valid station number.

Length

The length property specifies the length of the beam. Beams to be superimposed at the same station must share the same **Length** property. A beam defined for station i always extends from station i to station i+1. The inertia properties for the beam (when density>0) will be split between the degrees of freedom at station i and station i+1.

OD & ID

These are the outer and inner diameters of the beam. XLRotor permits only beams of circular cross section. The OD must be greater than the ID. When the option for conical beams is turned on, there will be two sets of diameters for the left and right ends of each beam. XLRotor also allows input of radius instead of diameter (see the Options|General dialog).

Density

This is the weight density of the beam. This value is used to compute the weight of the beam, and its weight moments of inertia (transverse and polar rotational inertias). If the beam is to be massless, set its density to zero. The density value will be divided by the "gravity" constant entered in the Options|General dialog.

Beam weights and inertias computed from the density are split evenly between the stations at either end of the beam.

Elastic & Shear Moduli, E & G

These moduli are used to compute the stiffness of the beam. If you do not want a particular beam to contribute any stiffness, enter both moduli as zero (or leave them blank). However, every station must have a net stiffness which is positive.

Added Weight and Inertia

For each beam, any specified added weight and rotational inertia values are lumped at the station number of the beam. These values can be negative, zero, or positive. These values will be added to those arising from computed beam weights and inertias. Put polar inertia values in the Ip column, and transverse inertia values in the It column.

Speed Factor

This column is required only for multi level models. If this column is missing when you create a multi level model, XLRotor will create the column for you. These values specify the relative speed of each beam in the model. For example, the Speed Factor should be 1 for the rotor, and 0 for a housing or bearing support.

The Speed Factor value is used only for determining gyroscopic contributions. It is multiplied by the polar inertia values computed for each beam, and the Added Polar inertia values entered for each station. You can see where this is done by inspecting the formulas in the **Beam Ip** column on the Beams Worksheet, and the **Station Ip** column on the Stations Worksheet.

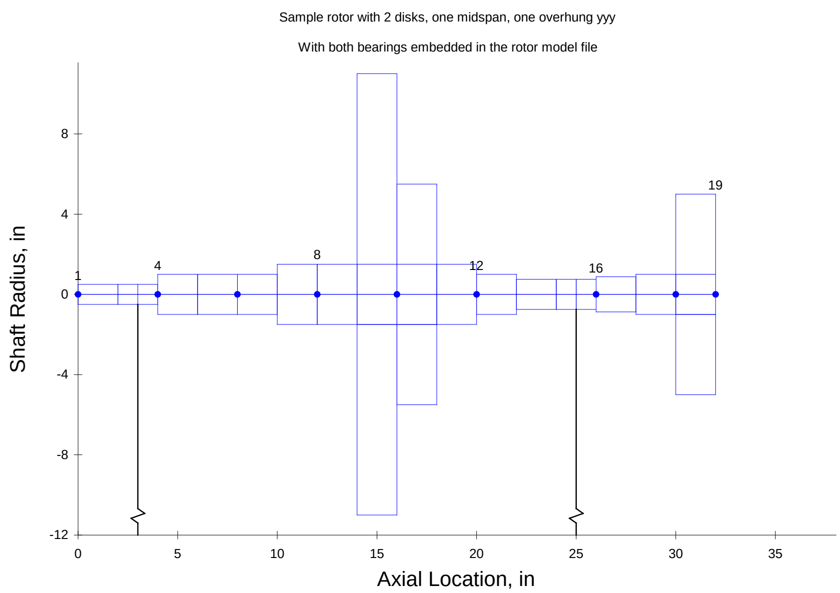
The Speed Factor is not used for evaluating bearing coefficients (except for coupled lateral-torsional models). This means that speed dependent bearing coefficients are assigned values at a speed equal to the input shaft speed. For an eigenvalue analysis the input shaft speed comes directly from the XLRotor Worksheet (the Eigen Analysis Speeds column), and for a response analysis from the Imb's Worksheet (the Response Speeds column).

In an example like an aircraft gas turbine, suppose the first level of the model is the primary rotor which spins at the speeds listed on the XLRotor Worksheet or Imb's Worksheet. The second level of the model is connected to the first level by intershaft bearings, and runs 40% faster than the primary rotor. The Speed Factor should be 1 for all beams making up the first level, and 1.4 for beams in the second level.

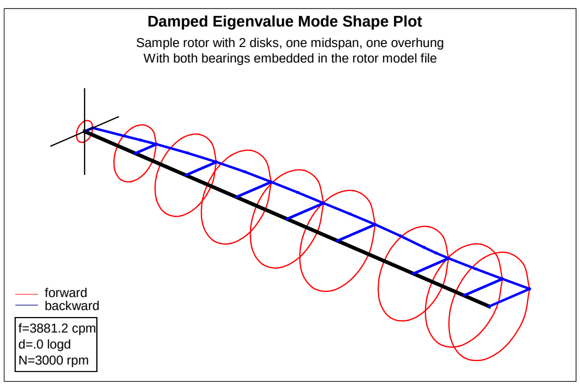
Station Display **(optional input column)**

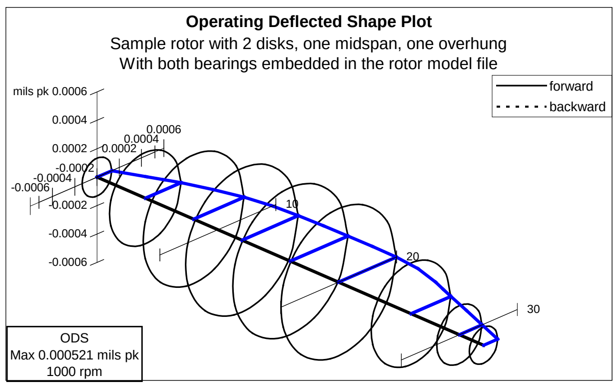
Added It	Speed Factor	Station Display
lb-in^2		
	1.0	TRUE
	1.0	
	1.0	
	1.0	TRUE
	1.0	
	1.0	TRUE

When XLRotor generates 3D mode shape & 3D ODS plots, models having a very large number of stations can lead to very dense plots. This column enables designating a subset of stations to be included in the plots. To use this feature, add a column heading of exactly **Station Display** as shown in the preceding image. Enter TRUE in cells for stations to be included in the 3D plots. The Geo Plot will subsequently display dot symbols at the stations which are tagged with TRUE.



3D Mode shape and ODS charts will then display only the designated stations.

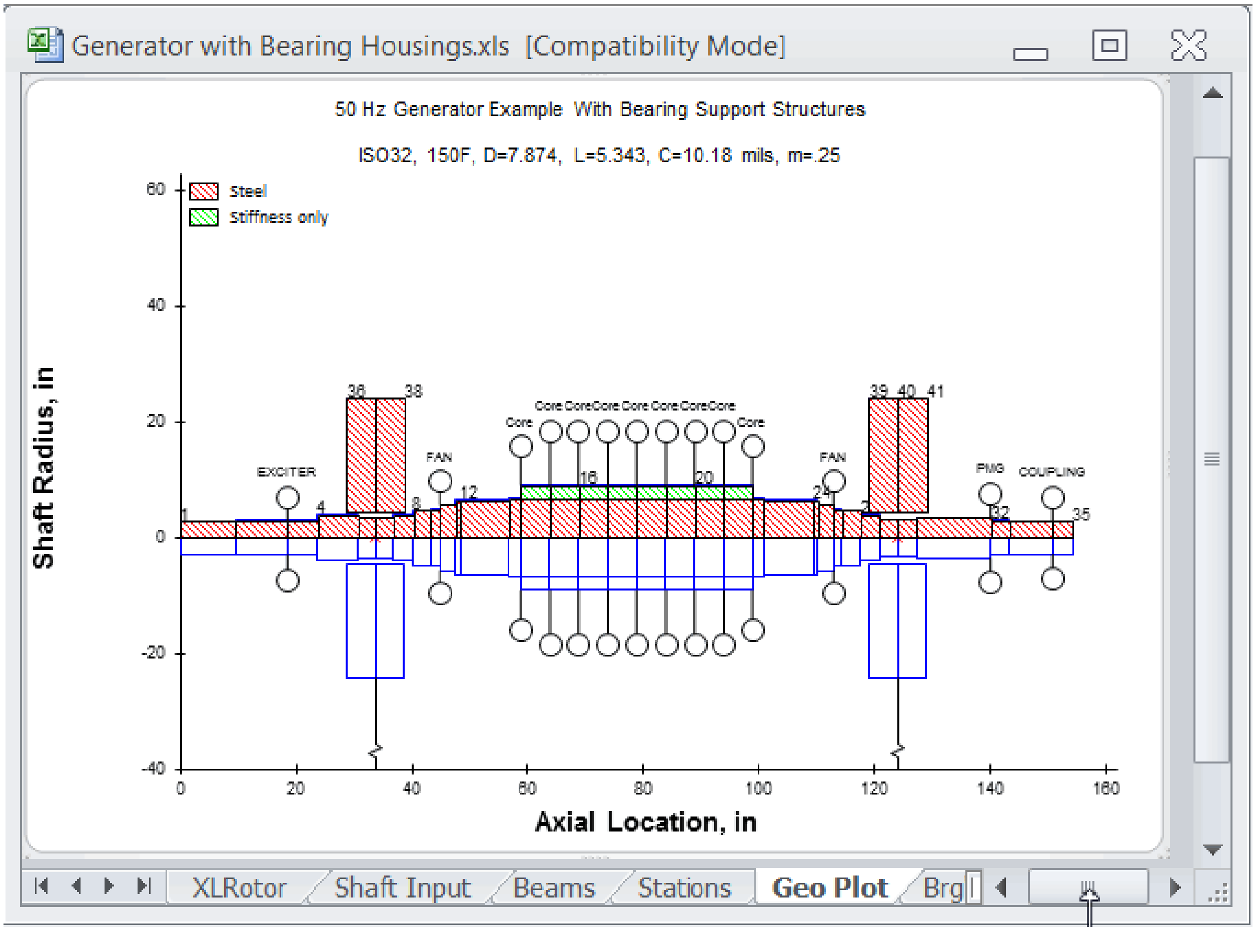




GeoPlot Labels (optional input column)

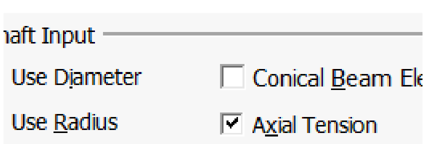
Added It	Speed Factor	GeoPlot Labels
lb-in^2		
	1	Steel
	1	
4934	1	EXCITER
	1	
	1	
	1	NDE BRG

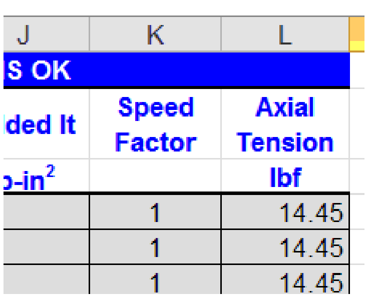
When XLRotor Updates the Geo Plot, or cross-hatches the Geo Plot, labels for the plot can be specified in a column on the Shaft Input sheet. To use this feature, add a column heading of exactly **GeoPlot Labels** as shown in the above image. The text appearing in this column is used in two ways; 1) to label added weights (in place of actual weight values), and 2) for legend entries when cross-hatching. The following sample image is from Generator with Bearing Housings.xls in the XLRotor Examples folder.



Axial Tension

On the Shaft Input sheet Axial Tension can also be specified for any station in lateral and coupled models. See the Options|General dialog box. Tension tends to increase natural frequencies, and compression to decrease natural frequencies. The effect is similar to tension in a violin string.





J	K	L
S OK		
ded It	Speed Factor	Axial Tension
-in^2		lbf
	1	14.45
	1	14.45
	1	14.45

This feature will in most cases be used in one of the following two ways.

1. Built-up multi-level rotor models with one level in tension (e.g. a draw bolt), and another level in compression (e.g. compressed rotor stack). The axial forces are internal to the rotor assembly. So therefore, in this case the length of shaft in tension should be exactly equal to the length of shaft in compression. It is important that these lengths be equal, otherwise there will be a nonzero net stiffness to ground due to the axial forces, as if there were an externally applied thrust force.
2. Rotors which are acted on by external axial thrust forces which stretch the shaft (e.g. pendulums and long vertical pumps). In this case some or all of the rotor will be in tension, and none will be in compression. This results in a nonzero stiffness to ground caused by the tension. This is precisely the case with a pendulum where gravity is the source of tension and therefore stiffness.

Only input nonzero values for the stations actually subjected to tension (negative for compression). Empty cells are treated as zero tension.

If multiple beams are input for the same station, input the tension value for the *first* beam for that station, and for the others either leave the input blank or fill in the same value.

For rotors that are preloaded (e.g. with drawbolts or tie rods), it is important to specify *both* the tension and compression portions of the rotor assembly. These spans of stations should have the same total axial length, and equal and opposite tension values. If this is not done, there will be a net stiffness to ground which could be either positive or negative (i.e. like a pendulum stiffness discussed above). It is recommended to crosshatch the Geo Plot by axial tension so as to double check the model.

Conical Beams

XLRotor has an option to define the rotor model using conical beam elements. See Options|General for details about this option. When this option is turned on the Shaft Input sheet contains two additional columns for shaft diameter inputs. In this case the inner and outer diameters are specified for both ends of every beam.

	A	B	C	D	E	F	G
1	INPUT TABLE OF BEAM AND STATION DEFINITIONS, MORE THAN ONE						
2	Station	Length	ID Left	OD Left	ID Right	OD Right	Density
3	#	mm	mm	mm	mm	mm	kg/m^3
6	1	2	142	146	142	146	7850

XLRotor has an option to define the shaft model using radius instead of diameter. Again, see Options|General for details about this option. When the radius option is selected, the Shaft Input worksheet will look as follows:

	A	B	C	D	G
1	INPUT TABLE OF BEAM AND STATION DEFINIT				
2	Station	Length	IR	OR	Densi
3	#	mm	mm	mm	kg/m
6	1	2	142	146	78

Beams Worksheet

	A	B	C	D	E	F	G	H
1	SUMMARY TABLE OF ALL BEAMS DEFINED IN MODEL							
2	Beam Number	Station #	Axial Location	Beam Weight	Beam It	Beam Ip	Beam EI	Beam GA
3			in	lb	lb-in^2	lb-in^2	lb-in^2	lb
6	1	1	0	0.070639	0.004363	0.004967	442.6E+3	4.9E+6
7	2	2	0.565	0.070639	0.004363	0.004967	442.6E+3	4.9E+6
8	3	3	1.13	0.068455	0.004316	0.007028	943.6E+3	7.2E+6
9	4	4	1.505	0.067305	0.004624	0.008152	1.3E+6	8.4E+6
10	5	5	1.8175	0.074036	0.005213	0.008967	1.3E+6	8.4E+6
11	6	6	2.16125	0.020838	0.001318	0.002605	1.4E+6	8.7E+6
12	7	7	2.255	0.194484	0.024564	0.024311	1.4E+6	8.7E+6
13	8	8	3.13	0.055567	0.003762	0.006946	1.4E+6	8.7E+6
14	9	9	3.38	0.013037	0.000769	0.001529	1.2E+6	8.2E+6

XLRotor / Shaft Input / Geo Plot / **Beams** / Stations / Brg's / Roots FF / Roots Da

See also

- XLRotor Overview
- Stations Worksheet
- XLCoupled Beams Worksheet

This worksheet shows parameters computed for each individual beam. You need to execute an Update|Beams worksheet command any time you want to see the results of changes made in the Station Number column of the Shaft Input Worksheet. Changes on the Shaft Input Worksheet which do not involve modifications in the Station Number column can be updated by simply pressing the formula Recalc key (F9).

You should not edit the cells on this worksheet. XLRotor takes care of updating the contents of the table when you click the Update button or press the *Recalc Key*, as appropriate.

The computed values displayed in this table correspond to individual beams specified on the Shaft Input worksheet.

Beam Number

This column should always contain consecutive numbers 1 through the number of beams in the rotor model.

Station Number

This column will always contain a copy of the values appearing in the analogous column on the Shaft Input Worksheet.

Axial Location

This is the distance from the left end of the rotor to the left end of the beam. Beams assigned to the same station will always be at the same axial location.

Beam Weight

This is the weight computed from the volume and density for the beam. Note that this is a weight value. When computing a rotor analysis, it will be divided by the "gravity" constant. You can see the formula used to compute the beam weight by looking at the contents of the worksheet cells.

Beam It and Ip

These are the transverse and polar weight moments of inertia computed for the beam, respectively. You can see the formulas used to compute the beam It and Ip by looking at the contents of the worksheet cells.

Beam EI

This is the cross sectional bending inertia value for the beam. It is the product of the elastic modulus and the second moment of area of the beam cross section.

Beam GA

This is the cross sectional shear deflection constant for the beam. It is the product of the shear modulus and the cross sectional area of the beam. This value is used directly in the shear deflection formula for the beam. The shear shape factor, alpha, is taken to be 0.75. However, when the consistent mass option is used, a shear shape factor due to Cowper is used.

Stations Worksheet

SUMMARY TABLE OF STATIONS IN THE MODEL, MULTIPLE BEAMS ARE COMBINED

Stn #	Axial Locatio	Length	Beam Weight	Beam It	Beam Ip	Station Weight	Station It	Station Ip	Station EI	Station GA
	in	in	lb	lb-in^2	lb-in^2	lb	lb-in^2	lb-in^2	lb-in^2	lb
1	0	0.565	0.070639	-0.001275	0.004967	0.03532	-0.000637	0.0024834	442649.3311	4903829.783
2	0.565	0.565	0.070639	-0.001275	0.004967	0.070639	-0.001275	0.0049668	442649.3311	4903829.783
3	1.13	0.375	0.068455	0.001909	0.007028	0.069547	0.000317	0.0059972	943641.0758	7159932.026
4	1.505	0.3125	0.067305	0.002981	0.008152	0.06788	0.002445	0.00759	1313581.613	8447613.024
5	1.8175	0.34375	0.074036	0.003026	0.008967	0.07067	0.003003	0.0085599	1313581.613	8447613.024
6	2.16125	0.09375	0.087437	0.02147	0.043197	0.080736	0.012248	0.026082	21017305.8	33790452.1
7	2.255	0.875	0.816074	0.097449	0.403168	0.451755	0.05946	0.2231821	21017305.8	33790452.1
8	3.13	0.25	0.981846	0.977417	1.975289	0.89896	0.537433	1.1892282	358141562.5	139486713.8

XLRotor / Shaft Input / Geo Plot / Beams / **Stations** / Brg's / Roots FF / Roots Damped

See also

- XLRotor Overview
- Beams Worksheet
- XLCoupled Stations Worksheet
- Options|General

This worksheet shows the net properties computed for each station. The number of rows in this table equals the number of stations in the model. Properties of any multiple beams have been superimposed by addition (inertia and elasticity). You need to execute the Update|Stations command any time you want to see the result of changing the number of stations in the shaft model. Changes on the Shaft Input Worksheet which do not involve changing the total number of stations can be updated by pressing the Excel formula *Recalc Key* (F9).

You should not edit any cells on this worksheet. XLRotor takes care of updating the contents of all cells when you click the Update button or the recalc key.

Note:
There is an area at the bottom of the worksheet that summarizes rotor properties like shaft weight and center of gravity. This table will contain one row for each level in your model, plus one additional row, and is assigned an Excel *range name* entitled "StationSheetSums".

Whenever the Stations Worksheet is Updated, the contents of this named range is repositioned at the bottom of the table. You can add your own new calculations to this cell area, and they will move and be updated with it. You can even resize the named cell area if you need more space.

See the Excel documentation on named ranges for more information on this important feature.

Station #

This column lists the station numbers. It will always be a consecutive list of 1 through the number of stations in the model.

Axial Location

These values come directly from those on the Beams Worksheet.

Length

The length comes directly from those on the Shaft Input Worksheet.

Beam Weight, It and Ip

These are the total weight and inertia values for all the beams assigned to each station. You can see the formulas used to compute the beam ***It*** and ***Ip*** by looking at the contents of the worksheet cells.

If the option for "Euler Beam with Corrected It" is selected in the Options|General dialog, then the cells for ***It*** will show a term like (-0.25*bswt*slength^2). Otherwise, this term is not present.

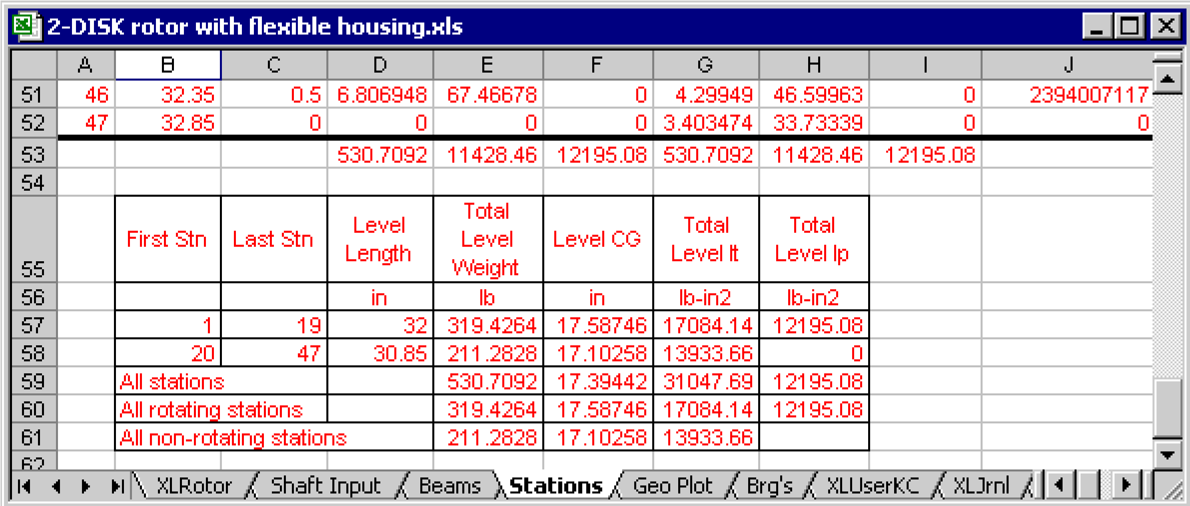
Station Weight, It and Ip

These are the final weight and inertia values which will be assigned to this station. They include added weight values for this station, and the half-beam weights for the beams to the immediate left and right of the station.

Station EI and GA

These are the net bending inertia and shear deflection constants for each station. They come from superposition of all beams input for this station.

At the bottom of the Stations worksheet there is a table summarizing the inertia properties of the model. Some of the cells in this table have defined names that you can use elsewhere in the file to refer to these values.

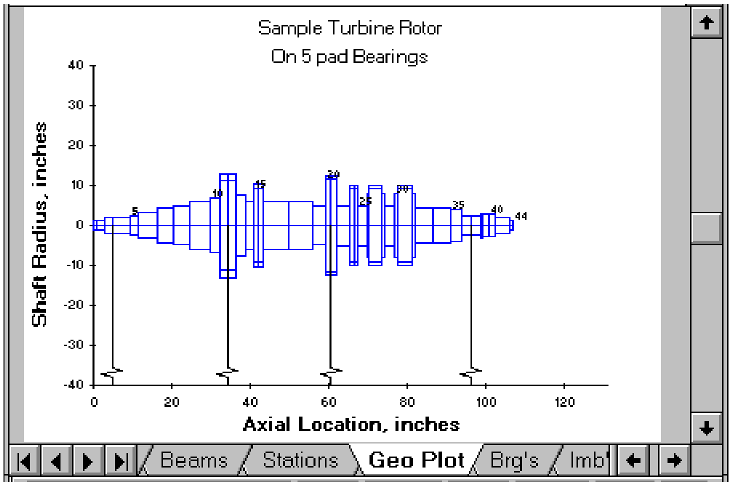


	A	B	C	D	E	F	G	H	I	J
51	46	32.35	0.5	6.806948	67.46678	0	4.29949	46.59963	0	2394007117
52	47	32.85	0	0	0	0	3.403474	33.73339	0	0
53				530.7092	11428.46	12195.08	530.7092	11428.46	12195.08	
54										
55		First Stn	Last Stn	Level Length	Total Level Weight	Level CG	Total Level It	Total Level Ip		
56				in	lb	in	lb-in2	lb-in2		
57		1	19	32	319.4264	17.58746	17084.14	12195.08		
58		20	47	30.85	211.2828	17.10258	13933.66	0		
59		All stations			530.7092	17.39442	31047.69	12195.08		
60		All rotating stations			319.4264	17.58746	17084.14	12195.08		
61		All non-rotating stations			211.2828	17.10258	13933.66			

These defined names are listed below, along with the particular cells that they refer to in the above picture. For the range names that refer to multiple cells, Excel's INDEX worksheet function can be used to reference individual cells in the range.

StationSheetSums	A53:K61
First_Stn	B57:B58
Last_Stn	C57:C58
Level_Length	D57:D58
Total_Shaft_Weight	E57:E58
Center_of_Gravity	F57:F58
Level_It	G57:G58
Level_Ip	H57:H58
Model_Weight	E59
Rotor_Weight	E60
Housing_Weight	E61
Model_CG	F59
Rotor_CG	F60
Housing_CG	F61
Model_It	G59
Rotor_It	G60
Housing_It	G61
Model_Ip	H59
Rotor_Ip	H60

Geo Plot Chartsheet



See also

> [XLRotor Overview]
> [Update|Geometry Chart]
> [Material Property Boxes]
> [XLCoupled Geometry Chart Worksheet]

This is an Excel chartsheet. The chart shows the rotor model geometry and depicts the locations of the bearings. Added concentrated weights can also be shown on the chart (see Options|General).

There is a button on the XLRotor toolbar for updating the geometry plot, and there is also a command on the pull down menu and XLRotor ribbon tab. Whenever you update the Beams or Stations worksheets, you should then update the geometry chart.

Note:
When you make a change to your beam or station configuration that requires an Update of either the Beams or Stations worksheets, you can click the Update Geometry Plot button, thus performing all necessary updates in one step.

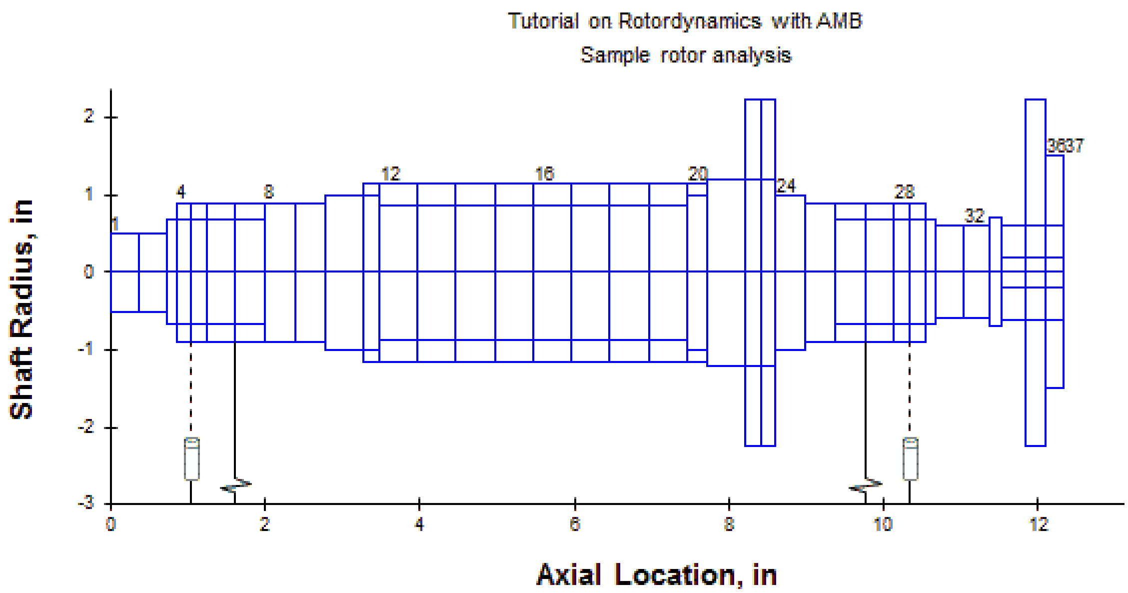
You will also need to Update the geometry plot when you change the number of bearings in the model. If you change only the station number of a bearing on the Brg's worksheet, hit the Excel *Recalc Key* (F9).

The geometry chart will also show added weights, if any, when you select the corresponding check box in the Options|General dialog box (click the Options button on the XLRotor toolbar, or use the pull down menu). In this case you will need to Update the geometry chart any time the axial location of any added weight changes, or you add or delete an added weight.

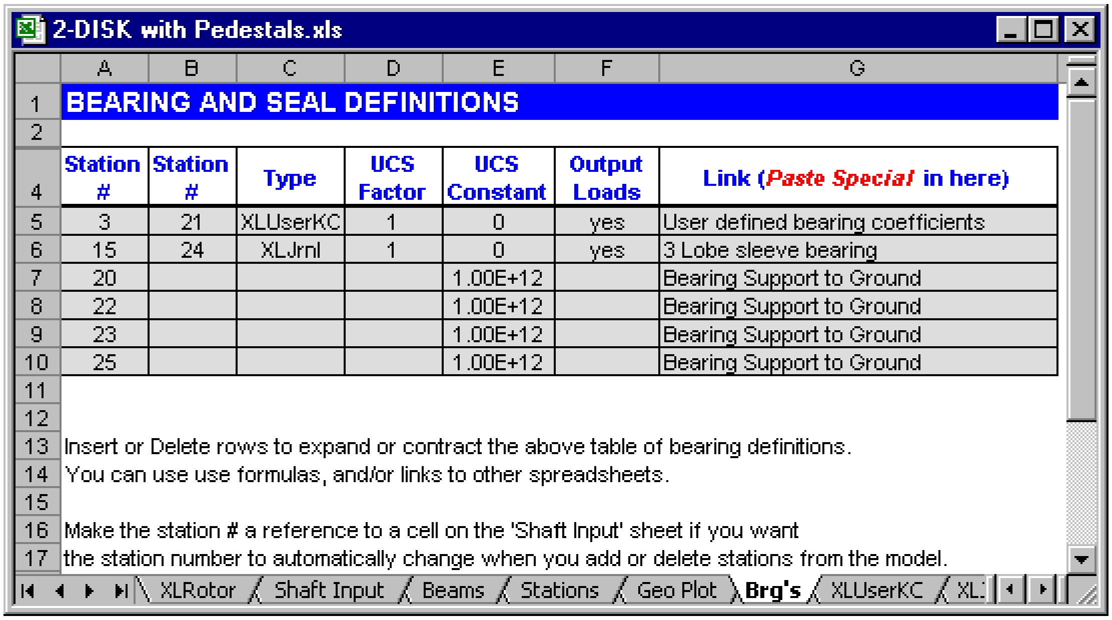
Note:
If the Geometry chart ever becomes corrupted such that executing an Update|Geometry

Chart command does not fix the problem, ***delete the chartsheet*** altogether. A new geometry chartsheet will be created the next time you execute an Update|Geometry Chart command.

If the model contains magnetic bearings with non-collocated sensors, the sensors will be displayed on the plot as in the following example. If the sensors are collocated, they will not be shown.



Brg's Worksheet



2-DISK with Pedestals.xls

BEARING AND SEAL DEFINITIONS

Station #	Station #	Type	UCS Factor	UCS Constant	Output Loads	Link (*Paste Special* in here)
3	21	XLUserKC	1	0	yes	User defined bearing coefficients
15	24	XLJrnl	1	0	yes	3 Lobe sleeve bearing
20				1.00E+12		Bearing Support to Ground
22				1.00E+12		Bearing Support to Ground
23				1.00E+12		Bearing Support to Ground
25				1.00E+12		Bearing Support to Ground

Insert or Delete rows to expand or contract the above table of bearing definitions.
You can use use formulas, and/or links to other spreadsheets.

Make the station # a reference to a cell on the 'Shaft Input' sheet if you want
the station number to automatically change when you add or delete stations from the model.

XLRotor / Shaft Input / Beams / Stations / Geo Plot / Brg's / XLUserKC / XL

See also

- XLRotor Overview
- Bearing Template Files
- Embedded Bearings
- Open Linked Bearing File
- Bearings Not at Same Axial Location

Use this worksheet to specify bearings, seals, etc. in the rotor model. The bearing stiffness and damping coefficients can be on worksheets in files separate from the rotor model file, or they can be on worksheets **in** the rotor model file. These worksheets are Linked to the rotor model file on the Brg's worksheet. In some cases, it is not necessary to Link bearing files when you specify bearings (see note below).

Your rotor model file can contain more than one "Brg's" worksheet. You might want multiple sheets so you can set up several configurations for your bearings. XLRotor will utilize the contents of whichever worksheet has the exact name of "Brg's". You can switch between configurations by simply renaming the worksheets. Click *here* for instructions on how to copy a worksheet.

Station #

These two columns specify the location of the bearing. You can type in the station value(s) directly, or better yet, use a reference to the contents of another cell, for example a cell on the Shaft Input Worksheet.

The second **Station #** column is used only for multi level models to specify bearings which are interconnections between levels. If the second **Station #** column is missing when creating a multi level model, XLRotor should offer to add the column for you when you execute an Update|Geometry Chart command.

If the second station is not at the same axial location as the first station, read the comments about this in the section on XLUserKC.XLS User Defined Bearing Template File .

If an XLTransferFunction worksheet is linked to the model, the next time the geometry plot is updated, two more columns will be added for specifying stations to use for displacement for each bearing. For ordinary bearings or seals, these two extra columns can be left empty. For magnetic bearings these two columns are for specifying the positions of non-collocated sensors. The columns can be left empty if the sensors are collocated. Relative stations are specified in the fourth column if the sensors are mounted in a housing.

Force		Displacement	
Station #	**Station #**	**Station #**	**Station #**
13		11	
44		46	

Note:
Instead of simply typing in a station number, it is strongly recommended to use a cell formula to refer to a cell on the Shaft Input Worksheet which contains the station number of where the bearing is located. Then, if the station number changes because you insert or delete stations to the left of the bearing, the bearing station number will automatically update. There are two easy ways to create these cell formulas, and these are explained below in the Link section of this Help topic.

Type

This column is for information, or comments only. The contents of this column are currently not used by XLRotor.

UCS Factor and UCS Constant

These two values tell XLRotor what to do with the bearing when performing an Undamped Critical Speed analysis (see Run|Undamped Crit. Spds). In this case, the stiffness of each bearing is determined from the following formula:

K = (k)**UCSFactor* + *UCSConstant*
where

> k refers to the values in the UCS ANALYSIS STIFFNESS column on the XLRotor Worksheet

These two inputs allow you to independently control the <u>lateral</u> stiffness of each bearing. Here are some examples of how to use UCSFactor and UCSConstant:

Example 1. A rotor model has two bearings and three seals, UCSFactor should be 1 for the bearings and 0 for the seals, and UCSConstant would be 0 for both bearings and all three seals. This would cause the two bearings to have the same stiffness, taken equal to k. The three seals would not have any stiffness.

Example 2. A rotor model has two bearings, and you want to produce a chart of undamped critical speeds versus the stiffness of bearing number 1 with the stiffness of bearing number 2 constant at 350,000 lb/in. For bearing number 1 enter UCSFactor=1 and UCSConstant=0. For bearing number 2 enter UCSFactor=0 and UCSConstant=350,000.

Example 3. A rotor model has two bearings, and you want to produce a chart of undamped critical speeds versus the stiffness of bearing number 1, with the stiffness of bearing number 2 being one third more than bearing number 1. For bearing number 1 enter UCSFactor=1 and UCSConstant=0. For bearing number 2 enter UCSFactor=1.33333 and UCSConstant=0.

It is also possible to have a bearing connection retain its own fully defined stiffness properties during a UCS analysis. See Run|Undamped Crit. Spds.

Output Loads

This column pertains to response calculations only. It specifies bearings for which to generate tables and charts of bearing load, when performing response calculations. To have the loads be output for a bearing, place any string that starts with an upper or lower case Y in this column. Anything else will suppress load output for that bearing. Bearing loads are also sometimes called bearing reaction forces.

Load cannot be output for bearings defined with PINNED, RIGID or GUIDED constraints. Instead, use a stiff spring to emulate the constraint. 1e12 is usually a good value to use in either English or SI units. A value that is excessively large could create roundoff problems when it is added to the system stiffness matrix. Whatever value is used, if it can be increased or decreased by a factor of 2 with negligible effect, then it is a good choice.

Link

This column is used to tell XLRotor where the stiffness and damping coefficients for the bearing are located. There are 4 valid types of entries for the cells in this column:

1. Enter a numerical value, and this value will be used for both Kxx and Kyy for the bearing. All other stiffness coefficients, and all damping coefficients, for this bearing will be zero. This is called a "Quick Bearing."
2. Enter one of the words PINNED, RIGID or GUIDED to create the corresponding type of constraint (see additional explanation below). However, see the above paragraph about load output.

3. Enter a cell formula referencing the Title cell on a bearing worksheet. This is called "Linking" a bearing worksheet to the rotor model (see additional explanation below). The bearing worksheet can be located in the rotor model file, or in another file.
4. The cell can be left blank, but this will limit you to performing only a UCS or Free-Free analysis because only these analysis types do not require a complete set of bearing coefficients.

Each station in the model has four dof; displacements x,y and rotations ax,ay.

A PINNED constraint between two stations i and j means there is <u>no relative displacement</u> between them. A PINNED constraint applied to one station means the station is pinned to ground, and dof x,y are exactly zero.

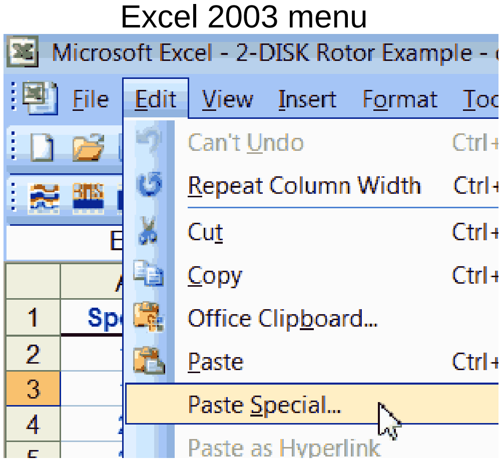
A GUIDED constraint between two stations i and j means there is <u>no relative rotation</u> between them. A GUIDED constraint applied to one station means the station is not allowed to rotate, and dof ax,ay are zero.

A RIGID constraint between two stations i and j means there is <u>no relative displacement or rotation</u> between them. A RIGID constraint applied to one station means the station is rigidly attached to ground, and all four dof are exactly zero.

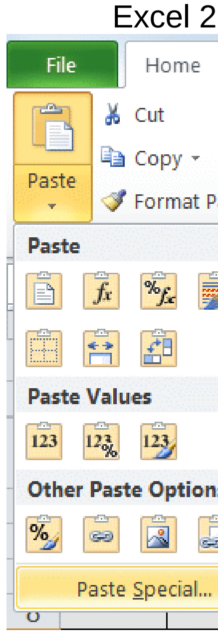
There are two ways to Link a bearing spreadsheet to a rotor model (item 3 above). Both ways accomplish the same thing:

1. Use the mouse or keyboard to copy and paste the **Title** cell from the bearing worksheet into the target cell in the **Link** column on the Brg's sheet. However, the paste operation ***<u>must</u>*** be done using **Edit/Paste Special** from the Excel menu, and click the **Link** button in the Paste Special dialog box.

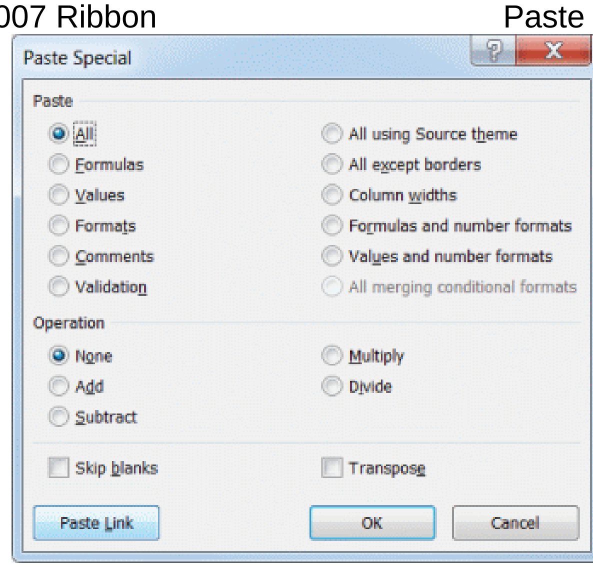
Excel 2003 menu



Excel 2007 Ribbon



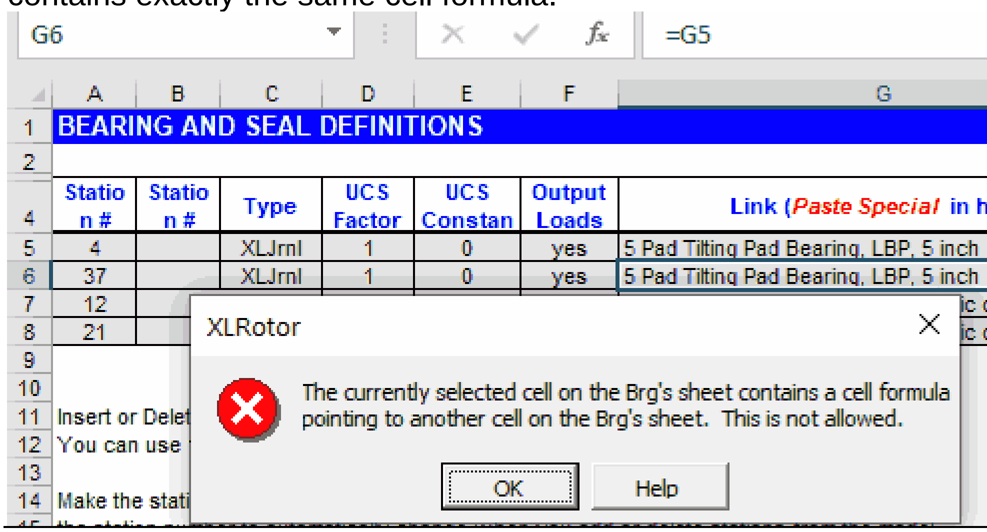
Paste Special D



2. Starting in the target cell of the **Link** column, press the "**=**" key on the keyboard, then navigate to the bearing worksheet and click on the **Title** cell, then press **Enter**.

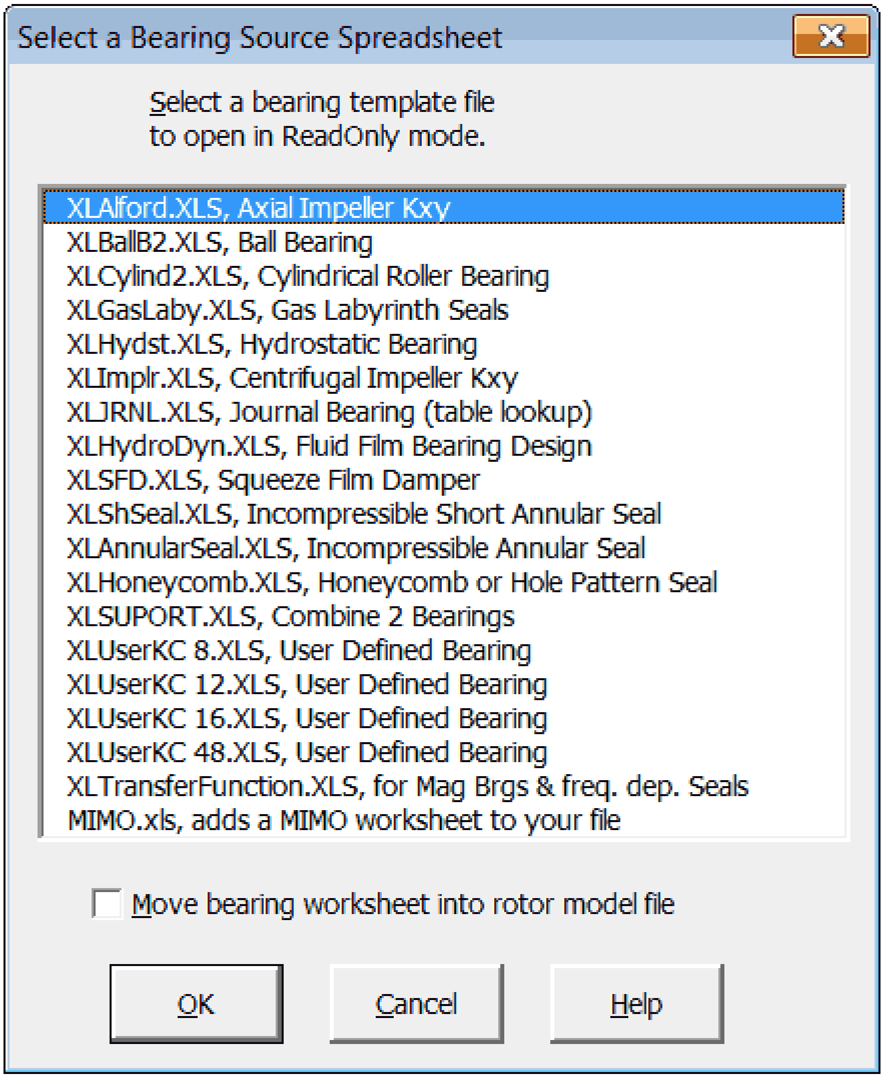
Either of these methods will place the same cell formula in the target cell in the Link column. If the bearing worksheet resides in the rotor model file, the formula will look similar to **=XLJrnl!$B$2**. If the bearing worksheet is in another file, the formula will look similar to **=[XLJrnl.xls]XLJrnl!$B$2** if the file is open. If the file is not open, the formula will include the path to the folder containing the file. The cell on the Brg's worksheet displays the contents of the referenced Title cell from the bearing spreadsheet file. The cell formula contains sufficient information for XLRotor to find the bearing worksheet when needed to perform a rotordynamic analysis.

Note: The cell formulas in the Link column are not permitted to reference another cell on the Brg's worksheet. Otherwise the following message is displayed. In the following example, the two bearings at stations 4 and 37 are utilizing the same XLJrnl worksheet. Cell **G5** contains a valid link to the XLJrnl sheet such as **=[XLJrnl.xls]XLJrnl!$B$2**. Cell **G6** should contain exactly the same link, but it contains the cell formula **=G5**, which displays the same text in cell G6 as in G5, but this is not an acceptable link to a bearing worksheet. The correct way is to simply copy and paste cell G5 to cell G6, which will copy the cell formula from cell G5 to G6 so that each contains exactly the same cell formula.

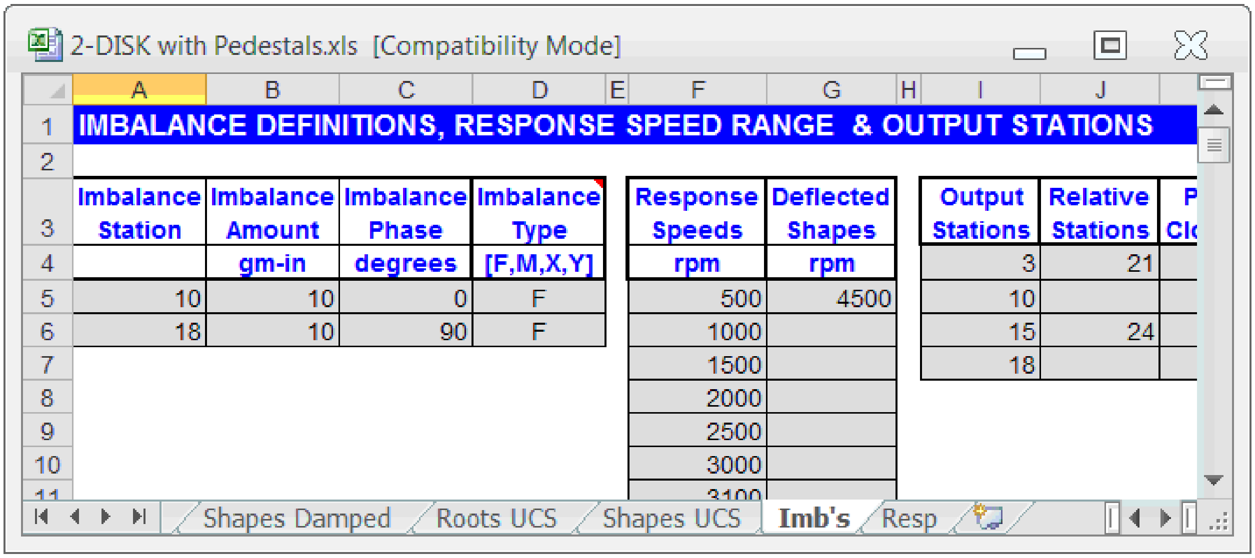


Bearing worksheets can be in files separate from the rotor model file, or within the rotor model file. See Embedded Bearings for more information about this.

When you are in an empty cell in the Link column, executing the Open Linked Bearing File command will display a dialog box of available choices for bearing and seal templates. You can also use this dialog box to copy (embed) the bearing template's worksheet directly in the rotor model file.


Select a Bearing Source Spreadsheet
Select a bearing template file
to open in ReadOnly mode.
XLAlford.XLS, Axial Impeller Kxy
XLBallB2.XLS, Ball Bearing
XLCylind2.XLS, Cylindrical Roller Bearing
XLGasLaby.XLS, Gas Labyrinth Seals
XLHydst.XLS, Hydrostatic Bearing
XLImplr.XLS, Centrifugal Impeller Kxy
XLJRNL.XLS, Journal Bearing (table lookup)
XLHydroDyn.XLS, Fluid Film Bearing Design
XLSFD.XLS, Squeeze Film Damper
XLShSeal.XLS, Incompressible Short Annular Seal
XLAnnularSeal.XLS, Incompressible Annular Seal
XLHoneycomb.XLS, Honeycomb or Hole Pattern Seal
XLSUPORT.XLS, Combine 2 Bearings
XLUserKC 8.XLS, User Defined Bearing
XLUserKC 12.XLS, User Defined Bearing
XLUserKC 16.XLS, User Defined Bearing
XLUserKC 48.XLS, User Defined Bearing
XLTransferFunction.XLS, for Mag Brgs & freq. dep. Seals
MIMO.xls, adds a MIMO worksheet to your file
Move bearing worksheet into rotor model file
OK
Cancel
Help

Imb's Worksheet

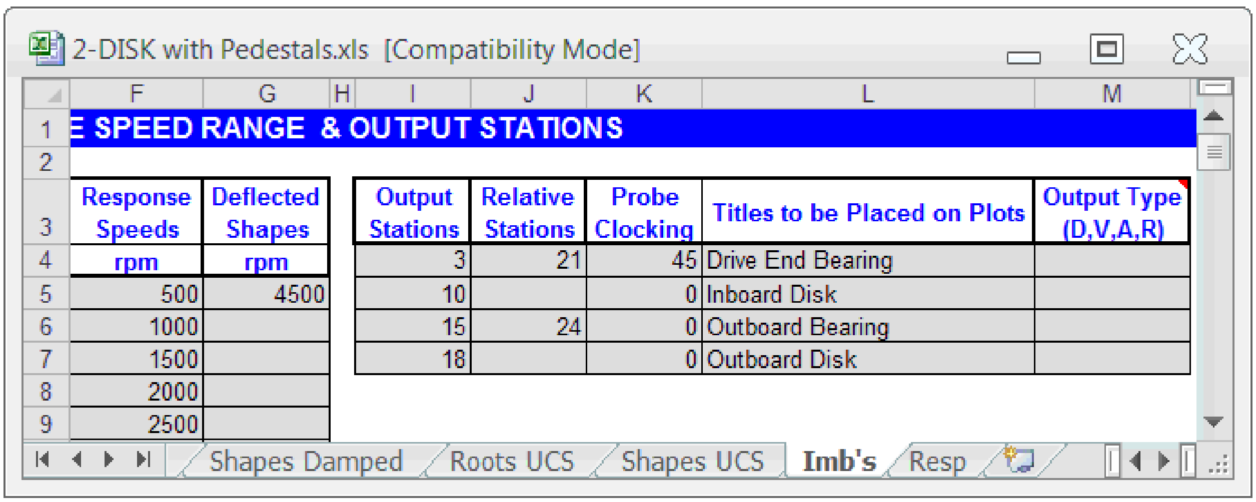


2-DISK with Pedestals.xls [Compatibility Mode]

IMBALANCE DEFINITIONS, RESPONSE SPEED RANGE & OUTPUT STATIONS

Imbalance Station	Imbalance Amount	Imbalance Phase	Imbalance Type	Response Speeds	Deflected Shapes	Output Stations	Relative Stations
	gm-in	degrees	[F,M,X,Y]	rpm	rpm	3	21
10	10	0	F	500	4500	10	
18	10	90	F	1000		15	24
				1500		18	
				2000			
				2500			
				3000			

Shapes Damped / Roots UCS / Shapes UCS / Imb's / Resp



2-DISK with Pedestals.xls [Compatibility Mode]

E SPEED RANGE & OUTPUT STATIONS

Response Speeds	Deflected Shapes	Output Stations	Relative Stations	Probe Clocking	Titles to be Placed on Plots	Output Type (D,V,A,R)
rpm	rpm	3	21	45	Drive End Bearing	
500	4500	10		0	Inboard Disk	
1000		15	24	0	Outboard Bearing	
1500		18		0	Outboard Disk	
2000						
2500						

Shapes Damped / Roots UCS / Shapes UCS / Imb's / Resp

See also

- XLRotor Overview
- Resp Worksheet
- Run|Response
- Brg's Worksheet
- XLCoupled Imb's Worksheet
- Run|Transient

This worksheet contains your specifications related to imbalance response calculations. You enter the amounts and locations of the imbalances, the speeds at which to compute responses, and specify what kinds of outputs you wish to receive.

In the appropriate columns enter the stations at which imbalances are applied, their amounts and their phases. The units for the imbalance amounts can be selected from those in the drop down list which appears in the Options|Response dialog box. The imbalance units you select are copied to the top of the Imbalance Amount column.

XLRotor is set up to perform imbalance response calculations and return results in one of two fashions:

1. Run|Response Compute plots of responses versus speed for selected station displacements and bearing loads.
2. Run|Deflected Shapes Compute plots of rotor operating deflected shape at selected speeds.

You execute these analyses from the Run submenu on the XLRotor pull down menu, or click a button on the XLRotor ribbon.

Your rotor model file can contain more than one "Imb's" worksheet. For example, you might want multiple sheets so you can setup several configurations of imbalance. XLRotor will utilize the contents of whichever worksheet has the exact name of "Imb's". You can switch between configurations by simply renaming the worksheets. Click ***here*** for instructions on how to copy a worksheet. Multiple sets of imbalances can also be setup and run in a single operation by using an API Response worksheet.

Note: The imbalances defined on this worksheet ***will*** be included in a transient analysis.

New in XLRotor version 5.0. When doing transient analysis with non-constant rotor speed, imbalances on the Imb's sheet are now permitted, whereas these were not allowed in earlier versions.

Imbalance Station

This column specifies the stations where the imbalances are located. If more than one imbalance is specified for the same station, they will be added.

Note:
Instead of simply typing in a station number, it is strongly recommended that you use a cell formula to refer to a cell on the Shaft Input Worksheet which contains the station number. Then, if the station number changes because you insert or delete stations in the model, the station number here will automatically update. There are two easy ways to create these cell formulas, see Link.

Imbalance Amount

This column specifies the amounts of imbalance. The imbalance units are selected fom a list on the Options|Response dialog box (i.e. gmin, oz-in, etc). It is important to select appropriate amounts for imbalance amount since response is proportional to imbalance. For many rotors, the most significant sources of imbalance are impellers, thrust bearing runners, coupling hubs, and other large masses mounted onto the shaft. So consider each large mass on the shaft, how each of these is pre-balanced before mounting, and to what tolerance the rotor is balanced when fully assembled. Quite often a reasonable starting point for imbalance amount is the following value which appears in many API documents:

$$U = \frac{4W}{N}(oz - in)$$

With *W* the entire rotor weight in lbm and *N* is operating speed in rpm. Or, in SI units:

$$U = \frac{6350W}{N}(gm - mm)$$

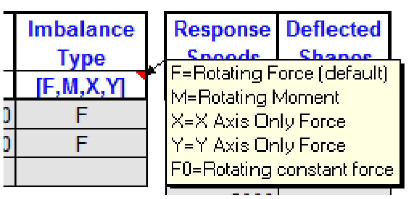
With *W* the entire rotor mass in kg and *N* is operating speed in rpm.

Imbalance Phase

This column specifies the phases (in degrees) of each imbalance weight. The phase input is ***lagging***. A positive input value moves the imbalance weight on the rotor in the direction ***opposite*** rotation. In XLRotor, positive rotation is ccw. An imbalance phase angle input of 10 degrees means the unbalance lags the zero degree spot by 10 degrees. Lagging is cw from the zero degree spot, i.e. opposite the direction of rotation.

Note: Prior to XLRotor version 5.0, imbalance phase angle input was ***leading***. Starting with 5.0, phase angles are ***lagging***.

Imbalance Type



This column specifies the type of excitation as a rotating ***F***orce, rotating ***M***oment, or individual oscillating force components in the ***X*** or ***Y*** directions. ***F***orce is the normal and default choice, and have units like oz-in or gm-mm. Moments are for couple imbalances with units like oz-in^2 or gm-mm^2. For example, a couple imbalance can be used to specify the shaking moment caused by a skew disk. The program looks only at the first letter of whatever is displayed in these cells. If the cell is blank, or if the first letter is anything other than ***F, M, X*** or ***Y,*** the type will be ***F***orce. When ***X*** or ***Y*** is specified, the units for the ***Amount*** are the same as would be for ***F***.

A forward rotating force can be created by inputting an ***X*** component with zero phase angle, and a ***Y*** component with +90 degree phase angle. Phase angle inputs are lagging phase, and for forward rotation Y lags X by 90 degrees.

New in version 5.61. A type of ***F0*** means the ***Amount*** has units of force (lbf for models in English units, Newtons for models in SI units). This enables specifying a rotating force which has constant magnitude for all speeds, but without needing to select the option for Asynchronous Response analysis.

Response Speeds & Deflected Shape Speeds

There are separate columns for listing these two speed ranges, Response Speeds (Run|Response) and deflected Shapes (Run|Deflected Shapes). In both columns you can list any number of speeds, in any order. Normally, you will want the Response Speeds to be equally spaced over the speed range of interest. Excel's features for automatically filling ranges with values makes this easy. The Deflected Shape speed column contains the speeds for which you want to check the entire rotor's deflected axis (i.e. similar to a mode shape).

Tip: In the Options|Response dialog there is an option to have the program automatically fill in additional speeds to assure having enough points to accurately define critical speed peaks.

Output Stations

This column is used to list stations for which you want to generate charts of displacement amplitude versus rotor speed (i.e. Bode Charts). You can list as many stations as you want, in any order that you want. You can even list the same station more than once. There is also a column for entering an additional title to be copied to the plots. See Options|Response to see how you can choose what units are used to present the displacement results.

Plots of bearing load versus rotor speed are generated for bearings which have been designated for load output on the Brg's Worksheet.

Relative Stations

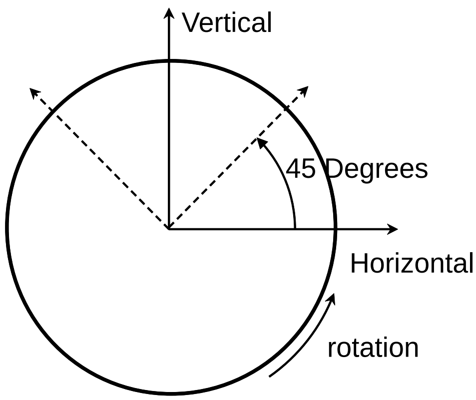
This column applies only for multi level models. Put a valid station value in this column *when you* want the relative displacement between two stations in the mode**l. If the second** Relative Stations column is missing when creating a multi level model, XLRotor should offer to add the column for you when you execute an Update|Geomety Chart command.

Note:
XLRotor does not check that the two stations are on different levels, or that their axial locations are equal.

Probe Clocking

Sometimes displacement probes are installed on machines at angles other than pure horizontal and vertical. XLRotor can rotate the horizontal and vertical response results to be in terms of a new set of axes by specifying a probe clocking angle in degrees in the direction of rotation. In the following illustration, probes have been installed in a bearing housing at 45 degrees from horizontal. You could then specify a ***Probe Clocking*** angle of 45 degrees on the Imb's Worksheet for the station corresponding to that bearing. Response results for that station are then in terms of the rotated set of axes, and can be compared directly to measured responses.

Bearing load results are not rotated, and neither are response deflected shapes.



Output Type (D,V,A,R)

In this column you direct the program to output response values in terms of ***D***isplacement, ***V***elocity, ***A***cceleration or ***R***otation. Displacement is the default. This option is useful when you want velocity or acceleration values to compare to measurements or vibration acceptance standards.

The program looks only at the first letter of whatever is displayed in these cells. If the cell is blank, or if the first letter is anything other than ***D***, ***V***, ***A*** or ***R***, the output will be displacement.

When ***V*** is specified, the program multiplies the displacement response by the frequency of the response in radians/second, and also invokes the velocity units output settings entered in the Options|Transient dialog box. Velocity leads displacement by 90 degrees. Phase angle output on a Resp sheet uses a lagging phase angle convention. So phase angles output for velocity are 90 degrees less than for displacement.

When ***A*** is specified, the program multiplies the displacement response by the square of the frequency of the response in radians/second, and also invokes the acceleration output settings entered in the Options|Transient dialog box. Acceleration has opposite phase from displacement. So phase angles output for acceleration are 180 degrees less than for displacement.

When ***R*** is specified, the program outputs angular deflections (i.e. rotations) of the shaft in radians. On the Resp Worksheet the columns labeled Horizontal will contain rotations from the ay degree of freedom (about y). The vertical columns will contain the ax rotational degree of freedom.

Other Sheets

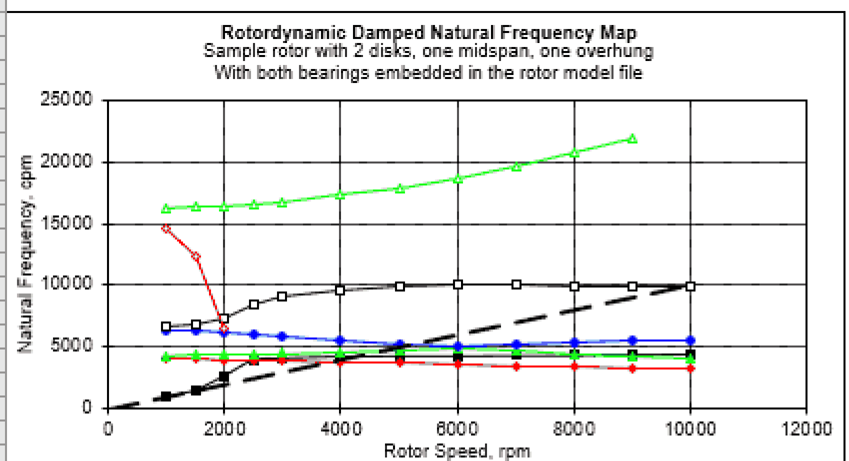
See also

XLRotor Overview

There are several *hidden sheets* in every XLRotor rotor model file. These sheets contain option settings, data series (used to construct the geometry chart), and a small amount of macro code. These sheets are Hidden from view using the Format|Sheet|Hide pull down menu command. You can Unhide the sheets if you want to inspect their contents. However, you should not alter them unless you are trying to customize the XLRotor environment.

Roots Damped Worksheet

Speed	logd1	cpm1	logd2	cpm2	logd3	cpm3	logd4	cpm4	logd5	cpm5
1000.	**9.757**	**1005.1**	0.040	4104.1	0.045	4299.5	0.171	6419.7	0.801	6691.1
1500.	9.282	1531.9	0.040	4055.2	0.051	4348.2	0.206	6283.7	1.215	6859.7
2000.	6.948	2705.8	0.041	4006.2	0.060	4397.0	0.218	6134.0	1.775	7373.3
2500.	3.219	3997.2	0.042	3957.2	0.072	4446.0	0.214	5981.7	1.597	8503.8
3000.	2.125	4158.8	0.044	3908.1	0.090	4495.7	0.201	5830.8	1.300	9068.9
4000.	1.139	4291.6	**0.051**	**3808.9**	0.151	4603.5	0.168	5539.4	1.035	9618.1
5000.	0.589	4333.1	0.061	3707.4	**0.220**	**4765.5**	**0.149**	**5269.9**	0.987	9889.1
6000.	0.323	4331.6	0.069	3605.6	0.101	4862.6	0.223	5110.8	1.042	10005.7
7000.	0.173	4354.6	0.078	3505.3	0.045	4682.5	0.218	5209.2	1.140	10016.8
8000.	0.077	4373.3	0.089	3406.6	0.022	4476.3	0.184	5345.7	1.241	9968.7
9000.	-0.037	4439.0	0.102	3309.2	0.046	4231.0	0.154	5484.1	1.326	9904.2
10000.	-0.109	4470.6	0.118	3213.3	0.041	4032.9	0.126	5620.0	**1.386**	**9853.2**



XLJrnl | Roots UCS | **Roots Damped** | Sh...

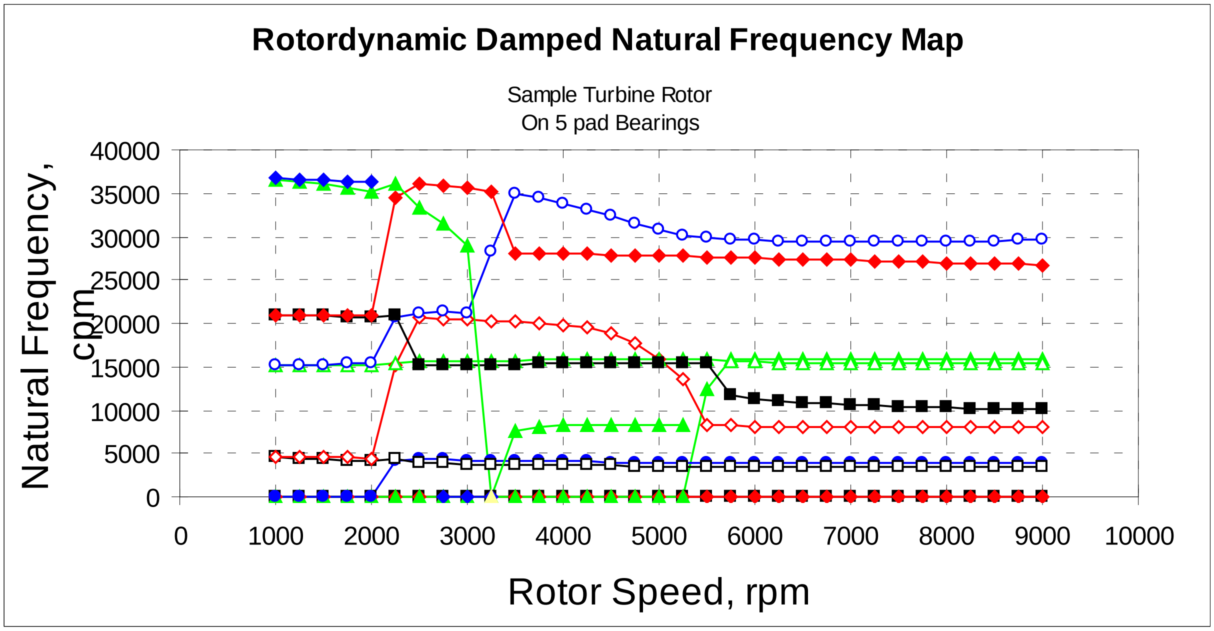
See also

- Roots UCS Worksheet
- Roots FF Worksheet
- Roots Tors Worksheet
- XLRotor Overview
- Swap Eigenvalues
- Run|Eigenvalues
- XLRGRPH.XLS Chart Template File

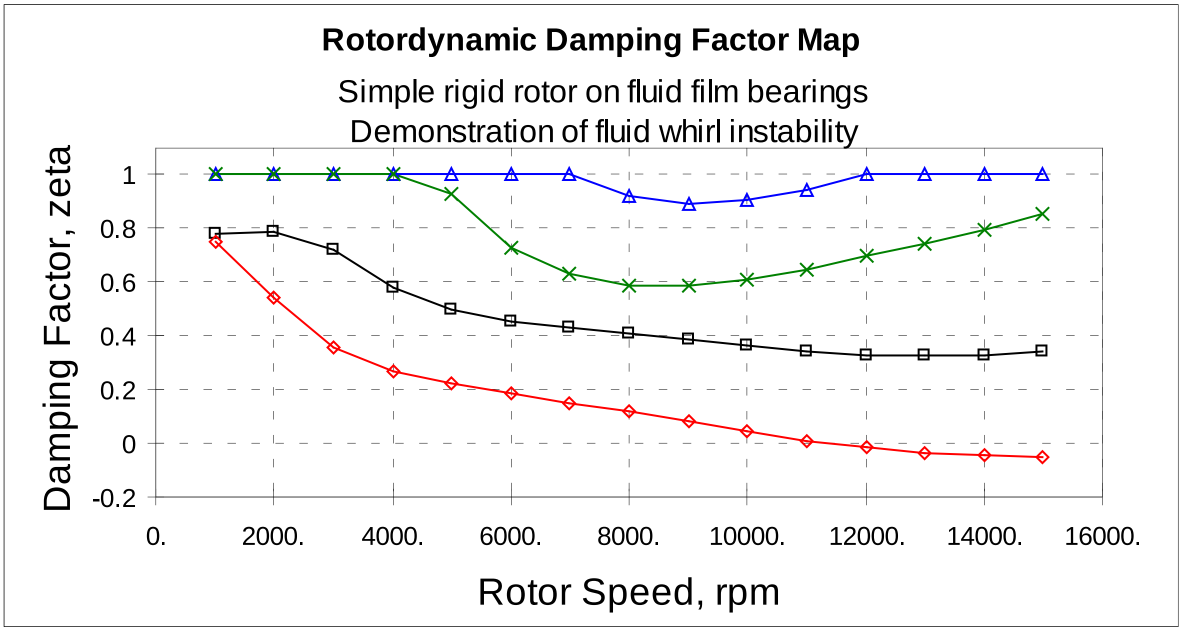
A **Roots Damped** worksheet displays the results of a damped eigenvalue analysis for lateral rotor models. A damped eigenvalue analysis is performed with the Run|Eigenvalues command. The computed eigenvalues will be placed on a worksheet named **Roots Damped**. If this worksheet already exists, its contents will be overwritten (see Append or Overwrite Worksheet).

The analysis results are a table of roots showing the real and imaginary parts of the eigenvalues versus running speed. There will also be one, two or three charts showing the roots. See Options|Eigenanalysis for your options on which charts are created.

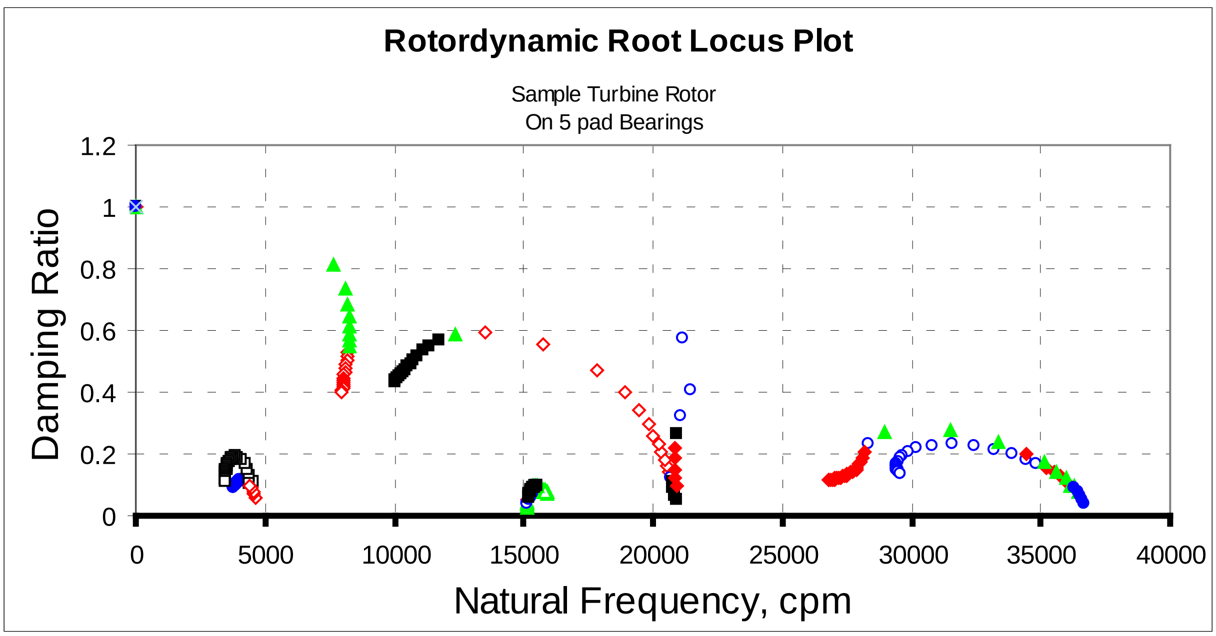
One chart that is always created is a Damped Natural Frequency Map. This plot shows how the natural frequencies of the model vary with running speed. Gyroscopics and speed dependent bearing coefficients cause the natural frequencies to depend on speed. This plot shows only the imaginary parts of the complex eigenvalues (see Change Eigenvalue Style). You can add a Synchronous Line to the plot to help identify the synchronous critical speeds of the damped rotor system.



The real parts of the damped eigenvalues are displayed versus speed in a Damping Factor map. This plot is useful for identifying threshold speeds of instability. For example, the following plot shows that the damping ratio, zeta, for one of the modes becomes negative at speeds above 11,000 rpm. So 11,000 rpm would be the instability threshold speed.

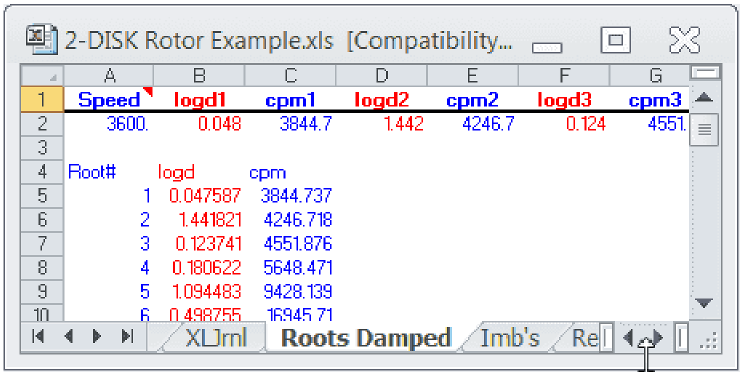


Another way to plot damped eigenvalues is to plot the real parts versus the imaginary parts (or vice versa). This plot is called a Root Locus plot.



The cell formatting for the table of damped eigenvalues is copied from a worksheet having the same name located in the XLRGRPH.XLS Chart Template File. For example, Excel conditional formatting can be used to highlight all cells containing a negative log dec or damping ratio.

If only a single speed has been run, for example operating speed, then instead of generating plots, a vertical table of the roots is listed below the normal horizontal table.



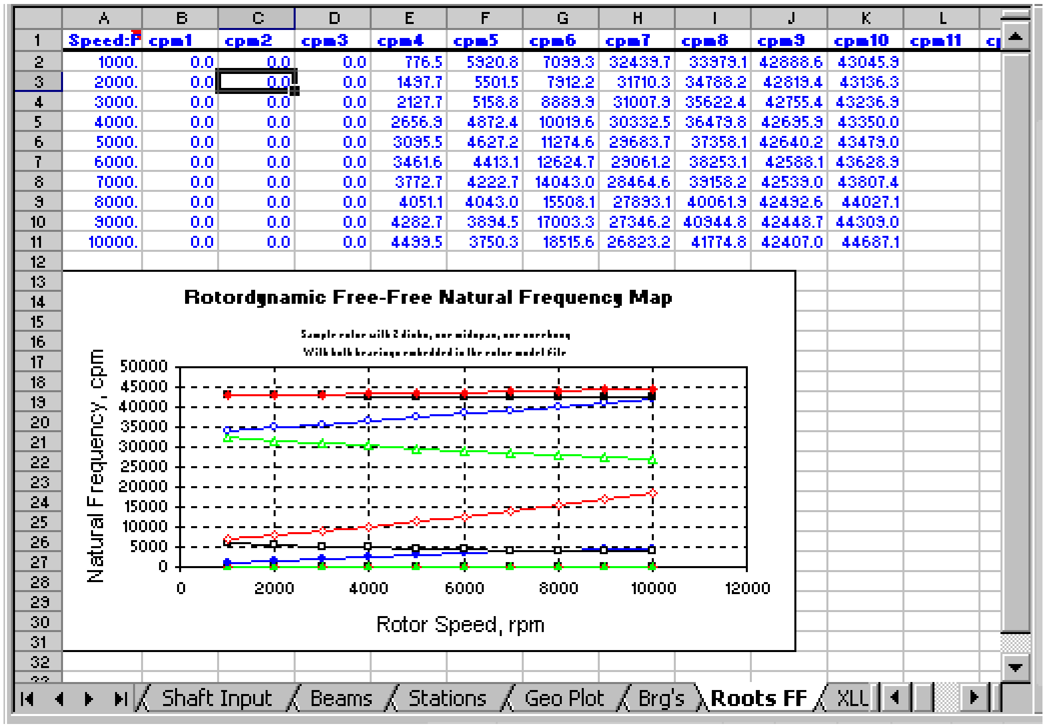
Note:
You have full control over the formats of these charts. You can edit the templates located in the XLRGRPH.XLS file, and resave the template file. Also, once the charts are created in your rotor model file, you can further modify their formats, and these format changes will be retained if you overwrite the sheet with a new calculation of roots.

Note:
When the analysis is completed, and the results are placed on this worksheet, a cell comment is placed at the upper left corner of the output table. This comment contains a summary of the analysis parameters used for the calculation.

Note:
Ordinarily, the charts will be (re)positioned immediately below the table of roots every time the roots are calculated. You can of course move the charts to new positions on the sheet. The charts will stay where you put them when roots are recalculated if the chart is not against the left edge of the worksheet.

Note:
When the program outputs damped roots, very heavily damped roots can be excluded from the output by creating an Excel defined name called ***Maximum_Damping_Factor_To_Plot*** and giving it a value equal to maximum damping constant to be output.

Roots FF Worksheet



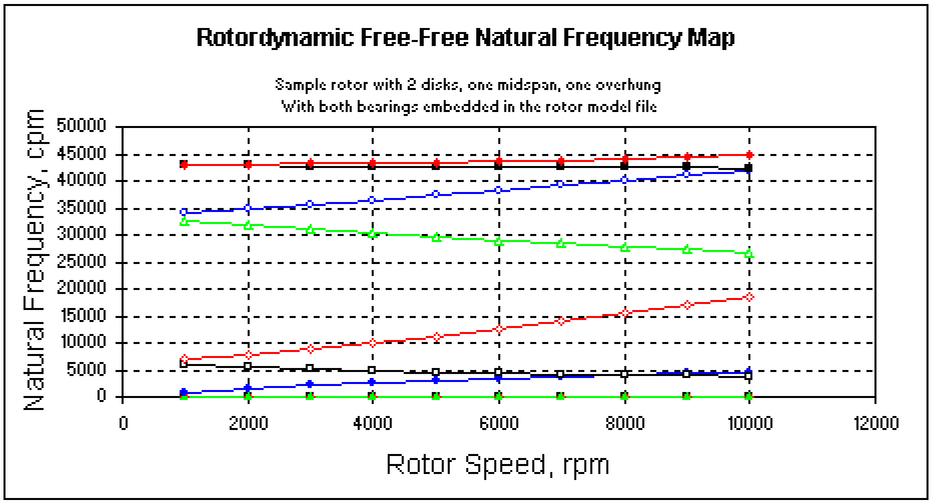
	A	B	C	D	E	F	G	H	I	J	K	L
1	Speed:F	cpm1	cpm2	cpm3	cpm4	cpm5	cpm6	cpm7	cpm8	cpm9	cpm10	cpm11
2	1000.	0.0	0.0	0.0	776.5	5920.8	7099.3	32439.7	33979.1	42888.6	43045.9	
3	2000.	0.0	0.0	0.0	1497.7	5501.5	7912.2	31710.3	34788.2	42819.4	43136.3	
4	3000.	0.0	0.0	0.0	2127.7	5158.8	8889.9	31007.9	35622.4	42755.4	43236.9	
5	4000.	0.0	0.0	0.0	2656.9	4872.4	10019.6	30332.5	36479.8	42695.9	43350.0	
6	5000.	0.0	0.0	0.0	3095.5	4627.2	11274.6	29683.7	37358.1	42640.2	43479.0	
7	6000.	0.0	0.0	0.0	3461.6	4413.1	12624.7	29061.2	38253.1	42588.1	43628.9	
8	7000.	0.0	0.0	0.0	3772.7	4222.7	14043.0	28464.6	39158.2	42539.0	43807.4	
9	8000.	0.0	0.0	0.0	4051.1	4043.0	15508.1	27893.1	40061.9	42492.6	44027.1	
10	9000.	0.0	0.0	0.0	4282.7	3894.5	17003.3	27346.2	40944.8	42448.7	44309.0	
11	10000.	0.0	0.0	0.0	4499.5	3750.3	18515.6	26823.2	41774.8	42407.0	44687.1	

See also

- [Roots Damped Worksheet]
- [Roots UCS Worksheet]
- [Roots Tors Worksheet]
- [XLRotor Overview]
- [Run|Free Free Modes]
- [XLRGRPH.XLS Chart Template File]

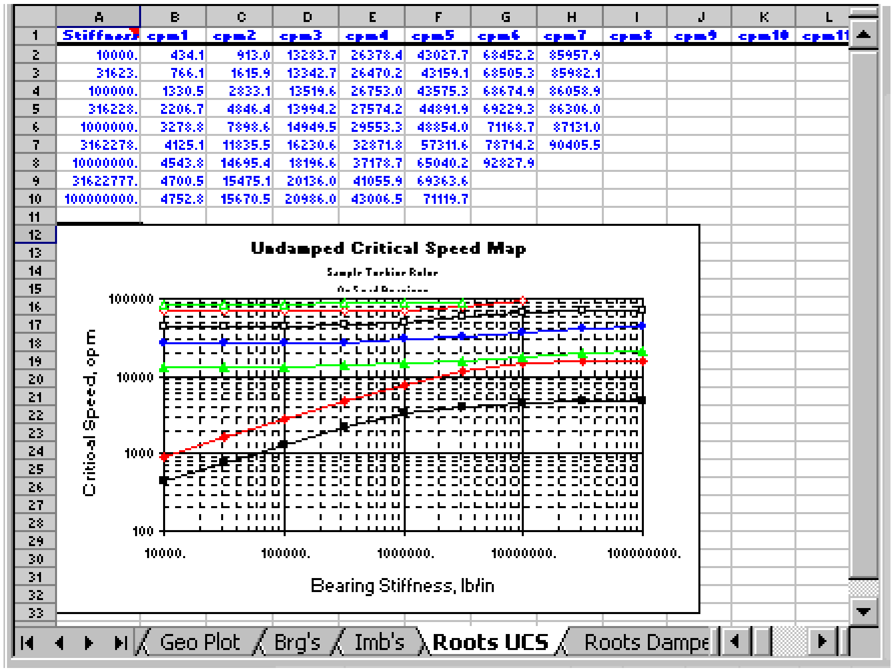
A **Roots FF** worksheet displays the results of an undamped free-free analysis for lateral rotor models. This type of eigenvalue analysis is performed with the Run|Free Free Modes command. The computed eigenvalues will be placed on a worksheet named **Roots FF**. If this worksheet already exists, its contents will be overwritten (see Append or Overwrite Worksheet).

The analysis results are a table of roots showing only the imaginary parts of the eigenvalues versus rotor speed since the real parts are always zero. There will also be a chart showing the roots versus speed.



Note:
When the analysis is completed, and the results are placed on this worksheet, a cell comment is placed at the upper left corner of the output table. This comment contains a summary of the analysis parameters used for the calculation.

Roots UCS Worksheet



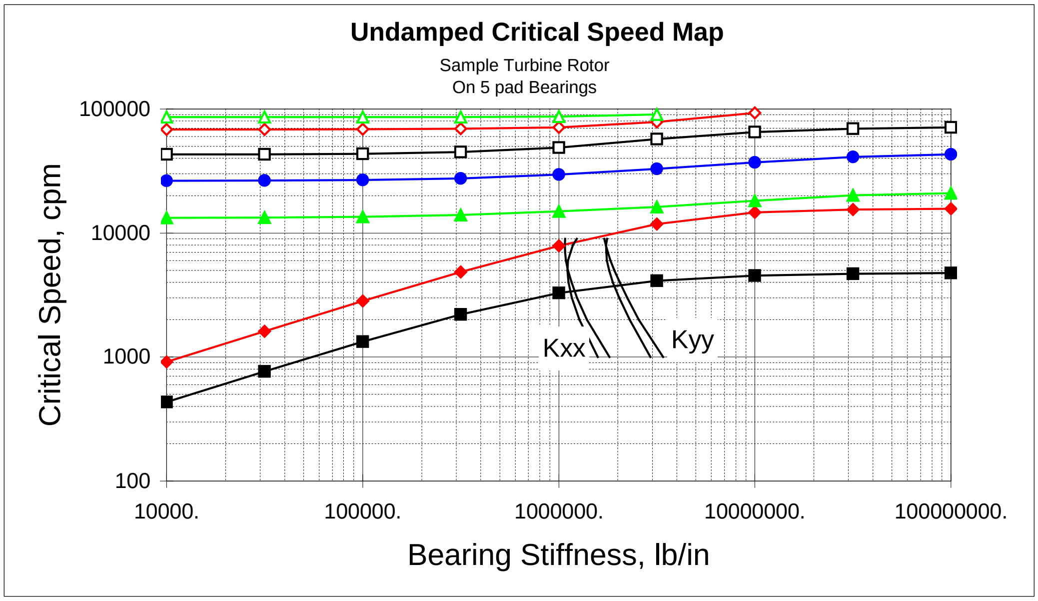
	A	B	C	D	E	F	G	H	I	J	K	L
1	Stiffness	cpm1	cpm2	cpm3	cpm4	cpm5	cpm6	cpm7	cpm8	cpm9	cpm10	cpm11
2	10000.	434.1	913.0	13283.7	26378.4	43027.7	68452.2	85957.9				
3	31623.	766.1	1615.9	13342.7	26470.2	43159.1	68505.3	85982.1				
4	100000.	1330.5	2833.1	13519.6	26753.0	43575.3	68674.9	86058.9				
5	316228.	2206.7	4846.4	13994.2	27574.2	44891.9	69229.3	86306.0				
6	1000000.	3278.8	7898.6	14949.5	29553.3	48854.0	71168.7	87131.0				
7	3162278.	4125.1	11835.5	16230.6	32871.8	57311.6	78714.2	90405.5				
8	10000000.	4543.8	14695.4	18196.6	37178.7	65040.2	92827.9					
9	31622777.	4700.5	15475.1	20136.0	41055.9	69363.6						
10	100000000.	4752.8	15670.5	20986.0	43006.5	71119.7						

See also

- Roots Damped Worksheet
- Roots FF Worksheet
- Roots Tors Worksheet
- XLRotor Overview
- Run|Undamped Crit. Spds
- XLRGRPH.XLS Chart Template File
- Put Kxx/Kyy on UCS

A **Roots UCS** worksheet displays the results of an undamped critical speed analysis for lateral rotor models. This type of eigenvalue analysis is performed with the Run|Undamped Crit. Spds command. The computed eigenvalues will be placed on a worksheet named **Roots UCS**. If this worksheet already exists, its contents will be overwritten (see Append or Overwrite Worksheet).

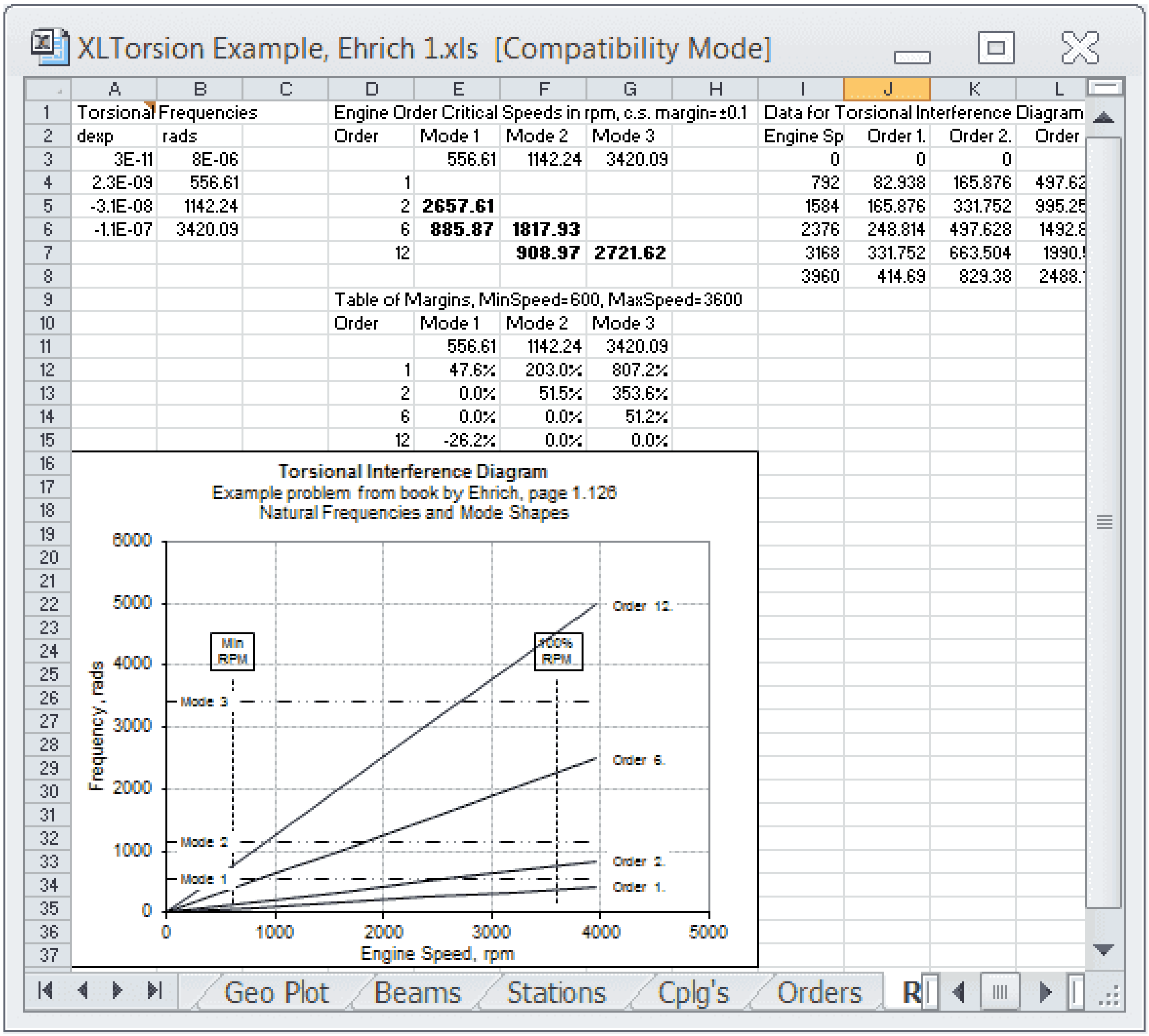
The analysis results are a table of roots showing only the imaginary parts of the eigenvalues versus support stiffness since the real parts are always zero. There will also be a chart showing the roots called an Undamped Critical Speed Map. This plot is often used in one of two ways: 1) if you have a general idea of how stiff your bearings will be you can get a good indication of how many critical speeds there will be and the speeds at which they will occur, and 2) if you know at what speeds you want the criticals to be you can see what value of support stiffness will be required to achieve this.



A UCS plot usually spans three regions of stiffness. To the left of the plot, where the bearings are very soft, the rotor is approaching a free-free condition and there will be one or two rigid body modes sloping downward to the left with the remainder of the modes being flexible modes having constant values. To the right of the plot, where the bearings are very stiff, the rotor is approaching a simply supported condition and all modes have constant values. In between these two regions the rotor transitions from unsupported to simply supported.

Note:
When the analysis is completed, and the results are placed on this worksheet, a cell comment is placed at the upper left corner of the output table. This comment contains a summary of the analysis parameters used for the calculation.
In addition, the bearing stiffnesses can be added to the plot as illustrated in the above image by using the Put Kxx/Kyy on UCS menu command.

Roots Tors Worksheet



See also

[XLRotor Overview]
[Torsional Analysis with XLRotor]
[XLTorsion Worksheet]
[Run|Eigenvalues]
[Torsional Resp Worksheet]

This worksheet is the torsional version of a Roots Damped Worksheet for lateral analysis. This worksheet is generated automatically when you execute a Run|Eigenvalues command with a torsional model. As can be seen in the sample above, this worksheet contains 4 tables.

1. The first table is of damped torsional eigenvalues. Unlike for a lateral analysis, these eigenvalues do not change with the speed of the rotor. So there is just one

set of values. See Options|Eigenanalysis about how to select the units for the roots.

2. The second table shows the critical speeds. Torsional critical speeds are engine (or motor) speeds that result in any listed natural frequency exactly coinciding with any of the engine orders which have been listed on the Orders Worksheet.
3. The third table (appearing below the second table) shows critical speed margins with respect to minimum and maximum speeds. Critical speeds between these two speeds have zero margin.
4. The fourth table is for constructing the lines that are placed on the torsional interference diagram (or Campbell diagram).

The critical speeds that are listed in the second table can be seen on the torsional interference diagram as points where the order lines (which are sloping) intersect the mode lines (which are horizontal). In the above example 5 intersections can be seen in the figure. These coincide with the 5 critical speeds listed in the second table.

In the eigenvalue table, the first eigenvalue listed will usually have a frequency very close to 0. This mode corresponds to rigid body rotation present in nearly any torsional system model, because there will not be any stiffness to ground. If you then have any damping to ground, the damping ratio of this mode will be 1 (critically damped).

When XLRotor attempts to place the roots on a "Roots Tors" worksheet, if the target worksheet already exists, it contents will be overwritten (see Append or Overwrite Worksheet), otherwise a new copy of the worksheet is created.

Mode shapes for torsional models are also placed on this worksheet. Torsional mode shapes are tabulated differently than for a lateral model. The mode shape amplitudes at every station actually have both a magnitude and phase. Since torsional models are generally lightly damped, the phase is generally very close to 0 or 180 degrees. Therefore only the magnitudes are put on the worksheet, with signs selected based on phase angles. The actual phase angles themselves are not placed on the worksheet.

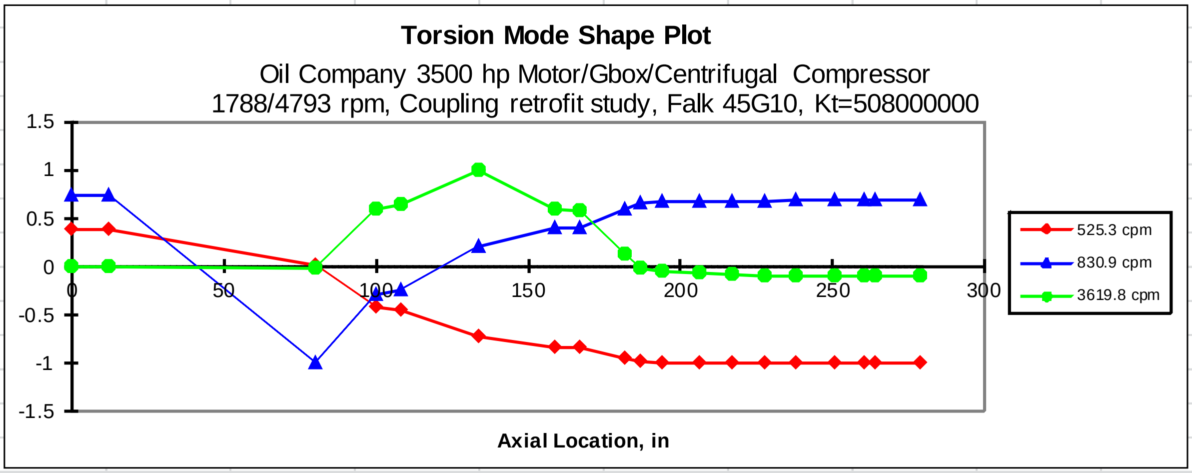
As for lateral mode shapes, the chart of model geometry can be overlaid onto the mode shape plot (see Overlay Geometry on Mode Shape). This was done for the example shown below.

Be aware that when you have a gearbox in the model, mode shapes deflections can exhibit a discontinuous jump in magnitude across the gear. This is due to the gear ratio.

As shown in the sample below, this worksheet can display multiple mode shapes on one chart. There are several option settings that affect torsional mode shape output in the Options|Eigenanalysis dialog box, including how many mode shapes to put on each chart.

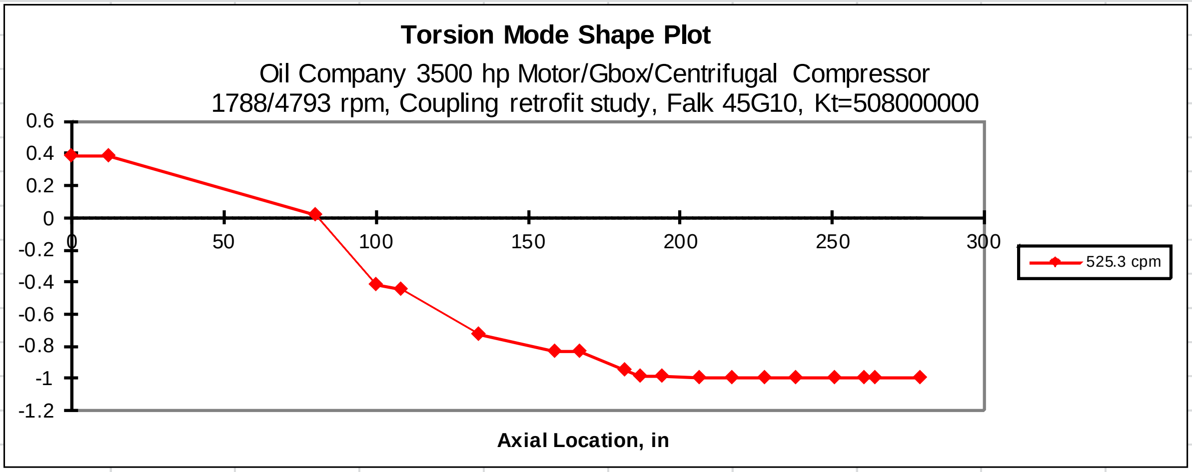
If 3 or fewer mode shapes are specified to be placed on each single chart (see Options|Eigenanalysis), extra columns in the mode shape table show the peak normalized stress at all stations for which beam elements have been defined. The stress amplitudes are normalized to a maximum value of +/-1. Above the column of stresses is the frequency of the mode, and the station number of maximum stress. For stations that do not have any beam elements defined with a nonzero shear modulus, the stress value is output as zero.

Stress concentration factors can be included in the calculation of normalized stress. These factors are specified on the Shaft Input sheet.



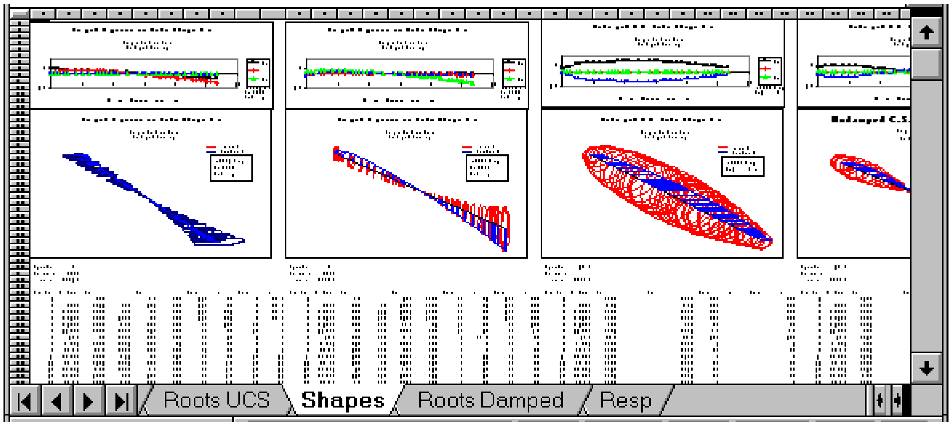
Re(root)=	logd		-3.9E-12	6.57E-14	2.59E-12	3	2	10	
Im(root)=	cpm		525.3025	830.9066	3619.797	525.3025	830.9066	3619.797	
Stn. No.	Ax. Loc.	CtrLn	Re(ax)	Re(ax)	Re(ax)	Stress	Stress	Stress	Re(ax)
1	0	0	0.388981	0.73313	0.000279	0.00	0.00	0.00	
2	12	0	0.388976	0.733106	0.000279	-0.35	-1.00	0.00	
3	80	0	0.021443	-1	-0.01224	-1.00	1.00	0.48	
4	100	0	-0.41672	-0.28711	0.594001	0.00	0.00	0.00	
5	108	0	-0.44846	-0.23543	0.636948	-0.58	0.58	0.27	
6	134	0	-0.7229	0.211886	1				
7	134	0	-0.7229	0.211886	1	-0.47	0.49	-0.62	

If the number of mode shapes per plot is 1 (see Options|Eigenanalysis), then strain and kinetic energy for each station are listed in the output table. If a spring on the Cplg's sheet connects station i to station j, the strain energy in that spring will be included in the strain energy value for station i. Also note that strain energy in RIGID constraints is zero.



Re(root)=	logd		-3.9E-12			3			
Im(root)=	cpm		525.3025			525.3025			
Stn. No.	Ax. Loc.	CtrLn	Re(ax)	Re(ax)	Re(ax)	Stress	Strain En.	Kinetic En	Re(ax)
1	0	0	0.388981			0.00	0.00	0.00	
2	12	0	0.388976			-0.35	0.26	0.27	
3	80	0	0.021443			-1.00	0.33	0.00	
4	100	0	-0.41672			0.00	0.02	0.00	
5	108	0	-0.44846			-0.58	0.20	0.00	
6	134	0	-0.7229				0.00	0.03	

Shapes Worksheet



See also

- XLRotor Overview
- Roots Damped Worksheet
- Animate Mode Shape
- Overlay Geometry on Mode Shape
- Mode Shapes for Torsional Models
- Mode Shapes for XLCoupled Models

This worksheet displays mode shapes in both tabular and pictorial form. To generate mode shapes it is necessary to first compute eigenvalues. Then on the Roots Damped Worksheet (or Roots UCS or Roots FF sheets), use the mouse to select one or more roots. On a worksheet of damped eigenvalues you must select **both** the damping and frequency parts of each root selected. Experiment with holding down the Shift or Control keys when selecting roots to see how you can select any combination of roots. When done selecting roots, click the Calc. Mode Shape button, or use the pull down menu. XLRotor will compute mode shapes for the eigenvalues in the same order you selected them.

There are 3 ways you can select which roots you want to compute mode shapes for:

1. Select any number and combination of roots by selecting the worksheet cells directly in a root table. This will compute mode shapes for all selected roots, in the order that you selected them.
2. In a natural frequency map or UCS map, select one charted data series by clicking on it with your mouse. This will compute mode shapes for all roots in the data series.
3. Again, in a natural frequency map or UCS map, select a single charted data point (by clicking on it one time slowly). This will compute the mode shape for that root only.

Note:
XLRotor will not compute mode shapes for modes with a frequency of exactly zero.

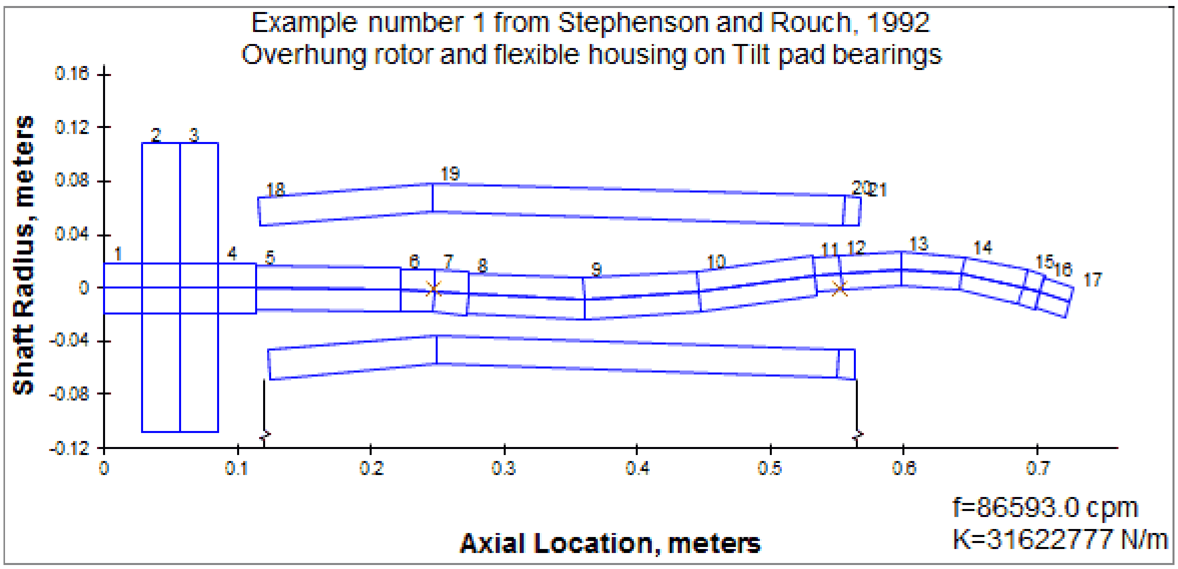
This includes critically damped modes resulting from a damped analysis, and rigid body modes resulting from a free-free analysis.

Note:
"Root" worksheets for free-free modes and undamped critical speeds do not contain damping factors, so just select the frequencies for mode shape calculation.

XLRotor attempts to place the mode shapes on a worksheet named "Shapes." If there is no worksheet by that exact name, then one will be created. If there is a worksheet by that name you will be prompted if you want to Append the new mode shapes to what is already there (see Append or Overwrite Worksheet).

The "Shapes" worksheet will display the mode shapes in table fashion, and contain either one or two *embedded charts* of each mode shape. The charts are 2D and 3D renditions of the mode shapes. Select the charts you want in the Options|Eigenanalysis dialog.

Mode shape output for Undamped Critical Speeds will include a table of strain energy distribution. The percentage of potential energy is given for each bearing and for each level of the model. The following example was made with the example file named *Stephenson and Rouch, Foundation Structure, 1992.xls*.

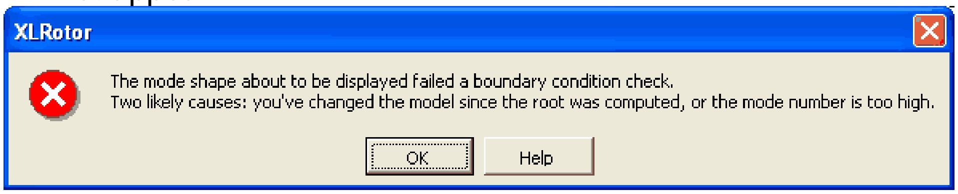


Modal Strain Energy Disrtibution					
Rotating Levels		NonRotating Levels		Bearings	
1	3.66641	2	91.79513	1	2.681698
				2	1.737203
				3	0.09483
				4	0.024727
Totals	3.66641		91.79513		4.538457

Note:
Be aware that a large number of 3D mode shapes can result in a very large spreadsheet file.

VERY IMPORTANT:
When computing mode shapes, XLRotor uses the current state of the rotor/bearing model. The model must be the same as it was when the eigenvalues were computed, including the definition of the stations on the "Shaft Input" worksheet, and the bearing definitions.

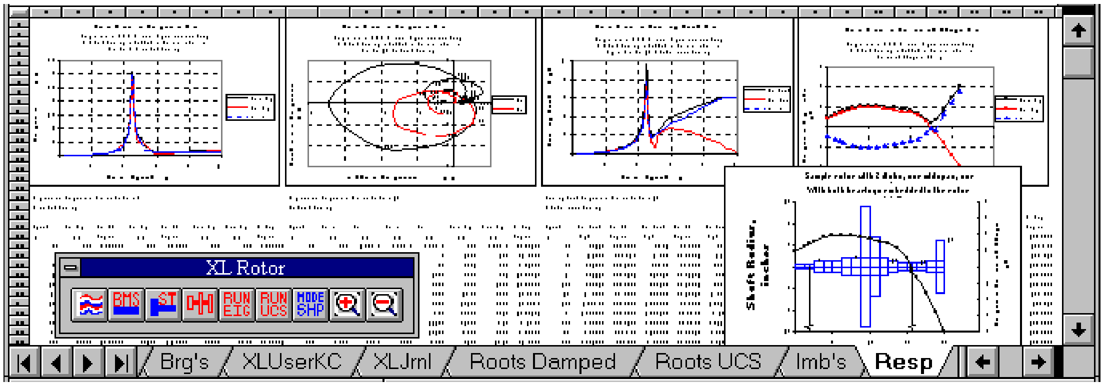
If the model has changed, an erroneous mode shape may result, in which case an error message will be displayed announcing that the mode shape failed a boundary condition check. If the model change has not significantly changed the eigenvalue, the message will not appear.



You can also get the failed boundary condition message when computing mode shapes for inaccurate high order modes (see Options|Eigenanalysis or Numerical Solution Method).

Note:
When the analysis is completed, and the results are placed on this worksheet, a cell comment is placed at the upper left corner of the output table. This comment contains a summary of the analysis parameters used for the calculation.

Resp Worksheet



See also

- XLRotor Overview
- Options|Response
- Run|Response
- Run|Deflected Shapes
- Run|Static Deflection
- Bode/Polar/Orbit Switch
- Label Peak Amplification Factors
- Imb's Worksheet
- Overlay Geometry on Mode Shape
- Torsional Resp Worksheet

This worksheet displays the results of calculations for either the Run|Response or Run|Deflected Shapes commands. The results are in the form of tables and plots of response.

XLRotor will attempt to place the tables and plots on a worksheet named "Resp". If there is no worksheet by that specific name then one will be automatically created. If there is a worksheet by that name, you will be prompted if you want to Append or Overwrite the new data (see Append or Overwrite Worksheet).

Note:
From the Options|Response dialog box, you can select the output units independently for the three types of charts/tables.

Note:
When the analysis is completed, and the results are placed on this worksheet, a cell comment is placed at the upper left corner of the output table. This comment contains a summary of the analysis parameters used for the calculation.

Transient Worksheet

See also

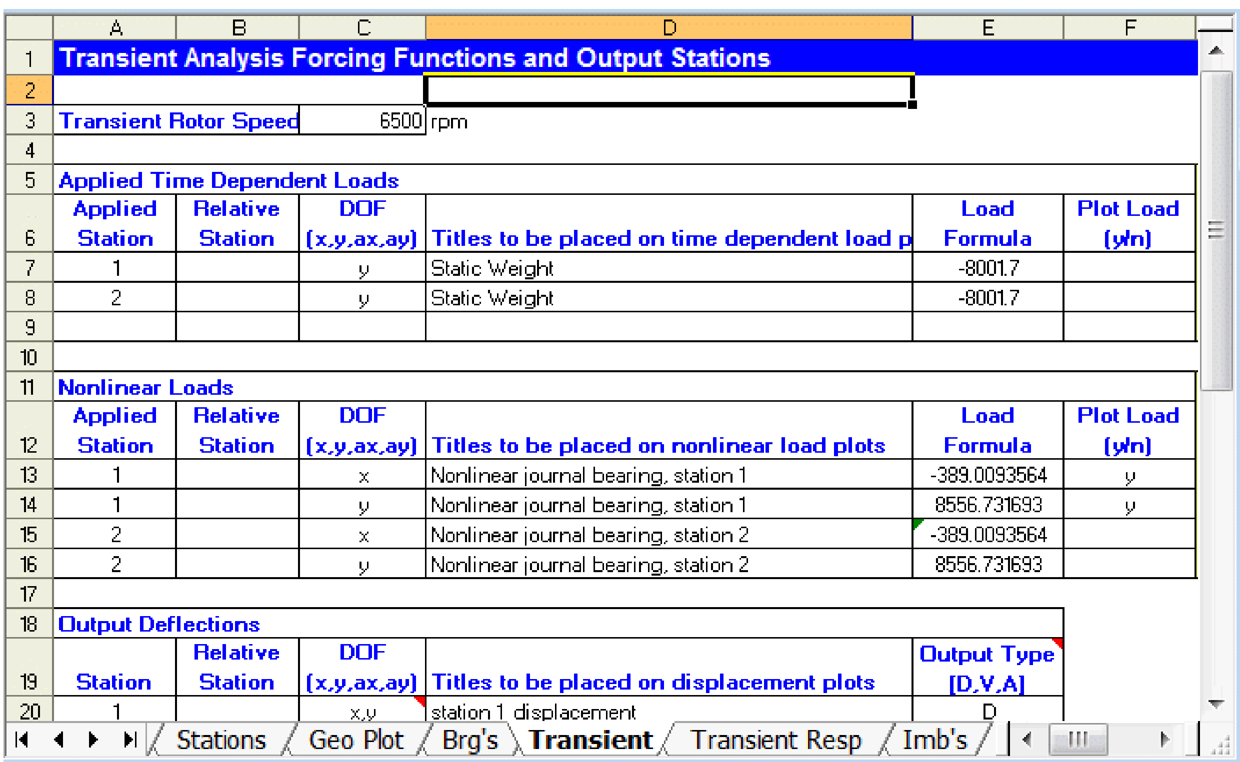
- XLRotor Overview
- Run|Transient
- Transient Resp Worksheet
- Options|Transient
- Time/Spectrum Switch
- Torsional Transient Worksheet

This worksheet is for inputting specifications related to transient response calculations. There are many inputs on this worksheet, separated into various sections in the form of tables. You can add or delete rows from any of the tables as needed. However, do not change the structure of the columns.

If your file does not contain a worksheet named ***Transient***, execute a Run|Transient command and one will be created.

When you execute a Run|Transient command, XLRotor uses your inputs from this worksheet. You can have more than one copy of this worksheet in your file, with different sheet names. But only the one having the exact name of "Transient" will be used for the analysis.

First we will cover the model inputs displayed in the following figure. Then we will cover the parts where you tell XLRotor what outputs to generate.



	A	B	C	D	E	F
1	Transient Analysis Forcing Functions and Output Stations					
2						
3	Transient Rotor Speed		6500	rpm		
4						
5	Applied Time Dependent Loads					
6	Applied Station	Relative Station	DOF (x,y,ax,ay)	Titles to be placed on time dependent load p	Load Formula	Plot Load (y/n)
7	1		y	Static Weight	-8001.7	
8	2		y	Static Weight	-8001.7	
9						
10						
11	Nonlinear Loads					
12	Applied Station	Relative Station	DOF (x,y,ax,ay)	Titles to be placed on nonlinear load plots	Load Formula	Plot Load (y/n)
13	1		x	Nonlinear journal bearing, station 1	-389.0093564	y
14	1		y	Nonlinear journal bearing, station 1	8556.731693	y
15	2		x	Nonlinear journal bearing, station 2	-389.0093564	
16	2		y	Nonlinear journal bearing, station 2	8556.731693	
17						
18	Output Deflections					
19	Station	Relative Station	DOF (x,y,ax,ay)	Titles to be placed on displacement plots	Output Type [D,V,A]	
20	1		x,y	station 1 displacement	D	

Stations / Geo Plot / Brg's / Transient / Transient Resp / Imb's

Transient Rotor Speed

This cell is used to specify the rotor speed in rpm (lateral models only). Most of the time this will be a constant value, but you can also type a formula into this cell to make speed be a function of time. XLRotor uses this speed value to determine the coefficients of bearings specified on the Brg's Worksheet, and also to compute gyroscopic effects. If you enter a formula in this cell, XLRotor will re-compute the bearing coefficients and gyroscopic matrix whenever it detects that the speed has changed.

If you enter a formula, you can use the letter "t" for time. For example, "=5000+1000*t" would cause the rotor speed to start at 5000 rpm, and ramp upward at 1000 rpm per second. You can also call a Visual Basic macro from this cell to compute the rotor rpm, for example "=mySpeedMacro(t)".

The transient rotor speed value is also used to compute imbalance forces for any imbalances defined on the Imb's Worksheet.

Note: New in XLRotor 5.0. When rotor speed is variable, XLRotor will now internally integrate the speed versus time to get the rotor rotation angle. This angle is required to calculate the imbalance forces for any imbalances entered on the Imb's worksheet. Prior to XLRotor 5.0, the program would not allow variable rotor speed unless there were no imbalances defined on the Imb's sheet.

Applied Time Dependent Loads

This table is used to specify external loads applied to the system that are purely time dependent or constant. Forces and/or moments can be applied to the system. If more than one load is applied at the same station or dof, they are summed.

Applied Station - This is the station at which to apply the load.

Relative Station - If the load is to be applied *between* two stations, this specifies the other station. This means that (-1) times the load is applied to this station.

DOF - This cell should contain a text string of the degree of freedom (dof) in which to apply the load. The only valid values are (without the quotes) "x", "y", "ax" and "ay". The dof "ax" is a right hand rotation about the x axis.
Note: if you ***create a cell comment*** on this cell that contains the word "orbit", then the chart will be formatted as an orbit chart.

Titles to be placed... - Whatever appears in these cells will be copied to the titles of any charts that are created.

Load Formula - In these cells you can enter constant values or formulas. If you enter a formula, you can use the letter "t" for time, whose value is continuously updated during the analysis. For example, "=5000*sin(2*PI()*100*t)" would apply a sinusoidal force of magnitude 5000 at a frequency of 100 Hz. The units of the force will be in the same units of your model.

Plot Load (y/n) - Anything in this cell that starts with a "y" will cause a chart to be automatically generated for this load. If the contents of this cell do not start with a "y", then no chart is created. If two consecutive dof entries in this table are of the same type at the same station, the two are plotted together on the same chart. Along with the chart, the values displayed in the chart will appear in a column on the results worksheet. If a plot is not created, then the load is not output to the results worksheet.

In addition to time dependent loads specified in this table, imbalances which are input on the Imb's Worksheet are also applied during a transient analysis. If the rotor speed is variable, the program will internally integrate speed to get the rotor rotation angle required to compute the imbalance forces.

Nonlinear Loads

This table is used to specify loads applied to the system that are dependent on time, displacement and/or velocity of the system. You do this by entering a cell formula in the **Load Formula** column.

Applied Station - See Time Dependent Loads above.

Relative Station - See Time Dependent Loads above.

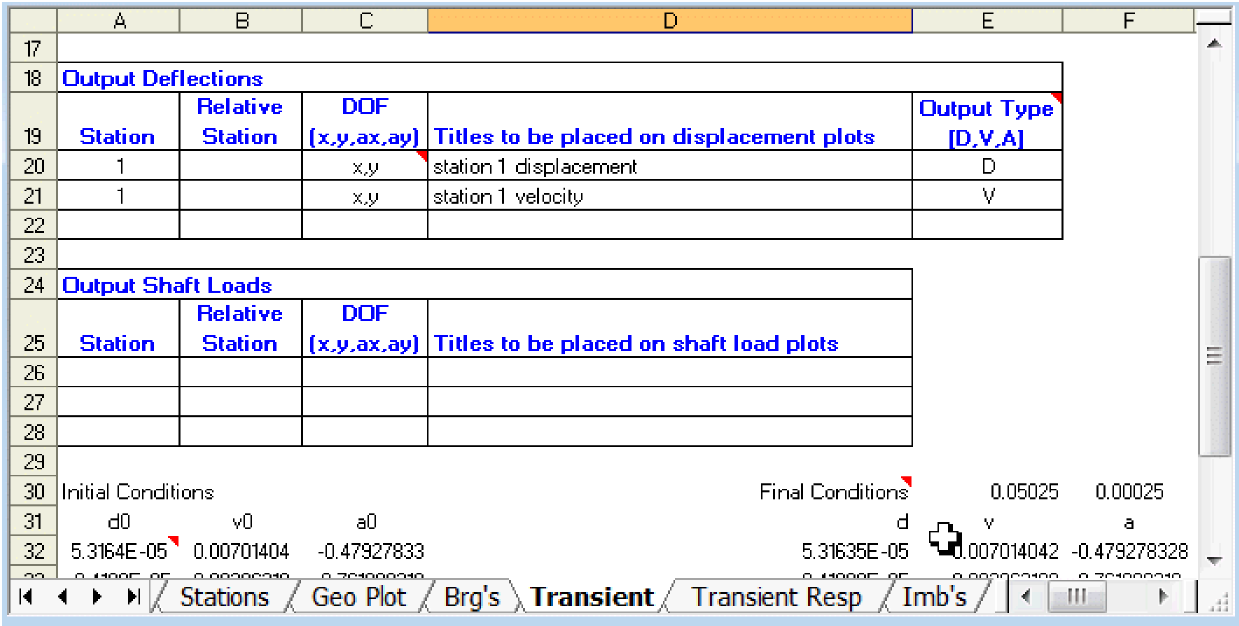
DOF - See Time Dependent Loads above. Same note applies about orbit charts.

Titles to be placed... - See Time Dependent Loads above.

Load Formula - In these cells you enter formulas that the program will use to compute the nonlinear loads. You can use the letters "t", "d" and "v" for time, displacement and velocity, respectively. The values for these variables are continuously updated during the analysis with values that correspond the dof specified in the **DOF** column. For example, "= -1e5*d^1.5 - 50*v" would apply a nonlinear spring restoring force with a stiffness of 100,000 but proportional to deflection raised to the 1.5 power, and a linear viscous damping force with a damping constant of 50. The formula in this cell can also call a Visual Basic macro. For example, "=Nonlineardamper(A18,B18,2,Transient_Rotor_Speed)".

Nonlinear forces that depend on <u>radial</u> deflection depend on <u>both</u> x and y, and so cannot be calculated with a simple cell formula. For this case, a Visual Basic macro can be used.

Plot Load (y/n) - See Time Dependent Loads above.



Output Deflections

This table specifies which stations to generate outputs for. Displacement, velocity and acceleration can be output.

Station - The station for which to output results for absolute motion.

Relative Station - Leave this cell blank to get absolute motion, or enter a station number to get the relative motion between two stations. Note: XLRotor will **not** check to make sure that the two stations are at the same axial location. Output values will be **Station** minus **Relative Station**. So therefore, the sign of the output values can be reversed by reversing the order of the stations.

DOF - This cell contains a text string which lists, separated by commas, the dof for which you want output. You can list any or all of the 4 dof at the station (only lateral models have this input because torsional models have just one dof per station). Here are some examples

x
x,y
x,ay
x,y,ax,ay

A table of values and corresponding charts will be created automatically on the results worksheet. Displacements and rotations at the same station are put onto separate charts.

Note: if you *create a cell comment* on the **DOF** cell containing the word "orbit", then the chart will be formatted as an orbit chart. But time charts can also be converted to orbit charts after the analysis.

Output Type [D,V,A] - Enter one of the letters ***D***, ***V*** or ***A*** to get output of displacement, velocity or acceleration. Units for each of these quantities are specified in the Options|Transient dialog box. However, for output of rotational dof (i.e. ax and ay), units are always radians, rad/s and rad/s^2.

Titles to be placed... - See Time Dependent Loads above.

Output Shaft Loads

This table is used to have the program output the shear and/or bending moment in sections of the shaft. When you ask for the shear or bending moment for station i, the program will output the loads in the shaft between stations i and i+1. In the case of moments, the values will correspond to the end of the element at station i (the shear is the same at both ends).

Station - The station for which to output results for internal shaft load.

Relative Station - This cell will normally contain the number of the next station (i.e. **Station**+1). If the cell is left blank, XLRotor will fill it in on the next run. Output values are computed effectively by using K*(**Station**-**RelativeStation**). For torsional models, but not for lateral, the sign of the output load can be reversed by reversing the order of the stations. This means that for lateral models, shear and bending moment can presently only be output for the left end of an element.

DOF - Same as Output Displacements. Same note applies about orbits charts.

Titles to be placed... - See Time Dependent Loads above.

Initial Conditions

When you wish to specify your own initial conditions, this table is used to specify initial displacement d0, velocity v0, and optionally acceleration a0, for **every** dof in the model. this is done in a 3 column table. One column each for d0, v0 and a0, in that order. The row order in the table is:

station 1 x

station 1 y

station 1 ax

station 1 ay

station 2 x

station 2 y

station 2 ax

station 2 ay

etc.

If you leave the third column, a0, blank, the program will compute the initial accelerations from a0 = (F0 - [C]*d0 - [K]*d0) / [M]

If you do not want to specify your own initial conditions, turn off the option for "Use Initial Conditions from Worksheet", which is in the Options|Transient dialog.   In this case the program will use zero for d0 and v0, and will compute a0 from the applied loads at t=0.

Do not try to specify your own initial accelerations when there are any applied loads at t=0.   Let the program compute a0 for you.   In general, we recommend that you either leave the a0 column blank, or use values that have been placed there by the program when you turn on the option for "Update Initial Conditions with Final Conditions", which is in the Options|Transient dialog.

Final Conditions

At the successful conclusion of every transient analysis, the program will write the final conditions to this table on the Transient worksheet, and will overwrite whatever is there. Generally, you should not edit what is in this table.

If you are offered the option to Append or Overwrite when running a transient analysis, choosing Append will direct the program to start the analysis with the Final Conditions read from this table.   This allows you to easily continue a simulation, picking up where it left off, by selecting the Append option.

Transient Resp Worksheet

See also

- Run|Transient
- Options|Transient
- Transient Worksheet
- Bode/Polar/Orbit Switch
- Time/Spectrum Switch

This worksheet displays the results of a transient analysis done by executing the Run|Transient command. The results are in the form of tables and plots of response versus time.

XLRotor will attempt to place the tables and plots on a worksheet named "Transient Resp". If there is no worksheet by that exact name then one will be automatically created. If there is already a worksheet by that name, you will be asked if you want to append or overwrite the new data to that worksheet (see Append or Overwrite Worksheet).

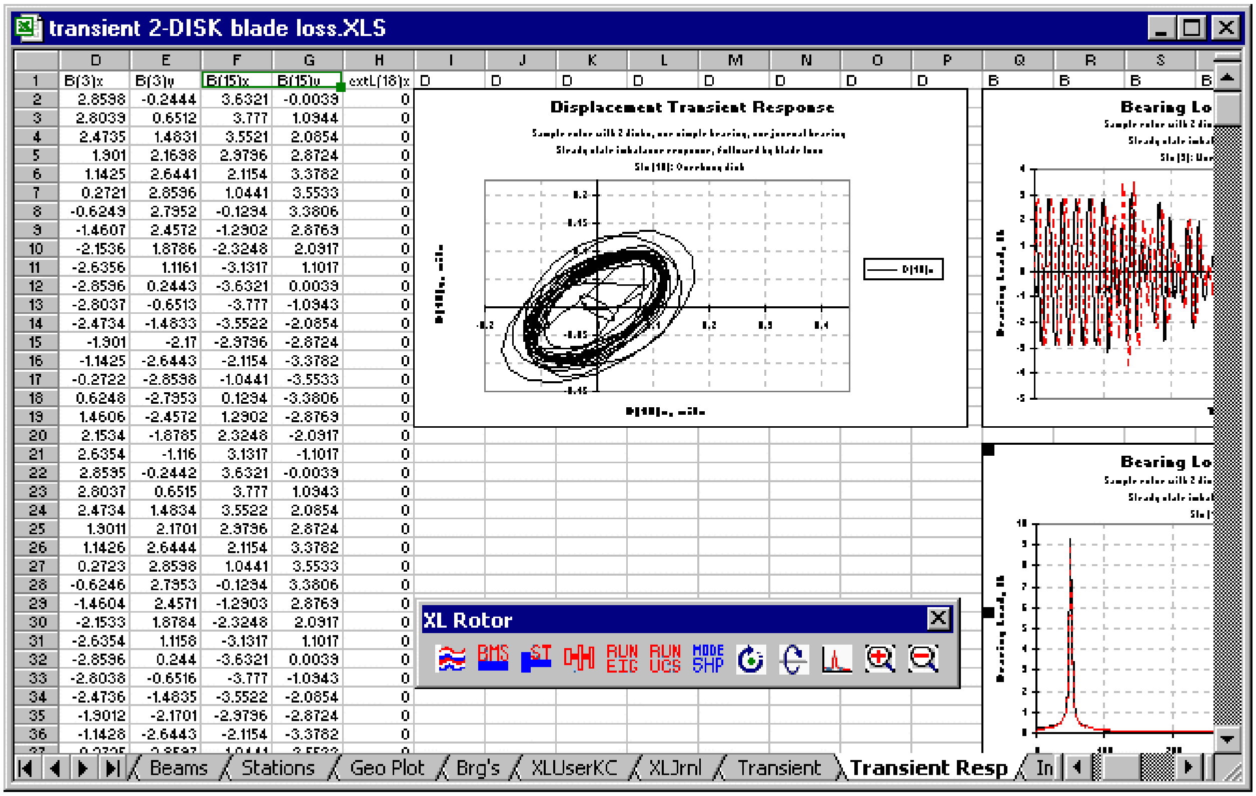
One way to save the results on an existing worksheet is to *rename the sheet*. Then when you run another analysis, another Transient Resp worksheet will be created.

All of the station outputs and load outputs you have requested will be placed in a single table. The first column of the table will always be the output times. The remaining columns list the outputs. Each column will have a heading that identifies the type, the station number, and dof.

To the right of the table will be charts displaying all the values in the table.

Note:
In the Options|Transient dialog box, you can select the output units independently for each type of output quantity.

Note:
When the analysis is completed, and the results are placed on this worksheet, a cell comment is placed at the upper left corner of the output table. This comment contains a summary of the analysis parameters used for the calculation.



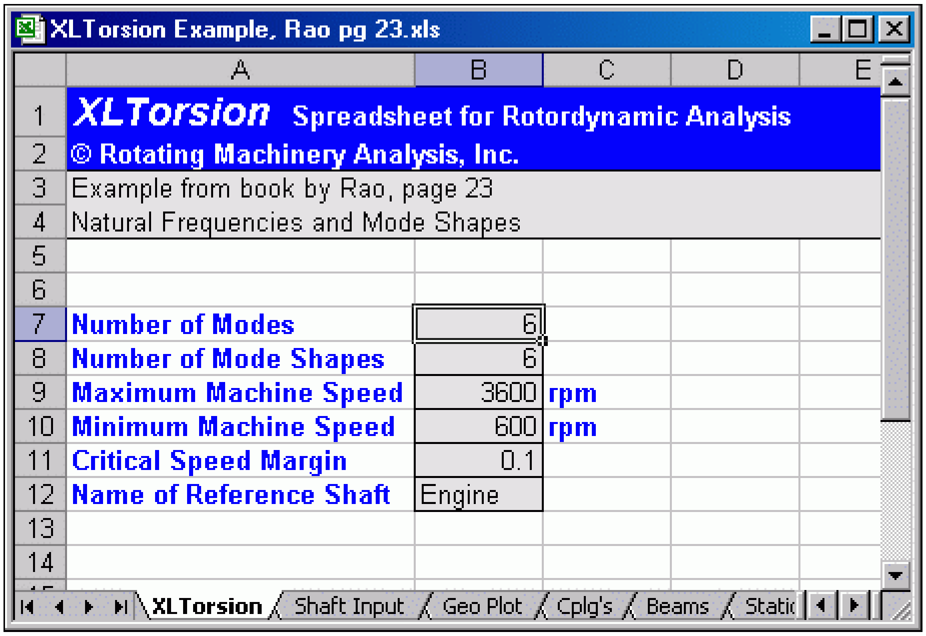
	D	E	F	G	H
1	B(3)x	B(3)y	B(15)x	B(15)y	extL(18)x
2	2.8598	-0.2444	3.6321	-0.0039	0
3	2.8039	0.6512	3.777	1.0944	0
4	2.4735	1.4831	3.5521	2.0854	0
5	1.901	2.1698	2.9796	2.8724	0
6	1.1425	2.6441	2.1154	3.3782	0
7	0.2721	2.8596	1.0441	3.5533	0
8	-0.6249	2.7952	-0.1294	3.3806	0
9	-1.4607	2.4572	-1.2902	2.8769	0
10	-2.1536	1.8786	-2.3248	2.0917	0
11	-2.6356	1.1161	-3.1317	1.1017	0
12	-2.8596	0.2443	-3.6321	0.0039	0
13	-2.8037	-0.6513	-3.777	-1.0943	0
14	-2.4734	-1.4833	-3.5522	-2.0854	0
15	-1.901	-2.17	-2.9796	-2.8724	0
16	-1.1425	-2.6443	-2.1154	-3.3782	0
17	-0.2722	-2.8598	-1.0441	-3.5533	0
18	0.6248	-2.7953	0.1294	-3.3806	0
19	1.4606	-2.4572	1.2902	-2.8769	0
20	2.1534	-1.8785	2.3248	-2.0917	0
21	2.6354	-1.116	3.1317	-1.1017	0
22	2.8595	-0.2442	3.6321	-0.0039	0
23	2.8037	0.6515	3.777	1.0943	0
24	2.4734	1.4834	3.5522	2.0854	0
25	1.9011	2.1701	2.9796	2.8724	0
26	1.1426	2.6444	2.1154	3.3782	0
27	0.2723	2.8598	1.0441	3.5533	0
28	-0.6246	2.7953	-0.1294	3.3806	0
29	-1.4604	2.4571	-1.2903	2.8769	0
30	-2.1533	1.8784	-2.3248	2.0917	0
31	-2.6354	1.1158	-3.1317	1.1017	0
32	-2.8596	0.244	-3.6321	0.0039	0
33	-2.8038	-0.6516	-3.777	-1.0943	0
34	-2.4736	-1.4835	-3.5522	-2.0854	0
35	-1.9012	-2.1701	-2.9796	-2.8724	0
36	-1.1428	-2.6443	-2.1154	-3.3782	0

Remember, the plots can be converted to orbit plots, or to frequency spectrums.

XLTorsion Worksheet

See also

- Torsional Analysis with XLRotor
- Creating New Rotor Model Files
- Running XLRotor
- XLRotor Worksheet
- Torsional Shaft Input Worksheet



This worksheet is the starting point for creating a ***torsional*** analysis rotor model. Here you type in a descriptive title, and a few other parameters that control program output.

Titles

Two cells are provided to enter titles that will be copied to charts created during analysis. The contents of these cells are **copied** to the charts, as opposed to being referenced. This means once a chart has been created, the titles appearing on the chart will not change.

Changes you make to the Title cells will **not** update automatically on **existing** charts (i.e. mode shapes, response, etc.). The geometry chart (Geo Plot Chartsheet), however, is an **exception.** Changes made to the Title cells **will** update automatically on the Geometry chart.

Number of Modes

This is the number of natural frequencies that will be output when you calculate eigenvalues with the Run|Eigenvalues command. For torsional models, the maximum number of modes which can be computed is equal to the number of stations which have nonzero inertia (minus the number of RIGID constraints, if any).

Note that each station which has zero inertia (if any) reduces by 1 the maximum number of modes which can be computed.

Number of Mode Shapes

This is the number of mode shapes that will be output when you calculate eigenvalues with the Run|Eigenvalues command. This number should be less than or equal to the Number of Modes being output.

Maximum Machine Speed

Minimum Machine Speed

These two speeds will be labeled on the Torsional Interference Diagram which is produced when you calculate eigenvalues with the Run|Eigenvalues command (see Roots Tors Worksheet).

Critical Speed Margin

This is the critical speed margin that the program will use to determine if there are any resonant interferences (i.e. critical speeds) of calculated natural frequencies with the excitation orders listed on the Orders Worksheet. For example, if m is the critical speed margin, a synchronous (1X) critical speed happens when the frequency of a mode is between (1-m)*MinimumMachineSpeed and (1+m)*MaximumMachineSpeed. For excitation orders other than 1X this becomes (1-m)*(X)*MinimumMachineSpeed and (1+m)*(X)*MaximumMachineSpeed where X is the order number (i.e. X=2 for a 2X excitation order).

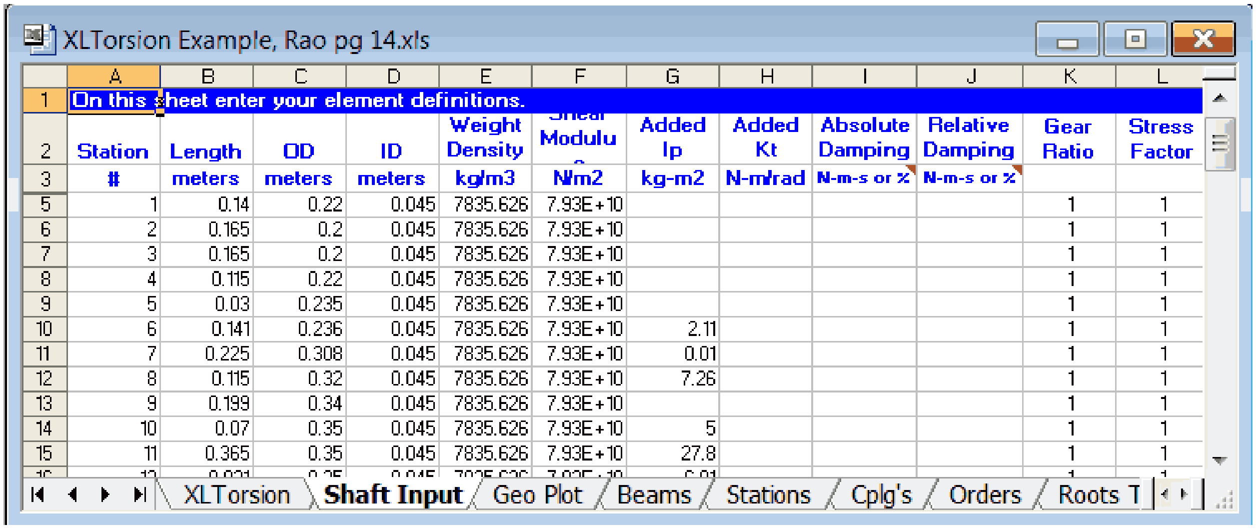
Name of Reference Shaft

This name will be used in the X axis title on the Torsional Interference Diagram (Roots Tors Worksheet), and also on response plots which appear on the Torsional Resp Worksheet. Common examples would be "Engine", "Motor", "Generator", "Pump", etc.

Torsional Shaft Input Worksheet

See also

- Torsional Analysis with XLRotor
- XLTorsion Worksheet
- Torsional Beams Worksheet
- Torsional Stations Worksheet
- Cplg's Worksheet
- Units in XLRotor



	A	B	C	D	E	F	G	H	I	J	K	L
1	On this sheet enter your element definitions.											
2	Station	Length	OD	ID	Weight Density	Shear Modulu	Added Ip	Added Kt	Absolute Damping	Relative Damping	Gear Ratio	Stress Factor
3	#	meters	meters	meters	kg/m3	N/m2	kg-m2	N-m/rad	N-m-s or %	N-m-s or %		
5	1	0.14	0.22	0.045	7835.626	7.93E+10					1	1
6	2	0.165	0.2	0.045	7835.626	7.93E+10					1	1
7	3	0.165	0.2	0.045	7835.626	7.93E+10					1	1
8	4	0.115	0.22	0.045	7835.626	7.93E+10					1	1
9	5	0.03	0.235	0.045	7835.626	7.93E+10					1	1
10	6	0.141	0.236	0.045	7835.626	7.93E+10	2.11				1	1
11	7	0.225	0.308	0.045	7835.626	7.93E+10	0.01				1	1
12	8	0.115	0.32	0.045	7835.626	7.93E+10	7.26				1	1
13	9	0.199	0.34	0.045	7835.626	7.93E+10					1	1
14	10	0.07	0.35	0.045	7835.626	7.93E+10	5				1	1
15	11	0.365	0.35	0.045	7835.626	7.93E+10	27.8				1	1

On this sheet you enter the geometry of a ***torsional*** rotor model. The rules for filling out this table are the same as for a Lateral Shaft Input Worksheet. The columns in this table are a little different than for a lateral model, as explained below.

Station Number

This column specifies the station number for each beam in the table. Each station has 1 distinct degree of freedom (dof) associated with it. Each beam must have a valid station number.

Length

The length property specifies the length of the beam. Beams to be superimposed at the same station must share the same **Length** property. A beam defined for station i always extends from station i to station i+1. The inertia property for the beam (when density>0) will be split evenly between the dof at station i and station i+1.

OD & ID

These are the outer and inner diameters of the beam. XLRotor permits only beams of circular cross section. The OD must be greater than the ID. When the option for conical beams is turned on, there will be two sets of diameters for the left and right ends of each beam.

There is also an option to input the shaft model with radius instead of diameter. See Shaft Input Worksheet or Options|General for details about these options.

Density

This is the density of the beam. This value is used to compute the polar moment of inertia. If the beam is to be massless, set its density to zero. The density value will be divided by the "gravity" constant entered in the Options|General dialog.

Beam inertias computed from the density are split evenly between the stations at either end of the beam.

Shear Modulus

This modulus is used to compute the stiffness of the beam. If you do not want a particular beam to contribute any stiffness, enter zero for the modulus (or leave it blank). However, when the model is fully assembled for analysis, every station must have a positive net stiffness.

Added Ip Polar Inertia

For each beam, any specified added polar inertia value is lumped at the station number of the beam. These values can be negative, zero, or positive. These values will be added to those arising from computed beam inertias, and so will also be divided by the "gravity" constant entered in the Options|General dialog.

Added Kt Stiffness

This column is for specifying additional torsional stiffness which will be added to that computed from the shear modulus. This stiffness will always connect this station to the next station, and therefore an added Kt value is not allowed for the last station in a level.

If your model has multiple levels, then you must define connections between these levels on the Cplg's Worksheet.

Absolute Damping

This column is for specifying absolute damping for any station. Absolute means the damping goes to ground. Entering a numerical value like 10, means a viscous damping constant of either C=10 N-m-s or C=10 in-lbf-s (matching the units of the model) will connect the station to ground. If the cell is formatted as using Excel's *percentage* format, the value will be displayed with a % symbol after it (i.e. 0.01 will display as 1%), then the damping constant is proportional to frequency such that

$C=2\zeta J\omega$ where ζ = the damping %, J = the polar inertia of the station, and ω = the frequency of vibration (also known as mass proportional damping). The damping constant is only applied for linear forced response calculations. It is not applied for eigenvalue analyisis or for transient response analysis.

A example use for this input is to enter a value for damping to ground for cylinders of reciprocating compressors or diesel engines.

Tip: Press shift-control-5 on the keyboard to format the current cell as percentage. Press shift-control-` to format the cell in default format.

If the Shaft Input sheet in your file does not have this column, you can create it manually or copy and paste it from another file. The text at the top of the column must be exactly ***Absolute Damping***.

Relative Damping

This column is for specifying relative damping for any station. Relative means a damping input for station i is applied to the relative velocity between station i and i+1. Entering a numerical value like 10, means a viscous damping constant of either C=10 N-m-s or C=10 in-lbf-s (matching the units of the model) will connect station i to station i+1. If the cell is formatted as using Excel's *percentage* format, then the damping constant is proportional to frequency such that $C=2\zeta K/\omega$ where ζ = the damping %, K = the torsional stiffness between stations i and i+1, and ω = the frequency of vibration (also known as stiffness proportional damping). The damping constant is only applied for linear forced response calculations. It is not applied for eigenvalue analyisis or for transient response analysis.

A example use for this input is to enter a percentage value for the damping of an elastomeric coupling element. Coupling catalogs often give a relative damping constant for the elastomer usually called Ψ defined as the ratio of dissipated energy to strain energy such that $C=\Psi K/(2\pi\omega)$. So the value to input to XLRotor is $\Psi/4\pi$, and formatted to display as a percentage value.

If the Shaft Input sheet in your file does not have this column, you can create it manually or copy and paste it from another file. The text at the top of the column must be exactly ***Relative Damping***.

Gear Ratio

When the torsional model includes a gearbox, this implies there are shafts running at different speeds. Select one shaft as a "reference" shaft, and enter a Gear Ratio of 1 for all its stations. For all the other shafts enter a Gear Ratio value in accordance with the speed of the shaft divided by the speed of the reference shaft. When all shafts run at the same speed, enter a value of 1 for every station in the model.

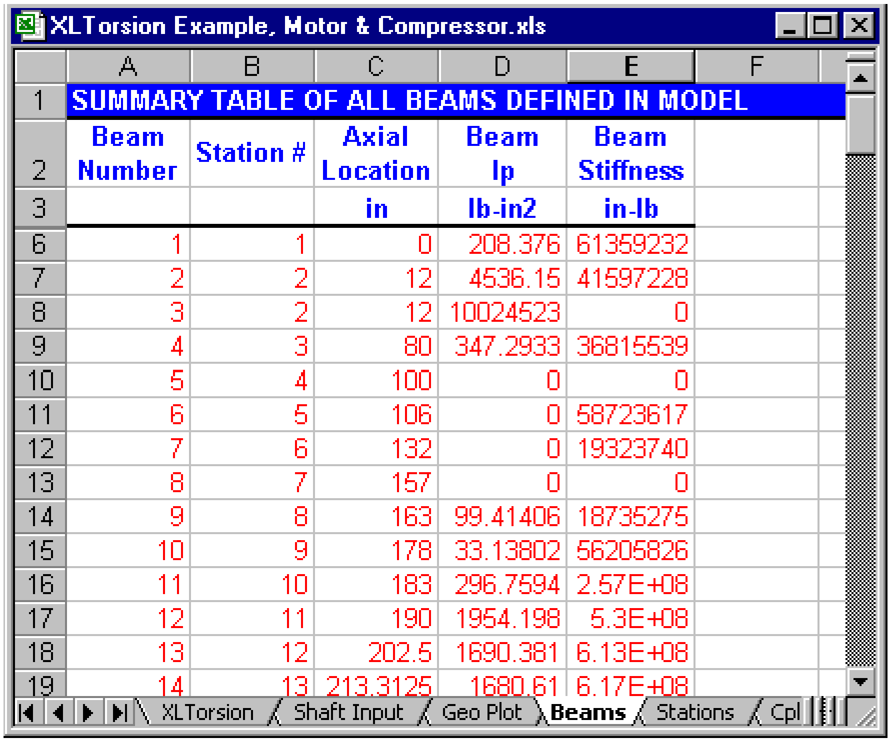
In a two stage gearbox having a gear ratio of 5 for the first stage, and 4 for the second stage, the Gear Ratio input should be 1 for the input shaft, 5 for the intermediate shaft, and 20 for the output shaft.

Stress Factor

This column is for specifying stress concentration factors which will be used when torsional mode shapes are output (see normalized stress). This input would normally be 1 for all beams. Locations of keyways and fillets are examples of where this input is used to specify stress concentration factors that are greater than 1.

If the Shaft Input sheet in your file does not have this column, you can create it manually or copy and paste it from another file. The text at the top of the column must be exactly ***Stress Factor***.

Torsional Beams Worksheet



XLTorsion Example, Motor & Compressor.xls

	A	B	C	D	E	F
1	SUMMARY TABLE OF ALL BEAMS DEFINED IN MODEL					
2	Beam Number	Station #	Axial Location	Beam Ip	Beam Stiffness	
3			in	lb-in2	in-lb	
6	1	1	0	208.376	61359232	
7	2	2	12	4536.15	41597228	
8	3	2	12	10024523	0	
9	4	3	80	347.2933	36815539	
10	5	4	100	0	0	
11	6	5	106	0	58723617	
12	7	6	132	0	19323740	
13	8	7	157	0	0	
14	9	8	163	99.41406	18735275	
15	10	9	178	33.13802	56205826	
16	11	10	183	296.7594	2.57E+08	
17	12	11	190	1954.198	5.3E+08	
18	13	12	202.5	1690.381	6.13E+08	
19	14	13	213.3125	1680.61	6.17E+08	

XLTorsion / Shaft Input / Geo Plot / Beams / Stations / Cpl

See also

- Torsional Analysis with XLRotor
- XLTorsion Worksheet
- Torsional Shaft Input Worksheet
- Torsional Stations Worksheet

This worksheet serves the same purpose as in a lateral rotor model file (see Beams Worksheet).

This worksheet shows parameters computed for each individual beam. You need to execute an Update|Beams worksheet command any time you want to see the results of changes you make in the Station Number column of the Torsional Shaft Input Worksheet. Changes on the Torsional Shaft Input Worksheet which do not involve modifications in the Station Number column can be updated by simply pressing the Excel formula *Recalc key* (F9).

You should not edit the cells on this worksheet. XLRotor takes care of updating the contents of the table when you click the Geometry Update button or press the *Recalc key*, whichever is appropriate.

The computed values displayed in this table correspond to individual beams specified on the Shaft Input worksheet. The number of rows in this table should **always** match the number of rows on the Shaft Input worksheet.

Beam Number

This column should always contain consecutive numbers 1 through the number of beams in the rotor model.

Station Number

This column will always contain a copy of the values appearing in the analogous column on the Shaft Input Worksheet.

Axial Location

This is the distance from the left end of the rotor to the left end of the beam. Beams assigned to the same station must always be at the same axial location.

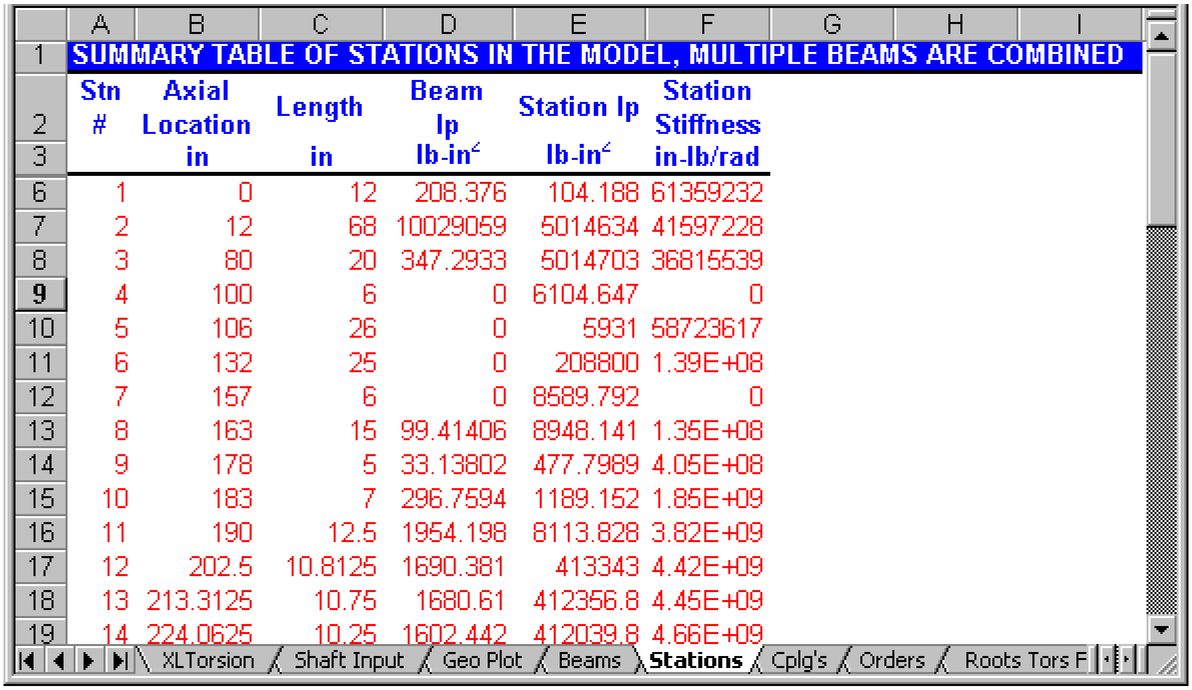
Beam Ip

This the polar inertia computed for the beam. You can see the formulas used to compute the Beam Ip by inspecting at the contents of the worksheet cells.

Beam Stiffness

This is the torsional stiffness computed for the beam from the diameters and shear modulus (JG/L). This does not include values from the ***Added Kt*** column on the Shaft Input worksheet. You can see the formulas used to compute the Beam Stiffness by inspecting the contents of the worksheet cells.

Torsional Stations Worksheet



Stn #	Axial Location in	Length in	Beam Ip lb-in²	Station Ip lb-in²	Station Stiffness in-lb/rad
1	0	12	208.376	104.188	61359232
2	12	68	10029059	5014634	41597228
3	80	20	347.2933	5014703	36815539
4	100	6	0	6104.647	0
5	106	26	0	5931	58723617
6	132	25	0	208800	1.39E+08
7	157	6	0	8589.792	0
8	163	15	99.41406	8948.141	1.35E+08
9	178	5	33.13802	477.7989	4.05E+08
10	183	7	296.7594	1189.152	1.85E+09
11	190	12.5	1954.198	8113.828	3.82E+09
12	202.5	10.8125	1690.381	413343	4.42E+09
13	213.3125	10.75	1680.61	412356.8	4.45E+09
14	224.0625	10.25	1602.442	412039.8	4.66E+09

See also

- Torsional Analysis with XLRotor
- XLTorsion Worksheet
- Torsional Shaft Input Worksheet
- Torsional Beams Worksheet
- Torsional Geometry Chart Sheet

This worksheet serves the same purpose as the Stations Worksheet in a lateral rotor model file.

This worksheet shows the net properties computed for each station. The number of rows in this table equals the number of stations in the model. Properties of any multiple beams have been superimposed by addition (inertia and elasticity). You need to execute the Update|Stations command any time you want to see the result of changing the number of stations in the shaft model. Changes on the Shaft Input Worksheet which do not involve changing the total number of stations can be updated by pressing the Excel formula *Recalc key* (F9).

You should not edit any cells on this worksheet. XLRotor takes care of updating the contents of all cells when you click the Update button or the recalc key.

Note:
There is an area at the bottom of the worksheet that summarizes total axial length and polar inertia for each level in the model. This table will contain one row for each level in your model, and is assigned an Excel *range name* entitled "StationSheetSums".

Whenever the stations worksheet is Updated, the contents of this named range are repositioned at the bottom of the table. You can add your own new calculations to this cell area, and they will move and be updated with it. You can even resize the named cell area if you need more space.

See the Excel documentation on named ranges for more information on this important feature.

Station

This column lists the station numbers. It will always be a consecutive list of 1 through the number of stations in the model.

Axial Location

These values come directly from those on the Torsional Beams Worksheet.

Length

The length comes directly from those on the Torsional Shaft Input Worksheet.

Beam Ip

This is the sum total polar inertia value for all the beams assigned to each station. The values displayed in this column have been multiplied by the square of the Gear Ratio. You can see the formulas used to compute the ***Beam Ip*** by looking at the contents of the worksheet cells.

Station Ip

These are the final polar inertia values which will be assigned to each station. This column includes added inertia values for each station, and the half-beam inertias for the beams to the immediate left and right of the station. The values displayed in this column have been multiplied by the square of the Gear Ratio.

Station Stiffness

This is the net torsional stiffness for each station. The values come from superposition of all beams input for this station, plus any ***Added Kt*** values. The values displayed in this column have been multiplied by the square of the Gear Ratio.

Station Sheet Sums

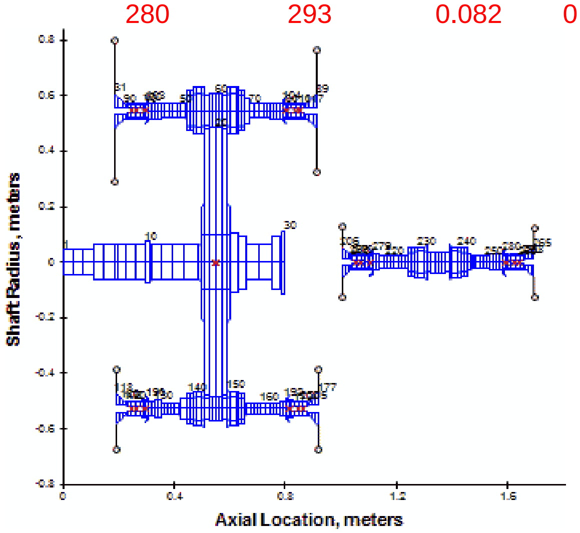
This is a table at the bottom of the sheet to summarize the properties for each level in the torsional model.

41	6877.6	250	0.073874	0.072593	1.19E+07
42	7127.6	0	0	0.036937	0.00E+00
			5.440624	**118.4406**	

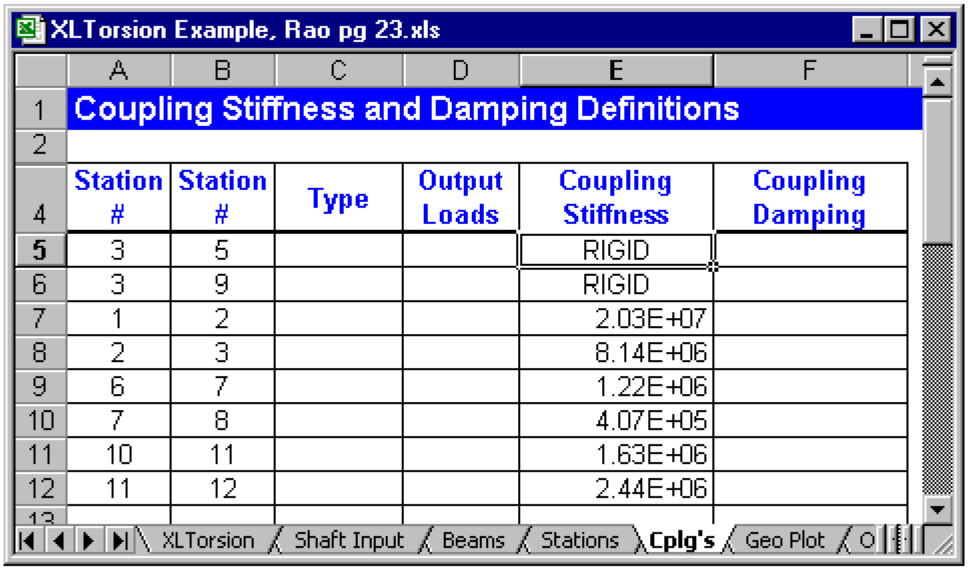
First Stn	Last Stn	Level Length	Total Level Ip
		mm	kg-m2
1	20	3350	57.75532
21	22	500	3
23	42	3277.6	57.6853

In cases where the Torsional Geometry Plot does not depict the model in an suitable way, the horizontal and vertical positions of each level can be manually overridden by adding two columns to the ***Station Sheet Sums*** table. The following is an example of a three-pinion IGC where the program could not determine a suitable position for the third pinion. To use this feature add the two columns as shown, and give them the <u>exact</u> column headings ***Horizontal Position*** and ***Vertical Position*** (tip: copy and paste the headings from below). Any cells left empty in these columns will default to their internally determined values. Values entered in the ***Horizontal Position*** column move the level <u>relative</u> to its default position. Values in the ***Vertical Position*** column are absolute.

First Stn	Last Stn	Level Length meters	Total Level Ip kg-m2	Horizontal Position meters	Vertical Position meters
1	30	0.8	53.45515		
31	89	0.727116	10.06181		
90	103	0.082	0.032877		
104	117	0.082	0.03288		
118	177	0.727922	5.209055		
178	191	0.082	0.067681		
192	205	0.082	0.067686		
206	265	0.689215	3.966625	0.8	0
266	279	0.082	0.081186	0.8	0
280	293	0.082	0.081193	0.8	0



Cplg's Worksheet



XLTorsion Example, Rao pg 23.xls

	A	B	C	D	E	F
1	Coupling Stiffness and Damping Definitions					
2						
4	Station #	Station #	Type	Output Loads	Coupling Stiffness	Coupling Damping
5	3	5			RIGID	
6	3	9			RIGID	
7	1	2			2.03E+07	
8	2	3			8.14E+06	
9	6	7			1.22E+06	
10	7	8			4.07E+05	
11	10	11			1.63E+06	
12	11	12			2.44E+06	

See also

- Torsional Analysis with XLRotor
- XLTorsion Worksheet
- Torsional Shaft Input Worksheet
- Torsional Beams Worksheet
- Torsional Geometry Chart Sheet
- Coupled Lateral-Torsional Analysis
- XLCoupled Cplg's Worksheet

This worksheet serves the same purpose as a Brg's Worksheet in a lateral rotor model file.

Use this worksheet to specify couplings, and other discrete stiffness and/or damping elements in the model.

Your rotor model file can contain more than one "Cplg's" worksheet. For example, you might want multiple sheets so you can setup several configurations for your couplings. XLRotor will utilize the contents of whichever worksheet has the exact name of "Cplg's". You can switch between configurations by simply renaming the worksheets. Click *here* for instructions on how to copy a worksheet.

Station #

These two columns specify the location of the coupling. You can type in the station value(s) directly, or better yet, use a reference to the contents of another cell, for example a cell on the Torsional Shaft Input Worksheet.

If you want the stiffness and damping to go to ground, leave the second **Station #** column blank. Otherwise the stiffness and damping will connect the station listed in the first column to the station listed in the second column. **It does not matter which**

station is listed first, unless the two stations rotate at different speeds (see below)**.**

Multilevel models require couplings between levels. This is because on the Shaft Input sheet there is no way to connect one level to another level.

Note:
You should use a cell formula to refer to a cell on the Torsional Shaft Input Worksheet, or any other sheet, which contains the station number of where the coupling is located. Then, if the station number changes because you insert or delete new stations to the left of the coupling, the coupling station number updates automatically.

Type

The contents of this column are put in the titles of load plots which are generated as part of either a linear response analysis or a transient response analysis. Also see the ***Output Loads*** input item in the next paragraph.

Output Loads

This column pertains to response calculations only. It specifies for which couplings to generate tables and charts of coupling load, when performing response calculations. To have the loads be output for a coupling, place any string that starts with an upper or lower case Y in this column. Anything else will suppress load output for that coupling.

Load cannot be output for couplings defined with a RIGID constraint. Instead, use a stiff spring to emulate the constraint. 1e12 is usually a good value to use in either English or SI units. A value that is excessively large could create roundoff problems when added to the system stiffness matrix. Whatever value is used, if it can be increased or decreased by a factor of 2 without significant change in results, then it is a good choice.

Also see the ***Type*** input item in the preceding paragraph.

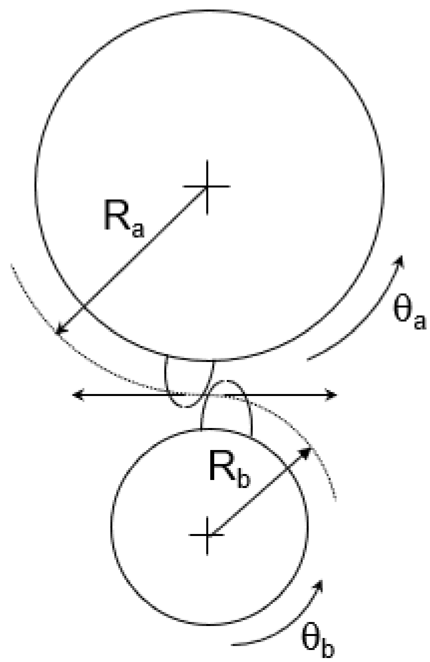
Coupling Stiffness & Damping

In these two columns, simply enter the torsional stiffness & damping of the coupling. You can also enter formulas that compute the values. These two columns must always display numerical values, or be left blank (blank=zero), except in the special case of a RIGID connection.

For a RIGID connection place the word "RIGID" in the stiffness column. A rigid connection constrains the displacements at the two connected stations to be identical. The damping value, if any, is ignored for RIGID connections. A RIGID connection to ground is specified by leaving the Relative Station entry blank.

There is one other way to specify damping for a torsional model. See the note about proportional damping in Options|Response.

By far the most common situation is a torsional stiffness value that connects two stations rotating at the same speed. So which station is listed first on the Cplg's sheet does not matter. When the two stations rotate at different speeds, then it matters which station is listed first. The input value for torsional stiffness is the stiffness as seen by the *first* station. A common example is the torsional stiffness of gear teeth. Gears are often considered to be rigid entities, including the teeth. All torsional deformation is thereby assumed to occur in the shaft. In actuality the gear body will twist, the teeth will bend, and there is Hertzian deformation at the point of contact. This happens in both of a meshing gear pair. Body, tooth and contact deformations under load are summed to get the total deflection. Load divided by deflection is the stiffness of the teeth which is k_{ga} and k_{gb} for mating gears a and b. The combined stiffness of the gear pair is k_g.



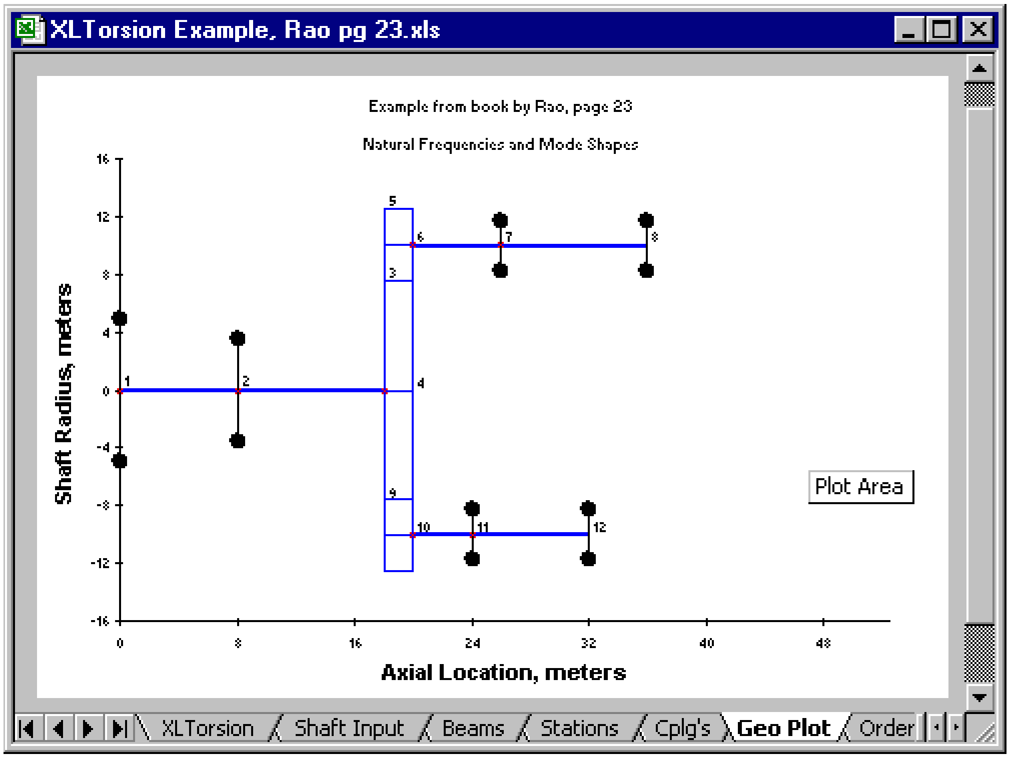
$$k_g = \left(k_{ga}^{-1} + k_{gb}^{-1}\right)^{-1}$$

If gear **b** is held fixed, and a torque applied to gear **a**, gear **a** will rotate due to k_g. The tangential force component is stiffness times deflection $k_g R_a \theta_a$ (units of F). The torque on gear **a** is force times radius $k_g R_a \theta_a R_a$ (units of F*L). So the torsional stiffness seen by gear **a** is $k_g(R_a)^2$ and has units of F*L/rad.

If instead gear **a** is fixed, the torsional stiffness seen by gear **b** is $k_g(R_b)^2$. So when inputting the torsional stiffness of the gear teeth, it is $k_g(R_a)^2$ if station **a** is listed first, or $k_g(R_b)^2$ if station **b** is listed first.

Note:
When RIGID is in the Stiffness column, it does not matter which station is listed first. Also, a very large stiffness such as 1E12 will result in negligible deflection of the spring, and which station is listed first will matter very little.

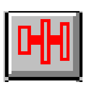
Torsional Geometry Chart Sheet



See also

- XLRotor Overview
- Torsional Analysis with XLRotor
- XLTorsion Worksheet
- Update|Geometry Chart
- Material Property Boxes

This is an Excel "Chartsheet". The chart shows the rotor model geometry. Springs defined on the Cplg's sheet are either indicated as springs connecting to ground, or as a red X at the point where it connects two stations together. Added concentrated inertias can also be shown on the chart (see Options|General).

 There is a button on the XLRotor toolbar and ribbon for updating the geometry plot, and there is also a command on the pull down menu. Whenever you update the Beams or Stations worksheets, you should also update the geometry chart.

Note: When you make a change to your beam or station configuration that requires an Update of either the Beams or Stations worksheets, you can click the Update Geometry Plot button, thus performing all necessary updates in one step.

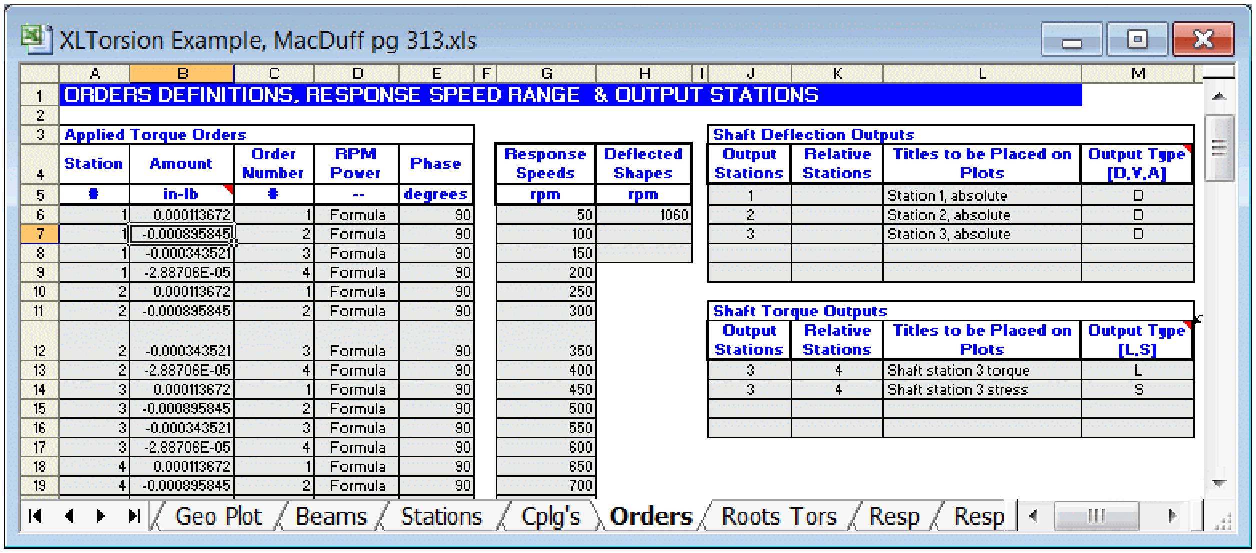
You will also need to Update the geometry plot when you change the number of couplings in the model. If you change only the station number of a coupling on the Cplg's Worksheet, you just need to hit the *Recalc key* (F9).

The geometry chart will also show added inertias, if any, when you select the corresponding check box in the Options|General dialog box. In this case you will need to Update the geometry chart any time you add or delete an added inertia.

Note: If the Geometry chart ever becomes corrupted such that executing an Update|Geometry Chart command does not fix the problem, *delete the chartsheet* altogether. A new geometry chartsheet will be created the next time you execute an Update|Geometry Chart command.

In the Geometry plot, the relative positions of levels in a multi-level model is determined by how the levels are interconnected on the Cplg's worksheet. The horizontal positions are exactly determined by the interconnetcs. The vertical positions are determined by examining gear ratios and station diameters. The logic for doing this will usually produce a suitable goemetry plot, but not always. The position of each level in the geometry plot can be manually overridden on the Stations worksheet.

Orders Worksheet



XLTorsion Example, MacDuff pg 313.xls

ORDERS DEFINITIONS, RESPONSE SPEED RANGE & OUTPUT STATIONS

Applied Torque Orders

Station	Amount	Order Number	RPM Power	Phase
#	in-lb	#	--	degrees
1	0.000113672	1	Formula	90
1	-0.000895845	2	Formula	90
1	-0.000343521	3	Formula	90
1	-2.88706E-05	4	Formula	90
2	0.000113672	1	Formula	90
2	-0.000895845	2	Formula	90
2	-0.000343521	3	Formula	90
2	-2.88706E-05	4	Formula	90
3	0.000113672	1	Formula	90
3	-0.000895845	2	Formula	90
3	-0.000343521	3	Formula	90
3	-2.88706E-05	4	Formula	90
4	0.000113672	1	Formula	90
4	-0.000895845	2	Formula	90

Response Speeds	Deflected Shapes
rpm	rpm
50	1060
100	
150	
200	
250	
300	
350	
400	
450	
500	
550	
600	
650	
700	

Shaft Deflection Outputs

Output Stations	Relative Stations	Titles to be Placed on Plots	Output Type [D,V,A]
1		Station 1, absolute	D
2		Station 2, absolute	D
3		Station 3, absolute	D

Shaft Torque Outputs

Output Stations	Relative Stations	Titles to be Placed on Plots	Output Type [L,S]
3	4	Shaft station 3 torque	L
3	4	Shaft station 3 stress	S

See also

- XLRotor Overview
- Torsional Analysis with XLRotor
- Run|Response
- Torsional Resp Worksheet

This worksheet serves the same purpose as an Imb's Worksheet in a lateral rotor model file.

This worksheet contains your specifications for computing response to engine orders. You enter the amounts and locations of the orders, the speeds at which to compute responses, and specify what outputs to generate.

There are two types of response calculations that can be performed.

1. Use Run|Response to compute plots of responses versus speed for selected station displacements, coupling loads and shaft torques.
2. Use Run|Deflected Shapes to compute plots of operating deflected shape at selected speeds.

The excitation orders that you list on this worksheet are also used to display excitation lines on a Torsional Interference Diagram (see Roots Tors Worksheet).

Your rotor model file can contain more than one "Orders" worksheet. XLRotor will utilize the contents of whichever worksheet has the exact name of "Orders". You can switch between configurations by simply renaming the worksheets. Click *here* for instructions on how to copy a worksheet.

Note: New in XLRotor version 5.0. Excitation torques input on the Orders sheet ***will be*** applied in a Transient analysis. Prior to 5.0 they were not applied. The instaneous rotation angle and rotational velocity of the station are used to evaluate the torques during integration. This makes the analysis nonlinear even if the rest of the model is linear.

Station #

This column specifies the stations where the order torques are applied.

Amount

This column specifies the magnitude of the order in units of torque consistent with the units of your model. However, as explained below, the amount value will be multiplied times the rpm value raised to a power equal to the input value for ***RPM Power***. So when ***RPM Power*** is any value other than zero, the actual units for ***Amount*** will be, for example, N-m/(rpm^RPM_Power).

Note: New in XLRotor version 5.0. The inputs in the ***Amount*** column can be completely arbitrary functions of rpm. To use this feature, put the word **Formula** in the column for ***RPM Power*** (see below), and enter a cell formula in the ***Amount*** column. In the cell formula, use a special variable called ***rpm*** (the ***rpm*** variable is actually an Excel Defined Name). For example, ***=1000+25*rpm+0.1*rpm^2***. The cell formula is not restricted to polynomials. Any type of functional relationship can be entered, including calls to user defined Visual Basic functions.

If Excel displays ***#NAME?*** after entering the cell formula, This is normal and happens because the defined name ***rpm*** hasn't been created, yet. After doing the first Run|Response analysis, the ***rpm*** defined name will get created, and the ***#NAME?*** will change to a number value calculated by the formula.

Order Number

This column specifies the numerical order. For example, a 1 means the excitation frequency is equal to the response speed. A value of 0.5 means the excitation frequency is equal to 0.5 times the response speed. A value of 3 means the excitation frequency is equal to 3 times the response speed. This input allows you to specify engine orders of any factor times the response speed.

A negative order number is used to specify a slip frequency of torsional excitation. For example, -2 specifies an excitation frequency at zero speed having a frequency of 2 times the maximum machine speed entered on the XLTorsion Worksheet. This excitation frequency decreases linearly to zero at the maximum machine speed. A line representing this excitation will be displayed on the torsional interference diagram (see Roots Tors Worksheet). The line will have a negative slope of 2. This type of excitation can be present in synchronous motors during startup. In a typical situation where the line frequency is 60 Hz, and the motor's synchronous speed is 3600 rpm, a value of -2 would be appropriate. If the line frequency is 60 Hz, but the motor's synchronous speed is 1800 rpm, enter -4 so the excitation frequency will still start at 120 Hz at zero motor speed.

When more than one harmonic has been specified, this means the system will be vibrating at more than one frequency at the same time. During the response calculation for each response speed, the response amplitude due to each harmonic frequency is computed separately, and these amplitudes are summed without accounting for relative phase angles to produce the total response value output for that response speed. In other words, the absolute value response peak for all harmonics are added to get the "worst case" peak response for that response speed. Alternatively, instead of simply summing absolute values, time waveform analysis can be done to determine response output values (see the Perform Time Waveform Analysis option).

RPM Power

The magnitude of the order will be multiplied times the response speed (in rpm) raised to this power. For example, enter a zero if the magnitude is to remain constant with speed. Enter a 2 if the magnitude is to increase with the square of the speed. The exact magnitude is determined with the following formula.

Magnitude = Amount * (ResponseSpeedinRPM)^(RPMPower)

Note: New in XLRotor version 5.0. Instead of a number, enter the word ***Formula***. See the above description for ***Amount*** for further explanation. Putting a "p" after the word ***Formula*** (e.g. ***Formula,p*** or ***Formula,plot***) will cause the program to output a plot of the torque magnitude versus rpm at the conclusion of a Run|Response analysis.

Phase

This specifies the phase of the excitation in degrees. The phase angle definition is a ***lagging phase***.

Applied Torque = Magnitude * Cos(OrderNumber*ResponseSpeedinRPM*pi/30*t - Phase*pi/180)

Response Speeds & Deflected Shape Speeds

There are separate columns for listing these two speed ranges, Response Speeds and Deflected Shapes. In both columns you can list as many speeds as you want, in any order that you want. Normally, you will want the Response Speeds (Run|Response) to be equally spaced over the speed range of interest. Excel's features for automatically filling ranges with values make this easy. The Deflected Shape (Run|Deflected Shapes) speed column contains the speeds for which you want to compute the entire rotor's deflected shape (i.e. like a mode shape).

Shaft Deflection Outputs

Output Stations - This column is used to list stations for which to generate charts of displacement amplitude versus rotor speed. Any number of stations be listed, in any order. The same station can be listed more than once. There is also a column for entering an additional title to be copied to the plots. See

Options|Response to see how you can choose what units are used to present the displacement results.

Relative Stations - Put a valid station value in this column when you want the *relative* deflection between two stations in the model.

Output Type - New in XLRotor 5.0. This is a new input column added for specifying either ***D***eflection, ***V***elocity or ***A***cceleration for the type of output. Enter either the first letter or entire word for the type of desired output. The separate input table for ***Velocity Outputs*** used prior to XLRotor 5.0 is no longer used. Units for deflection come from the Options|Response dialog. Units for velocity and acceleration come from the Options|Transient dialog.

Shaft Torque Outputs

Output Stations - This column is used to list stations for which you want to generate charts of shaft torque amplitude versus rotor speed. You can list as many stations as you want, in any order that you want. There is also a column for entering an additional title to be copied to the plots. See Options|Response to see how you can choose what units are used to present the torque results.

Relative Stations - Stations for load or stress output must always connect consecutive station numbers. So this column must be 1 greater than the **Output Station**. Entries that are left blank in this column will be filled in with the correct value when an analysis is run.

Output Type - New in XLRotor 5.0. This is a new input column added for specifying either ***L***oad or ***S***tress for the type of output. Enter either the first letter or entire word for the type of desired output. Units for load come from the Options|Response dialog. Units for stress are always **ksi** for models using English units, and **MPa** for models using SI units.

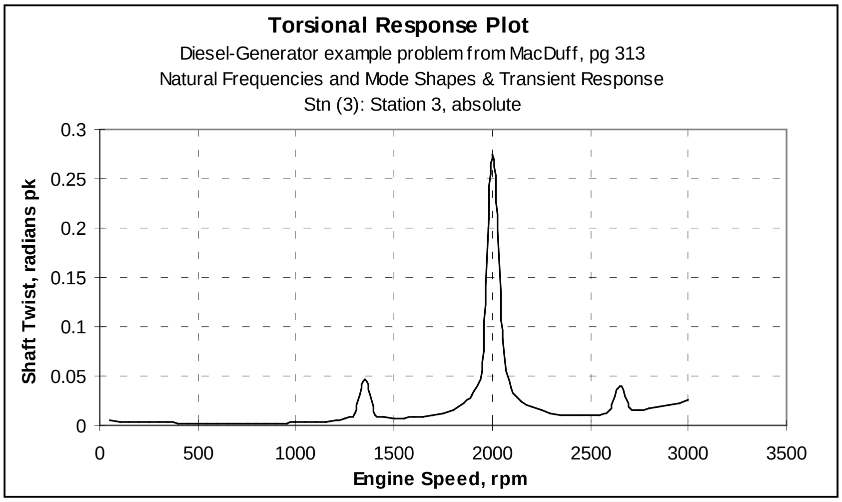
When a station consists of a single beam, ***Load*** output is simply the torque in the beam, and ***Stress*** output is the shear stress on the outer surface of the beam. If the beam is conical, the stress will be computed at the end of the beam with the larger stress. The stress value will include the input value for Stress Factor on the Shaft Input sheet.

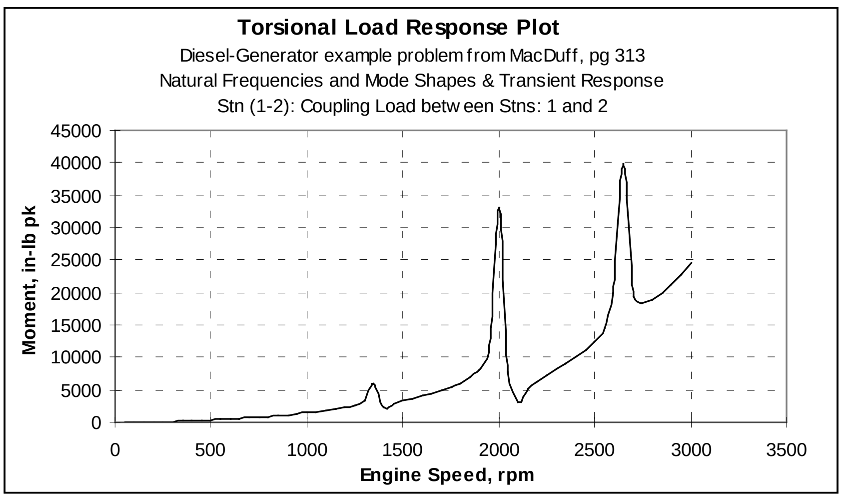
When a station consists of multiple stacked beams, ***Load*** output is the torque transmitted by all beams. ***Stress*** output is determined by first evaluating the torque in each beam (i.e. its stiffness times twist), and computing the shear stress on the outer surface at each end of the beam. The largest of all such stress values is the value output for the station. The stress value will include the input value for Stress Factor on the Shaft Input sheet.

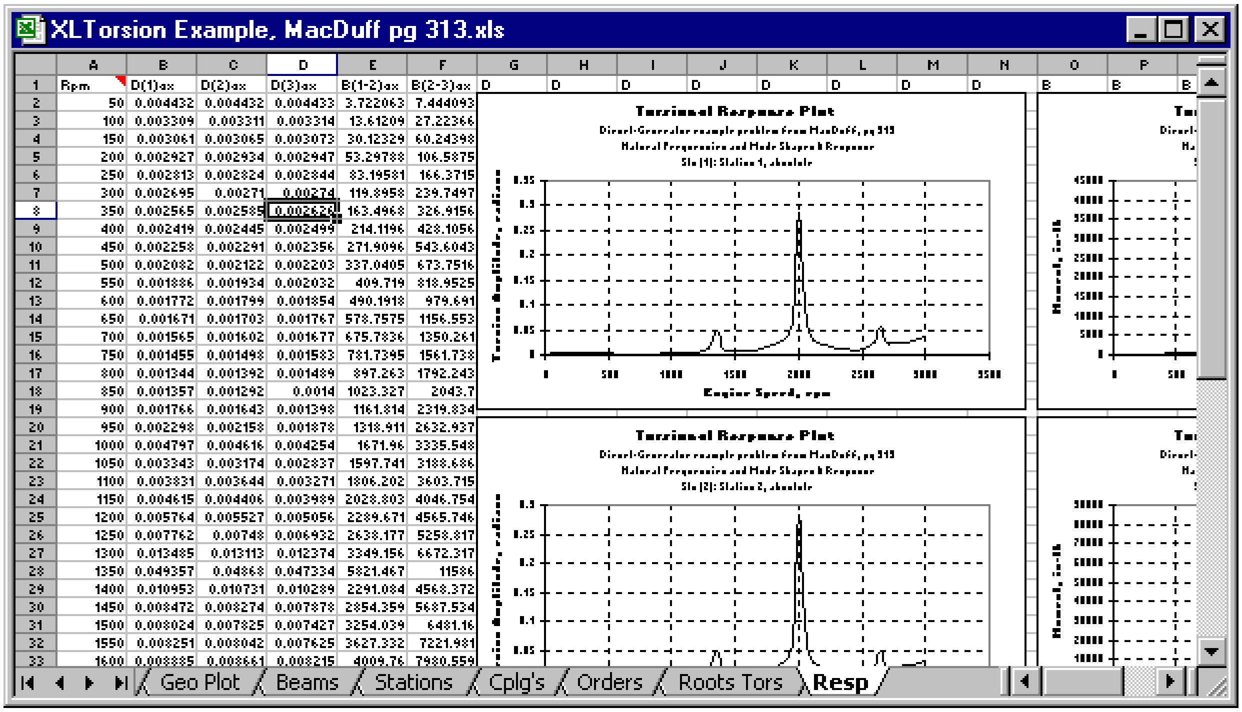
The signs of the output values can be reversed by reversing the order of the Output Station and Relative Station.

Coupling Load Output - In addition to the above outputs, output of coupling load versus rotor speed will be generated for couplings which have been designated for load output on the Cplg's Worksheet.

Torsional Resp Worksheet







See also

- XLRotor Overview
- Torsional Analysis with XLRotor
- Run|Response
- Run|Deflected Shapes

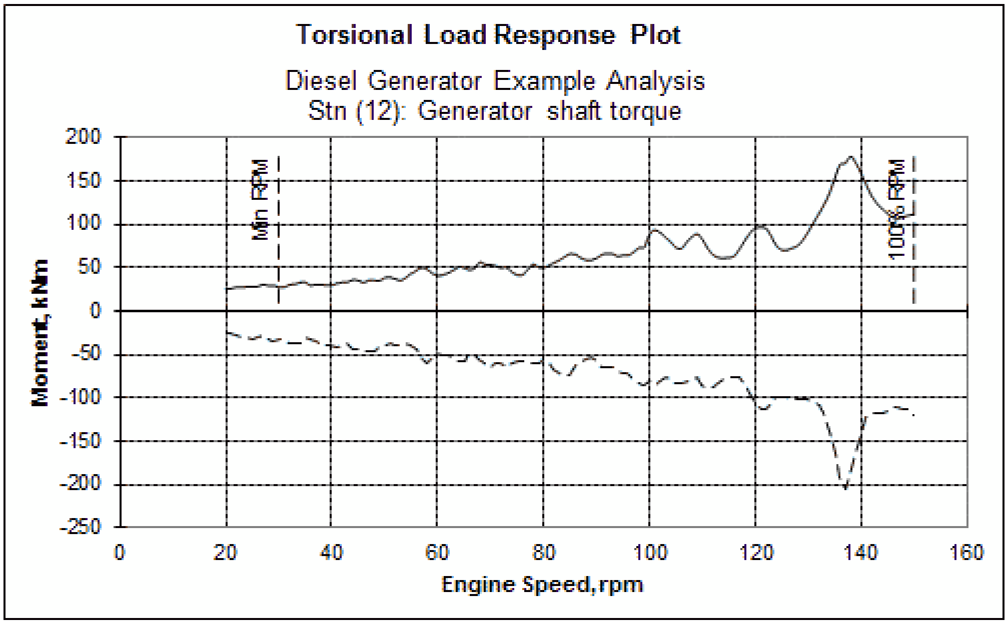
This worksheet is the torsional version of a Resp Worksheet for lateral analysis.

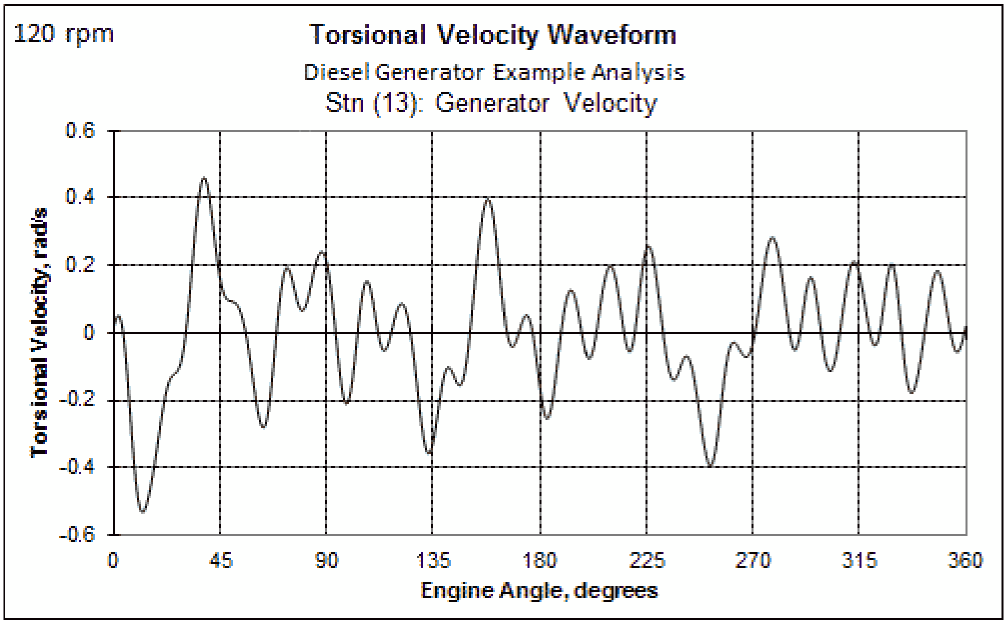
This worksheet displays the results of executing a Run|Response or Run|Deflected Shapes command for an XLRotor ***torsional*** model. The forcing functions and analysis speed range are taken from the Orders Worksheet. As the example above shows, this worksheet will display a table and charts of shaft twist, shaft torque, and coupling torque versus engine or motor speed.

As always, the charts are generated from templates in the XLRGRPH.XLS chart template file, which you can customize.

XLRotor will attempt to place the tables and plots on a worksheet named "Resp". If there is no worksheet by that specific name then one will be automatically created. If there is a worksheet by that name, you will be asked if you want to Append or Overwrite the new data to what is already there (see Append or Overwrite Worksheet).

When multiple harmonics are applied to the system, output values at each engine speed can be determined either by summing absolute peak values of all harmonics (as in the plots shown above), or doing a time waveform analysis. Refer to the note on harmonic analysis in Orders Worksheet and also Perform Time Waveform Analysis. When time waveform analysis is done, plots from a Run|Response analysis then contain two data series for the max and min values as in the following example. Plots from a Run|Deflected Shapes analysis will include plots of response for one revolution as in the second example plot.





Note:
From the Options|Response dialog box, you can select the output units independently for each output data type.

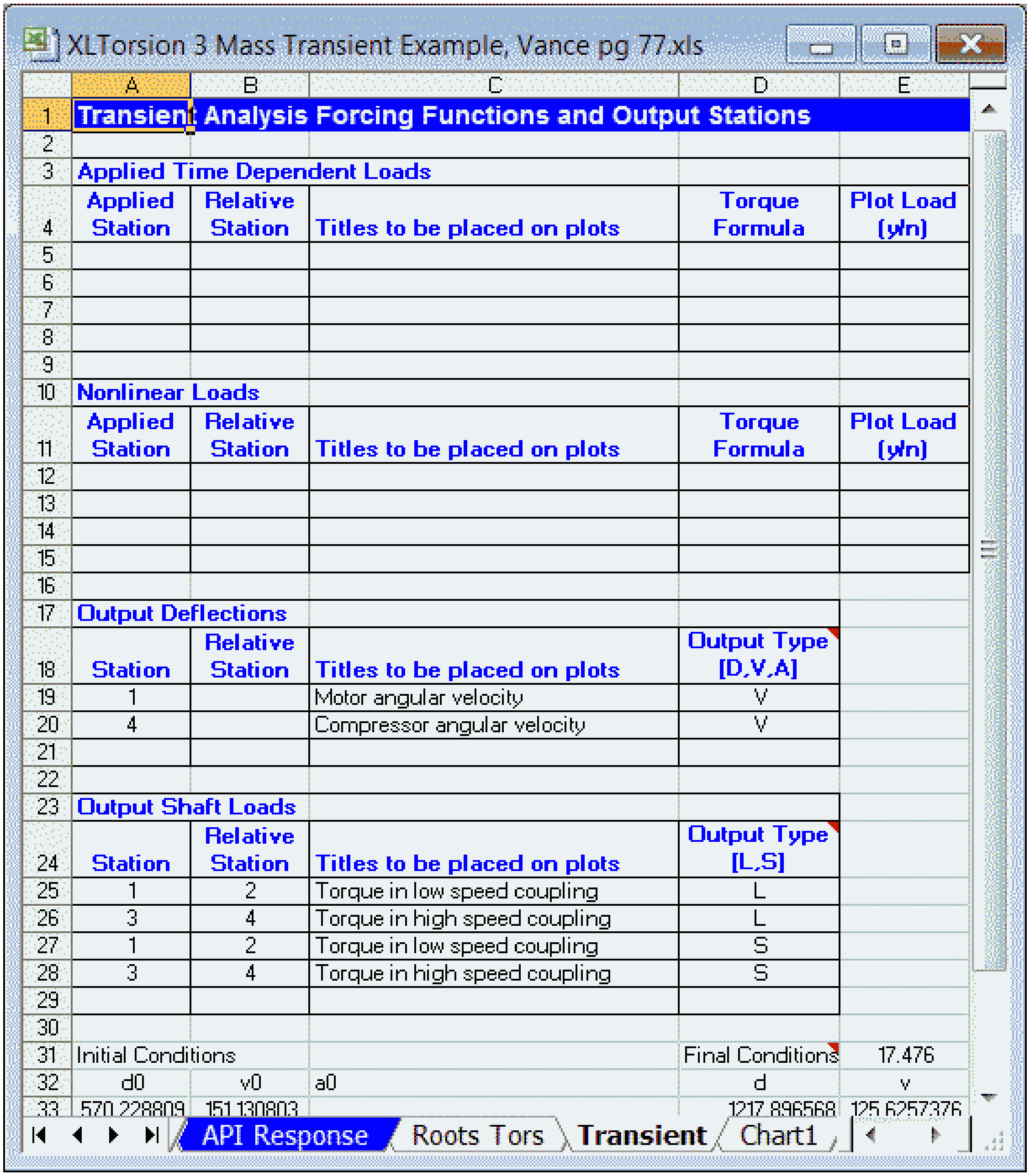
Note:
When the analysis is completed, and the results are placed on this worksheet, a cell comment is placed at the upper left corner of the output table. This comment contains a summary of the analysis parameters used for the calculation.

Torsional Transient Worksheet

See also

Run|Transient
Transient Worksheet

The Transient Worksheet for torsional models is quite similar to the sheet for lateral models, but with some differences. The torsional version does not have an input for transient rotor speed, and the table for specifying ***Output Shaft Loads*** allows for the output of either shaft torque or torsional shear stress. Also, there is no input for dof because torsional models have only one dof per station. All other elements of this worksheet work identically to their counterparts on the sheet for lateral model.



	A	B	C	D	E
1	Transient Analysis Forcing Functions and Output Stations				
2					
3	Applied Time Dependent Loads				
4	Applied Station	Relative Station	Titles to be placed on plots	Torque Formula	Plot Load (y/n)
5					
6					
7					
8					
9					
10	Nonlinear Loads				
11	Applied Station	Relative Station	Titles to be placed on plots	Torque Formula	Plot Load (y/n)
12					
13					
14					
15					
16					
17	Output Deflections				
18	Station	Relative Station	Titles to be placed on plots	Output Type [D,V,A]	
19	1		Motor angular velocity	V	
20	4		Compressor angular velocity	V	
21					
22					
23	Output Shaft Loads				
24	Station	Relative Station	Titles to be placed on plots	Output Type [L,S]	
25	1	2	Torque in low speed coupling	L	
26	3	4	Torque in high speed coupling	L	
27	1	2	Torque in low speed coupling	S	
28	3	4	Torque in high speed coupling	S	
29					
30					
31	Initial Conditions			Final Conditions	17.476
32	d0	v0	a0	d	v
33	570.228809	151.130803		1217.896568	125.6257376

Fatigue Life Worksheet

See also

Options|Transient

Torsional Fatigue Life Calculation With XLRotor

XLRotor can compute the fatigue life of a shaft from the results of a transient response analysis. A common application is torsional vibration which happens during startup of synchronous motor driven turbomachinery. A time history of shaft torque response is passed to a cycle counting algorithm along with material property data. The algorithm returns the life as a "Number of Starts", along with the number of vibration cycles whose alternating amplitude component exceeds the endurance limit.

Torsional fatigue analysis should be thought of like L10 fatigue life of rolling element bearings. When a shaft is cyclically stressed above its endurance limit, its life is limited, but the life cannot be estimated with pinpoint precision because of variations in grain structure, surface finish, environment, etc. The goal of fatigue analysis is to estimate the life with the best available inputs, and assign an appropriate level of confidence, or reliability, to the result.

Two life estimation methods are currently available in XLRotor; Stress-Life and Strain-Life. Both of these are done in post processing fashion, after a transient response analysis has already been completed. The remainder of this section first describes Sress-Life first, then Strain-Life.

Stress-Life Method

Nirmal 74 station torsional model.xls

	A	B	C
1	Fatigue life via the Stress-Life Method		
2			
3	INPUTS	Component Name	Station 27
4		Material	4340, BHN 243
5		Shaft Outer Diameter	13.17
6		Shaft Inner Diameter	0
7		Theoretical Stress Concentration Factor, K_t	1.55
8		Ultimate Tensile Strength, σ_u	120000
9		Ratio of τ_u to σ_u	0.8
10		Surface Finish Factor, k_a	0.9
11		Size Factor, k_b	0.667
12		Load Factor, k_c	0.577
13		Temperature Factor, k_d	1
14		Reliability Factor, k_e	0.7407
15		Miscellaneous Factor, k_f	1
16		Notch Sensitivity, q	0.91
17		Ratio of 10e3 Cycle Limit to Ultimate, f	0.9
18		Ratio of 10e6 Cycle Limit to Ultimate, $(\sigma_e : \sigma_u)$	0.5
19	OUTPUTS	Fatigue Notch Factor, $K_f = 1+q(K_t-1)$	1.5005
20		Ultimate Shear Strength, τ_u	96,000
21		10e3 Cycle Shear Fatigue Strength	86,400
22		10e6 Cycle Shear Fatigue Strength	15,394
23		10e3 Cycle Torque Limit	25,826,464
24		10e6 Cycle Torque Limit	4,601,642
25		Torque at $\tau_u/K_f = T_{ult}$	28,696,072
26		Life in number of starts	14109
27		Number of cycles in life calculation	9
28			

Roots Tors / Transient / Transient Resp / **Stress Life** / Strain Life

To use the above worksheet, first have XLRotor put a copy of it in your file (see Options|Transient). Cells C3 through C18 contain inputs for your material and shaft. Cells C19 through C27 contain cell formulas that perform the fatigue calculation. Normally you will not need to change the formulas in these cells, but you can if you want to. The formula appearing in the two cells C26:C27 is entered as an Excel array formula. This formula calls a specially defined Visual Basic Function in XLRotor, and has the following calling syntax:

```
Function StressLifeFatigue(Rng As Range, S10e3#, S10e6#, Optional Sult# = 1E+15)
         As Variant
```

```
'Rng = cell range for which to compute life, can be entire worksheet column like
         C:C or a range of cells like C2:C2000
```

```
'S10e3 value in same units as the input Rng corresponding to N=10e3 life (low cycle
        fatigue), should include Kf
'S10e6 value in same units as the input Rng corresponding to N=10e6 life (high
        cycle fatigue), should include Kf
'Sult ultimate in same units as input Rng, used to do adjustment for mean component,
        should include Kt
'if Sult is not input, then use 1e15 which essentially means that Salt is not
        adjusted for Smean
'if a peak is found exceeding S10e3 then return a life of 0
```

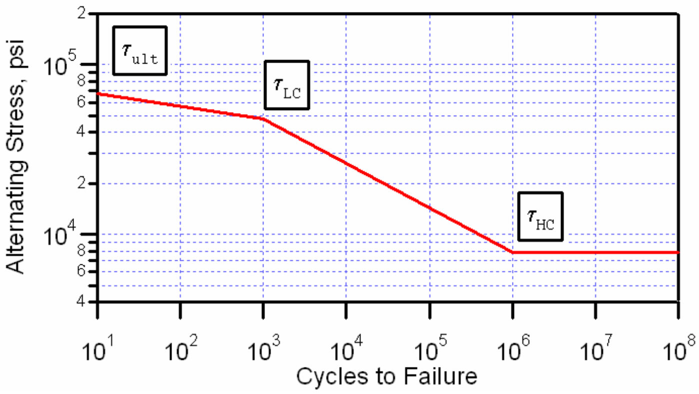
Whenever you edit this formula, you must press **Shift-Control-Enter** instead of simply **Enter** so that Excel will interpret it as an array formula. The reason this function is called an array formula is because it returns an array of two values instead of just one.

This method follows closely the one described in the book by Shigley (Ref. 2). A 3-line, log-log S-N curve is constructed as depicted in the graph below. For the purpose of calculating the practical life of a turbomachinery shaft, the primary interest is in the sloping line connecting τ_{LC} at N=10^3 to τ_{HC} at N=10^6. Constructing this figure is a three step process.

1. Determine τ_{ult}
   From the shaft material's ultimate tensile strength, σ_{ult}, determine a value for its ultimate shear strength, τ_{ult}. This is generally done by simply multiplying σ_{ult} by an appropriate factor related only to the different manner of loading used to determine σ_{ult} (uni-axial tension) and that of your shaft (torsional shear). For steels for example, Shigley (Ref. 2) recommends using 0.67*σ_{ult} and Juvinall (Ref. 1) recommends using 0.8*σ_{ult}.
2. Determine τ_{LC}
   From τ_{ult} determine a value for the Low Cycle endurance limit τ_{LC}. This is often done by simply multiplying τ_{ult} by an appropriate factor, f, which for steel depends on its ultimate strength. For moderate strength steels Shigley recommends about 0.9, but for high strength steels it is less. Shigley presents f values for 4 different σ_{ult} from 60 to 200 ksi, which has been curve fit as follows:

   $$f = -7.3052(10^{-8})\sigma_{ult}^3 + 3.6391(10^{-5})\sigma_{ult}^2 - 6.5427\sigma_{ult} + 1.2073$$

   (σ_{ult} is in ksi)
3. Determine τ_{HC}
   From the shaft material's endurance limit, σ_e, determine a value for its shear endurance limit τ_{HC}. In cases where σ_e is not available, it can be *roughly* approximated as 0.504*σ_{ult} for steels with σ_{ult}=212 ksi (Ref. 2). Then, τ_{HC} is determined from σ_e by applying a set of "knock down" factors described below.



Actual alternating shaft stresses less than τ_{HC} are considered fatigue free, and any alternating stresses greater than τ_{LC} are taken to automatically mean the life is too short to be computed with a high degree of confidence, and is therefore considered zero.

σ_{ult}	Average ultimate tensile strength of a lab specimen
σ_e	Endurance limit, either measured or approximated as $0.504\sigma_{ult}$
τ_{ult}	Shear ultimate strength Ref. 1 presents $0.8\sigma_{ult}$ Ref. 2 presents $0.67\sigma_{ult}$ distortion-energy theory suggests $0.57\sigma_{ult}$
$\tau_{LC} = f * \tau_{ult}$	Low Cycle endurance limit (N=10^3), f=0.9 or else use formula given above
τ_{HC}	High Cycle endurance limit (N=10^6)
$\tau_{HC} = k_a k_b k_c k_d k_e k_f \sigma_e$	
$k_a = \bar{a}\sigma_{ult}^{\bar{b}}$	Surface condition factor (Ref. 2) The following are from Ref. 2, σ_{ult} in ksi Ground steel $\bar{a} = 1.34,\ \bar{b} = -0.085$ Machined steel $\bar{a} = 2.70,\ \bar{b} = -0.265$ Hot-rolled steel $\bar{a} = 14.4,\ \bar{b} = -0.718$ As-forged steel $\bar{a} = 39.9,\ \bar{b} = -0.995$
$k_b = D^{-0.19}$	Size factor (could also use $(D/0.3)^{-0.1133}$
$k_c = 0.59$	Load factor (τ / σ ratio) 0.50 maximum shear stress 0.577 distortion energy theory (Von Mises) 0.59 per Ref. 2

$k_d \approx 1$	Temperature factor. Ref. 2 suggests:

$$k_d = .975 + .000432F - 1.15 * 10^{-6}F^2 + 1.04 * 10^{-9}F^3 - 5.95 * 10^{-13}F^4$$

where F is degrees Fahrenheit
Important above about 600F

k_e	Reliability factor (1/Safety Factor) 1.0 = 50% reliability .897 = 90% .868 = 95% .814 = 99% .753 = 99.9% .702 = 99.99%
$k_f = 1$	Miscellaneous factor

Transient torsional analysis with XLRotor produces shaft torque. Shaft torque is converted to stress using the standard equation:

$$\tau = K_f T * \left(\frac{c}{J}\right) \qquad \frac{c}{J} = \frac{16}{\pi}\frac{D_o}{D_o^4 - D_i^4}$$

where

K_t	Theoretical stress concentration factor
q	Fatigue notch sensitivity
$K_f = 1 + q(K_t - 1)$	Fatigue notch factor

In common situations like fillets and keyways, K_t is obtained from a handbook of stress concentration factors (Ref. 3), and depends only on the geometry of the shaft.

The value of q depends on both the shaft geometry, and the material strength. Shigley (Ref. 2) presents a figure for q for torsional loading which can be approximated with the following formulas when the fillet radius r is at least 0.02 inches. These formulas will produce q values very close to what is shown in the book's figure. Note that larger q values are more conservative.

$$q = \frac{1}{1 + \frac{0.007}{\sqrt{r}}}$$

For quenched and drawn steels (Bhn>200)

In Ref. 2 for r>=0.04 inches, q>=0.96

$$q = \frac{1}{1 + \frac{0.02422}{\sqrt{r}}}$$

For annealed steels (Bhn<200)

In Ref. 2 for r>=0.06 inches, q>=0.91

The time history of shaft torque is examined to determine the maximum (peak) and minimum (valley) torque values of each cycle. Then mean and alternating torque components for each cycle are evaluated as follows:

T_m = (peak + valley)/2 — Mean torque component

T_a = (peak - valley)/2 — Alternating torque component

$\tau_m = K_f(T_m c/J)$ — Mean shear stress corresponding to mean torque component

$\tau_a = K_f(T_a c/J)$ — Alternating shear stress corresponding to alternating torque component

$\tau_{ao} = \tau_a /(1 - \tau_m / \tau_{ult})$ — Alternating shear stress adjusted for mean stress

The cycle counting method used by XLRotor is described in Ref. 5 where it is termed "simple range counting". This method enables accounting for the effect of mean stress. Cycle counting to account for variable load histories is also discussed by Shigley (Ref. 2) on page 365.

When $\tau_{HC} \le \tau_{ao} \le \tau_{LC}$, the number of cycles of life for any combination of τ_{ao}, τ_{HC} and τ_{LC} is:

$$N = 10^{\left[3+3\frac{\log(\tau_{LC})-\log(\tau_{ao})}{\log(\tau_{LC})-\log(\tau_{HC})}\right]} = 10^{\left[3+3\frac{\log(\tau_{LC}/\tau_{ao})}{\log(\tau_{LC}/\tau_{HC})}\right]}$$

In terms of torque this becomes:

$$N = 10^{\left[3+3\frac{\log(T_{LC})-\log(T_{ao})}{\log(T_{LC})-\log(T_{HC})}\right]} = 10^{\left[3+3\frac{\log(T_{LC}/T_{ao})}{\log(T_{LC}/T_{HC})}\right]}$$

where

$$T_{LC} = \tau_{LC}(J/c)/K_f$$
$$T_{HC} = \tau_{HC}(J/c)/K_f$$
$$T_{ult} = \tau_{ult}(J/c)/K_f$$
$$T_{ao} = T_a(1 - T_m/T_{ult})$$ (Goodman type adjustment)

Note that the stress concentration factor embedded in K_f is effectively applied to both the mean and alternating components of shaft stress at all levels of stress. The reliability factor, which is comparable to 1/Safety Factor, is applied only to setting the value of T_{HC}, but not T_{LC}, and so has full affect at low alternating stress levels approaching τ_{HC}, but minimal affect at high alternating stress levels approaching τ_{LC}.

The life N is computed separately for every rise and every fall of torque which has a mean-adjusted alternating component τ_{ao} exceeding τ_{HC}(or $T_{ao} \geq T_{HC}$). Since each of these is one half of a full cycle, the total life is then calculated using Miner's rule as:

$$N = \frac{1}{\sum \frac{0.5}{N_i}}$$

If any cycles are found to have $T_{ao} > T_{LC}$, the life is considered to be zero.

Strain-Life Method

Nirmal 74 station torsional model.xls

	A	B	C
1	Fatigue life via the Strain-Life Method		
2			
3	INPUTS	Component Name	Station 27
4		Material	4340, BHN 243
5		Shaft Outer Diameter	13.17
6		Shaft Inner Diameter	0
7		Theoretical Stress Concentration Factor, K_t	1.55
8		Ultimate Tensile Strength, σ_u	120000
9		Ratio of τ_u to σ_u	0.8
10		Ratio of Shear Stress to Normal Stress, k_c	0.577
11		Surface Finish Factor, k_a	0.9
12		Size Effect Factor, k_b	0.667
13		Safety Factor, SF	1.35
14		Reduction of Area in Tensile Test, RA	0.4
15		Elastic Modulus, E	2.85E+07
16		Elastic Strain Slope, b	-0.085
17		Plastic Strain Slope, c	-0.6
18		Notch Sensitivity, q	0.91
19	OUTPUTS	Fatigue Notch Factor, $k_f = 1+q(K_t-1)$	1.5005
20		Ultimate Shear Strength, τ_u	96,000
21		True Stress at Failure, $\sigma' = \sigma_u/(1-RA)$	200,000
22		True Strain at Failure, $\varepsilon' = -LN(1-RA)$	0.5108
23		Elastic Stress Magnitude, $\sigma'\ k_c/(SF{*}k_a k_b)$	142,398
24		Plastic Stress Magnitude, $E\varepsilon'\ k_c/(SF{*}k_a k_b)$	10,365,523
25		Elastic Torque Magnitude	63,869,117
26		Plastic Torque Magnitude	4,649,202,367
27		Elastic Exponent	-0.188249886
28		Plastic Exponent	-0.703249886
29		10e3 Cycle Stress Limit	119,302
30		10e6 Cycle Stress Limit	11,194
31		10e3 Cycle Torque Limit, T_{LC}	53,509,788
32		10e6 Cycle Torque Limit, T_{HC}	5,020,610
33		Torque at $\tau_u/K_f = T_{ult}$	28,696,072
34		Life in number of starts	21858
35		Number of cycles in life calculation	7.5
36			

Roots Tors / Transient / Transient Resp / Stress Life / **Strain Life**

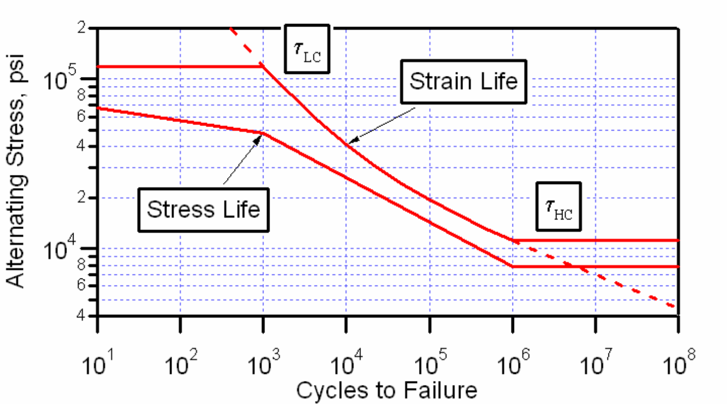
To use the above worksheet, first have XLRotor put a copy of it in your file (see Options|Transient). Cells C3 through C18 contain inputs for your material and shaft. Cells C19 through C35 contain cell formulas that perform the fatigue calculation. Normally you will not need to change the formulas in these cells, but you can if you want to. The formula appearing in the two cells C34:C35 is entered as an Excel array formula. This formula calls a specially defined Visual Basic Function in Xlrotor, and has the following calling syntax:

```
Function StrainLifeFatigue(Rng As Range, Sel#, Spl#, Eel#, Epl#, Optional Sult#
         = 1E+15) As Variant

'Rng = cell range for which to compute life, can be entire worksheet column like
         C:C or a range of cells like C2:C2000

'Sel = S elastic magnitude, in same units as Rng

'Spl = S plastic magnitude, in same units as Rng

'Eel = S elastic exponent

'Epl = S plastic exponent

'Sult ultimate in same units as input Rng, used to do adjustment for mean component,
         should include Kt

'if Sult is not input, then use 1e15 which essentially means that Salt is not
         adjusted for Smean

'if a peak is found exceeding S evaluated at N=1000 then return a life of 0
```

Whenever you edit this formula, you must press Shift-Control-Enter instead of simply Enter so that Excel will interpret it as an array formula. The reason this function is called as an array formula is because it returns an array of two values instead of just one.

This method differs from the stress-life method in how the log-log S-N curve is constructed. The form in which it is presented here is that recommended by Corbo (Ref. 4). The most recent edition of Shigley (7^{th}, Ref. 2) recommends the Stress-Life method over this method. The sample S-N plot below, and also the one given earlier, was constructed for the example case given in Ref. 4. It is evident from the plot that the Stress-Life S-N curve is more conservative. The main differences of the strain-life method are:

- The S-N plot is constructed using a different set of material constants, and is curved instead of straight
- A greater number of material property constants are required from laboratory tests (5 instead of 1 or 2)
- The Fatigue Stress Concentration Factor is applied less at higher stress levels
- The Safety Factor is applied equally at all stress levels
- The values of τ_{LC} and τ_{HC} are determined by the curve instead of vice-versa.



σ_{ult}	Average ultimate tensile strength of a lab specimen
RA	Reduction in area in ultimate tensile test
$\sigma'_f = \sigma_u/(1-RA)$	Fatigue Strength Coefficient (true stress at failure)
$\varepsilon'_f = Ln[1/(1-RA)]$	Fatigue Ductility Coefficient (true strain at failure)
E	Elastic modulus
b	Fatigue strength exponent (also called elastic strain slope, Ref. 2, pg 319)
c	Fatigue ductility exponent (also called plastic strain slope, Ref. 2, pg 319)
τ_{ult}	Shear ultimate (Juvinall suggests 0.8σ_{ult} and Shigley suggests 0.67σ_{ult})
$\sigma(N) = \sigma'_f N^b + E\varepsilon'_f N^c$	Tensile fatigue strength vs N (Coffin-Manson expression)
$\tau(N) = \sigma_f(N)\dfrac{k_a(N)\,k_b(N)\,k_c}{SF\ K_f(N)}$	Shear fatigue strength vs N
$k_a(N) = \dfrac{1}{\hat{k}_a} N^{\frac{1}{3}\log \hat{k}_a}$	Surface finish factor, a function of N $\hat{k}_a = k_a$ given earlier for Stress-Life method
$k_b(N) = \dfrac{1}{\hat{k}_b} N^{\frac{1}{3}\log \hat{k}_b}$	Size factor, a function of N $\hat{k}_b = k_b$ given earlier for Stress-Life method
$k_c = 0.59$	Load factor (τ / σ ratio) (Ref. 2)

$$K_f(N) = N^{\frac{1}{6}\log \hat{K}_f}$$

Fatigue stress concentration factor, a function of N

$\hat{K}_f = 1 + q(K_t - 1)$

K_t Theoretical stress concentration factor

q Fatigue notch sensitivity, same as given earlier for Stress-Life method

SF Safety Factor, or 1/reliability factor
Ref. 4 recommends SF=1.35=1/0.74

From the above definitions, the expression for $\tau(N)$ is then

$$\tau(N) = \sigma(N) * \frac{k_c}{SF}\frac{1}{\hat{k}_a\hat{k}_b} N^{\frac{1}{3}\log\left(\hat{k}_a\hat{k}_b / \sqrt{\hat{k}_f}\right)} = S_{el}N^{E_{el}} + S_{pl}N^{E_{pl}}$$

This stress equation is recast in terms of shaft torque by multiplying by (J/c).

$$T(N) = \tau(N) * (J / c) \quad \text{where} \quad (J / c) = \frac{\pi}{16}\frac{D_o^4 - D_i^4}{D_o}$$

$$T(N) = T_{el}N^{E_{el}} + T_{pl}N^{E_{pl}}$$

$$T_{el} = \sigma'_f\left(\frac{k_c}{SF}\frac{1}{\hat{k}_a\hat{k}_b}\frac{\pi}{16}\frac{D_o^4 - D_i^4}{D_o}\right)$$

$$T_{pl} = E * \varepsilon'_f\left(\frac{k_c}{SF}\frac{1}{\hat{k}_a\hat{k}_b}\frac{\pi}{16}\frac{D_o^4 - D_i^4}{D_o}\right)$$

$$E_{el} = b + \frac{1}{3}\log\left(\hat{k}_a\hat{k}_b / \sqrt{\hat{k}_f}\right)$$

$$E_{pl} = c + \frac{1}{3}\log\left(\hat{k}_a\hat{k}_b / \sqrt{\hat{k}_f}\right)$$

$\tau_{LC} = \tau(10^3)$ Low cycle endurance limit (includes K_f)

$\tau_{HC} = \tau(10^6)$ High cycle endurance limit (includes K_f)

$\tau_{ult} = 0.8\sigma_{ult} / K_f$ Shear ultimate (Juvinall suggests $0.8\sigma_{ult}$)

$T_{LC} = \tau_{LC}(J / c)$ Includes K_f and SF

$T_{HC} = \tau_{HC}(J / c)$ Includes K_f and SF

$T_{ult} = \tau_{ult}(J / c)$	Used to adjust for mean torque, includes K_f
$T_m = (peak + valley)/2$	Mean torque component
$T_a = (peak - valley)/2$	Alternating torque component
$T_{ao} = T_a(1 - T_m/T_{ult})$	Alternating torque adjusted for mean torque (T_{ult} includes K_f) (Goodman type adjustment)

When $T_{HC} \leq T_{ao} \leq T_{LC}$, the number of cycles of life, N, corresponding to this torque is determined using Newton-Raphson iteration

Solve $T_{ao} = T_{el}N^{E_{el}} + T_{pl}N^{E_{pl}}$ for N.

Note that the stress concentration factor embedded in K_f has full affect at low alternating stress levels near τ_{HC}, but at high stress levels near τ_{LC} its affect reduces to $\sqrt{K_f}$. The Safety Factor, which is comparable to 1/Reliability Factor, is applied equally at all stress levels. In Ref. 4 Corbo assumed that the effect of mean stress is low enough to be safely ignored. Here, however, the mean component has been used to perform a standard Goodman type adjustment to the alternating component, with T_{ult} itself having been adjusted for K_f, as recommended in Ref. 2.

The life N is computed separately for every rise and every fall of torque which has a mean-adjusted alternating component T_{ao} which exceeds T_{HC}. Since each of these is one half of a full cycle, the total life is then:

$$N = \frac{1}{\sum \frac{0.5}{N_i}}$$

If any cycles are found to have $T_{ao} > T_{LC}$ the life is considered to be zero.

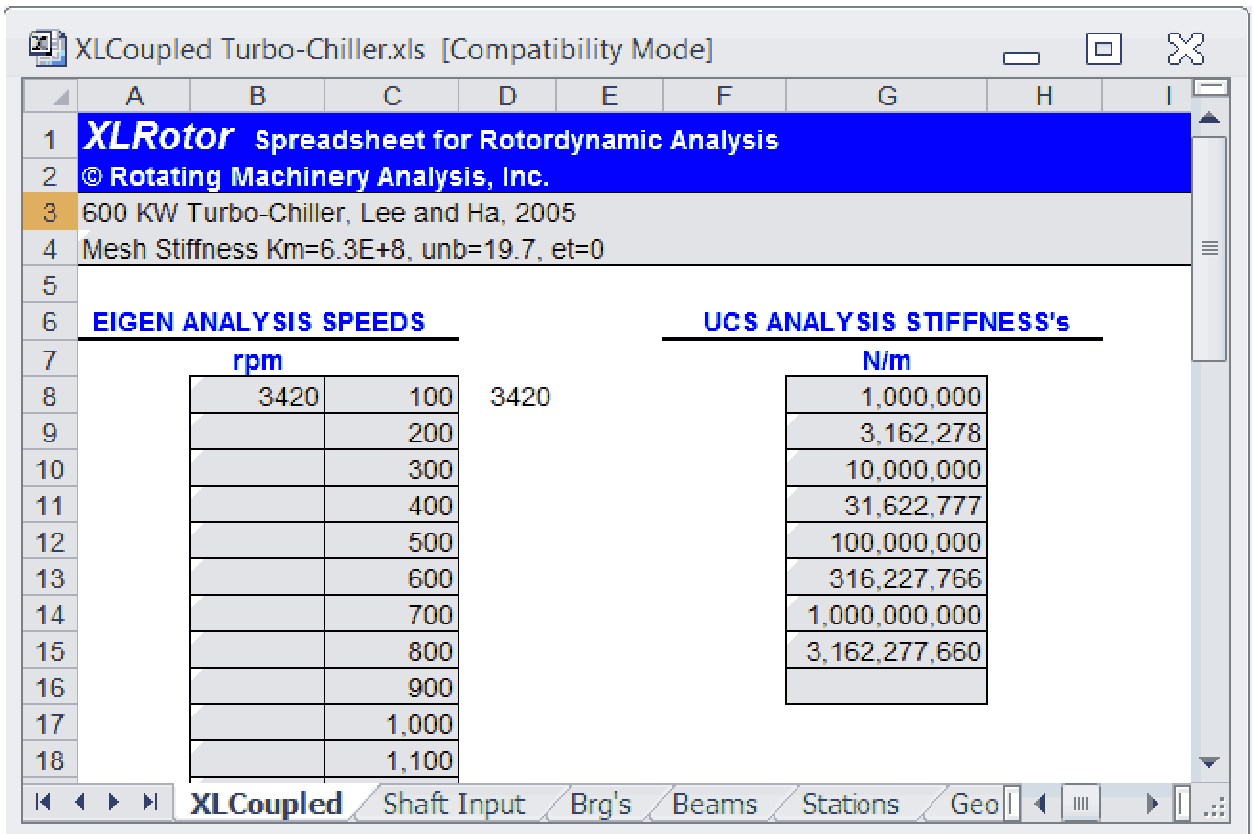
References

1. Juvinall, R.C. and Marshek, K.M., *Fundamentals of Machine Component Design 3rd Edition*, John-Wiley, 2000.
2. Shigley, J.E., Mischke, C.R. and Budynas, R.G., *Mechanical Engineering Design 7th Edition*, McGraw-Hill, 2004.
3. Pilkey, W.D., Peterson, R.E., Peterson's Stress Concentration Factors 2nd Edition, Wiley-Interscience, 1997.
4. Corbo, M.A., Cook, C.P., Yeiser, C.W. and Costello, M.J., "Torsional Vibration Analysis and Testing of Synchronous Motor-Driven Turbomachinery," *Proceedings of the 31st Turbomachinery Symposium*, Turbomachinery Laboratory, Texas A&M University, 2002, pp 153-176.
5. Bannantine, J. A., Comer, J. J. and Handrock, J. L., *Fundamentals of Metal Fatigue Analysis,* Prentice Hall, 1990, page 186.

XLCoupled Worksheet

See also

Coupled Lateral-Torsional Analysis
XLRotor Worksheet
XLTorsion Worksheet
XLCoupled Shaft Input Worksheet
XLCoupled Cplg's Worksheet
XLCoupled Imb's Worksheet



This worksheet is the starting point for creating rotor models for analysis of coupled lateral and torsional vibration. It is essentially the same as the XLRotor worksheet in a file used for lateral vibration.

Titles

Two cells are provided to enter titles that will be copied to charts created during analysis. The contents of these cells are **copied** to the charts, as opposed to being referenced. This means once a chart has been created, the titles appearing on the chart will not change.

Changes you make to the Title cells will **not** update automatically on **existing** charts (i.e. mode shapes, response, etc.). The geometry chart (Geo Plot Chartsheet), however, is an **exception.** Changes made to the Title cells **will** update automatically on the Geometry chart.

Eigen Analysis Speeds

The rotor speeds entered in this column are used for two types of eigenanalysis; 1) calculation of damped eigenvalues, and 2) free-free modes. When performing either of these types of analyses, the eigenvalues for the rotor will be computed for each value of rotor speed entered in this column.

Use Excel's Auto Fill features to easily enter a series of speed values. The list of speeds must start in the cell just below the column heading, and must run consecutively down the column. The first blank cell signifies the end of the list. The speed values in the list can appear in any order.

Note: When just a single speed is listed, a Run|Eigenvalue command will also automatically output mode shapes for all modes, plus a table of strain and kinetic energy distributions for each mode. See the XLCoupled Roots Damped Worksheet.

UCS Analysis Stiffness

A UCS analysis is not presently available for XLCoupled models. The inputs are present on this worksheet for possible future use.

XLCoupled Shaft Input Worksheet

See also

- Coupled Lateral-Torsional Analysis
- XLCoupled Worksheet
- XLCoupled Beams Worksheet
- XLCoupled Stations Worksheet
- XLCoupled Cplg's Worksheet

	A	B	C	D	G	H	I	J	K	L	M	N	O	P
1	INPUT TABLE OF BEAM AND STATION DEFINITIONS, MORE THAN ONE BEAM PER STATION IS OK													
2	Station	Length	ID	OD	Density	Elastic Modulus	Shear Modulus	Added Weight	Added Ip	Added It	Added Kt	Absolute Damping	Relative Damping	Speed Factor
3	#	meters	meters	meters	kg/m³	N/m²	N/m²	kg	kg-m²	kg-m²	N-m/rad	N-m-s or %	N-m-s or %	
6	1	0.1		0.3	7800	2.07E+11	7.95E+10							1
7	2	4.24		0.3	7800	2.07E+11	7.95E+10	525.7	32.2	16.1				1
8	3	1.16		0.22	7800	2.07E+11	7.95E+10	116.04	6.23	3.115				1
9	4	0.3		0.22	7800	2.07E+11	7.95E+10							1
10	5							726.4	113.9	56.95				1
11	4	0.3	0.22	2.138772										1
12	6	0.3		0.15	7800	2.07E+11	7.95E+10	5	0.004	0.002				-14.26087
13	7	5		0.15	7800	2.07E+11	7.95E+10							-14.26087

XLCoupled | Shaft Input | Beams | Stations | Geo Plot | Brg's | brg1 | brg2 | Table 10.8 | Cplg'

On this sheet you enter the geometry of a *coupled* lateral-torsional model. This worksheet has input columns for all the inputs of an XLRotor *lateral* model, plus all but two of the input columns of an XLTorsion *torsional* model. The two XLTorsion columns not present for a coupled model are the ***Gear Ratio*** column and ***Stress Factor*** column.

The ***Speed Factor*** column has an additional use only for coupled analysis. It is used to determine speeds for which bearing force coefficients are evaluated during eigenvalue or forced response calculations.

The input columns for ***Absolute Damping*** and ***Relative Damping*** apply only to the torsional part of a coupled model.

Note: The order of the columns can be changed to suit your preference. A column can be moved left or right by first clicking on the column heading letter, then click and drag the border of the selected column while holding down the shift key.

XLCoupled Beams Worksheet

	A	B	C	D	E	F	G	H	J
1	SUMMARY TABLE OF ALL BEAMS DEFINED IN MODEL								
2	Beam Number	Station #	Axial Location	Beam Weight	Beam It	Beam Ip	Beam EI	Beam GA	Beam Stiffnes
3			meters	kg	kg-m²	kg-m²	N-m²	N	N-m/rad
6	1	1	0	55.13495	0.35608	0.620268	82304819	5.62E+09	6.32E+08
7	2	2	0.1	2337.722	3515.369	26.29937	82304819	5.62E+09	14910293
8	3	3	4.34	343.9441	39.60803	2.080862	23802960	3.02E+09	15761580
9	4	4	5.5	88.95105	0.93621	0.538154	23802960	3.02E+09	60944777
10	5	5	5.8	0	0	0	0	0	0
11	6	4	5.5	0	0	0	0	0	0
12	7	6	5.8	41.35121	0.368284	0.1163	5144051	1.4E+09	13170759
13	8	7	6.1	689.1869	1436.775	1.938338	5144051	1.4E+09	790245.5
14	9	8	11.1	13.78374	0.03087	0.038767	5144051	1.4E+09	39512277
15	10	9	11.2	0	0	0	0	0	0
16	11	6	5.8	0	0	0	0	0	0
17				**3570.07**	**4993.44**	**31.6321**			

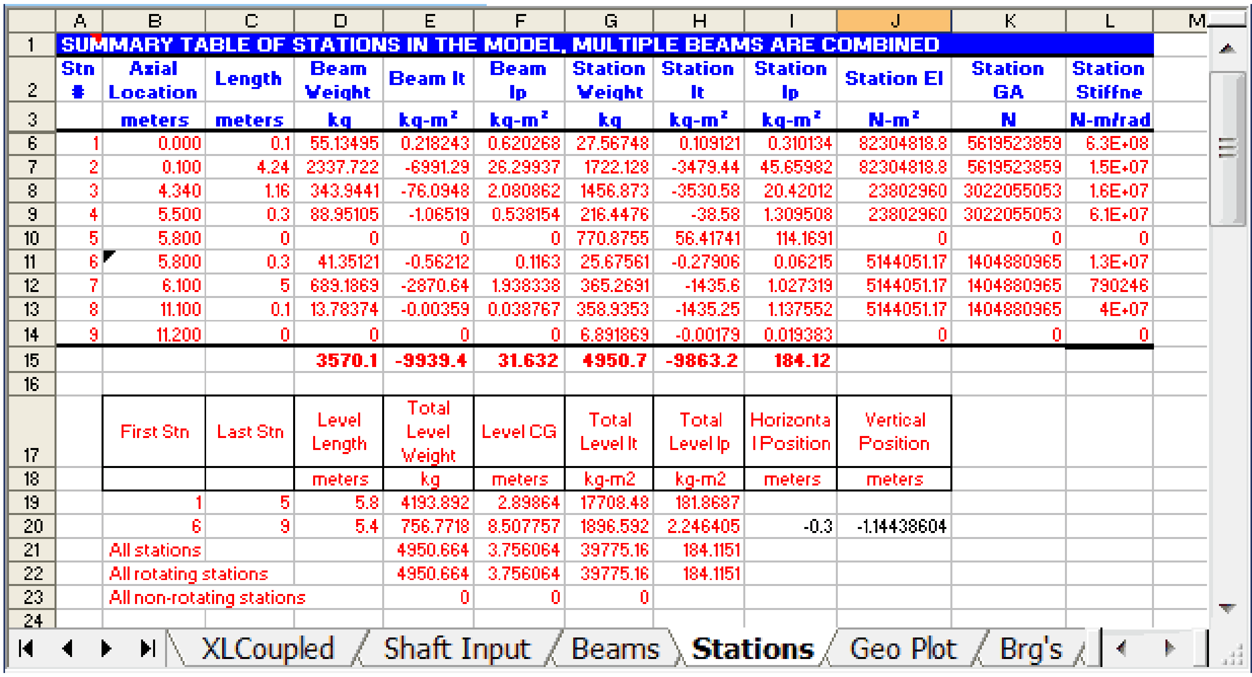
XLCoupled / Shaft Input / **Beams** / Stations / Geo Plot

See also

Coupled Lateral-Torsional Analysis
XLCoupled Worksheet
XLCoupled Shaft Input Worksheet
XLCoupled Stations Worksheet

This worksheet serves the same purpose as in lateral and torsional rotor model files (see Beams Worksheet and Torsional Beams Worksheet). This version of the worksheet contains all the same columns which appear on either of those worksheets.

XLCoupled Stations Worksheet



	A	B	C	D	E	F	G	H	I	J	K	L
1	SUMMARY TABLE OF STATIONS IN THE MODEL, MULTIPLE BEAMS ARE COMBINED											
2	Stn #	Axial Location	Length	Beam Weight	Beam It	Beam Ip	Station Weight	Station It	Station Ip	Station EI	Station GA	Station Stiffne
3		meters	meters	kg	kg-m²	kg-m²	kg	kg-m²	kg-m²	N-m²	N	N-m/rad
6	1	0.000	0.1	55.13495	0.218243	0.620268	27.56748	0.109121	0.310134	82304818.8	5619523859	6.3E+08
7	2	0.100	4.24	2337.722	-6991.29	26.29937	1722.128	-3479.44	45.65982	82304818.8	5619523859	1.5E+07
8	3	4.340	1.16	343.9441	-76.0948	2.080862	1456.873	-3530.58	20.42012	23802960	3022055053	1.6E+07
9	4	5.500	0.3	88.95105	-1.06519	0.538154	216.4476	-38.58	1.309508	23802960	3022055053	6.1E+07
10	5	5.800	0	0	0	0	770.8755	56.41741	114.1691	0	0	0
11	6	5.800	0.3	41.35121	-0.56212	0.1163	25.67561	-0.27906	0.06215	5144051.17	1404880965	1.3E+07
12	7	6.100	5	689.1869	-2870.64	1.938338	365.2691	-1435.6	1.027319	5144051.17	1404880965	790246
13	8	11.100	0.1	13.78374	-0.00359	0.038767	358.9353	-1435.25	1.137552	5144051.17	1404880965	4E+07
14	9	11.200	0	0	0	0	6.891869	-0.00179	0.019383	0	0	0
15				3570.1	-9939.4	31.632	4950.7	-9863.2	184.12			

	B	C	D	E	F	G	H	I	J
17	First Stn	Last Stn	Level Length	Total Level Weight	Level CG	Total Level It	Total Level Ip	Horizontal Position	Vertical Position
18			meters	kg	meters	kg-m2	kg-m2	meters	meters
19	1	5	5.8	4193.892	2.89864	17708.48	181.8687		
20	6	9	5.4	756.7718	8.507757	1896.592	2.246405	-0.3	-1.14438604
21	All stations			4950.664	3.756064	39775.16	184.1151		
22	All rotating stations			4950.664	3.756064	39775.16	184.1151		
23	All non-rotating stations			0	0	0			

See also

- Coupled Lateral-Torsional Analysis
- XLCoupled Worksheet
- XLCoupled Shaft Input Worksheet
- XLCoupled Beams Worksheet
- XLCoupled Cplg's Worksheet

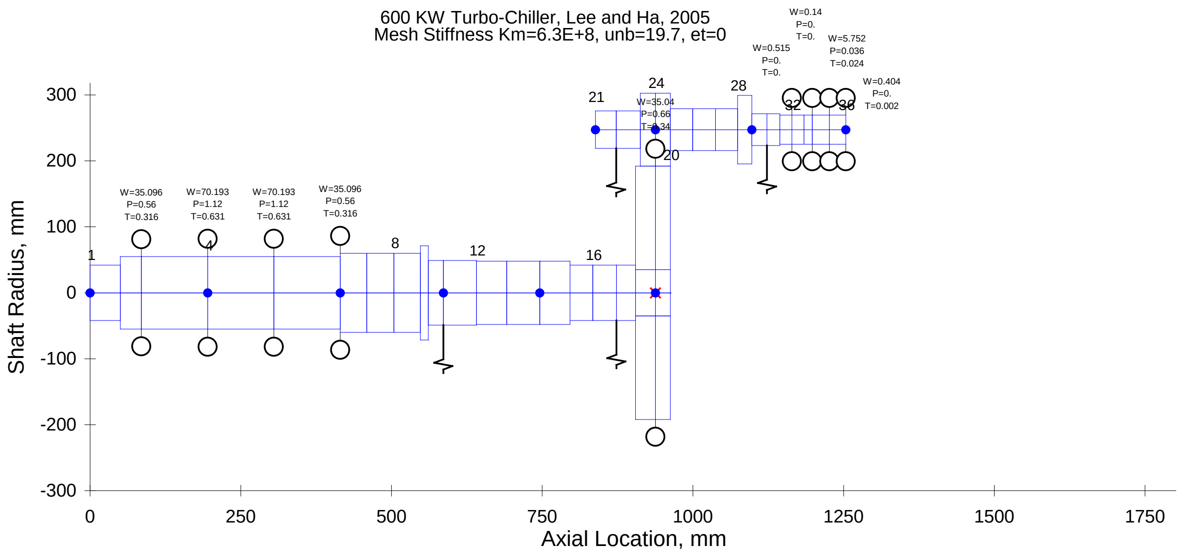
This worksheet serves the same purpose as in lateral and torsional rotor model files (see Stations Worksheet and Torsional Stations Worksheet). This version of the worksheet contains all the same columns which appear on either of those worksheets.

Note that in the same way as for torsional models, for coupled system models manual overrides for ***Horizontal Position*** and ***Vertical Positions*** can be entered in the summary table at the bottom of the sheet. See the Torsional Stations Worksheet for more about this feature.

XLCoupled Geometry Chart Sheet

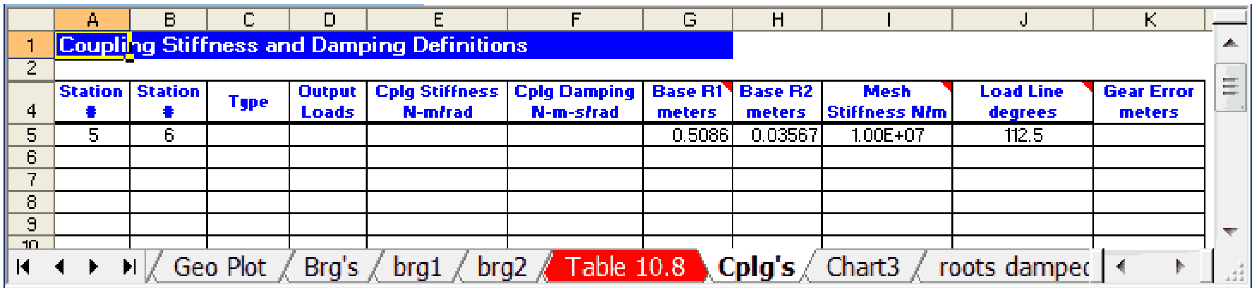
See also

- Coupled Lateral-Torsional Analysis
- XLCoupled Worksheet
- XLCoupled Shaft Input Worksheet
- XLCoupled Cplg's Worksheet



The Geo Plot for an XLCoupled model is created the same way as for a torsional model. If the positions of the rotors are not satisfactory, use the manual override feature described for the Torsional Stations Worksheet.

XLCoupled Cplg's Worksheet



	A	B	C	D	E	F	G	H	I	J	K
1	Coupling Stiffness and Damping Definitions										
2											
4	Station #	Station #	Type	Output Loads	Cplg Stiffness N-m/rad	Cplg Damping N-m-s/rad	Base R1 meters	Base R2 meters	Mesh Stiffness N/m	Load Line degrees	Gear Error meters
5	5	6					0.5086	0.03567	1.00E+07	112.5	
6											
7											
8											
9											

Geo Plot / Brg's / brg1 / brg2 / Table 10.8 / Cplg's / Chart3 / roots dampe(

See also

- Coupled Lateral-Torsional Analysis
- XLCoupled Worksheet
- XLCoupled Shaft Input Worksheet
- XLCoupled Beams Worksheet
- XLCoupled Stations Worksheet
- XLCoupled Imb's Worksheet
- XLCoupled Geometry Chart Sheet

This worksheet serves the same purpose as a Cplg's Worksheet in a torsional rotor model file.

Use this worksheet to specify couplings, and other discrete stiffness and/or damping elements in the model.

Your rotor model file can contain more than one "Cplg's" worksheet. For example, you might want multiple sheets so you can setup several configurations for your couplings. XLRotor will utilize the contents of whichever worksheet has the exact name of "Cplg's". You can switch between configurations by simply renaming the worksheets. Click *here* for instructions on how to copy a worksheet.

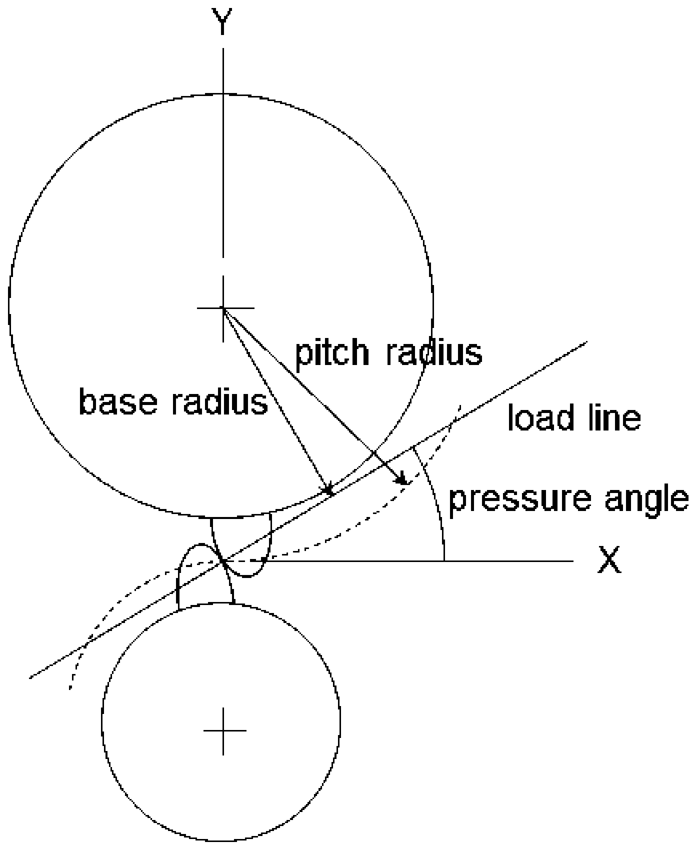
Station #, Type, Output Loads, Coupling Stiffness & Damping

These inputs are described on the page for Cplg's Worksheet.

Base Radius R1 & R2 (inches or meters)

These are the base radii of a mating pair of gears. Be sure to input *radius* and not diameter because this value is used to relate gear tooth forces to shaft torques (i.e. torque=force*radius). The ratio of the two radii should equal the ratio of the respective Speed Factors on the Shaft Input worksheet.

Base Radius = Pitch Radius*cos(pressure angle)



Mesh Stiffness (N/m or lbf/in)

This is the *linear* stiffness of the mesh contact point, in units of N/m or lbf/in. This is sometimes called the tooth stiffness, but it can include all sources of compliance in both gears. The most significant contributor is often bending of the teeth. Other contributions may include Hertzian contact deformation, and twisting of the gear bodies.

It is common for the mesh stiffness to be high enough to have little to no influence on results of either a torsional analysis or coupled lateral-torsional analysis. Coupling between lateral and torsional dynamics occurs even if the mesh stiffness is inifinite. However, do not input an excessively large value like 1e30 because this can cause numerical problems.

If you do not have an estimate for the stiffness, and just want to make it "rigid", use a value just large enough such that making larger has negligible effect. For example, compare results with 1e12 and 1e13. Results will probably match closely, in which case 1e12 would be a good choice.

Load Line (degrees)

The angle between the X axis and the line of action of the gear force, measured ccw (i.e. counter-clockwise). ccw is the direction of positive rotation. The above image illustrates this angle. If the gear pressure angle is input for the load line angle, that implies that the centers of both gears are on the Y axis.

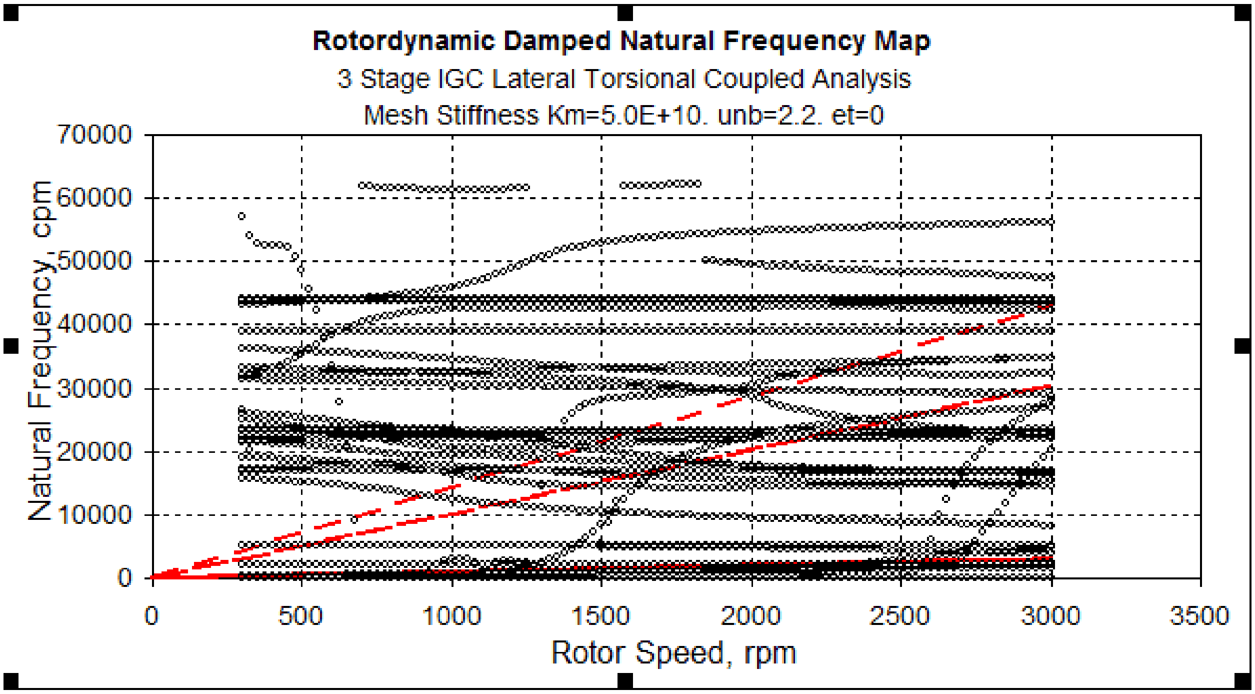
As an example, consider the pressure angle to be 20 degrees in the above image, with both gear centers on the Y axis. The input value for Load Line can be either 20 or 20+180=200, Both values will produce the same results for eigenvalues and mode shapes (i.e. it does not matter which direction the gears are rotating). However, it does matter for response calculations (phase angle output will be different).

Gear Error (inches or meters)

Gear error is used as an excitation for forced response calculations. It is not used for eigenvalues or mode shapes. The program will in effect multiply the gear error times the mesh stiffness to produce a force, and equal and opposite harmonic forces are applied at the stations connected by the gear mesh. What gear error physically represents is dictated by the frequency at which it is applied. If applied at the frequency of rotation of either gear, then it represents pitch line runout of the gear. If it is applied at gear mesh frequency, it represent tooth-to-tooth spacing error.

The frequency of excitation for a forced response calculation is determined as explained in XLCoupled Imb's Worksheet.

XLCoupled Roots Damped Worksheet



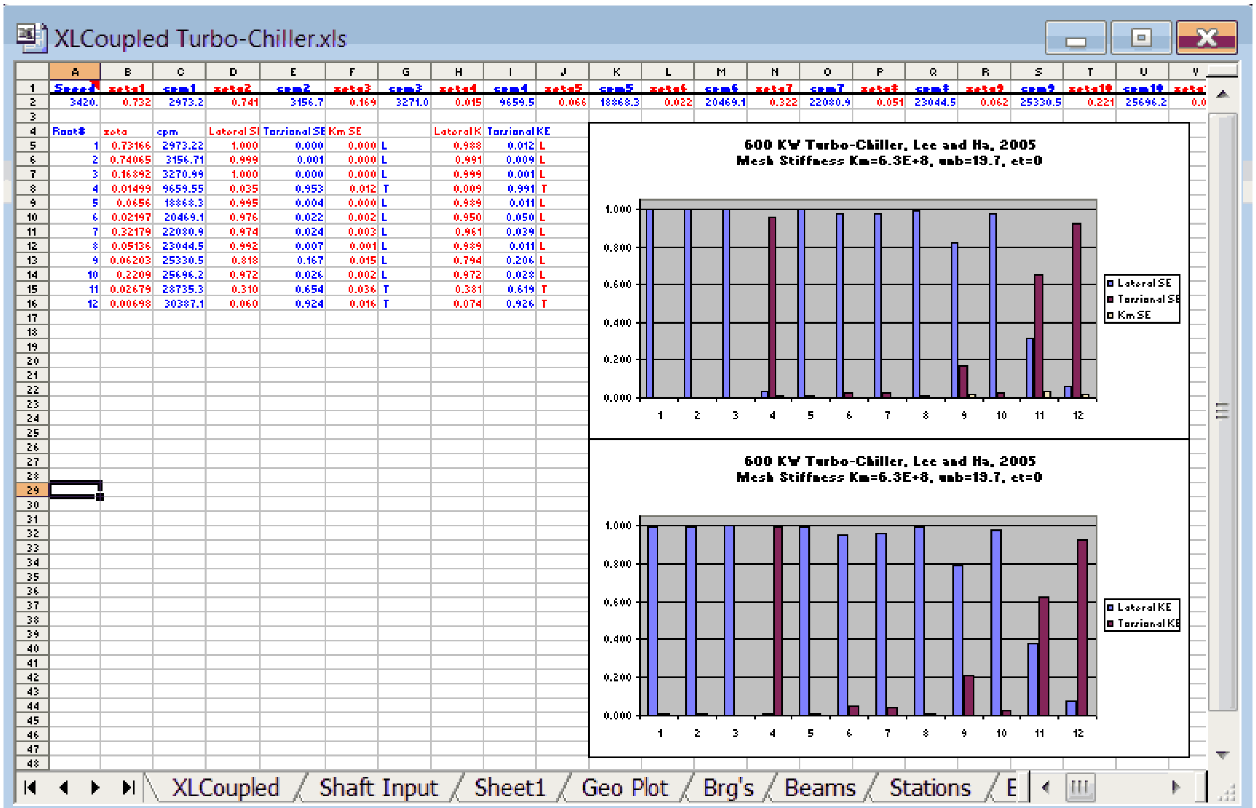
See also

- Coupled Lateral-Torsional Analysis
- Run|Eigenvalues
- XLCoupled Shapes Worksheet

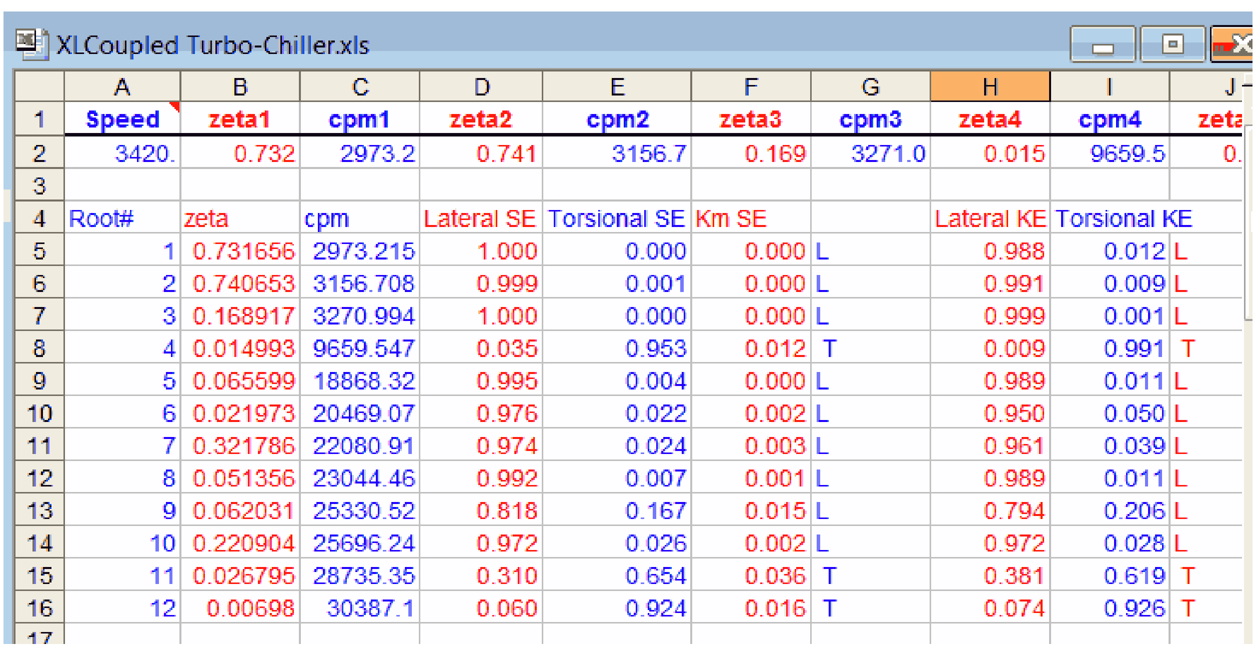
A **Roots Damped** worksheet displays the results of a damped eigenvalue analysis for both *lateral* XLRotor models and *coupled* XLCoupled models. A damped eigenvalue analysis is performed with the Run|Eigenvalues command. See Roots Damped Worksheet for more information about how this sheet is created.

One of the inherent difficulties of coupled system analysis is the large number of modes output by an eigenvalue calculation. The sample plot shown above is for an integrally geared compressor comprised of a motor driving two high speed pinions with a single bull gear (file for this model is in the Examples collection). The damped natural frequency plot (DNF) includes all the lateral modes of four separate rotors, plus all torsional modes. The red dashed curves in the plot are the synchronous excitation lines of the three different shaft speeds. It is challenging to identify which modes corresponds to which rotor, or which modes are dominated by lateral motion or torsional motion.

The speed range covered in the DNF plot is the list of speeds appearing on the XLCoupled Worksheet. If only a single speed were listed, for example operating speed, then instead of generating a DNF plot, a table of strain energy and kinetic energy is output, along with two histogram plots showing the energy distribution for each mode. In addition, when only a single speed is being run, *mode shapes for all* *roots are generated automatically at the conclusion of the run*, so a prompt may appear asking to append or overwrite the mode shapes on a Shapes Worksheet.

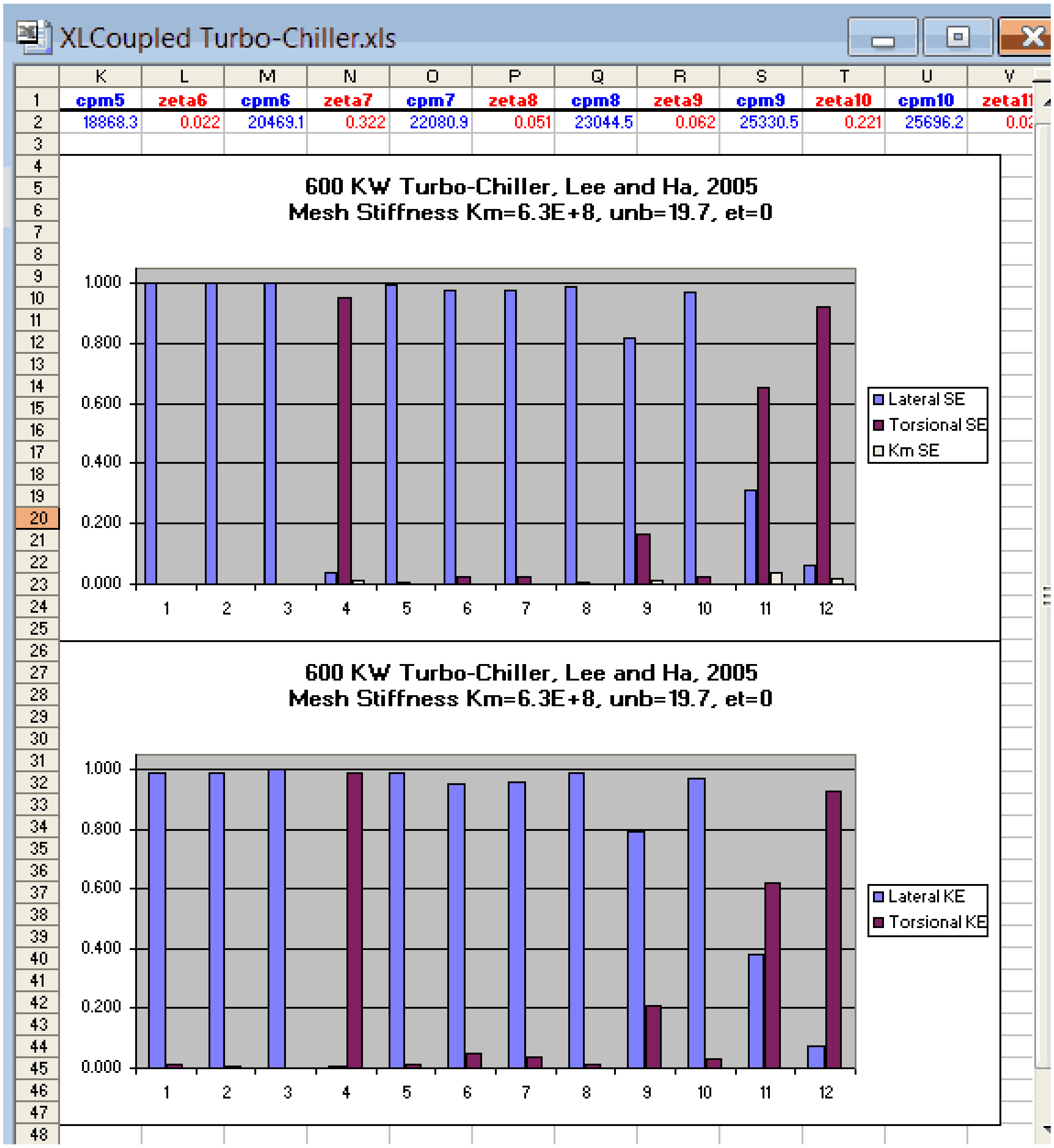


The above example is an overhung turbo-chiller which is the subject of several published papers by Lee and Ha (file for this model is in the Examples collection). The analysis was done for operating speed, which is 3420 rpm for the reference shaft, which in this model is the drive motor.

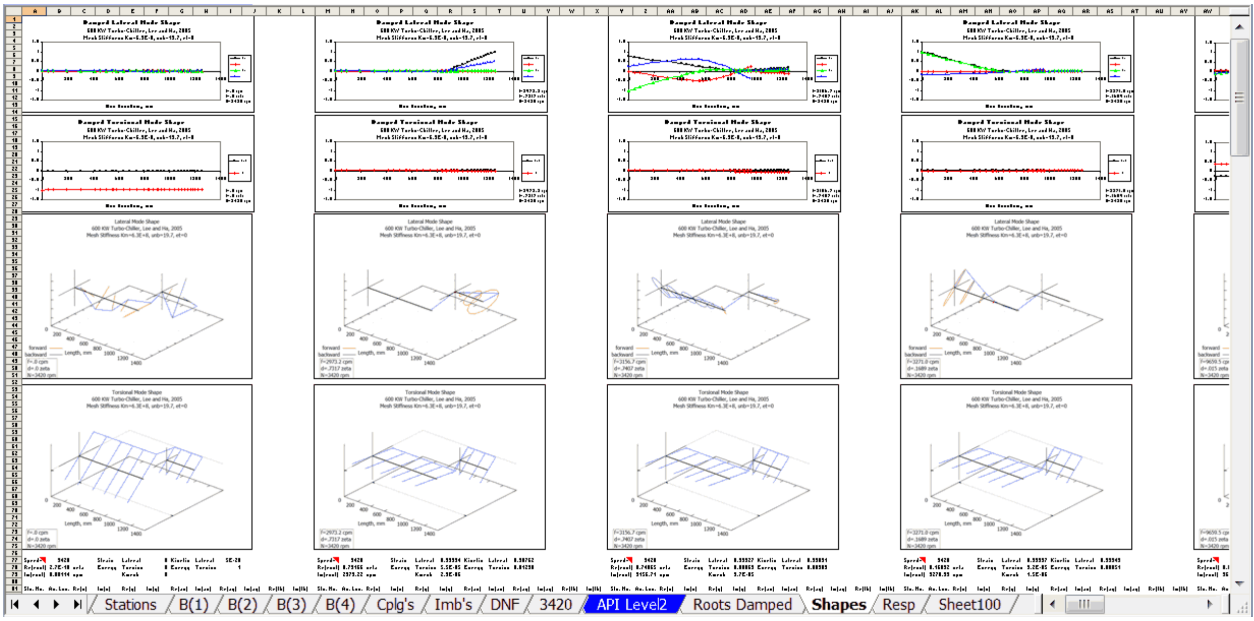

XLCoupled Turbo-Chiller.xls

	A	B	C	D	E	F	G	H	I	J
1	Speed	zeta1	cpm1	zeta2	cpm2	zeta3	cpm3	zeta4	cpm4	zeta
2	3420.	0.732	2973.2	0.741	3156.7	0.169	3271.0	0.015	9659.5	0.
3										
4	Root#	zeta	cpm	Lateral SE	Torsional SE	Km SE		Lateral KE	Torsional KE	
5	1	0.731656	2973.215	1.000	0.000	0.000	L	0.988	0.012	L
6	2	0.740653	3156.708	0.999	0.001	0.000	L	0.991	0.009	L
7	3	0.168917	3270.994	1.000	0.000	0.000	L	0.999	0.001	L
8	4	0.014993	9659.547	0.035	0.953	0.012	T	0.009	0.991	T
9	5	0.065599	18868.32	0.995	0.004	0.000	L	0.989	0.011	L
10	6	0.021973	20469.07	0.976	0.022	0.002	L	0.950	0.050	L
11	7	0.321786	22080.91	0.974	0.024	0.003	L	0.961	0.039	L
12	8	0.051356	23044.46	0.992	0.007	0.001	L	0.989	0.011	L
13	9	0.062031	25330.52	0.818	0.167	0.015	L	0.794	0.206	L
14	10	0.220904	25696.24	0.972	0.026	0.002	L	0.972	0.028	L
15	11	0.026795	28735.35	0.310	0.654	0.036	T	0.381	0.619	T
16	12	0.00698	30387.1	0.060	0.924	0.016	T	0.074	0.926	T
17										

The energy table lists the distribution of strain energy for each mode, along with a letter L,T or M indicating the largest component. ***Km SE*** is the strain energy in the mesh spring. A similar corresponding table for kinetic energy is also output (note: the mesh spring has no kinetic energy). A pair of histograms display this data in graphical form.



XLCoupled Shapes Worksheet



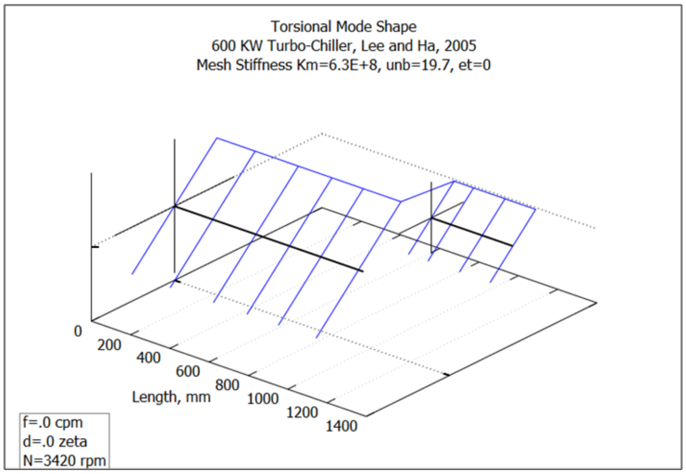
See also

- Coupled Lateral-Torsional Analysis
- Run|Eigenvalues
- Shapes Worksheet
- XLCoupled Roots Damped Worksheet

A **Shapes Worksheet** is where mode shapes are output for either lateral or lateral-torsional coupled models. For both types of models, mode shapes are generated in the same way as explained in Run|Mode Shapes.

Mode shapes for coupled models contain a great deal of information to be interpreted. The lateral and torsional mode shape data are displayed in separate plots. The above sample image shows mode shapes for the first four modes of a sample coupled system (file for Turbo-Chiller in the Examples folder). The 1st and 3rd rows of plots present lateral data. The 2nd and 4th rows present torsional data.

The first mode (i.e. lowest) has zero frequency, and is rigid body rotation of the entire train. All torsional and coupled models should have exactly one mode like this. Torsional mode shape data for coupled models is *always* presented in *equivalent shaft* form to make interpretation easier (see Options|Eigenanalysis). *Equivalent shaft* means the entire model rotates in the same direction at the same speed, and this is exhibited in the mode shape for the rigid body rotation mode.



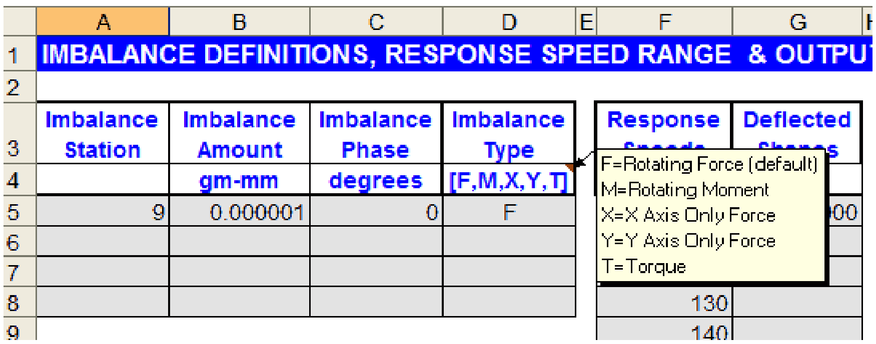
Torsional mode shape data is in radians. To enable direct comparison of torsional deflection to lateral deflection, all torsional mode shape data is multipled by the average diameter of all beams in the model. The 1st and 2nd rows of mode shape plots (i.e. the 2D plots) are plotted with the same Y axis scale, so the lateral and torsional plots are directly comparable, and will indicate the relative amounts of lateral and torsional motion. However, be aware that a mode which has very little torsional strain energy can still exhibit large torsional deflection if there is significant lateral movement at the gear mesh.

Unlike the 2D plots, the pair of 3D plots in the 3d and 4th rows are both scaled to maximize display of the motion. So their relative amplitudes are not directly comparable.

XLCoupled Imb's Worksheet

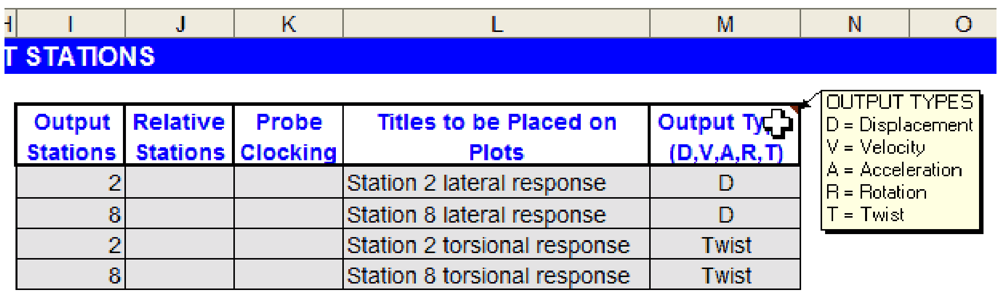
See also

- Coupled Lateral-Torsional Analysis
- XLCoupled Worksheet
- XLCoupled Shaft Input Worksheet
- XLCoupled Cplg's Worksheet
- XLCoupled Geometry Chart Sheet
- XLCoupled Resp Worksheet



IMBALANCE DEFINITIONS, RESPONSE SPEED RANGE & OUTPU

Imbalance Station	Imbalance Amount	Imbalance Phase	Imbalance Type	Response Speeds	Deflected Shapes
	gm-mm	degrees	[F,M,X,Y,T]		
9	0.000001	0	F		00
				130	
				140	



T STATIONS

Output Stations	Relative Stations	Probe Clocking	Titles to be Placed on Plots	Output Type (D,V,A,R,T)
2			Station 2 lateral response	D
8			Station 8 lateral response	D
2			Station 2 torsional response	Twist
8			Station 8 torsional response	Twist

This worksheet serves the same purpose as an Imb's Worksheet in a lateral rotor model file. The are only the following two differences for XLCoupled models.

Imbalance Type can be specified as ***T*** for torques to be applied at the corresponding station.

Output Type can be specified as ***T*** for twist. The program will output the absolute angle for single stations, or the relative twist between two stations. Output units is always milliradians.

All other input columns on this sheet have the same meanings as described for the lateral Imb's Worksheet.

The input columns for ***Response Speeds*** and ***Deflected Shapes*** will be further discussed here because coupled systems have rotors running at different speeds. For instance, imbalance response analyses for imbalance on the low speed or high speed shafts must be run separately because the frequencies of excitation are different.

In the following paragraphs, the rotor(s) which has a Speed Factor equal to 1.0 is referred to as the "reference" shaft.

In analyses with purely *lateral* or purely *torsional* models, a value from the ***Response Speeds*** or ***Deflected Shapes*** column will *always* be the frequency of excitation, but not always for *coupled* models. For a *coupled* model, an imbalance on the *reference* shaft can be run like any normal imbalance response analysis. But if the imbalance is on a high speed shaft, that requires switching to the option for ***Asynchronous*** response (see Options|Response), and all values in the ***Response Speeds*** and ***Deflected Shapes*** columns would need change to cover the relevant speed range of the high speed shaft.

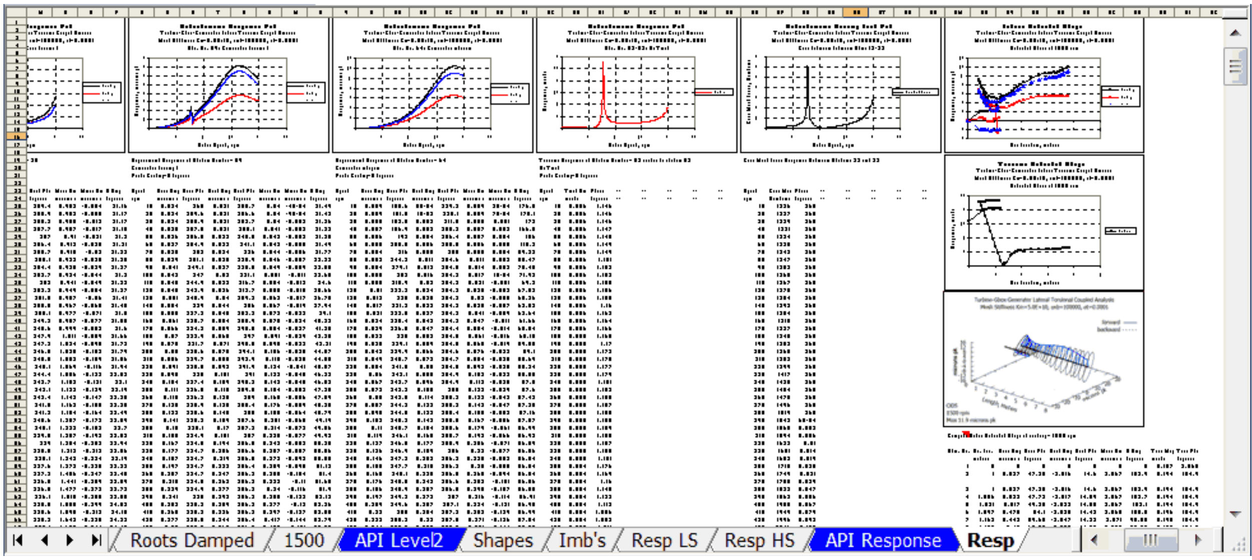
To make things easier for the user, if the imbalance is on a high speed shaft of a coupled model, XLRotor will automatically do the analysis as an asynchronous analysis, and change the excitation frequency to match the speed of the high speed shaft, but this is only done for *XLCoupled* models. This feature means an imbalance response analysis can be run with imbalance on *any* of the rotors in the model, without needing to change program options or input speeds. The program checks that all imbalances are on rotors running at the same speed, and will not allow imbalances to be applied simultaneously on rotors running at different speeds.

Example:

- The reference shaft is a motor with 3000 rpm maximum operating speed.
- The high speed shaft is an intregrally geared compressor rotor with 28,500 rpm maximum operating speed.
- The gearbox is single stage. The gear ratio is 28500/3000=9.5.
- On the Shaft Input sheet the Speed Factor for the low speed shaft line is +1.0, and -9.5 for the high speed shaft line.
- We first run a synchronous response analysis with imbalance on the motor.
- In the Options|Response dialog we select the Forcing Function/Imbalance option (i.e. a regular synchronous response analysis).
- We input a suitable list of Response Speeds covering the motor's speed range, from 100 rpm to 4000 rpm.
- We input imbalance at stations of the motor.
- If we have a non-zero gear error on the Cplg's sheet, that will be applied along with the imbalance, and represents pitch line runout of the low speed gear.
- We do Run|Response and the output will be tables and plots of response from 100 rpm to 4000 rpm.
- We then move the imbalance from the motor rotor to the compressor rotor.
- If the gear error is still non-zero, it will now represent pitch line runout of the high speed gear.
- We do Run|Response and the output will be tables and plots of response from 950 rpm to 38,000 rpm.
- Since the imbalance was moved to the high speed shaft, XLRotor automatically modified the analysis parameters to correspond to the speed range of the high speed

rotor, and this is reflected in the output because it spans 950-38,000 rpm even though the input speed range on the Imb's sheet was 100-4000.

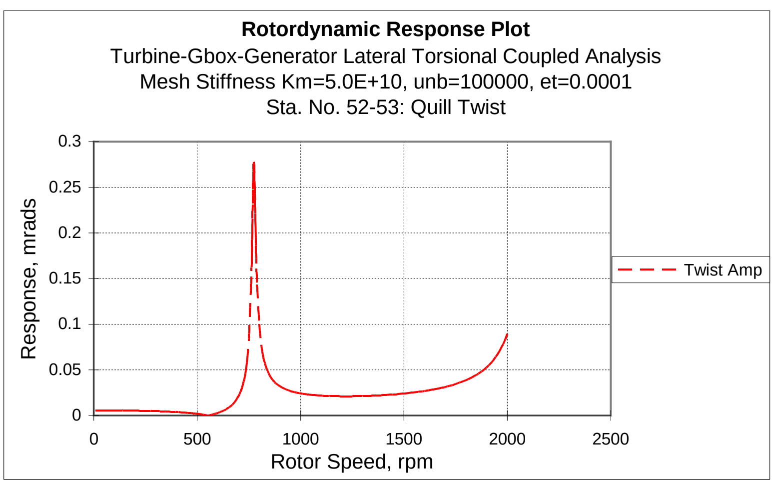
XLCoupled Resp Worksheet

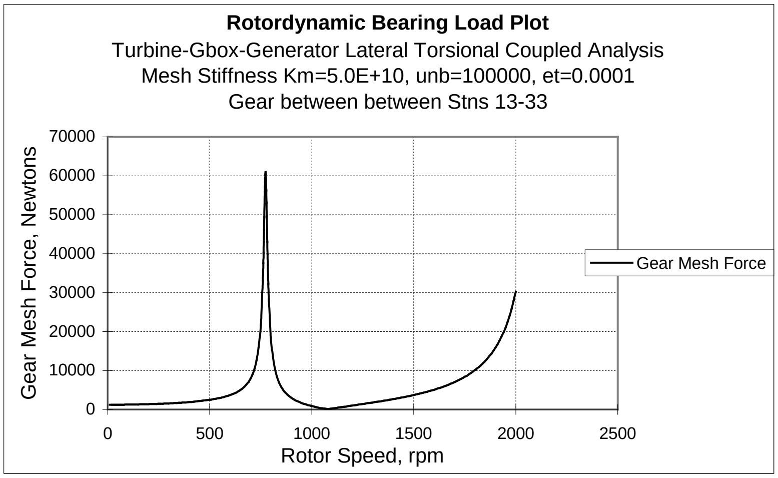


See also

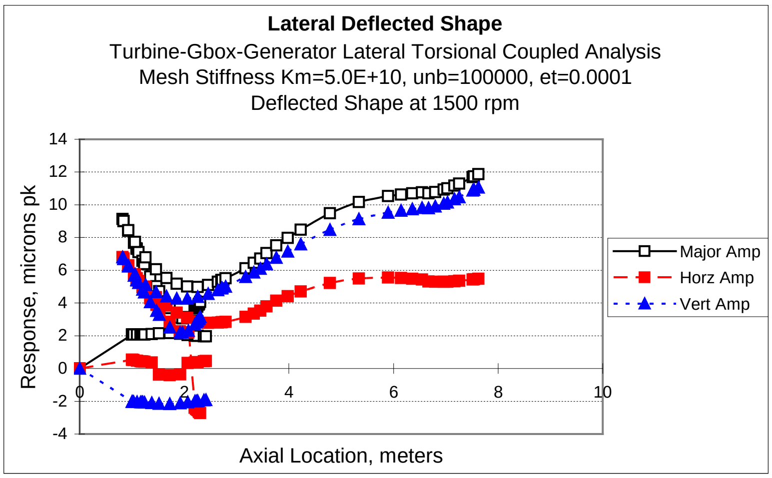
- Coupled Lateral-Torsional Analysis
- Resp Worksheet
- Torsional Resp Worksheet
- XLCoupled Imb's Worksheet

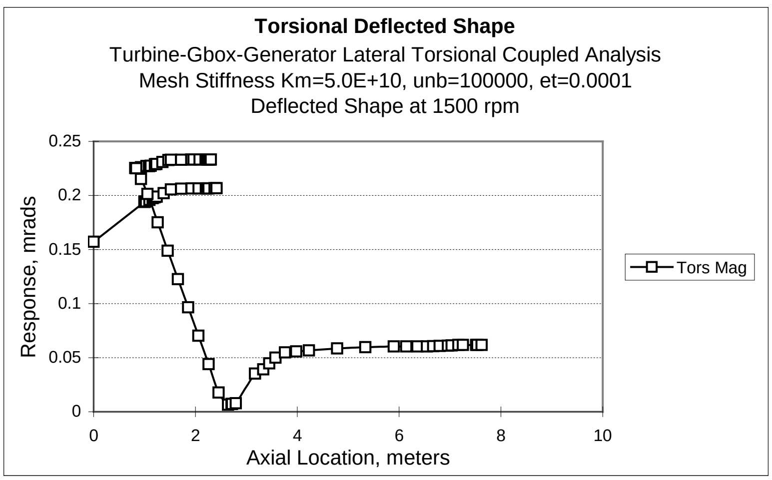
This worksheet displays the results of calculations for either the Run|Response or Run|Deflected Shapes commands. This worksheet is similar to those created for lateral and torsional models. Output can include shaft ***Twist*** in milliradians by secifying ***T*** on the Imb's Worksheet, and gear mesh force by putting ***Yes*** in the ***Output Loads*** column on the Cplg's Worksheet.

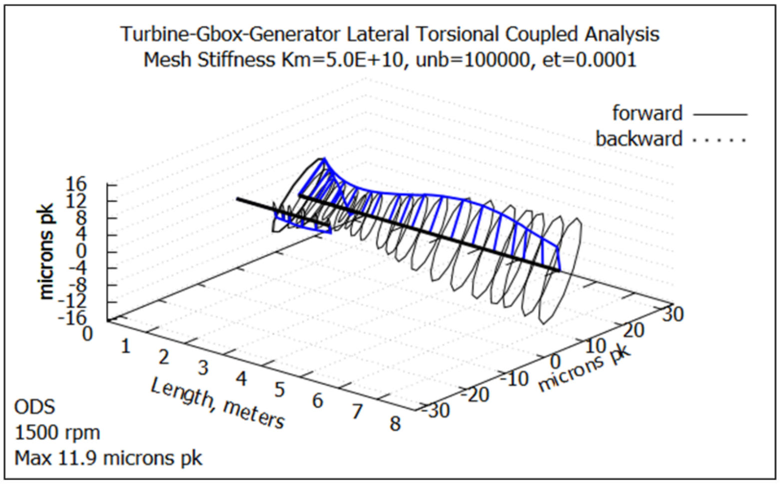




Deflected shape output has separate 2D plots for lateral and torsional deflection, and a 3D plot of lateral deflection. The 3D plot is generated using the Gnuplot plotting library.






Turbine-Gbox-Generator Lateral Torsional Coupled Analysis
Mesh Stiffness Km=5.0E+10, unb=100000, et=0.0001
forward
backward
microns pk
16
12
8
4
0
-4
-8
-12
-16
0
1
2
3
4
5
6
7
8
Length, meters
-30
-20
-10
0
10
20
30
microns pk
ODS
1500 rpm
Max 11.9 microns pk

Bearing Template Files

See also

- Brg's Worksheet
- Embedded Bearings
- Open Linked Bearing File

XLRotor models bearings and seals on separate worksheets. These worksheets can be in separate files from the rotor model, or in the rotor model file. There is a different spreadsheet driver for each basic type of bearing. To create a new file to setup and analyze a particular type of bearing, open its template file.

To see the easiest way to copy a bearing worksheet into your rotor model file, see the Open Linked Bearing File command.

The current set of bearing types (i.e. template files) that are part of XLRotor are:

XLJrnl	Standard Hydrodynamic Bearings
XLUserKC	User Defined Stiffness and Damping (you type in all the values)
XLBallB	Ball Bearing Stiffness, Stress and Deflection
XLCylind	Cylindrical Roller Bearing Stiffness, Stress and Deflection
XLAlford	Empirical Aerodynamic Crosscoupling for Axial Flow Stages
XLImplr	Empirical Aerodynamic Crosscoupling for Centrifugal Impellers
XLSFD	Worksheet for Squeeze Film Dampers
XLSuport	Worksheet for combining bearings with compliant supports (this sheet is obsolete)
XLHydst	Pocketed Hydrostatic Journal Bearings (i.e. pressure fed)
XLHydrodyn	(extra cost module) In-depth design of hydrodynamic bearings
XLShSeal	Incompressible Short Annular Seals (L/D<0.5)
XLAnnularSeal	Incompressible Annular Seals
XLGasLaby	Compressible flow labyrinth seals, straight through or interlocking
XLHoneycomb	Honeycomb and Round Hole Pattern Seals
XLUVA	XLRotor Drivers for the ROMAC Family of Bearing Codes
XLTransferFunction	Transfer functions, for active magnetic bearings and frequency dependent seals.
MIMO Transfer Functions	Multi-Input-Multi-Output transfer functions.

XLThrustBearing (extra cost module) analysis of oil lubricated thrust bearings

Each of these files contains worksheets in English and SI units. It is recommended to delete the sheet that is not being used. One workbook file can contain multiple copies of the same sheet. For example, an XLJrnl file can contain sheets for two or more bearings. Click *here* for instructions on copying worksheets.

All of these files should be marked as *READ ONLY* to prevent accidentally saving your work over the templates.

Each of the template workbook files should be located in:

for Windows Vista and later **C:\ProgramData\XLRotor\Templates**, or

for Windows XP **C:\Documents and Settings\All Users\Application Data\XLRotor\Templates.**

Note: In XLRotor versions 3.942 and later, units on a bearing sheet (US or SI) can be different than the rotor model units. XLRotor will internally convert units prior to model assembly. In addition, on XLUserKC sheets which are in SI units, units such as kN/m or kN/mm can be used. Simply enter the units which correspond to values entered on the sheet. A warning is displayed if the units for Kxx are not recognized as valid units. Only the units for Kxx are checked, and the same form is used for all other columns.

Embedded Bearings

See also

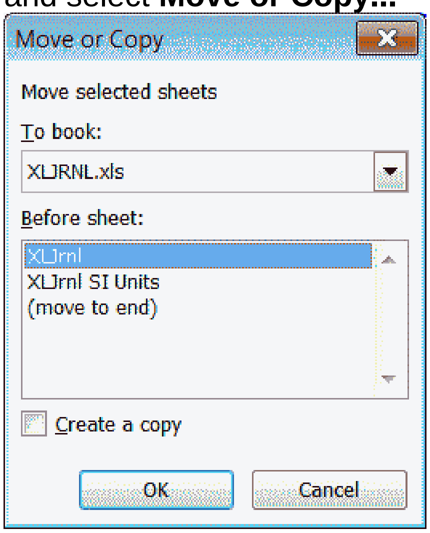
> Brg's Worksheet
> Bearing Template Files

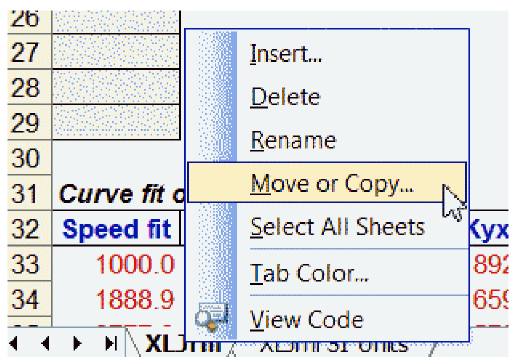
Normally, bearings are set up in files separate from the rotor model file, and are Linked to the rotor model file. An **embedded bearing** is a bearing that is setup on a worksheet right inside the rotor model file. In this way the entire model can be contained in a single workbook file.

Bearing worksheets can be moved into a rotor model file automatically (see Open Linked Bearing File) or manually. To do this manually, use the following procedure where you will essentially be *moving* the bearing worksheet from the bearing file to the rotor file.

1. Open your rotor model file, and open the your bearing file (see Bearing Template Files).

2. In the bearing file, while on the worksheet showing the stiffness and damping values, go to the **Edit** menu and select **Move or Copy Sheet**. Or right click the sheet tab and select **Move or Copy...**





3. In the dialog box that appears, make sure the **Create a Copy** option is *not* selected (do not use the Copy option since it does not always copy *embedded charts* correctly).

4. In the **To Book** list, select the destination rotor model file, and in the **Before Sheet** list select the position within the file to which to move the worksheet. Select **Ok**.

5. Close the bearing file without saving changes since the worksheet is no longer in the bearing file.

6. The Move operation is now complete. Save the rotor model file. Any buttons on the bearing worksheet will still function.

7. Finally, Link the title cell located on the bearing worksheet to the Brg's Worksheet in the normal fashion.

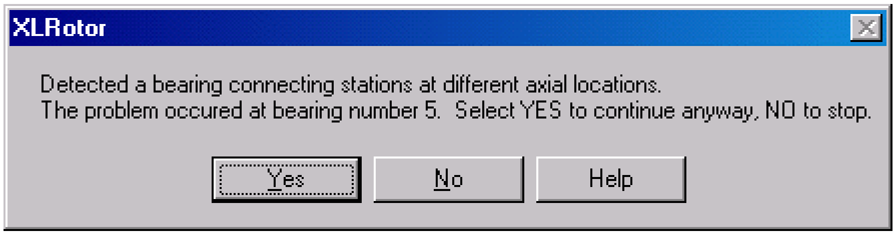
Note: Within the rotor model file you can ***rename*** the embedded bearing worksheet, this allows you to have more than one bearing worksheet inside the rotor model file - each with its own descriptive name.

Bearings Not at Same Axial Location

See also

- Brg's Worksheet
- XLUserKC.XLS User Defined Bearing Template File

Multiple levels in a rotor model need to to be connected to each other by bearings. This is how XLRotor determines the axial location of the various levels with respect to one another. So, if XLRotor finds that two stations connected to each other by a bearing cannot possibly be at the same axial location, this could mean there is an error in the model, but not always. That's why you get the warning, but also the option to continue the calculation anyway.



Curve Fitting

See also

XLJrnl.XLS Journal Bearing Template File

XLRotor uses polynomial curve fits versus speed for the stiffness and damping coefficients. Each of the 4 stiffness and 4 damping coefficients will be fit with its own polynomial. The parameters of the curve fit are: the Order of the Fit and the First Power of speed in the curve fit polynomial. The curve fit polynomial takes the following form:

$$Kxx(N) = N^{(FirstPower)}\left(a_0 N^0 + a_1 N^1 + \ldots + a_{OrderOfFit} N^{OrderOfFit}\right)$$

And similarly for all other stiffness and damping coefficients. The a's are the coefficients of the curve fit, which are computed and displayed on this worksheet.

It is recommended to always click the **Update Curve Fit** button whenever you change the stiffness and damping values, or either of the curve fitting parameters. This will allow you to verify the quality of the curve fit. However, if the curve is not updated, that will not affect any subsequent rotordynamic calculations.

When you perform an eigenvalue or response analysis, XLRotor retrieves the source stiffness and damping coefficients, along with the ***Order of Fit*** and ***First Power*** parameters. The cells which contain the curve fit coefficients are **not** utilized for the analysis. The curve fits are recalculated by the rotor analysis module, and that curve fit is used for the requested rotor analysis calculation.

N is speed in rpm. It will be either the current EIGENANALYSIS SPEED from the XLRotor Worksheet, or the current RESPONSE SPEED from the Imb's worksheet.

Important Note: For coupled lateral torsional analysis only, if the Speed Factor on Shaft Input worksheet is different that 1, it is multiplied times N. In addition, for bearings connecting *two* stations, the *difference* between their Speed Factors is used (i.e. relative speed).

Order of Fit

Enter this value into the appropriate cell on this worksheet. This is the degree of the polynomial to be fit to the stiffness and damping data points. The number of terms in the polynomials will be one plus the ***Order of Fit***.

The ***Order of Fit*** will usually be a number from 0 to 3. It can be any whole number greater than or equal to zero, but must be less than the number speeds in the coefficient data which is being curve fit.

Instead of curve fitting the data, piecewise linear interpolation will be used when the ***Order of Fit*** = -1 and the ***First Power*** = 0. This is the only situation where the ***Order of Fit*** can be negative.

First Power

Enter this value into the appropriate cell on this worksheet. It must be a whole number. The first term of the polynomial shown above will have the speed, N, raised to the ***First Power***. This input value cannot be greater than zero.

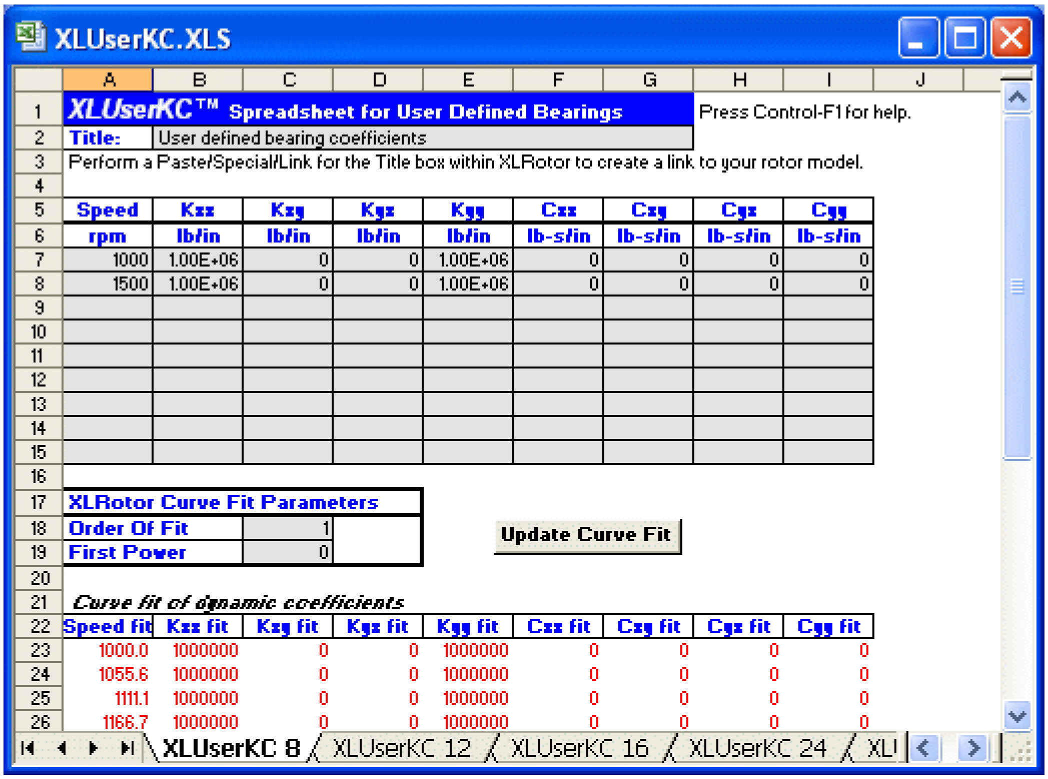
Note:
The ***First Power*** would usually be 0 or minus 1. In most cases it would be 0. This input would be -1 for bearings whose stiffness or damping asymptotically approach large values at zero speed. ***First Power*** cannot be greater than zero.

Note:
There is a table on this worksheet with columns named "Speed fit", "Kxx fit", etc. This table is used only to generate values for overplotting on the accompanying charts of stiffness and damping. If you want to increase or decrease the number of rows in this table, use the INSERT ROWS or EDIT DELETE menu commands to add or remove rows from the MIDDLE of the table. Then press the UPDATE CURVE FITS button to update the values in the table and charts. **Be sure to do your adding and deleting *between* the first and last rows of the table**.

XLUSERKC.XLS Template File
User Defined Bearing

See also

- Bearing Template Files
- Brg's Worksheet
- Embedded Bearings



This is a spreadsheet template file for defining your own stiffness and damping coefficients. Use this file for entering the stiffness and damping properties of a bearing or seal for which you get the values from a source outside of XLRotor (e.g., your own bearing program, or coefficients you get from someone else).

You enter the stiffness and damping coefficients directly into the table on the XLUserKC worksheet, along with the rotor speed in rpm. Curve Fitting is also done in exactly the same fashion as for an XLJrnl journal bearing file.

There are also charts showing your coefficients with the curve fits overlaid for comparison. See the Curve Fitting for a discussion of the curve fitting process.

You Link the contents of the Title cell located on the XLUserKC worksheet to a rotor model file (see Linking bearings to rotors).

This file is marked as a *READ ONLY* file.

As the above picture shows, there are multiple worksheet templates in this file. There are 6 in English units, and 6 in SI units. The 6 worksheets differ in the number of columns in the coefficient input table. It is recommended to delete any unused worksheets from the file.

1. XLUserKC 8 & XLUserKC 8 SI - This worksheet contains 8 input columns for; 4 lateral stiffness inputs and 4 lateral damping inputs. This is the worksheet that is used most often.

$$\begin{bmatrix} K_{xx} & K_{xy} \\ K_{yx} & K_{yy} \end{bmatrix} \& \begin{bmatrix} C_{xx} & C_{xy} \\ C_{yx} & C_{yy} \end{bmatrix}$$

2. XLUserKC 12 & XLUserKC 12 SI - This worksheet contains 12 input columns for; 4 lateral stiffness, 4 lateral damping, and 4 lateral inertia inputs.

$$\begin{bmatrix} K_{xx} & K_{xy} \\ K_{yx} & K_{yy} \end{bmatrix} \& \begin{bmatrix} C_{xx} & C_{xy} \\ C_{yx} & C_{yy} \end{bmatrix} \& \begin{bmatrix} M_{xx} & M_{xy} \\ M_{yx} & M_{yy} \end{bmatrix}$$

3. XLUserKC 16 & XLUserKC 16 SI - This worksheet contains 16 input columns for; 4 lateral stiffness, 4 lateral damping, 4 rotational stiffness, and 4 rotational damping.

$$\begin{bmatrix} K_{xx} & K_{xy} & & \\ K_{yx} & K_{yy} & & \\ & & K_{axax} & K_{axay} \\ & & K_{ayax} & K_{ayay} \end{bmatrix} \& \begin{bmatrix} C_{xx} & C_{xy} & & \\ C_{yx} & C_{yy} & & \\ & & C_{axax} & C_{axay} \\ & & C_{ayax} & C_{ayay} \end{bmatrix}$$

4. XLUserKC 24 & XLUserKC 24 SI - This worksheet has inputs in 24 columns;
   12 columns for lateral stiffness, damping and inertia.
   12 columns for rotational stiffness, damping and inertia.

$$\begin{bmatrix} K_{xx} & K_{xy} & & \\ K_{yx} & K_{yy} & & \\ & & K_{axax} & K_{axay} \\ & & K_{ayax} & K_{ayay} \end{bmatrix} \& \begin{bmatrix} C_{xx} & C_{xy} & & \\ C_{yx} & C_{yy} & & \\ & & C_{axax} & C_{axay} \\ & & C_{ayax} & C_{ayay} \end{bmatrix} \& \begin{bmatrix} M_{xx} & M_{xy} & & \\ M_{yx} & M_{yy} & & \\ & & M_{axax} & M_{axay} \\ & & M_{ayax} & M_{ayay} \end{bmatrix}$$

5. XLUserKC 32 & XLUserKC 32 SI - This worksheet has inputs in 32 columns;
   16 columns for a fully populated stiffness matrix.
   16 columns for a fully populated damping matrix.

$$\begin{bmatrix} K_{xx} & K_{xy} & K_{xax} & K_{xay} \\ K_{yx} & K_{yy} & K_{yax} & K_{yay} \\ K_{axx} & K_{axy} & K_{axax} & K_{axay} \\ K_{ayx} & K_{ayy} & K_{ayax} & K_{ayay} \end{bmatrix} \& \begin{bmatrix} C_{xx} & C_{xy} & C_{xax} & C_{xay} \\ C_{yx} & C_{yy} & C_{yax} & C_{yay} \\ C_{axx} & C_{axy} & C_{axax} & C_{axay} \\ C_{ayx} & C_{ayy} & C_{ayax} & C_{ayay} \end{bmatrix}$$

6. XLUserKC 48 & XLUserKC 48 SI - This worksheet is the most general version, allowing inputs in 48 columns.
   16 columns for a fully populated stiffness matrix.
   16 columns for a fully populated damping matrix.

16 columns for a fully populated inertia matrix.

$$\begin{bmatrix} K_{xx} & K_{xy} & K_{xax} & K_{xay} \\ K_{yx} & K_{yy} & K_{yax} & K_{yay} \\ K_{axx} & K_{axy} & K_{axax} & K_{axay} \\ K_{ayx} & K_{ayy} & K_{ayax} & K_{ayay} \end{bmatrix} \& \begin{bmatrix} C_{xx} & C_{xy} & C_{xax} & C_{xay} \\ C_{yx} & C_{yy} & C_{yax} & C_{yay} \\ C_{axx} & C_{axy} & C_{axax} & C_{axay} \\ C_{ayx} & C_{ayy} & C_{ayax} & C_{ayay} \end{bmatrix} \& \begin{bmatrix} M_{xx} & M_{xy} & M_{xax} & M_{xay} \\ M_{yx} & M_{yy} & M_{yax} & M_{yay} \\ M_{axx} & M_{axy} & M_{axax} & M_{axay} \\ M_{ayx} & M_{ayy} & M_{ayax} & M_{ayay} \end{bmatrix}$$

After you have selected which worksheet to use, delete all unused worksheets, and save the file with a new file name. Or see Embedded Bearings if you want to embed the bearing worksheet in the rotor model file.

Note: In versions 3.942 and later, units on a XLUserKC bearing sheet (US or SI) can be different than the rotor model units. XLRotor will internally convert units prior to model assembly. In addition, on XLUserKC sheets which are in SI units, units such as kN/m or kN/mm can also be used by simply changing the unit strings in the column headings. However, the units appearing in the Kxx column is the only one actually read by the program. A warning is displayed if the units for Kxx are not recognized as valid units. Only the units for Kxx are checked, and the same form is used for all other columns.

How your inputs get assembled into the system model

On an XLUserKC worksheet you can specify up to a full 4x4 matrix of coefficients for each of stiffness, damping, and inertia. When the XLUserKC worksheet is used to connect a station to ground, your input values are assembled directly onto the 4 degrees of freedom associated with the station.

When the XLUserKC worksheet is used to connect two stations to each other, how XLRotor assembles the input values depends on whether or not the two stations are at the same axial location.

Here is what happens when the two stations being connected are at the same axial location (this is the normal case). Where K represents the 4x4 stiffness matrix for the bearing. A similar thing is done for the damping and inertia matrices.

Global System Stiffness Matrix

$$\begin{array}{r} station\ 1 \\ \\ \\ station\ 2 \\ \\ \end{array} \begin{bmatrix} K & \bullet & \bullet & -K & \bullet \\ \bullet & \bullet & \bullet & \bullet & \bullet \\ \bullet & \bullet & \bullet & \bullet & \bullet \\ -K & \bullet & \bullet & K & \bullet \\ \bullet & \bullet & \bullet & \bullet & \bullet \end{bmatrix} \quad \text{where} \quad K = \begin{bmatrix} K_{xx} & K_{xy} & K_{xax} & K_{xay} \\ K_{yx} & K_{yy} & K_{yax} & K_{yay} \\ K_{axx} & K_{axy} & K_{axax} & K_{axay} \\ K_{ayx} & K_{ayy} & K_{ayax} & K_{ayay} \end{bmatrix} \begin{Bmatrix} x \\ y \\ ax \\ ay \end{Bmatrix}$$

When the two stations are ***not*** at the same axial location, the bearing is assembled as follows:

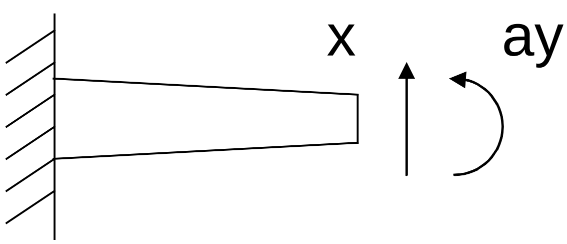
$$\begin{array}{r} station\ 1 \\ \\ \\ station\ 2 \\ \\ \end{array}\begin{bmatrix} L^T KL & \bullet & \bullet & -L^T K & \bullet \\ \bullet & \bullet & \bullet & \bullet & \bullet \\ \bullet & \bullet & \bullet & \bullet & \bullet \\ -KL & \bullet & \bullet & K & \bullet \\ \bullet & \bullet & \bullet & \bullet & \bullet \end{bmatrix}$$

where

$$L = \begin{bmatrix} 1 & 0 & 0 & (z2 - z1) \\ 0 & 1 & (z1 - z2) & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

and z1 and z2 are the axial locations of the two stations being connected (when the two stations are at the same axial location, the L matrix is equal to an Identify matrix). You provide the values that go in the 4x4 K matrix on an XLUserKC worksheet, and XLRotor computes the L matrix and uses it to compute the rest of the values for assembly into the global system stiffness matrix. The L matrix, and the way it is applied, arises from enforcing static equilibrium conditions across the stiffness element connecting the two stations. Pay special attention to the fact that the K matrix gets applied at station 2, and LtKL gets applied at station 1.

An example of where you might want to connect two stations in this fashion is when you want to input your own special beam element stiffness matrix.



Suppose for the above cantilevered beam you determine its stiffness properties (in the plane of the paper) to be as follows:

$$\begin{Bmatrix} F_x \\ M_{ay} \end{Bmatrix} = \begin{bmatrix} k_1 & k_3 \\ k_3 & k_2 \end{bmatrix} \begin{Bmatrix} x \\ ay \end{Bmatrix}$$

(note k3 is usually negative, but it can be positive).

In two planes, using the degree of freedom definitions of XLRotor, the 4x4 stiffness matrix at the right end of this beam is then:

$$\begin{Bmatrix} F_x \\ F_y \\ M_{ax} \\ M_{ay} \end{Bmatrix} = \begin{bmatrix} k_1 & 0 & 0 & k_3 \\ 0 & k_1 & -k_3 & 0 \\ 0 & -k_3 & k_2 & 0 \\ k_3 & 0 & 0 & k_2 \end{bmatrix} \begin{Bmatrix} x \\ y \\ ax \\ ay \end{Bmatrix}$$

This is the matrix you input on an XLUserKC worksheet.

If this beam connects two stations in the model, let the left end of the beam be at station 1, and the right end is at station 2. The 4x4 stiffness matrix shown relates loads applied at station 2, to the deflections at station 2, with the left end fixed. You input this 4x4 stiffness matrix to XLRotor, and XLRotor uses conditions of static equilibrium (given above) to complete the required 8x8 element stiffness matrix for the beam that gets assembled into the system stiffness matrix.

$$K=\begin{bmatrix} \frac{12EI}{L^3} & 0 & 0 & \frac{-6EI}{L^2} \\ 0 & \frac{12EI}{L^3} & \frac{6EI}{L^2} & 0 \\ 0 & \frac{6EI}{L^2} & \frac{4EI}{L} & 0 \\ \frac{-6EI}{L^2} & 0 & 0 & \frac{4EI}{L} \end{bmatrix} \begin{Bmatrix} x \\ y \\ ax \\ ay \end{Bmatrix}$$

Example of a beam of <u>constant</u> cross section, without shear terms, when station 2 is to the ***<u>right</u>*** of station 1.

$$K=\begin{bmatrix} \frac{12EI}{L^3} & 0 & 0 & \frac{6EI}{L^2} \\ 0 & \frac{12EI}{L^3} & \frac{-6EI}{L^2} & 0 \\ 0 & \frac{-6EI}{L^2} & \frac{4EI}{L} & 0 \\ \frac{6EI}{L^2} & 0 & 0 & \frac{4EI}{L} \end{bmatrix} \begin{Bmatrix} x \\ y \\ ax \\ ay \end{Bmatrix}$$

Example of a beam of <u>constant</u> cross section, without shear terms, when station 2 is to the ***<u>left</u>*** of station 1. The signs on the off diagonal terms change because of the right hand rule.

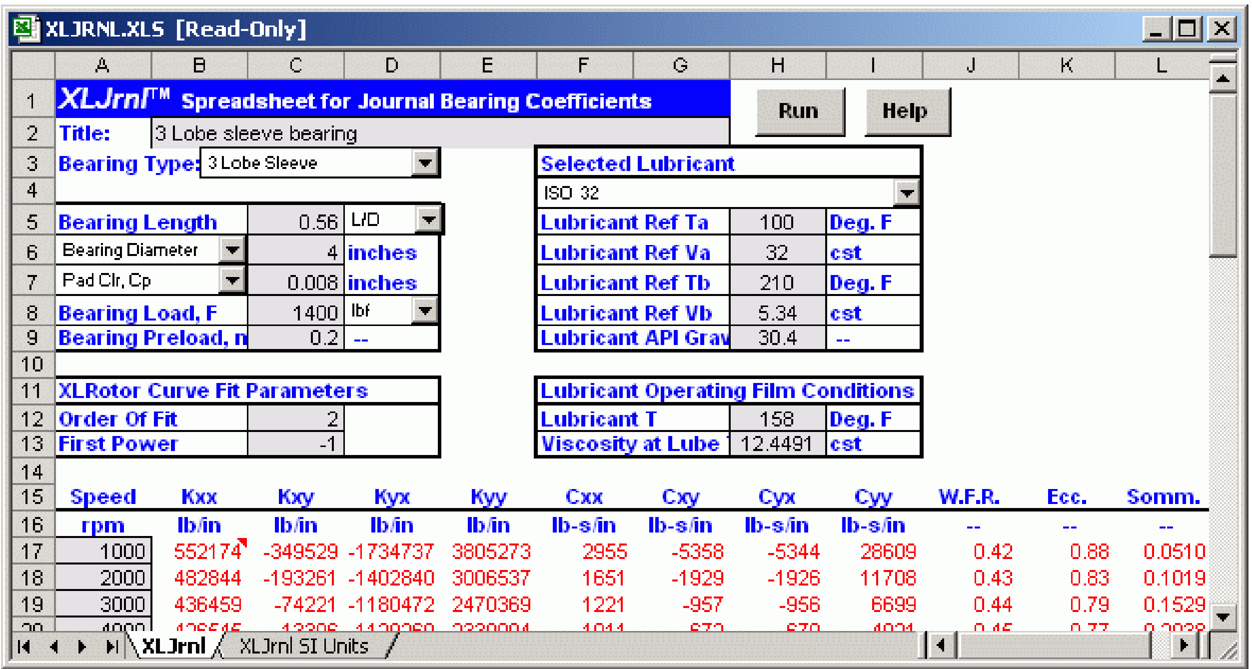
To enter either of the above example matrices on an XLUSERKC worksheet would require using either the 32 or 48 column version so you can enter the lateral-rotational coupling terms.

NOTE: When connecting two stations that are ***<u>not</u>*** at the same axial location, it matters whether station 2 is to the left or right of station 1. Station 1 is the station you enter in the first column on the Brg's Worksheet, and station 2 is listed in the second column.

XLJRNL.XLS Journal Bearing Template File

See also

- Bearing Template Files
- XLHydrodyn Template File
- Curve Fitting
- XLJRNL.DAT Database File
- Brg's Worksheet



The spreadsheet file, XLJRNL.XLS, is a driver for a hydrodynamic journal bearing program. This program outputs rotordynamic stiffness and damping coefficients for a variety of standard journal bearing types (tilt-pad, sleeve, partial arc, etc.). XLJRNL is a "lookup table" type of bearing program, and is based on the data and methods described in the book ***Journal Bearing Data Book***, by Tsuneo Someya, Springer-Verlag, 1989 (ISBN 354017074X). A "lookup table" type of bearing program is often adequate for analyzing rotor bearing system dynamics with hydrodynamic bearings, but it is not adequate for designing bearings for manufacture. This is mainly because critical oil film parameters such as peak pressure and temperature are not computed by the program (see the optional XLHydrodyn module). In addition, XLJRNL cannot address arbitrary loading directions (the load must be in the negative Y direction).

The original data in the Someya book was calculated for a small set of preloads and assuming laminar and isoviscous conditions. Starting with XLRotor version 3.90, the XLJrnl lookup table has been calculated entirely with XLHydrodyn. The same calculation assumptions were used, and ranges preload and Sommerfeld number were expanded.

To analyze a bearing, open this file and perform a File|Save As command to save a copy using a name of your choice. Then enter the parameters of your bearing and compute the rotordynamic coefficients.

You Link the contents of the Title cell located on the XLJrnl worksheet to a rotor model file (see Linking bearings to rotors).

This template file is marked as a *READ ONLY* file.

The input parameters are explained below. After defining or modifying your parameters, click the on-sheet **Run** button to update the stiffness and damping values, shown in a table on this sheet.

Running the XLJrnl Worksheet

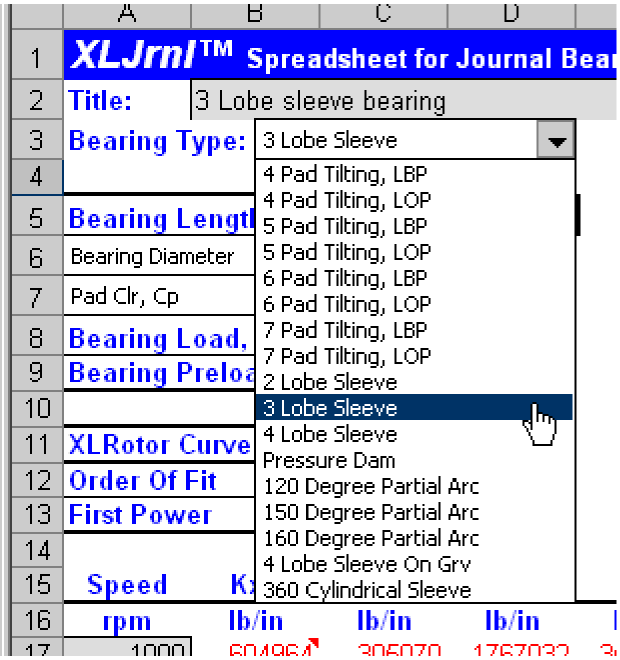
You run an analysis by doing any of the following:

- Click the ***Run*** button to execute the analysis on the currently active worksheet.
- Use the ***Shift*** and ***Control*** keys to select multiple worksheet tabs, then clicking the ***Run*** button will run the analysis on all the selected worksheets. Any of the selected sheets that are not XLJrnl sheets will be skipped.
- Hold the Shift key down and click the ***Run*** button, then all XLJrnl worksheets from the current worksheet to the end of the file will be run.

Title

Enter a descriptive title into this cell. This title will appear within the XLRotor rotor model file(s) to which it is Linked. It will also be copied to any charts of bearing load created during a response analysis. If you want the title to indicate the type of selected bearing, use the value in cell C3 (see next paragraph).

Bearing Type

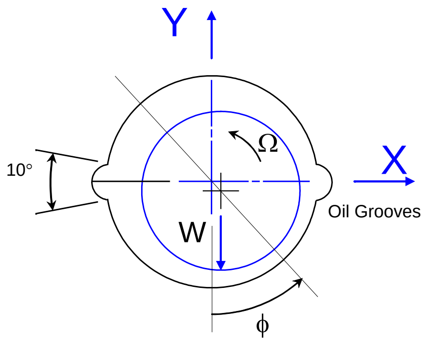


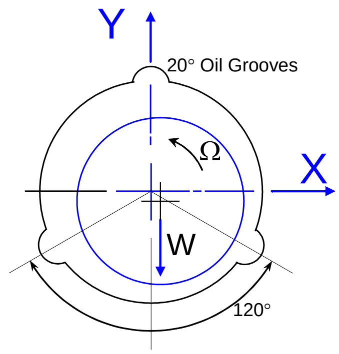
Select a bearing type from the drop down list. Depending on the type you select, some of the bearing input parameters are deactivated when they do not apply. The tilting pad bearings depicted below in a load-between-pad configuration are also available in a load-on-pad configuration. The 4 lobe sleeve bearing is also available in an orientation with a feed groove at the bottom, in line with the applied load. The bearing type you have selected is displayed in the drop down list, and is also placed in worksheet cell C3 (behind the drop down box). You can refer to cell C3 in other places where you want to show the selected bearing type.

Unlike all the other bearing types in XLJrnl, the "360 Cylindrical Sleeve" bearing is not treated by "lookup table." This is a very plain cylindrical sleeve bearing without oil supply grooves, either axially or circumferential. This type of bearing is used, for example, in long multistage pumps. The solution for this bearing is determined directly from analytical expressions due to Child's (***Turbomachinery Rotordynamics*** by Dara W. Childs, Wiley Interscience, 1993). The specific solution programmed in XLJrnl is for a laminar flow finite-length bearing with pi cavitation. This solution assumes that the bearing is adequately supplied with lubricant in some fashion so as to avoid lubricant starvation.

2 Lobe Sleeve
(elliptic, lemon bore)

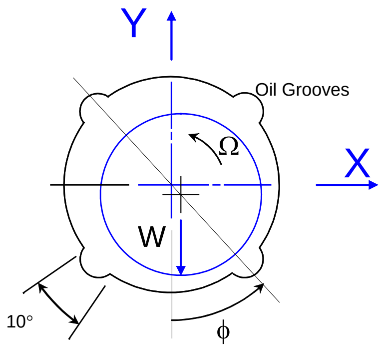
3 Lobe Sleeve

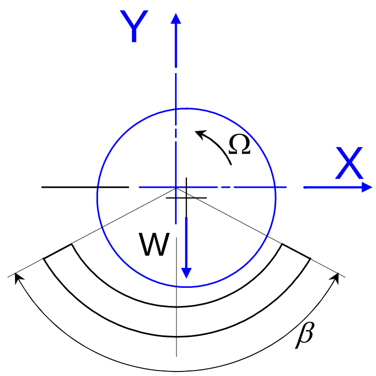




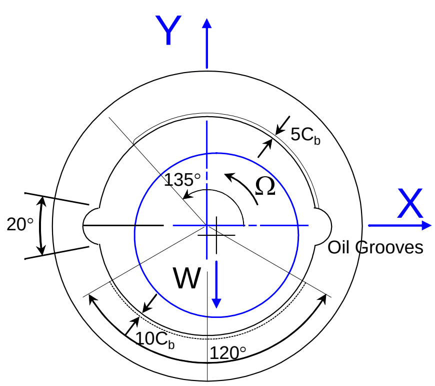
4 Lobe Sleeve

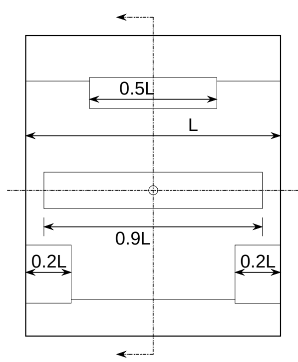
Partial Arc





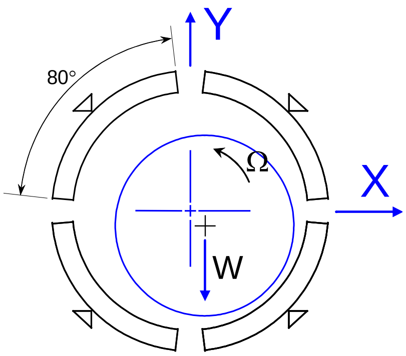
Pressure Dam



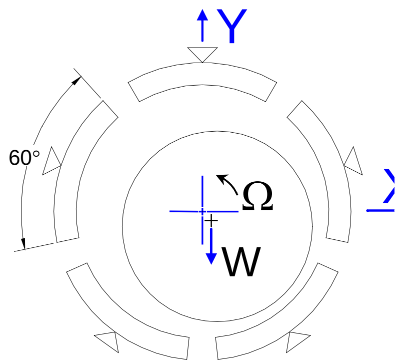


4 Pad Tilting

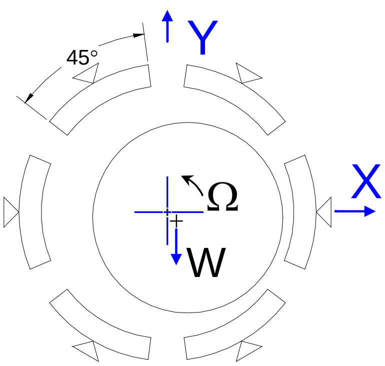
5 Pad Tilting

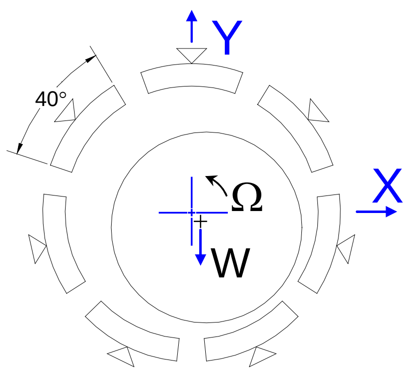


6 Pad Tilting



7 Pad Tilting

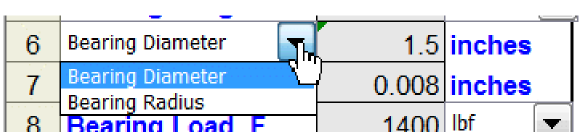




Bearing Length

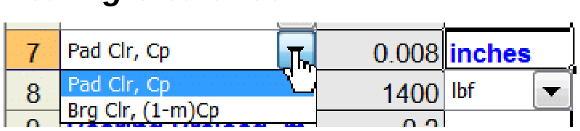
The bearing length can be entered as either a length in inches (meters), or as an L/D ratio. Make your selection from the adjoining drop down list, and enter the corresponding parameter.

Bearing Diameter



The size of the bearing journal can be entered as either a diameter or a radius. Make your selection from the adjoining drop down list, and enter the corresponding parameter.

Bearing Clearance



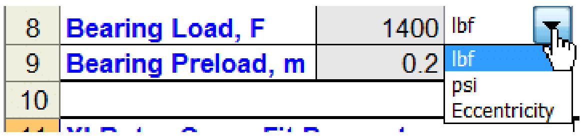
The diametral clearance of the bearing can be entered as either the original as-machined Pad Clearance (Cp, also known as pad bore clearance), or as the set preloaded clearance often called the Assembled Bearing Clearance (Cb). Make your selection from the adjoining drop down list, and enter the corresponding parameter. Note that the clearance must always be entered as a diametral value.

These two clearance definitions are related as follows:

Bearing Clearance = Cb = Cp*(1-m)

Where m is the preload fraction. When the preload is zero, the pad bore clearance and assembled clearance are equal.

Bearing Load



The static journal load can be entered either as a load in pounds (Newtons), or as a **projected load** in psi (N/m^2). Make your selection from the adjoining drop down list, and enter the corresponding parameter.

Load = (Projected Load)*(D*L)

As depicted in the above images of the various bearing types available in the data base, the load must be directed downward. For situations where the load is not downward, the bearing and its loading should be analyzed in detail as opposed to using a lookup table data base. See the optional XLHydrodyn module.

There is also an option to input the static ***eccentricity*** instead of the static load. With this option selected, enter a dimensionless static eccentricity value between zero and 1 in the ***Load*** input cell. The program will determine the load corresponding to the eccentricity, and an output column for Load will be added to worksheet. The dimensionless eccentricity is the true radial eccentricity divided by the radial pad bore clearance.

If both the bearing and the load are oriented *clockwise* an angle θ from the -Y axis, the coordinate system of the force coefficients output by XLJrnl can be rotated to correspond to X & Y using the following expression:

$$\begin{bmatrix} K_{xx} & K_{xy} \\ K_{yx} & K_{yy} \end{bmatrix}_{rotated} = \begin{bmatrix} \cos\theta & -\sin\theta \\ \sin\theta & \cos\theta \end{bmatrix}^T \begin{bmatrix} K_{xx} & K_{xy} \\ K_{yx} & K_{yy} \end{bmatrix}_{XLJrnl} \begin{bmatrix} \cos\theta & -\sin\theta \\ \sin\theta & \cos\theta \end{bmatrix}$$

The same expression applies to the damping coefficients. An XLUserKC sheet could be used to perform this calculation.

Note that for the special case of an angle of 180 degrees (i.e. up instead of down), the rotated coefficients are identical to the original force coefficients output by XLJrnl.

Bearing Preload

The as-machined Pad Bore Clearance is often reduced by moving the bearing pads closer to the journal. The fraction by which the clearance is reduced is the preload fraction, m. A preload of 1 would result in line to line contact of the pads on the journal. A preload of 0.2 reduces the Pad Clearance by 20% (each pad would be moved closer to the journal an identical amount).

In XLJrnl, the preload cannot be less than 0, and cannot be greater than the tabulated maximum for the particular bearing type (usually 0.80).

Not all available bearing types have preload (e.g., partial arc). For these, the preload input is deactivated.

Selected Lubricant

Use your mouse to select an appropriate lubricant from the drop down list. The lubricant's reference properties are then read from a file named LUBE.XLS, and are placed in the 5 corresponding input cells. If the lubricant you want is not included in the drop down list, select the lubricant named USER DEFINED, and enter your own values for the lubricant properties.

The name of the selected lubricant which is currently displayed in the drop down is also placed in the worksheet cell immediately behind the dropdown. This is to enable you to easily refer to the name of the lubricant somewhere in your file.

Each time the selected lubricant is changed, a worksheet cell formula in the ***Viscosity at Lube T*** cell is refreshed.

Lubricant T

The temperature you enter here can be used, along with the lubricant reference properties, to compute the lubricant ***Viscosity at Lube T***, which in turn is used to compute the Sommerfeld number for the bearing (see below). This temperature input is not used for anything else.

Viscosity at Lube T

This is the kinematic viscosity value entered in units of cst. After conversion to absolute viscosity, it is used to evaluate the Sommerfeld number (see below). It is computed from the following equation for viscosity as a function of temperature. Normally this worksheet cell will contain this formula. If this cell is empty, the equation is put in the cell when you change the ***Selected Lubricant*** in the drop down list. The viscosity/temperature equation is as follows:

$$\mu(T) = \mu_A e^{\left[\left(\frac{T-T_A}{T_B-T_A}\right)\ln\left(\frac{\mu_B}{\mu_A}\right)\right]}$$

You can replace the cell formula for the above expression with your own formula, or simply enter a numerical value for viscosity.

Sommerfeld Number at Lube T

The Sommerfeld number for the bearing is computed from:

$$S = \frac{\mu NLD}{60W}\left(\frac{R}{C_p}\right)^2$$

This formula appears in many textbooks and also API specification documents. Where ***N*** is the rotor speed in ***rpm***, and ***C*** is the radial pad bore clearance. In some applications the clearance would be the assembled bearing clearance, but here it is the pad bore clearance (see below). Be aware that there is another definition of Sommereld number (sometimes called a European definition) that is the reciprocal of the above expression and uses speed in radians per second instead of rpm/60.

XLRotor computes this value, then multiplies it by the ratio of the L/D of your bearing divided by the L/D of the database's "reference" bearing, with this ratio raised to a power which is different for different bearing types. The reference L/D happens to always be 0.5 for all data in the XLJRNL.DAT database file. So, whenever your bearing L/D is 0.5 the Sommerfeld number on the worksheet will exactly match the value computed with the above expression. But when the L/D is other than 0.5 it can be different.

As is done in the Someya journal bearing data book, the pad bore clearance is used to compute the Sommerfeld number. When a preload is specified between preload values in the database, an interpolation is performed. Using the pad bore clearance to compute the Sommerfeld number then means the same Sommerfeld number is used for each preload during the interpolation. The database for most of the bearings contains preloads ranging from 0 to 0.8.

Also be aware that the Sommerfeld number output by many full featured journal bearing design programs may use viscosity at the oil supply temperature, and not temperature in the film land, and also might use the assembled bearing clearance instead of the pad bore clearance.

Reynolds Number at Lube T

This is the Reynolds number. The kinematic viscosity ν is the input value for ***Viscosity at Lube T***. ***R*** is the journal radius. ω is the journal speed in radians per second, and ***C*** is the radial pad bore clearance.

$$\mathrm{Re} = \frac{R\omega C}{\nu}$$

The database is evaluated assuming laminar flow conditions (i.e. **Re**=0). Per Someya, the transition from laminar to turbulent flow generally occurs for **Re** numbers between 1500 and 3000, though it depends on the size of the bearing and operating conditions. The effect of turbulence can be approximated by essentially increasing the viscosity, which in turn increases the Sommerfeld number, according to the following expression due to Someya. This expression is not implemented in the XLJrnl program.

$$S_{eff} = \left(1 + 0.0007768\,\mathrm{Re}^{0.9}\right) \cdot S$$

Journal Speed

Enter a list of journal speeds (in rpm) for which to compute the rotordynamic coefficients. You can enter as many speeds as you want, in any order that you want. **The program will stop at the first blank cell in the column.**

Order of Fit

This is the degree of the polynomial to be fit to the stiffness and damping data points. The number of terms in the polynomials will be one plus the Order of Fit. See Curve Fitting for more details about curve fitting.

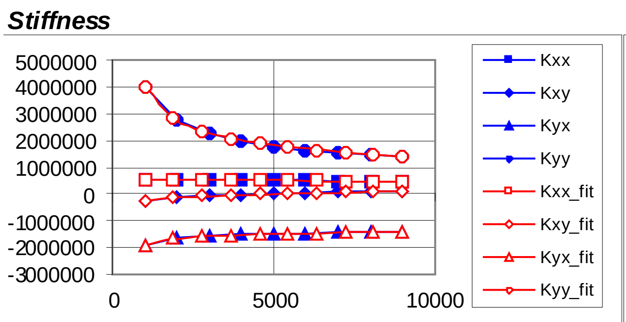
First Power

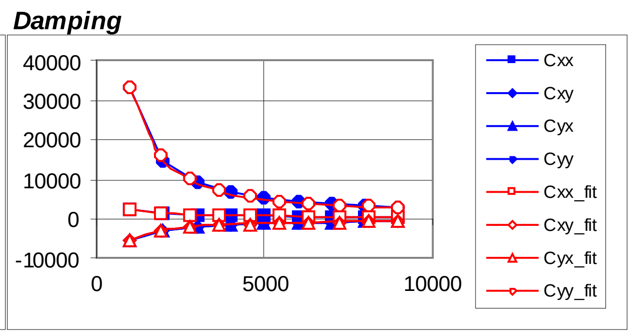
The first term of the curve fit polynomial will have the speed, N, raised to the First Power. See Curve Fitting for more details about curve fitting.

Kxx...Cyy Stiffness and Damping Coefficients

These are the primary outputs that are updated when you click the RUN button. The first cell in the Kxx column is also given a cell comment that documents the date and time of the analysis, along with the analysis inputs.

The worksheet also contains charts that show both the computed stiffness and damping values and their corresponding curve fits. You may modify the formats of these charts as you wish.





Whirl Frequency Ratio & Eccentricity

The Whirl Frequency Ratio (WFR) is calculated from the cross coupled stiffness and direct damping. It is often close to 0.5 for fixed geometry journal bearings, and zero (or close to zero) for tilting pad bearings.

$$WFR = \frac{K_{xy} - K_{yx}}{\frac{\pi}{30} N (C_{xx} + C_{yy})}$$

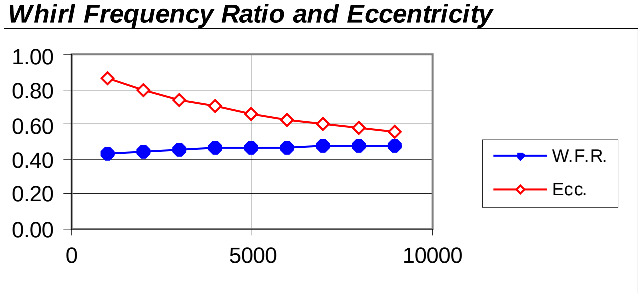
where N = journal speed, in rpm

The static eccentricity ratio is defined as the radial journal displacement from the bearing center, divided by the radial bearing clearance (in this case the assembled bearing clearance, not the pad bore clearance). A value of 0 means the journal is at the center of the bearing, and 1 means the journal is close to rubbing on the bearing. In tilting pad bearings this ratio can be greater than one when the journal static displacement is between two pads.

The database used by XLJrnl ranges from eccentricities of about 0.05 to 0.95. It does not go all the way to either 0 or 1. If the input conditions of speed and load would have the bearing running at eccentricities less than about 0.05 or greater than about 0.95, the program will display a warning about the journal being too close to the center or too close to rubbing.

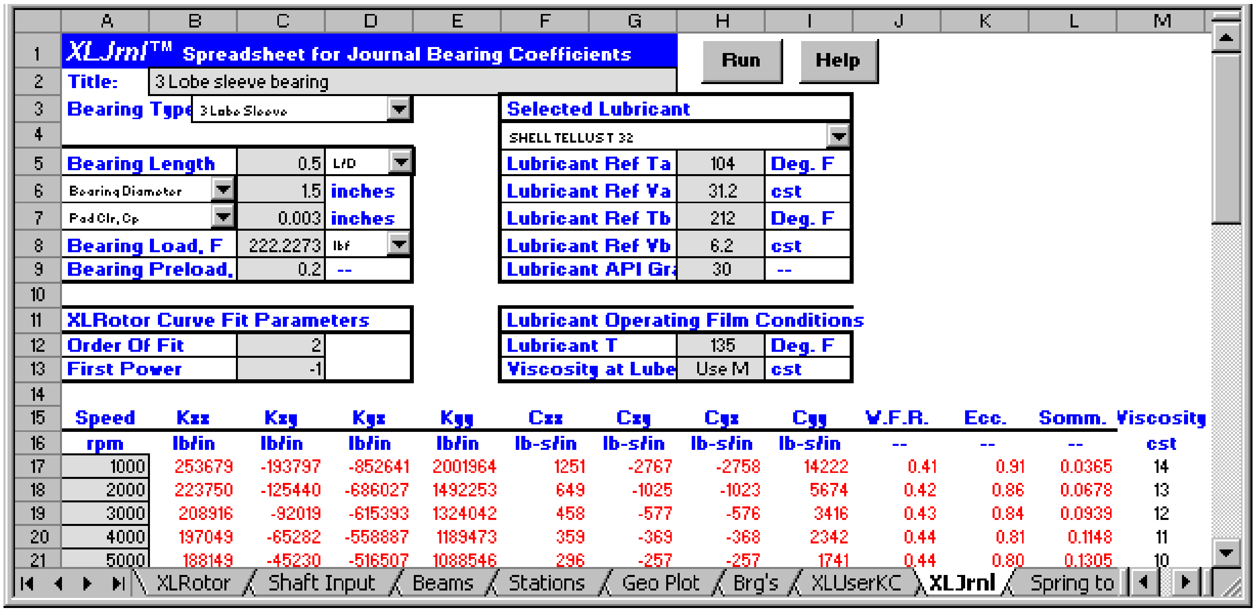
The accompanying chart illustrates how these two parameters vary with speed.

Whirl Frequency Ratio and Eccentricity



Speed dependent inputs

Some of the XLJrnl inputs may change with rotor speed (e.g., viscosity). When this is the case, you can add a column of inputs on the right hand side of the Speed input table. The figure below shows that a column (column M) has been added, and the string "***Use M***" has been placed in the viscosity input cell. This tells XLRotor to look in ***column M*** for a viscosity input at each speed. This same technique can also be used with any of the other inputs.



Speed	Kxx	Kxy	Kyx	Kyy	Cxx	Cxy	Cyx	Cyy	V.F.R.	Ecc.	Somm.	Viscosity
rpm	lb/in	lb/in	lb/in	lb/in	lb-s/in	lb-s/in	lb-s/in	lb-s/in	--	--	--	cst
1000	253679	-193797	-852641	2001964	1251	-2767	-2758	14222	0.41	0.91	0.0365	14
2000	223750	-125440	-686027	1492253	649	-1025	-1023	5674	0.42	0.86	0.0678	13
3000	208916	-92019	-615393	1324042	458	-577	-576	3416	0.43	0.84	0.0939	12
4000	197049	-65282	-558887	1189473	359	-369	-368	2342	0.44	0.81	0.1148	11
5000	188149	-45230	-516507	1088546	296	-257	-257	1741	0.44	0.80	0.1305	10

XLJRNL.DAT Database File

See also

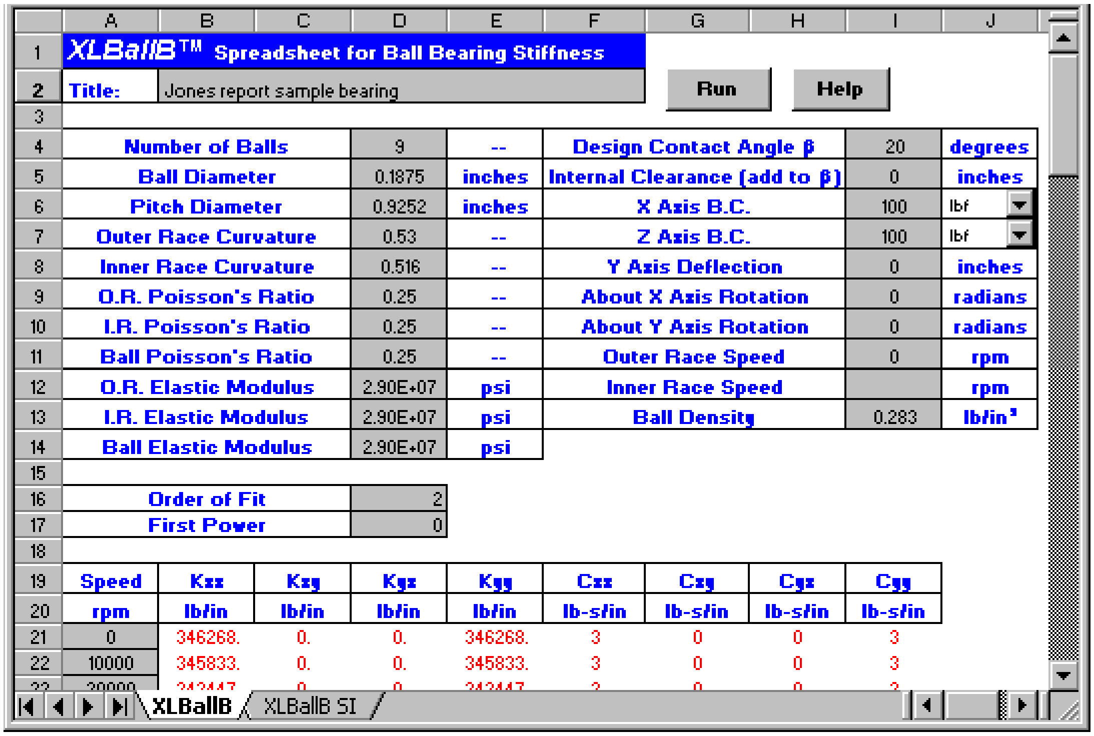
XLJrnl.XLS Journal Bearing Template File

This is a data base file of dimensionless dynamic coefficients for the bearings available in XLJrnl. This file should be in the XLRotor program folder. The data base is keyed on the bearing Sommerfeld number. Adding additional bearing design data based on Sommerfeld number is extremely easy. Contact RMA, Incorporated if you wish to do this.

XLBALLB.XLS Ball Bearing Template File

See also

- Bearing Template Files
- Brg's Worksheet
- XLBallB Input Parameters
- XLBallB Output Tables
- XLCYLIND.XLS



XLBallB™ Spreadsheet for Ball Bearing Stiffness									
Title:	Jones report sample bearing					Run	Help		
Number of Balls		9	--	Design Contact Angle β		20	degrees		
Ball Diameter		0.1875	inches	Internal Clearance (add to β)		0	inches		
Pitch Diameter		0.9252	inches	X Axis B.C.		100	lbf		
Outer Race Curvature		0.53	--	Z Axis B.C.		100	lbf		
Inner Race Curvature		0.516	--	Y Axis Deflection		0	inches		
O.R. Poisson's Ratio		0.25	--	About X Axis Rotation		0	radians		
I.R. Poisson's Ratio		0.25	--	About Y Axis Rotation		0	radians		
Ball Poisson's Ratio		0.25	--	Outer Race Speed		0	rpm		
O.R. Elastic Modulus		2.90E+07	psi	Inner Race Speed			rpm		
I.R. Elastic Modulus		2.90E+07	psi	Ball Density		0.283	lb/in³		
Ball Elastic Modulus		2.90E+07	psi						
Order of Fit		2							
First Power		0							
Speed	Kxx	Kxy	Kyx	Kyy	Cxx	Cxy	Cyx	Cyy	
rpm	lb/in	lb/in	lb/in	lb/in	lb-s/in	lb-s/in	lb-s/in	lb-s/in	
0	346268.	0.	0.	346268.	3	0	0	3	
10000	345833.	0.	0.	345833.	3	0	0	3	

The spreadsheet file, XLBALLB.XLS, is a driver for a ball bearing analysis program. After the bearing analysis, this file would be linked to an XLRotor rotor model file (see Brg's Worksheet).

This program computes the following operating characteristics for angular contact ball bearings, including the effects of speed and load:

- rotordynamic stiffness
- defect frequencies
- operating contact angles
- ball/race contact stresses
- ball/race contact deflections
- Hertz contact zone dimensions

To analyze a bearing, open this file and perform a File|Save As to save a copy, using a name of your choice. Then, enter the parameters of your bearing and compute the rotordynamic coefficients. Curve Fitting is also done in exactly the same fashion as for an XLJrnl journal bearing file.

You Link the contents of the Title cell located on the XLBallB worksheet to a rotor model file (see Linking bearings to rotors).

This file is marked as a ***READ ONLY*** file.

Note: There are two versions of this file in the Templates folder. One version, named XLBALLB2.XLS, has all inputs and outputs on a single worksheet, and this version of the file contains one worksheet in US units and another worksheet in SI units. When using this file, delete the sheet which you do not need. The second version is named XLBALLB.XLS (US units) and XLBALLSI.XLS (SI units). These files have all inputs one sheet, and all outputs are on other sheets. All of these files can be linked to a rotor model file in exactly the same way. An advantage of the single sheet file is those sheets can be embedded in a rotor model file.

XLBallB Input Parameters

See also

Bearing Template Files
XLBALLB.XLS
XLBallB Output Tables
XLCYLIND.XLS

Number of Balls

This is the number of rolling elements. The value must be between 1 and 60, inclusive.

Ball Diameter

This is the ball diameter. The value must be greater than zero.

Pitch Diameter

This is the bearing's pitch diameter. The pitch diameter is the diameter of a circle which passes through center of each ball. The value must be greater than zero. For many bearings, the pitch diameter is close to the average of the bore and outer diameter.

Raceway Curvature

This is the bearing raceway curvature for the inner and outer races. Raceway curvature is defined as the ratio of the radius of curvature of the raceway groove, to the ball diameter (r/d).

The value must be greater than 0.5. For many ball bearings, this value is between 0.51 and 0.57. The value is often based on stiffness versus life requirements.

Poisson's Ratio

This is the dimensionless Poisson's ratio. Enter it separately for the inner race, outer race, and the balls. The values must be greater than zero. For most metals, Poisson's ratio is between 0.25 and 0.33.

Elastic Modulus

This is the elastic modulus. Enter it separately for the inner race, outer race, and the balls. The values must be greater than zero. For many bearing materials, the elastic modulus is around 28 to 29 million psi (around 200,000 MPa). For ceramic balls, however, it can be much higher.

Ball Density

This is the density of the rolling elements, and it must be greater than or equal to zero. The density is used only to compute the centrifugal loading on the rolling elements. For many bearing materials, the density is around 0.283 to 0.3 lbm/in^3 (or about 8.3 gm/cm^3).

Contact Angle & Internal Clearance

The internal looseness of a ball bearing can be expressed as a Contact Angle **or** Internal Clearance. These two quantities are related by the formula shown below. XLBallB allows you to input **both** parameters, and sums the looseness due to each to get the total looseness. In this context, the terms looseness, internal clearance, and contact angle refer to the same thing. Once the total looseness is computed, the resultant contact angle and internal clearance are determined.

$$\cos\beta = 1 - \frac{C}{2Bd}$$

where

β	= contact angle
C	= diametral internal clearance
d	= ball diameter
B	= bearing total curvature = fi + fo - 1
fi	= inner raceway curvature
fo	= outer raceway curvature

The **design** Contact Angle is defined for an **unloaded** bearing when the shaft is moved axially just enough to take up its internal clearance. It is the angle between a line passing radially through the bearing, and a line passing through a ball center and its point of contact with the outer race. This would actually be the outer race contact angle for one of the balls, but for an unloaded bearing, the inner and outer race contact angles are equal. Also, in an unloaded bearing all balls have the same contact angle. When you enter a non-zero value for contact angle, the program will compute the corresponding assembled internal clearance using the expression shown above.

The assembled Internal Clearance (also called diametral clearance) is the full amount of free play in the unloaded bearing (laterally, not axially), and could be measured by conducting a radial push-pull on the shaft. Normally, the internal clearance is calculated from the design contact angle. However, if you enter zero for the contact angle, you can then specify the internal clearance directly, and the program will compute the design contact angle using the expression shown above.

As an example, say you know what the design contact angle is (from a catalog), but the outer race has an interference fit with its housing, thereby reducing its diameter by 1 mil. You would enter the catalog value for Contact Angle, and enter the increase in outer race diameter for the Internal Clearance (-0.001 inches for this example). The program will compute the design internal clearance from the design contact angle, and add to that the 1 mil decrease. The result is the actual **assembled internal clearance**, from which the actual **mounted contact angle** is computed.

X Axis Boundary Condition

In the X direction (radial), you must specify either the load applied to the outer race, or the deflection of the outer race. Make your selection from the adjoining drop down list. The program will then compute the boundary condition which is not specified.

Note:
The bearing is modeled in 5 dimensions (rotation about the bearing centerline is not a degree of freedom in the model).

Z Axis Boundary Condition

In the Z direction (axial), you must specify either the load applied to the outer race, or the deflection of the outer race. Make your selection from the adjoining drop down list. The program will then compute the boundary condition which is not specified.

About X Axis Rotation

Enter the rotational deflection of the bearing about the X axis. The value is in radians, and is normally zero. This program does <u>not</u> permit you to specify the load in this axis.

About Y Axis Rotation

Enter the rotational deflection of the bearing about the Y axis. The value is in radians, and is normally zero. This program does <u>not</u> permit you to specify the load in this axis.

Note:
Current program limitations allow you to specify the load only in the X (radial) and Z (axial) directions. For the other 3 dimensions, you must always specify the deformation value (normally zero). Within these limitations, you can directly analyze a bearing where the raceways can move radially and axially, but cannot tilt relative to each other. If a raceway can tilt, it is either completely free to tilt (like the outer race in some self-aligning bearings), or it tilts against some restraint (like a preload spring). In these cases, you do not know what the value of tilt is (the About Y Rotation), but you do know that the moment is either zero (for self-aligning) or linearly proportional to tilt (for preload spring). You then run the program for two different values of tilt, and the program will compute the resulting moments. Use the computed moments to estimate what the tilt would need to be to get the right value for moment. If the load/deflection characteristics of a bearing were perfectly linear, this process would yield the correct answer the first time. However, since Hertzian contact deformation is not linear, one or two iterations may be required.

Outer Race Speed & Inner Race Speed

You should only put a value in one of these two cells, and leave the other one blank. For the one that is blank you instead enter a range of raceway speed values in the ***Speed*** column.

As a typical example, you would enter zero in the cell for ***Outer Race Speed***, and leave the cell for ***Inner Race Speed*** blank. Then in the ***Speed*** column you would enter a range of values which the program will use as inner race speed.

Note:
Speed dependent inputs - Some of the inputs may change with rotor speed (e.g., applied loads). When this is the case, you can add a column of inputs on the right hand side of the Speed input table. See XLJrnl Template File for the details of how to do this.

XLBallB Output Tables

See also

Bearing Template Files
XLBALLB.XLS
XLBallB Input Parameters
XLCYLIND.XLS

This section explains and defines the various outputs generated by XLBallB. The bearing analysis is conducted in a quasi-steady state fashion. The complete bearing is analyzed at a snapshot in time, taking into account the centrifugal and gyroscopic forces at work within the bearing. The analysis output includes overall bearing deflection, load and stiffness, and tables of individual ball characteristics, such as contact load, stress, and contact area dimensions.

Note:
The bearing analysis is computed in its entirety for each shaft speed increment. The tables which display the detailed results described below contain the results only for the ***last*** shaft speed calculated.

Kxx,Kxy,Kyx,Kyy and Cxx,Cxy,Cyx,Cyy

This is the primary output of the program. For ball bearings the ***Kxx*** and ***Kyy*** values are always the same, and the value is equal to 2/3 of the theoretical tangent stiffness. See the paragraph below about **Stiffness Matrix** for more about this.

The damping values listed in the table are not computed by the XLBALLB module. This is because damping in ball bearings is often quite small, and there is no widely accepted way to compute a value. So whatever value is entered for ***Cxx*** in the first row of the table is copied to all other ***Cxx*** and ***Cyy*** values when the Run is button pressed. This allows you to enter a damping value which you feel is suitable for your bearing. If the worksheet cell for ***Cxx*** in the first row is empty, then a value of 3 lb-s/in (525.3 N-s/m) is automatically filled in when the Run button is pressed.

Since ball bearings do not possess any cross coupling affects, ***Kxy, Kyx, Cxy*** and ***Cyx*** are always zero.

Total Internal Clearance & Mounted Contact Angle

This is the resulting contact angle and corresponding diametral internal clearance for the **mounted** bearing in its **unloaded** state. It is computed by adding the effects of both the internal clearance and contact angle which you input.

Mounted Axial Endplay

This is bearing looseness in the axial direction, and could be measured via push-pull.

Mass of One Ball

The ball mass is used to compute the centrifugal force on the ball. This force becomes important at high speed when it is a significant part of the ball to race contact forces.

Ball Pass Outer Race   Cage Speed
Ball Pass Inner Race   Ball Spin Speed

These are bearing defect frequencies computed from the mounted, but as yet unloaded, contact angle, and the inner and outer raceway speeds. They are often used in ball bearing condition monitoring applications.

Bearing Reactions

These are forces and moments applied by the bearing's inner race to the shaft. In the program input you specify loads applied to the outer race, which in turn are reacted by the bearing. For applied load values you specify as input, the program iterates the deflection values to achieve an acceptable match on load. Therefore, the loads listed here will be very close to, but may not match exactly, your input values.

Bearing Deformation

These are the relative displacements between the outer and inner raceways, expressed as outer minus inner. Zero deformation is at the point where the races are displaced axially just enough to take up the internal clearance.

Stiffness Matrix

The values displayed here are theoretical approximations to the slope of the load deflection curve for the bearing in its fully loaded state. In the absence of any thrust load, these approximations are very accurate, and correspond well to stiffness values you would obtain from a complete load deflection curve. With combined radial and axial loadings, however, it is better to derive the bearing's stiffness directly from the load and deflection values (for example, compute K as Reaction/Deflection).

The radial stiffness values, Kxx and Kyy, which are output by the program to the stiffness and damping table are equal to 2/3 of this theoretical radial stiffness. The 2/3 factor is an empirical constant derived from bearing stiffness testing.

Ball Number

In the series of tables that make up the majority of the output, only values for loaded balls are shown. Ball number one is always on the X axis. Unloaded balls can occur only in a bearing subjected to radial load, and they exist on the side of the bearing away from the heaviest loaded ball.

Ball Azimuth

This is the angular location of the ball. Zero degrees corresponds to the +X axis, and 90 degrees corresponds to the +Y axis.

Contact Load

This is the compressive load between the ball and the raceway. Due to centrifugal forces acting on the balls, the outer race contact load is always greater than, or equal to, the inner race contact load. Unloaded balls are not shown in the table. Unloaded balls are balls that are not loaded against the inner race, and do not help carry the bearing's applied load.

Contact Angle

The contact angle for each ball in the loaded bearing is shown for both inner and outer race contacts. In the absence of centrifugal ball loads, the inner and outer race contact angles for a given ball are equal. The contact angles for different balls vary only when there are both radial and axial loads applied to the bearing.

Centrifugal Force

The centrifugal force on each ball can vary slightly because in a radially loaded bearing, each ball can be running at a slightly different distance from the bearing centerline.

Type of Control

In an angular contact bearing each ball is assumed to roll without slipping on one race, and roll with some slipping on the other race, due to a small amount of spin. The controlling race hypothesis assumes all spin occurs at one contact while none occurs at the other. The contact at which no spin exists is designated the controlling race. The contact, outer or inner, with the largest friction torque is the controlling race (the coefficient of friction is assumed equal for inner and outer contacts). Lightly loaded bearings may depart somewhat from this situation. Note that raceway curvature has a strong effect on the size of contact areas, and also spin friction torque. For each ball the controlling race can change with speed, and possibly at different speeds. Which race is the controlling race influences contact angles and therefore stiffness. So as a function of speed, if the controlling race changes for any ball(s), this may cause an abrupt change in stiffness.

Contact Area Length & Width

The shape of the contact zone between the ball and race is elliptic. The length and width values define the size of the major and minor axes of this ellipse. When the size of the contact area becomes large relative to the ball size (as would happen in a very heavily loaded bearing), very high stresses result (see below).

Mean Compressive Stress

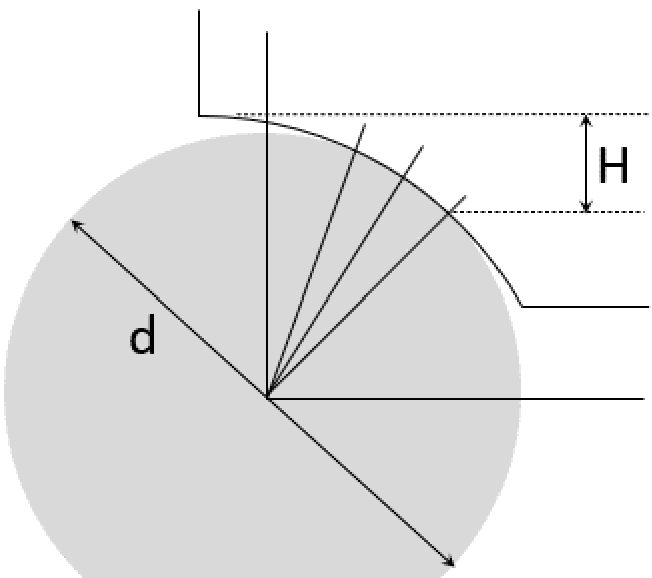
These are principal compressive stress values in the inner and outer race contact areas. High stress values generally lead to premature fatigue failure of the bearing. However, reliable prediction of fatique life requires consideration of other factors such as cleanliness of lubrication.

Contact Deflection

This is the distance that the center of the ball moves toward a race as the load is applied. For example, in a bearing subjected to pure radial load (i.e. zero contact angle), the sum of the inner and outer race contact deflections for the heaviest loaded ball (in line with the load) should equal the radial bearing deflection.

H/d Value

After some hours of operation, a visual inspection of a bearing's inner and outer raceways will reveal the presence of load tracks. The width of the load track is the major axis length of the contact ellipse. The H value is the distance the load track extends up the raceway groove in a radial direction. H/d expresses this value as a fraction of the ball diameter. If the bearing is too heavily loaded, the load track may exceed the extent of the raceway.



Spin Velocity

This is how fast the ball spins as it travels around the race. A defect on a ball can produce vibration at this frequency. Note: this is <u>not</u> the ball spin referred to in the description of ***Type of Control***.

Orbital Velocity

This is the cage speed of the bearing. In a radially loaded bearing, each ball will have a slightly different orbital velocity due to the different contact loads. Differences in orbital velocity increase with applied radial load. The mismatch in orbital velocity sometimes results in premature cage failures in heavily loaded bearings. A damaged or severely worn cage can produce vibration at this frequency.

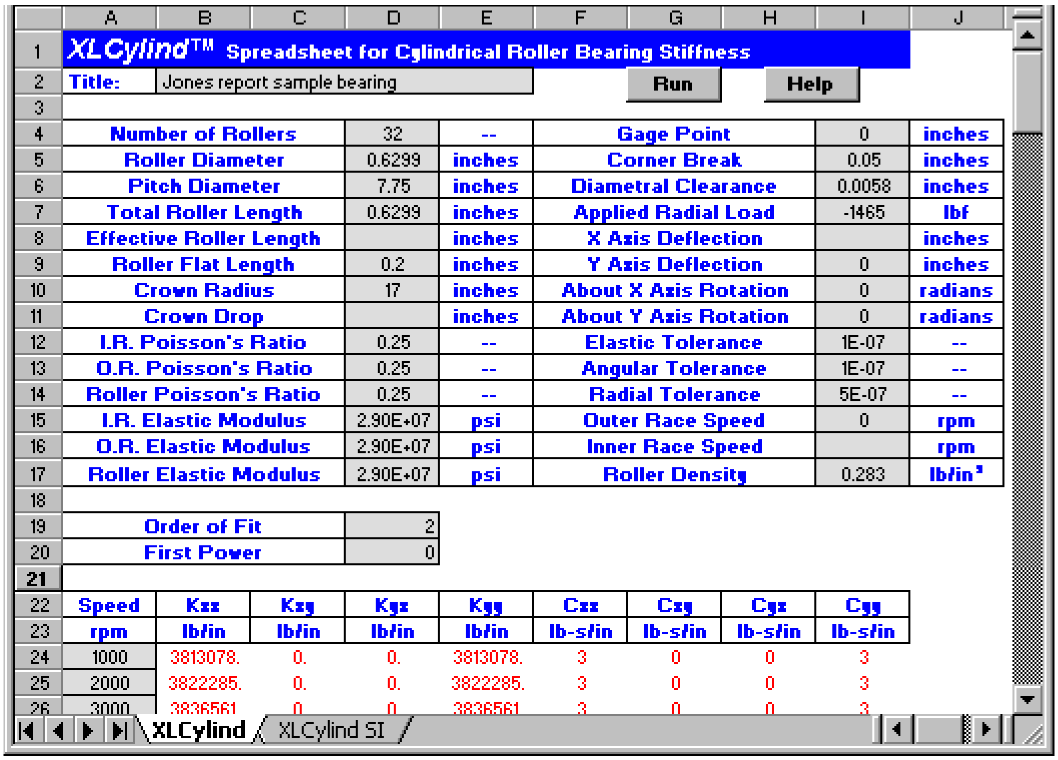
Gyroscopic Moment

This is the gyroscopic moment that results when the absolute angular velocity vector for the ball changes direction as the ball travels around the bearing. This happens only when the contact angle is not zero. With zero contact angle (no thrust load), the angular velocity vector always points parallel to the bearing centerline, in which case the gyroscopic moment is zero.

XLCYLIND.XLS Cylindrical Roller Bearing Template File

See also

- Bearing Template Files
- Brg's Worksheet
- XLCylind Input Parameters
- XLCylind Output Tables
- XLBALLB.XLS



	A	B	C	D	E	F	G	H	I	J
1	XLCylind™ Spreadsheet for Cylindrical Roller Bearing Stiffness									
2	Title:	Jones report sample bearing					Run		Help	
3										
4	Number of Rollers			32	--	Gage Point			0	inches
5	Roller Diameter			0.6299	inches	Corner Break			0.05	inches
6	Pitch Diameter			7.75	inches	Diametral Clearance			0.0058	inches
7	Total Roller Length			0.6299	inches	Applied Radial Load			-1465	lbf
8	Effective Roller Length				inches	X Axis Deflection				inches
9	Roller Flat Length			0.2	inches	Y Axis Deflection			0	inches
10	Crown Radius			17	inches	About X Axis Rotation			0	radians
11	Crown Drop				inches	About Y Axis Rotation			0	radians
12	I.R. Poisson's Ratio			0.25	--	Elastic Tolerance			1E-07	--
13	O.R. Poisson's Ratio			0.25	--	Angular Tolerance			1E-07	--
14	Roller Poisson's Ratio			0.25	--	Radial Tolerance			5E-07	--
15	I.R. Elastic Modulus			2.90E+07	psi	Outer Race Speed			0	rpm
16	O.R. Elastic Modulus			2.90E+07	psi	Inner Race Speed				rpm
17	Roller Elastic Modulus			2.90E+07	psi	Roller Density			0.283	lb/in³
18										
19	Order of Fit			2						
20	First Power			0						
21										
22	Speed	Kxx	Kxy	Kyx	Kyy	Cxx	Cxy	Cyx	Cyy	
23	rpm	lb/in	lb/in	lb/in	lb/in	lb-s/in	lb-s/in	lb-s/in	lb-s/in	
24	1000	3813078.	0.	0.	3813078.	3	0	0	3	
25	2000	3822285.	0.	0.	3822285.	3	0	0	3	
26	3000	3836561	0	0	3836561	3	0	0	3	

The spreadsheet file, XLCYLIND.XLS, is a driver for a cylindrical roller bearing analysis program. After the bearing analysis, this file could be linked to an XLRotor rotor model file (see Brg's Worksheet), or the worksheet can be embedded in a rotor model file (see Embedded Bearings).
This program computes the following operating characteristics for crowned or uncrowned cylindrical roller bearings, including the effects of speed and load:

- rotordynamic stiffness
- defect frequencies
- roll/race contact stresses
- roll/race contact deflections
- Hertz contact zone dimensions

To analyze a bearing, open this file and perform a File|Save As to save a copy, using a name of your choice. Then, enter the parameters of your bearing and compute the rotordynamic coefficients.. Curve Fitting is also done in exactly the same fashion as for an XLJrnl journal bearing file.

You can Link the contents of the Title cell located on the XLCylind worksheet to a rotor model file (see Linking bearings to rotors).

This file is marked as a ***READ ONLY*** file.

Note: There are two versions of this file in the Templates folder. One version, named XLCYLIND2.XLS, has all inputs and outputs on a single worksheet, and this version of the file contains one worksheet in US units and another worksheet in SI units. When using this file, delete the sheet which you do not need. The second version is named XLCYLIND.XLS in US units. This file has all inputs one sheet, and all outputs are on other sheets. All of these files can be linked to a rotor model file in exactly the same way. An advantage of the single sheet file is those sheets can be embedded in a rotor model file.

XLCylind Input Parameters

See also

- Bearing Template Files
- XLCYLIND.XLS
- XLCylind Output Tables
- XLBALLB.XLS

This section explains the input parameters for the XLCylind program.

Number of Rollers

This is the number of cylindrical rolling elements. The value must be between 1 and 60, inclusive.

Roller Diameter

This is the roller diameter. The value must be greater than zero. The roller diameter is measured at the center of the roller after it's flat has been machined.

Pitch Diameter

This is the bearing's pitch diameter. The pitch diameter is the diameter of the bearing at the center of the rollers. For many bearings this is close to the average of the bore and outer diameter.

Poisson's Ratio

This is the dimensionless Poisson's ratio. Enter it separately for the inner race, outer race, and the rollers. The values must be greater than zero. For most metals, Poisson's ratio is between 0.25 and 0.33.

Elastic Modulus

This is the elastic modulus. Enter it separately for the inner race, outer race, and the rollers. The values must be greater than zero. For many bearing materials, the elastic modulus is around 28 to 29 million psi (around 200,000 MPa). For ceramic rollers, however, it can be much higher.

Roller Density

This is the density of the rolling elements, and it must be greater than or equal to zero. The density is used only to compute the centrifugal loading on the rolling elements. For many bearing materials, the density is around 0.283 to 0.3 lbm/in^3 (or about 8.3 gm/cm^3).

Diametral Clearance

The diametral clearance (also called internal clearance) is the full amount of free play in the unloaded bearing, and can be measured by doing a radial push-pull on the shaft.

X Axis Deflection & Applied Radial Load

In the X direction (radial), you must specify **either** the load applied to the outer race, or the deflection of the outer race. You specify one of these by entering a value, and leave the other one blank. The program will compute the one you leave blank. Most of the time you will probably enter a load value and leave the deflection blank.

Note:
The bearing is modelled in 4 dimensions (axial motion and rotation about the bearing centerline are not degrees of freedom in the model).

Y Axis Deflection

In the Y direction (radial), you must specify the deflection of the outer race. Normally, for the Y axis this will be zero.

About X Axis Rotation

Enter the rotational deflection of the bearing about the X axis. The value is in radians, and is normally zero. This program does <u>not</u> permit you to specify the load in this axis.

About Y Axis Rotation

Enter the rotational deflection of the bearing about the Y axis. The value is in radians, and is normally zero. This program does <u>not</u> permit you to specify the load in this axis.

Outer Race Speed & Inner Race Speed

You should only put a value in <u>one</u> of these two cells, and leave the other one blank. For the one that is blank you instead enter a range of raceway speed values in the ***Speed*** column.

As a typical example, you would enter zero in the cell for ***Outer Race Speed***, and leave the cell for ***Inner Race Speed*** blank. Then in the ***Speed*** column you would enter a range of values which the program will use as inner race speeds.

Total Length & Effective Length

You must always specify <u>either</u> the ***Total Length*** or ***Effective Length***, but not both since one can be computed from the other using the expression given below. The ***Total Length*** of the roller is the actual physical length of the roller that would be measured with a caliper. The ***Effective Length*** of the roller is the amount of roller length available for bearing load. The ***Effective Length*** is equal to ***Total Length*** minus the ***Corner Breaks***, if any, at each end of the roller.

Flat Length

If the roller has a flat in its midsection, the ***Flat Length*** is the axial distance from one edge of the flat to the other edge of the flat. The flat is always taken to be centered between the ends of the rollers. The ***Flat Length*** is never negative, but can be zero (fully crowned rollers), and it must always be less than the ***Effective Length***.

Lt = Le + 2B

where

Lt = Total Roller Length

Le = Effective Roller Length

B = Corner Break

Corner Break

The corner break is the axial length (axial being along the axis of the roller) of the rounded off end of the roller. The rounded off end of the roller never comes into contact with either raceway no matter how heavily the bearing is loaded. In fact, during analysis the program checks to make sure this does not happen on any roller.

Gage Point

This is the distance from the end of the roller to the point where the crown drop is measured. In this definition the "end of the roller" is where the load bearing surface of the roller begins. When the corner break is zero, the "end of the roller" by this definition is also the physical end of the roller. The gage point must be greater than or equal zero. A zero gage point means that the crown drop is measured at the "end of the roller." Note that the gage point must not be greater than one half of the difference between the ***Effective Length*** and the ***Flat Length*** (i.e. you can't measure the crown drop on the flat).

Crown Radius & Crown Drop

You must specify <u>either</u> the ***Crown Radius*** or ***Crown Drop***, but not both since one can be computed from the other using the expression given below. The ***Crown Drop*** is measured between the flat and some point on the curved part of the roller's load bearing surface. The point where the drop is measured at is specified by the ***Gage Point***. The ***Crown Drop*** would be measured by taking the roller radius at the flat (i.e. one half the roller diameter) minus the roller radius measured at the ***Gage Point***. The ***Crown Radius*** is the radius of curvature of the roller crown. This value generally must be obtained from the bearing manufacturer, or it can be computed from the other input values using the expression given below. It must be greater than zero. Too large a radius relative to the amount of load on the bearing will cause the contact zone to extend past the end of the roller

Rc**2 = {(Le/2-G)**2 - (Lf/2)**2 - D**2}**2/{2D}**2 + {Le/2-G}**2 \

where

Rc = Crown Radius
Le = Effective Roller Length
Lf = Roller Flat Length
G = Gage Point
D = Crown Drop

Elastic, Angular & Radial Tolerances

These are computational convergence tolerances used to control the iterative calculations performed by the program. Normally these parameters should not be changed from their default values which are:

Te = elastic tolerance = 1.0e-8
Ta = angular tolerance = 1.0e-8
Tr = radial tolerance = 5.0e-8

XLCylind Output Tables

See also

- Bearing Template Files
- XLCYLIND.XLS
- XLCylind Input Parameters
- XLBALLB.XLS

This section explains the various outputs generated by XLCylind. The bearing analysis is conducted in a quasi-steady state fashion. The complete bearing is analyzed at a snapshot in time, taking into account the centrifugal forces at work within the bearing. The analysis output includes overall bearing deflection, load and stiffness, and tables of individual roller characteristics, such as contact load, stress, and contact area dimensions.

Note:
The bearing analysis is computed in its entirety for each shaft speed increment. The tables which display the detailed results described below contain the results only for the ***last*** shaft speed calculated.

Total Roller Length

See XLCylind Input Parameters.

Effective Roller Length

See XLCylind Input Parameters.

Crown Radius

See XLCylind Input Parameters.

Crown Drop

See XLCylind Input Parameters.

Individual Roller Mass & Centrifugal Force Of Roller

The roller mass is used to compute the centrifugal force on the roller.

Roller Orbital Velocity

This is the number of times per minute that each roller travels 360 degrees around the bearing. This is analogous to the fundamental train frequency (cage speed) of a bearing.

Roller Spin Velocity

This is how fast the roller spins as it travels around the race. A defect on a roller can produce vibration at this frequency.

Roller Pass Outer Race
Roller Pass Inner Race

These are bearing defect frequencies. They are often used in roller bearing condition monitoring applications.

Bearing Reactions

These are forces and moments applied by the bearing's inner race to the shaft. In the program input you specify loads applied to the outer race, which in turn are reacted by the bearing. For applied load values you specify as input, the program iterates the deflection values to achieve an acceptable match on load. Therefore, the loads listed here will be very close to, but may not match exactly, your input values.

Bearing Deformation

These are the relative displacements between the outer and inner raceways, expressed as outer minus inner. At close to zero load, the deformation will be equal to half of the diametral internal clearance.

Stiffness Matrix

The values displayed here are analytical approximations to the slope of the load deflection curve for the bearing in its loaded state.

Roller Number

In the series of tables that make up the majority of the output, only values for loaded rollers are shown. Roller number one is always on the X axis. Unloaded rollers exist on the side of the bearing away from the heaviest loaded roller.

Roll Azimuth

This is the angular location of the roller. Zero degrees corresponds to the +X axis, and 90 degrees corresponds to the +Y axis.

Contact Load & Contact Moment

This is the compressive load between the roller and the raceway. Due to centrifugal forces acting on the rollers, the outer race contact load is always greater than, or equal to, the inner race contact load. Unloaded rollers are not shown in the table. Unloaded rollers are rollers that are not loaded against the inner race, and do not help carry the bearing's applied load.

Outer & Inner Path Extremity

These values indicate how far the roller's contact zone extends from the midplane of the bearing (in the axial direction). One value is to the left of midplane, the other to the right. The difference between these two values is equal to the Contact Length.

Contact Misalignment

Contact Misalignment happens only when the bearing reacts a moment. So the Contact Misalignment will usually be zero. It will only be nonzero when you specify nonzero values for ***About X Axis Rotation*** or ***About Y Axis Rotation.***

Contact Length & Maximum Contact Width

The is the size of the contact zone between the roller and both raceways. The ***Contact Length*** is always less than or equal to the ***Effective Roller Length.*** When they are equal this probably means the bearing is too heavily loaded.

Maximum Contact Deflection

This is the distance that the center of the roller moves toward a race as the load is applied. For example, in a bearing subjected to radial load, the sum of the inner and outer race contact deflections and the radial internal clearance (for the heaviest loaded roller) should equal the radial bearing deflection.

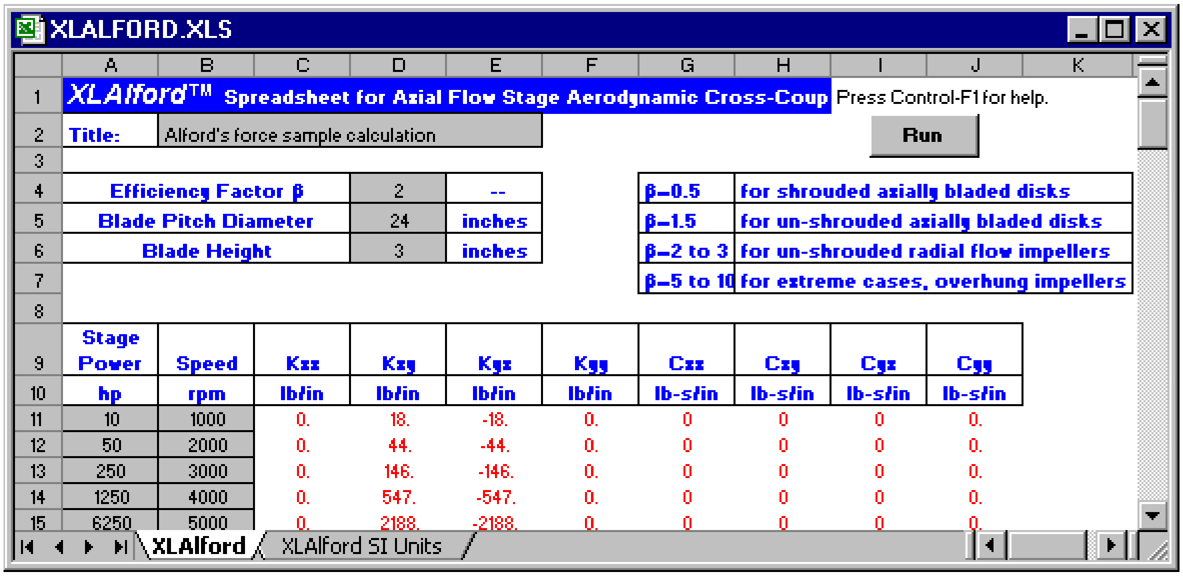
Maximum Hertz Stress & Location of Max Values

These are principal compressive stress values in the inner and outer race contact areas. High stress values generally lead to premature fatigue failure of the bearing.

XLALFORD.XLS Template File

See also

Bearing Template Files
Brg's Worksheet



Stage Power	Speed	Kxx	Kxy	Kyx	Kyy	Cxx	Cxy	Cyx	Cyy
hp	rpm	lb/in	lb/in	lb/in	lb/in	lb-s/in	lb-s/in	lb-s/in	lb-s/in
10	1000	0.	18.	-18.	0.	0	0	0	0.
50	2000	0.	44.	-44.	0.	0	0	0	0.
250	3000	0.	146.	-146.	0.	0	0	0	0.
1250	4000	0.	547.	-547.	0.	0	0	0	0.
6250	5000	0.	2188.	-2188.	0.	0	0	0	0.

The spreadsheet file, XLALFORD.XLS, is a driver for computing aerodynamic cross coupled stiffness for axial flow impellers. After Kxy is calculated, this file would be linked to an XLRotor rotor model file (see Brg's Worksheet). The analytical formula for Kxy is credited to J.S. Alford.
To analyze an impeller, open this file and perform a File|Save As to save a copy, using a name of your choice. Then, enter the parameters of your impeller and compute the Kxy coefficients.. Curve Fitting is also done in exactly the same fashion as for an XLJrnl journal bearing file.

You Link the contents of the Title cell located on the XLAlford worksheet to a rotor model file (see Linking bearings to rotors).

This file is marked as a ***READ ONLY*** file.

Alford's formula is as follows:

$$K_{xy} = \frac{\beta P}{\omega D H}$$

Where

Kxy = Cross Coupled Stiffness (lb/in)

β = Stage efficiency factor

P = Stage Power (in-lb/s)

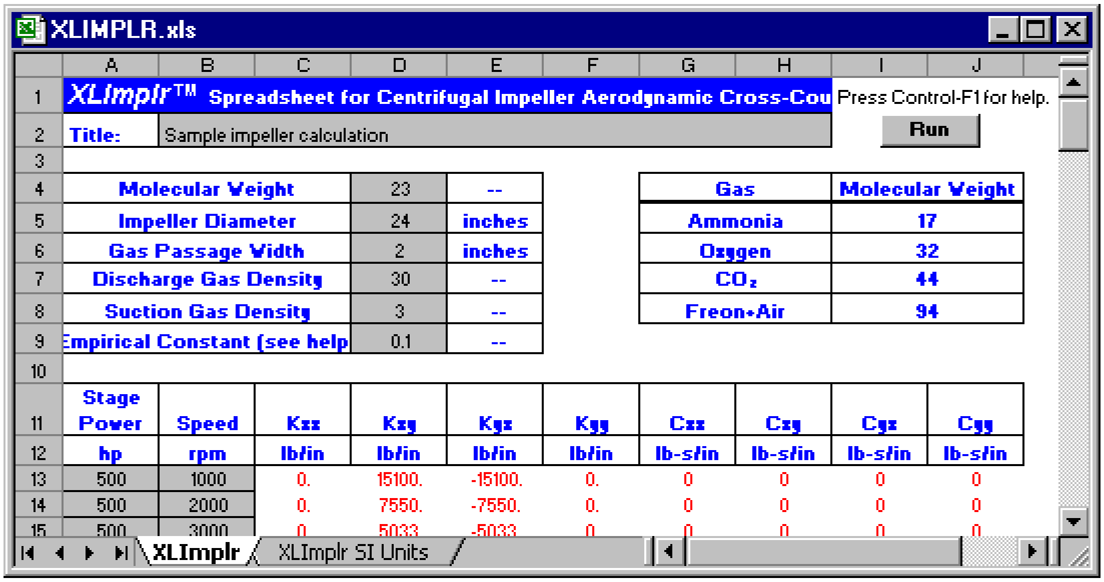
ω	= Rotor Speed (rad/s)
D	= Blade Pitch Diameter
H	= Blade Height

The XLALFORD.XLS file shows recommended values for the efficiency factor for different types of machines.

XLIMPLR.XLS Impeller Cross Coupling Template File

See also

- Bearing Template Files
- Brg's Worksheet


XLIMPLR.xls

XLImplr™ Spreadsheet for Centrifugal Impeller Aerodynamic Cross-Cou

Press Control-F1 for help.

Run

Title: Sample impeller calculation

Molecular Weight	23	--
Impeller Diameter	24	inches
Gas Passage Width	2	inches
Discharge Gas Density	30	--
Suction Gas Density	3	--
Empirical Constant (see help	0.1	--

Gas	Molecular Weight
Ammonia	17
Oxygen	32
CO_2	44
Freon+Air	94

Stage Power	Speed	Kxx	Kxy	Kyx	Kyy	Cxx	Cxy	Cyx	Cyy
hp	rpm	lb/in	lb/in	lb/in	lb/in	lb-s/in	lb-s/in	lb-s/in	lb-s/in
500	1000	0.	15100.	-15100.	0.	0	0	0	0
500	2000	0.	7550.	-7550.	0.	0	0	0	0
500	3000	0.	5033	-5033	0.	0	0	0	0

XLImplr | XLImplr SI Units

The spreadsheet file, XLIMPLR.XLS, is a driver for computing aerodynamic cross coupled stiffness for centrifugal flow impellers. After Kxy is calculated, this file would be linked to an XLRotor rotor model file (see Brg's Worksheet). The empirical formula for Kxy is due to J.C. Wachel. See, for example, the following paper: "Rotordynamic Instability Field Problems", Rotordynamic Instability Problems in High-Performance Turbomachinery, NASA Conference Publication 2250, Texas A&M University, May 10-12, 1982, pages 1-19.

To analyze an impeller, open this file and perform a File|Save As to save a copy using a name of your choice. Then enter the parameters of your impeller and compute the Kxy coefficients. Curve Fitting is also done in exactly the same fashion as for an XLJrnl journal bearing file.

You Link the contents of the Title cell located on the XLImplr worksheet to a rotor model file (see Linking bearings to rotors).

This file is marked as a *READ ONLY* file.

In dimensional form, Wachel's formula is as follows:

$$K_{xy} = \frac{6300PM}{NDH} \frac{\rho_{\text{discharge}}}{\rho_{\text{suction}}}$$

Where

Kxy	= Cross Coupled Stiffness (lb/in)
6300	= An empirical dimensional constant (6300 in-lb-rpm/hp)
P	= Stage Power (hp)
M	= Gas Molecular Weight (number of grams in one mole of gas molecules)
N	= Rotor Speed (rpm)
D	= Impeller Discharge Diameter (inches)
H	= Gas Passage Width (inches)
ρ_{suct}	= Suction Gas Density (any units)
ρ_{disc}	= Discharge Gas Density (same units as suction density)

This can also be expressed as:

$$K_{xy} = \frac{0.1PM}{\omega DH} \frac{\rho_{\mathrm{discharge}}}{\rho_{\mathrm{suction}}}$$

Here the empirical constant is dimensionless. The value of 0.1 is offered by Mr. Wachel based on his experience in applying it to "several instability problems". The value is therefore not precise, and no other values have been noted in the open literature. Your own experience may dictate a different value is more applicable to the machines you work with.

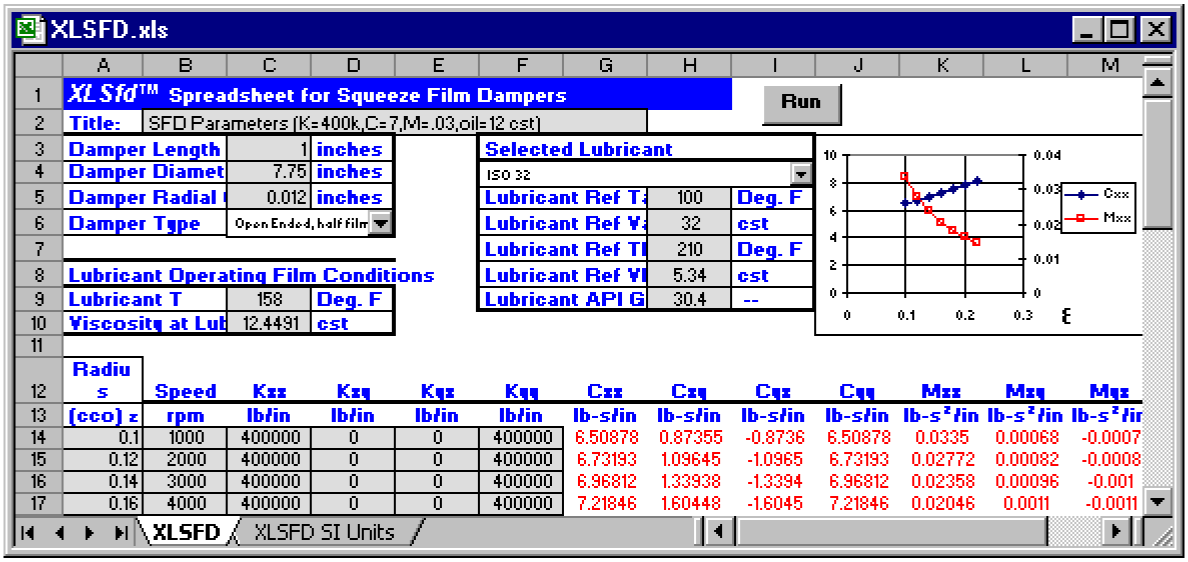
When using the dimensionless form, the units of all other values must be consistent, except the gas molecular weight which is always grams per mole (i.e. the sum of the atomic weights of each atom in the gas molecule). The speed here then must be radians/second.

Document API 684 (2010) explains and recommends on page 3-37 that the molelular weight, MW, be fixed at 30. This is based on experience with additional instability field cases after the original work by Wachel.

XLSFD.XLS Squeeze Film Damper Template File

See also

Bearing Template Files
Brg's Worksheet



The spreadsheet file, XLSFD.XLS, is a driver for computing damping and inertia properties for squeeze film dampers executing circular centered orbits (cco). The analytical formulas used to compute the damping and inertia properties are from a series of technical papers on dampers by Dr. Luis San Andres of Texas A&M University.

1. EFFECT OF FLUID INERTIA ON SQUEEZE-FILM DAMPER FORCES FOR SMALL-AMPLITUDE CIRCULAR-CENTERED MOTIONS. San Andres, Luis A. (Texas A&M Univ, College Station, TX, USA); Vance, John M. ASLE Transactions, v 30, n 1, Jan, 1987, p 63-68.
2. FORCE COEFFICIENTS FOR OPEN-ENDED SQUEEZE-FILM DAMPERS EXECUTING SMALL-AMPLITUDE MOTIONS ABOUT AN OFF-CENTER EQUILIBRIUM POSITION. San Andres, Luis A. (Texas A&M Univ, College Station, TX, USA); Vance, John M. ASLE Transactions, v 30, n 1, Jan, 1987, p 69-76.
3. EFFECTS OF FLUID INERTIA AND TURBULENCE ON THE FORCE COEFFICIENTS FOR SQUEEZE FILM DAMPERS. San Andres, L. (Texas A&M Univ, College Station, TX, USA); Vance, J. M. American Society of Mechanical Engineers (Paper 85-GT-191), 1985, 8p

SFD's are nonlinear because the damping and inertia properties are a function of the radius of the circular centered orbit. SFD's do not possess a stiffness originating from the squeeze film. So to ensure that the damper journal will orbit about the center of the damper, some sort of centering spring must be provided. This is often done with either o-ring seals at the ends of the squeeze film, or with a structural member directly supporting the damper journal (e.g., a squirrel cage). On the XLSFD worksheet you enter the centering spring stiffness value in the Kxx and Kyy columns.

Damper Length

This is the axial length of the squeeze film.

Damper Diameter

This is the diameter of the damper journal.

Damper Radial Clearance

This is the damper clearance.

Selected Lubricant

Use your mouse to select a lubricant from the drop down list. The lubricant's reference properties are then read from a file named LUBE.XLS, and are placed in the 5 corresponding input fields. If the lubricant you want is not included in the drop down list, select the lubricant named USER DEFINED, and enter your own values for the lubricant properties.

These values are not directly used by XLSFD, they are intended only to be used to compute the viscosity at the ***Lubricant T***.

Lubricant T

The temperature you enter here can be used, along with the lubricant's reference properties, to compute the lubricant viscosity.

Viscosity at Lube T

This is the viscosity of the lubricant in the squeeze film in units of cst. Just the lubricant viscosity and API gravity are used to compute the SFD damping and inertia properties.

The viscosity is computed from the following equation for viscosity as a function of temperature. Normally this worksheet cell will contain this formula. If this cell is empty, the equation is put in the cell when you change the ***Selected Lubricant*** in the drop down list. The viscosity/temperature equation is as follows:

$$\mu(T) = \mu_A e^{\left[\left(\frac{T-T_A}{T_B-T_A}\right)\ln\left(\frac{\mu_B}{\mu_A}\right)\right]}$$

You can replace the cell formula for the above expression with your own formula, or simply enter a numerical value for viscosity.

Damper Type

Three different types of boundary conditions governing the flow of oil in the squeeze film are selectable from this drop down list.

> *Closed Ended, Full Film* - means both ends of the damper are sealed, and no cavitation is present in the film (perhaps due to external pressurization of the damper).
>
> *Open Ended, Full Film* - means both ends of the damper are not sealed, and no cavitation is present in the film (perhaps due to external pressurization of the damper).
>
> *Open Ended, Half Film* - means both ends of the damper are not sealed, and cavitation is present in half the circumference of the squeeze film.

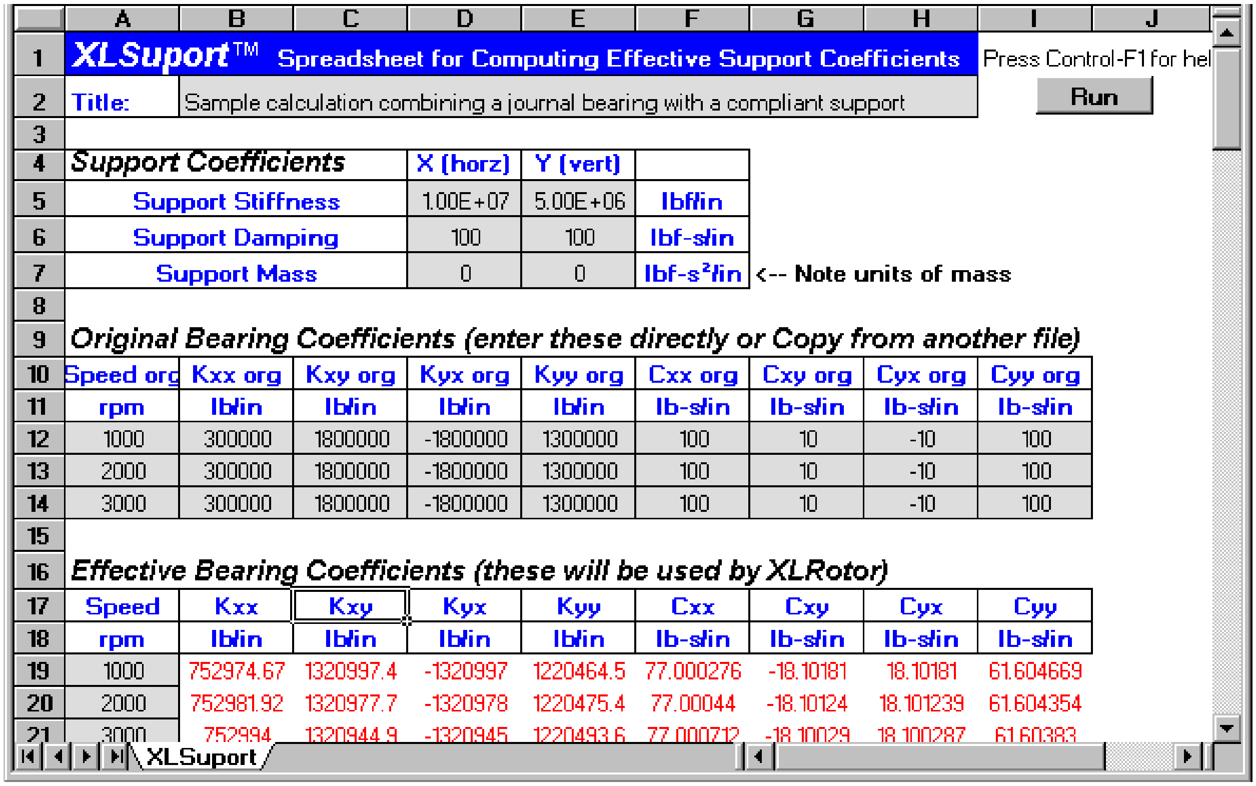
Orbit Radius

This is a dimensionless description of the size of the journal orbit. It is equal to the actual orbit radius divided by the damper radial clearance.

XLSUPORT.XLS Template File

See also

Bearing Template Files
Brg's Worksheet



	A	B	C	D	E	F	G	H	I	J
1	XLSuport™ Spreadsheet for Computing Effective Support Coefficients								Press Control-F1 for hel	
2	Title:	Sample calculation combining a journal bearing with a compliant support							Run	
3										
4	Support Coefficients			X (horz)	Y (vert)					
5	Support Stiffness			1.00E+07	5.00E+06	lbf/in				
6	Support Damping			100	100	lbf-s/in				
7	Support Mass			0	0	lbf-s²/in	<-- Note units of mass			
8										
9	Original Bearing Coefficients (enter these directly or Copy from another file)									
10	Speed org	Kxx org	Kxy org	Kyx org	Kyy org	Cxx org	Cxy org	Cyx org	Cyy org	
11	rpm	lb/in	lb/in	lb/in	lb/in	lb-s/in	lb-s/in	lb-s/in	lb-s/in	
12	1000	300000	1800000	-1800000	1300000	100	10	-10	100	
13	2000	300000	1800000	-1800000	1300000	100	10	-10	100	
14	3000	300000	1800000	-1800000	1300000	100	10	-10	100	
15										
16	Effective Bearing Coefficients (these will be used by XLRotor)									
17	Speed	Kxx	Kxy	Kyx	Kyy	Cxx	Cxy	Cyx	Cyy	
18	rpm	lb/in	lb/in	lb/in	lb/in	lb-s/in	lb-s/in	lb-s/in	lb-s/in	
19	1000	752974.67	1320997.4	-1320997	1220464.5	77.000276	-18.10181	18.10181	61.604669	
20	2000	752981.92	1320977.7	-1320978	1220475.4	77.00044	-18.10124	18.101239	61.604354	
21	3000	752994	1320944.9	-1320945	1220493.6	77.000712	-18.10029	18.100287	61.60383	

XLSuport

The spreadsheet file, XLSUPORT.XLS, can be used when a bearing is mounted on a flexible support, and you want to combine these two entities into a single equivalent entity. ***This worksheet is now obsolete.*** Version 1.0 of XLRotor could not model a bearing support as a separate entity in the rotor system model. For this reason, the XLSUPORT sheet provided a way to combine a bearing support with the bearing. With XLRotor version 2.0 and later, it is recommend that a bearing support be defined in the model as a separate entity, instead of using the XLSUPORT sheet.

This spreadsheet is used as follows:

1. Enter the X and Y ***Support Coefficients*** in the cells on the worksheet. The two stiffness values should never be zero, but the damping and mass values can be zero.

2. Copy (or Link) the ***Original Bearing Coefficients*** from the source bearing worksheet. The source bearing worksheet can be in the same file as the XLSuport worksheet, or in another file.

3. Click the Run button to compute the ***Effective Bearing Coefficients***. The formula used for this calculation is:

D = Z/(1+Z/S)

Z = 2x2 dynamic stiffness matrix of the bearing (i.e. Zxx=Kxx_org+i*omega*Cxx_org, etc.)

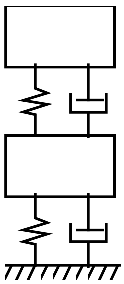
S = 2x2 dynamic stiffness matrix of the support

D = 2x2 dynamic stiffness matrix of the bearing ***combined with*** the support

Kxx = Real(Dxx)

Cxx = Imag(Dxx)/omega

omega = frequency of vibration in radians per second



4. Set the curve fit parameters ***First Power*** and ***Order of Fit***, and click the Update Curve Fits button on the worksheet to check the appearance of the curve fits.
5. Link the title cell in the usual fashion to the Brg's Worksheet in the rotor model file (see Linking bearings to rotors).

This file is marked as a *READ ONLY* file.

Note:
When the effective bearing coefficients are computed, a value for frequency (omega) must be specified. The original bearing coefficients are computed as a function of shaft speed. In the calculation of dynamic stiffness, D, the shaft speed value is used for omega (converted internally to radians per second). ***This means that the effective bearing coefficients at a particular vibration frequency are computed directly from the original bearing coefficients at that corresponding speed frequency.*** This, in turn, means that the effective bearing coefficients are valid only when the rotor system is vibrating at exactly that frequency. This condition will always be satisfied when computing synchronous responses due to imbalance.

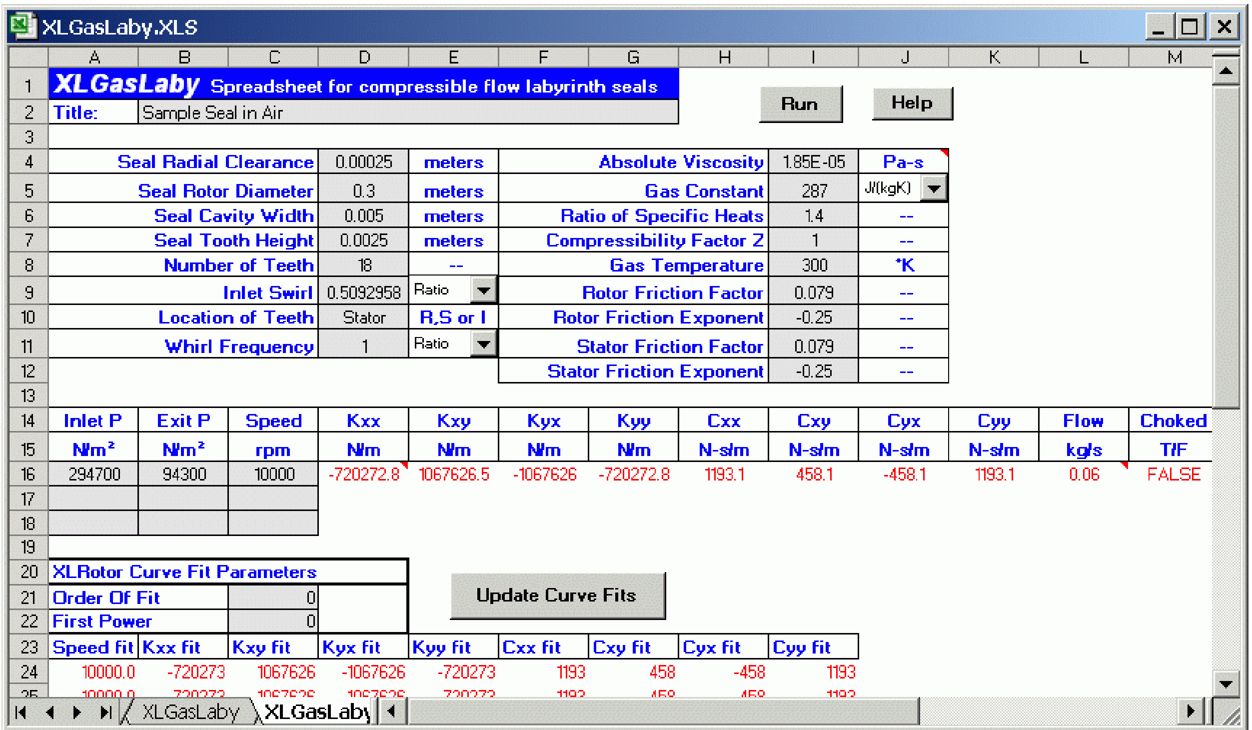
Therefore, **the effective bearing coefficients should be used only for computing synchronous response**. Eigenvalue calculations using effective bearing coefficients must be done in an iterative manner for each mode of interest, so that the frequency of each resulting mode is equal to the frequency used to compute the effective bearing coefficients. Iteration is not required for synchronous response calculations since the frequency of vibration is known beforehand.

Another important point about using XLSUPORT for eigenvalue analysis of damped systems is that calculation of effective coefficients does not consider the real part of the eigenvalue. This means there will be slight errors in damped system eigenvalues that are computed using an XLSUPORT sheet. Such errors do not occur when the model is completely undamped. Such errors also do not apply for forced response analysis.

XLGasLaby.XLS Labyrinth Seal Template File

See also

- Bearing Template Files
- Brg's Worksheet



The ***XLGasLaby*** module is used for analyzing compressible flow labyrinth seals such as those commonly used on compressors and turbines. The method of analysis is based on a one control volume model presented in the book *Turbomachinery Rotordynamics*, by Dara W. Childs, Wiley Interscience, 1993.

An important assumption in this analysis is that the gas temperature remains constant from inlet to exit (i.e., isothermal). As the gas expands from cavity to cavity its temperature will tend to drop due to pure thermodynamic affects. However, there is considerable friction occurring within the seal which will tend to increase the gas temperature. So as a first approximation, the temperature is simply assumed to be constant. The temperature would have to vary considerably to have a significant affect on the stiffness and damping coefficients. Overall, as temperature goes up, the stiffness and damping tend to go down. To get a sense for how sensitive this is, simply compare coefficients computed with different temperatures.

The template file contains two worksheets - one for English units and one for SI units. After you open the template file, it is recommended that you delete the unused worksheet. You can also move the worksheet you want to use from the template to your rotor model file (see Embedded Bearings).

The input parameters for this analysis are as follows:

Note:
Speed dependent inputs - Some of the inputs may change with rotor speed (e.g., clearance). When this is the case, you can add a column of inputs on the right hand side of the Speed input table. See XLJrnl Template File for the details of how to do this.

Seal Geometry Parameters

Seal Radial Clearance

This is the radial clearance of the seal, and is constant throughout the seal. For example, for a teeth on stator seal this is the radius at the tip of the tooth minus the radius of the shaft.

Seal Rotor Diameter

The diameter of the shaft, and is constant throughout the seal. If the teeth are on the rotor, this is the diameter at the bottom of the cavities between the teeth.

Seal Cavity Width

This is the width in the axial direction of each seal cavity, and is constant for all cavities.

Seal Tooth Height

This is the radial height of every tooth. If the seal has interlocking teeth, the teeth on the rotor are assumed to have the same height as the teeth on the stator.

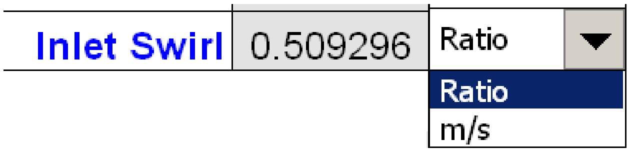
Number of Teeth

This is the total number of teeth in the seal. The number of cavities is always one less than the number of teeth. The number of teeth must be at least two, and there is no upper limit to the number of teeth. For interlocking teeth, this is total number of teeth (# teeth on rotor + # teeth on stator). For high pressure seals, you can use the output of the analysis to help determine the minimum number of teeth required to avoid choking.

Inlet Swirl Ratio

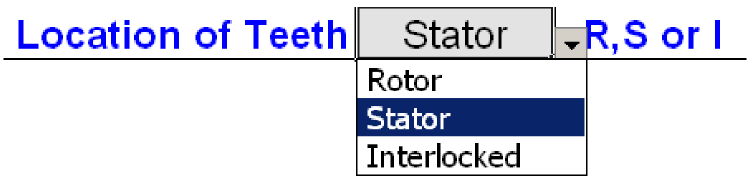
This is a boundary condition, and is the circumferential velocity of the gas as it enters the first seal cavity. This velocity can be entered in one of two ways that you select from the drop down list.

> ***Ratio*** = A fraction of the surface speed of the rotor. A typical value would be 0.5 indicating the gas is swirling at 50% of the speed of the rotor surface.
>
> ***m/s*** = Specify the swirl directly as a circumferential velocity value. In English units this would be as inches/s. You'll need to use this option when you want to run a case at zero rpm.



Location of Teeth

This input must be a single letter or a text string starting with one of the letters "R", "S" or "I" where R means the teeth are on the rotor, S means the teeth are on the stator, and I means there are teeth on both in an alternating/interlocking arrangement. A drop down list should appear when you click on this cell. You can use the drop down to select a value, or just type the value into the cell.

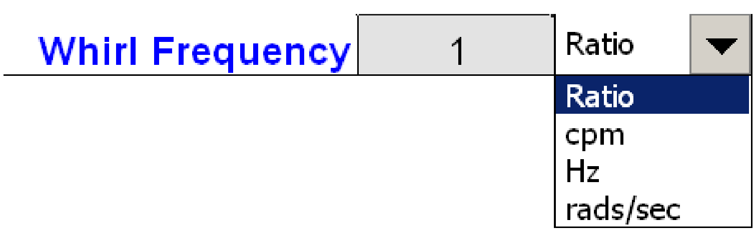


Whirl Frequency

This input specifies what rotor whirl speed to use to compute seal reaction forces on which to base the stiffness and damping coefficients. The reason this option is required is because the seal reaction forces are *not* linear functions of frequency. What the program will do is compute radial and tangential seal reaction forces at (+) and (-) values of the whirl speed you designate, and then get the stiffness and damping coefficients by essentially connecting two points with a straight line on a force versus frequency plot. The radial force leads to the Kxx and Cxy values, and the tangential force leads to the Kxy and Cxx values.

Make a selection from the drop down list as follows:

> ***Ratio*** This specifies the whirl speed as a fraction of the rotor speed. In most case use this option and enter a value of 1, which means to use the synchronous frequency.
>
> ***cpm,Hz,rads/sec*** Use one of these options to specify the whirl speed directly in the units you choose.



The program can be used to explore the frequency dependency of the radial and tangential seal forces. To do this run a set of cases at constant pressure and speed, and vary the whirl frequency by using the ***Use N*** feature for speed dependent inputs. Then from the stiffness and damping coefficients compute radial and tangential seal forces for a typical value of whirl amplitude. The seal forces will, of course, be linearly proportional the whirl amplitude.

Fluid Properties

Absolute Viscosity

This is the viscosity of the fluid in the seal. Since the temperature is taken to be constant, the absolute viscosity is also constant, throughout the seal. Absolute viscosity for a gas is generally a function of temperature, but not pressure. Viscosity increases with temperature because of increased molecular activity. Use the internet or the CRC Handbook of Chemistry and Physics to help find viscosity values. Typical values for dry air are as follows:

Absolute Viscosity of Dry Air

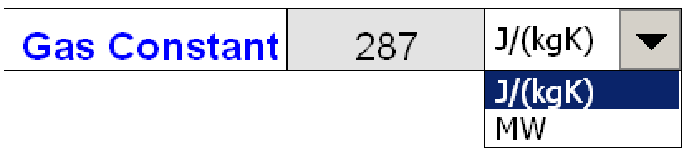
Celsius	Pa-s	Fahrenheit	psi-s
-40	1.570E-05	-40	2.285E-09
-20	1.630E-05	-20	2.319E-09
0	1.710E-05	0	2.347E-09
5	1.730E-05	10	2.389E-09
10	1.760E-05	20	2.431E-09
15	1.800E-05	30	2.486E-09
20	1.820E-05	40	2.500E-09
25	1.850E-05	50	2.556E-09
30	1.860E-05	60	2.604E-09
40	1.870E-05	70	2.653E-09
50	1.950E-05	80	2.681E-09
60	1.970E-05	90	2.708E-09
70	2.030E-05	100	2.736E-09
80	2.070E-05	140	2.868E-09
90	2.140E-05	160	2.931E-09
100	2.170E-05	200	3.118E-09
200	2.530E-05	300	3.451E-09
300	2.980E-05	400	3.639E-09
400	3.320E-05	500	4.028E-09
500	3.640E-05	750	4.729E-09
1000	5.040E-05	1000	5.451E-09

Viscosity of some other gases.

Gas at 20C	Pa-s
Air	0.000018
Helium	0.000019
Methane	0.000020
Nitrogen	0.000018
Oxygen	0.000020
Steam 100C	0.000013

Gas Constant

To specify the particular gas, enter either its ***specific gas constant*** in the units shown, or enter its molecular weight (***MW***) in grams per mole. Use the drop down list to select which type of input to use:



Specific Gas Constant

In the units shown, this value is equal to the Universal Gas Constant of 8.314 N-m/(K-mol) which is the same for all gases, divided by the molecular weight of the gas. For example, air (which is mostly Nitrogen, N2) has an overall molecular weight of approximately 28.97 grams/mole, and so its gas constant is 287 N-m/(kg-K).

$$\text{Air Gas Constant} = \frac{8.314\,\frac{\text{N-m}}{\text{mol-K}}}{0.02897\,\frac{\text{kg}}{\text{mol}}} = 287\,\frac{J}{kg-K}$$

$$\text{Helium Gas Constant} = \frac{8.314\,\frac{\text{N-m}}{\text{mol-K}}}{0.004003\,\frac{\text{kg}}{\text{mol}}} = 2077\,\frac{J}{kg-K}$$

Molecular Weight (MW)

When you select this option, enter the standard molecular weight of the gas in grams per mole. See the examples in the following table:

Gas	Molecular Weight gram/mole	R (J/kg K)
Air	28.97	286.9
Argon, Ar	39.94	208

Carbon Dioxide, CO_2	44.01	188.9
Carbon Monoxide, CO	28.01	297
Helium, He	4.003	2.077
Hydrogen, H_2	2.016	4.124
Methane - natural gas, CH_4	16.04	518.3
Nitrogen, N_2	28.02	296.8
Oxygen, O_2	32	259.8
Propane, C_3H_8	44.09	189
Sulfur dioxide, SO_2	64.07	130
Water vapor	18.02	461.5

Ratio of Specific Heats

The ratio of specific heats is the ratio of the heat capacity of a gas in a constant pressure process - to the heat capacity of a gas in a constant volume process, and is a key thermodynamic property for a gas.

Gas	Ratio of Specific Heats
Carbon Dioxide	1.3
Helium	1.66
Hydrogen	1.41
Methane or Natural Gas	1.31
Nitrogen	1.4
Oxygen	1.4
Air (dry)	1.4

Compressibility Factor

This value accounts for deviations from the ideal gas law of PV=mRT such that PV=ZmRT where Z = 1 for an ideal gas.

Rotor/Stator Friction Factor and Friction Exponent

As the gas expands from cavity to cavity, shearing stresses with the rotor surface tend to swirl the gas, and shearing stresses with the stator tend to retard swirl. An expression for the shearing stress for turbulent flow in a pipe was determined by Blasius in 1913 as:

$$\tau_r = \frac{1}{2}\rho U^2 n_r \left(\frac{UD}{\nu}\right)^{m_r}$$

Where n_r is the **friction factor** for the rotor and m_r is the **friction exponent** for the rotor. An expression of identical form is used for the stator. For this labyrinth seal analysis, the velocity ***U*** is the average velocity of the circumferential flow relative to respective surface (rotor or stator). If the surfaces of the rotor, stator and blades are smooth, as they generally are, appropriate values for these constants are ***n = 0.079*** and ***m = -0.25*** (note the minus sign on ***m***) for both rotor and stator. These values were determined by Yamada in 1961 for flow between annular surfaces. These values should not be changed unless you have flow test data for the actual surfaces in your seal.

Seal Operating Parameters

Inlet & Exit Pressures

These are the **absolute** gas pressures just upstream of the first blade and downstream of the last blade. Do not input gage pressures. These pressures must be absolute.

Speed

This is the speed of the rotor, and should always be entered in units of **rpm**.

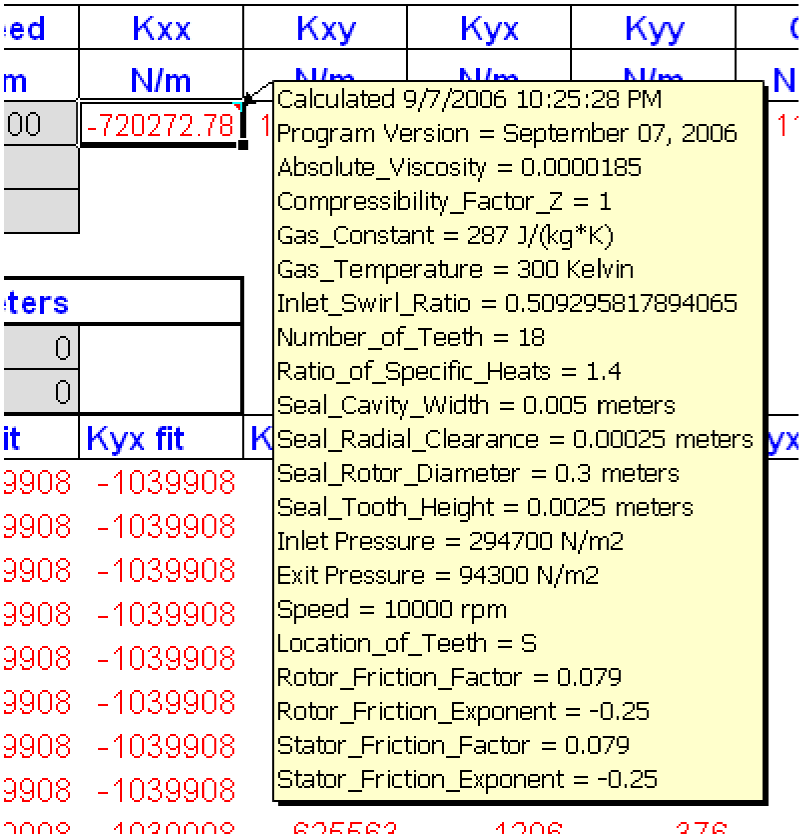
You can enter as many sets of values of these three parameters as you wish. You can insert or delete rows from the worksheet as needed. The program will continue down the Speed column until finding a blank cell.

Analysis Outputs

The following outputs are calculated and placed on the worksheet when you click the **RUN** button located near the top of worksheet.

Kxx,Kxy,Kyx,Kyy,Cxx,Cxy,Cyx,Cyy

These eight values are the stiffness and damping properties calculated for the seal. Because the rotor is assumed to be whirling about the center of the seal clearance, the following conditions will always hold among the coefficients: Kxx=Kyy, -Kxy=Kyx, Cxx=Cyy, and -Cxy=Cyx. Each of the cells containing a ***Kxx*** value will also contain a cell comment which is displayed when you position the mouse cursor over the cell. The cell comment documents the parameters used for the analysis.

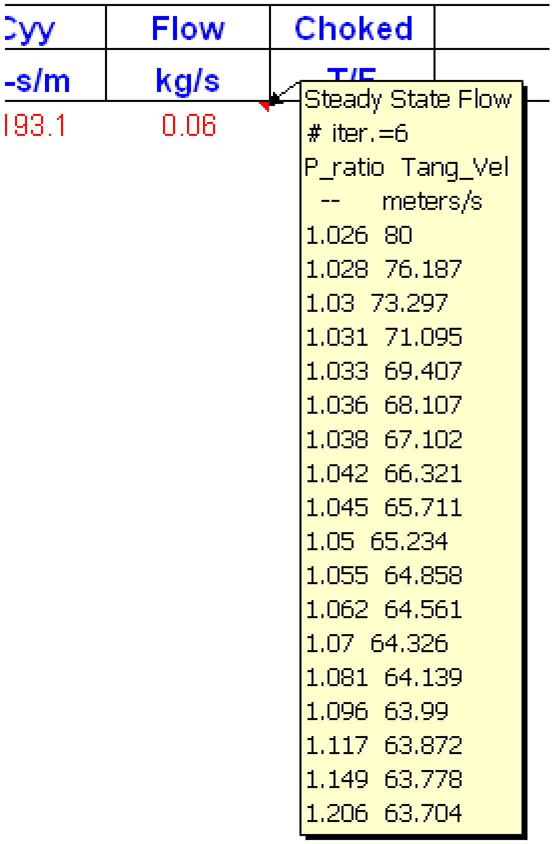


Flow

This is the steady state mass flow rate of the gas through the seal (i.e. leakage rate). The determination of steady state flow begins with an iterative calculation to get the leakage rate and pressure in each cavity by using a standard flow formula for the flow across one blade. After this is done, the circumferential flow velocity within each cavity is computed, one cavity at a time.

The leakage rates calculated by ***XLGasLaby*** will not be a function of rotor speed or the rotor&stator friction factors & exponents. Only the circumferential flow velocities will depend on these parameters.

Each cell containing the leakage flow rate will also contain a cell comment listing the pressure ratio across each blade, and the circumferential swirl velocity in the cavity upstream of each blade. The first swirl velocity value listed is thus the inlet swirl velocity. The swirl velocity in the exit region, downstream of the last blade, is not computed.



On an SI unit worksheet the mass flow rate units will kg/s, and on an English units worksheet the units will sn/s (the unit sn stands for snail = 1 lbf-s^2/in = 386 lbm).

Choked

This cell will contain the word TRUE or FALSE indicating whether or not the flow is choked across the last blade. If the pressure ratio across a blade is high enough, the flow will be choked. This can only happen at the last blade (flow follows a Fanno line).

$$\text{pressure ratio limit for choked flow} = \left(\frac{2}{1+k}\right)^{\frac{k}{1-k}}$$

For a stationary gas, the minimum pressure ratio to choke is a function only of the ratio of specific heats.

Order of Fit

This is the degree of the polynomial to be fit to the stiffness and damping data points. The number of terms in the polynomials will be one plus the ***Order of Fit***. See Curve Fitting for more details about curve fitting.

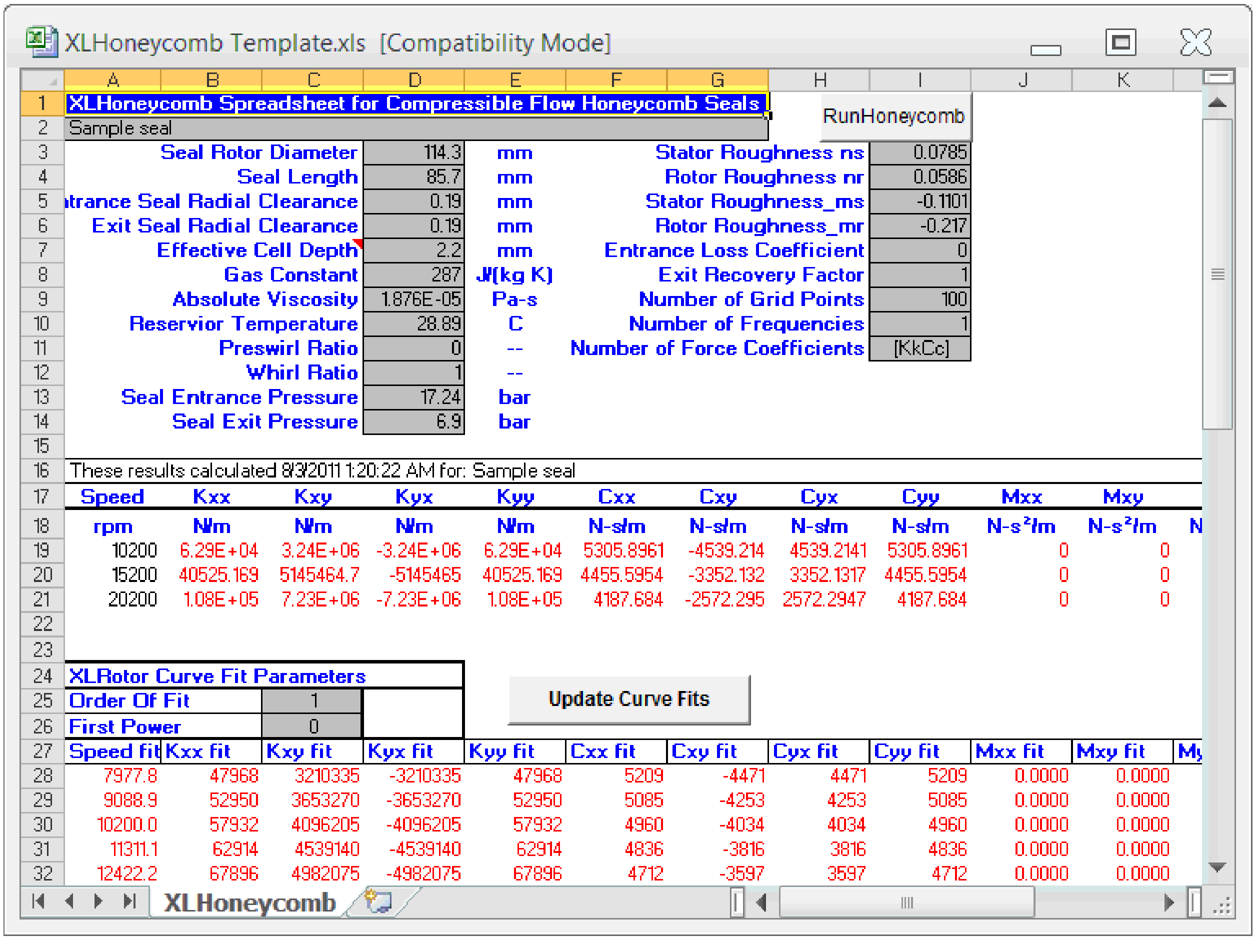
First Power

The first term of the curve fit polynomial will have the speed, N, raised to the ***First Power***. See Curve Fitting for more details about curve fitting.

XLHoneycomb Template File

See also

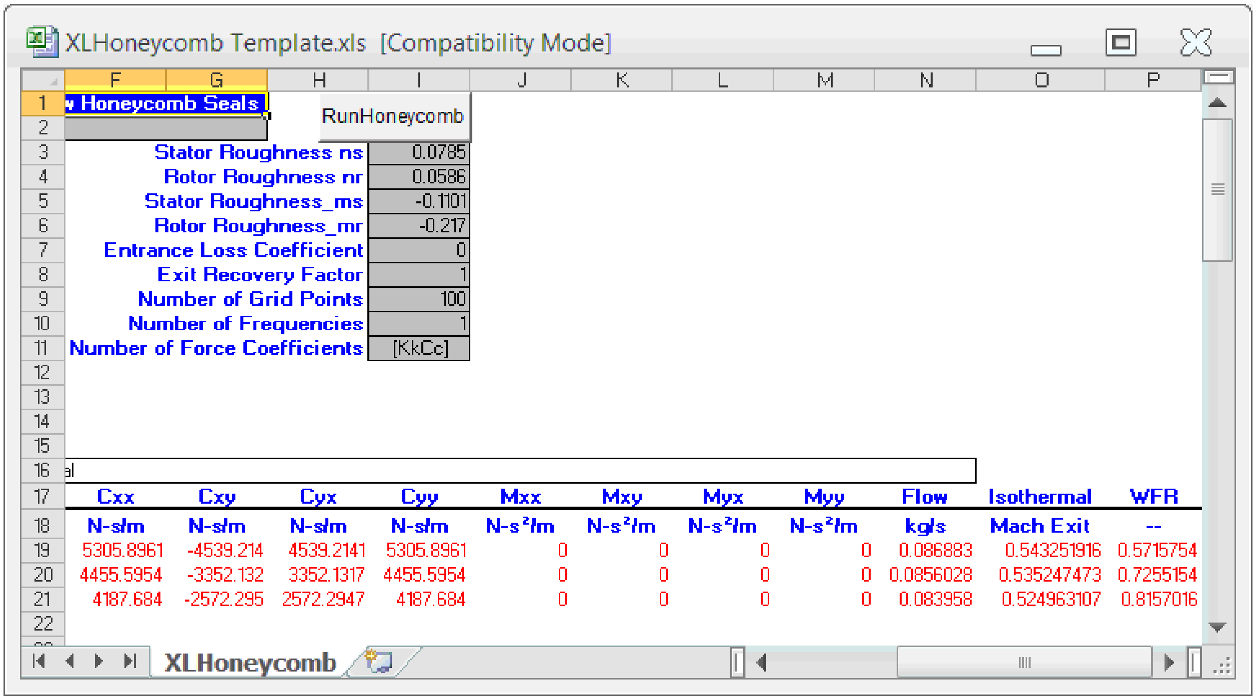
[Bearing Template Files](#)
[Brg's Worksheet](#)



XLHoneycomb Template.xls [Compatibility Mode]

	A	B	C	D	E	F	G	H	I	J	K
1	XLHoneycomb Spreadsheet for Compressible Flow Honeycomb Seals							RunHoneycomb			
2	Sample seal										
3			Seal Rotor Diameter	114.3	mm		Stator Roughness ns	0.0785			
4			Seal Length	85.7	mm		Rotor Roughness nr	0.0586			
5			ıtrance Seal Radial Clearance	0.19	mm		Stator Roughness_ms	-0.1101			
6			Exit Seal Radial Clearance	0.19	mm		Rotor Roughness_mr	-0.217			
7			Effective Cell Depth	2.2	mm		Entrance Loss Coefficient	0			
8			Gas Constant	287	J/(kg K)		Exit Recovery Factor	1			
9			Absolute Viscosity	1.876E-05	Pa-s		Number of Grid Points	100			
10			Reservior Temperature	28.89	C		Number of Frequencies	1			
11			Preswirl Ratio	0	--		Number of Force Coefficients	[KkCc]			
12			Whirl Ratio	1	--						
13			Seal Entrance Pressure	17.24	bar						
14			Seal Exit Pressure	6.9	bar						
15											
16	These results calculated 8/3/2011 1:20:22 AM for: Sample seal										
17	Speed	Kxx	Kxy	Kyx	Kyy	Cxx	Cxy	Cyx	Cyy	Mxx	Mxy
18	rpm	N/m	N/m	N/m	N/m	N-s/m	N-s/m	N-s/m	N-s/m	N-s²/m	N-s²/m
19	10200	6.29E+04	3.24E+06	-3.24E+06	6.29E+04	5305.8961	-4539.214	4539.2141	5305.8961	0	0
20	15200	40525.169	5145464.7	-5145465	40525.169	4455.5954	-3352.132	3352.1317	4455.5954	0	0
21	20200	1.08E+05	7.23E+06	-7.23E+06	1.08E+05	4187.684	-2572.295	2572.2947	4187.684	0	0
22											
23											
24	XLRotor Curve Fit Parameters										
25	Order Of Fit		1		Update Curve Fits						
26	First Power		0								
27	Speed fit	Kxx fit	Kxy fit	Kyx fit	Kyy fit	Cxx fit	Cxy fit	Cyx fit	Cyy fit	Mxx fit	Mxy fit
28	7977.8	47968	3210335	-3210335	47968	5209	-4471	4471	5209	0.0000	0.0000
29	9088.9	52950	3653270	-3653270	52950	5085	-4253	4253	5085	0.0000	0.0000
30	10200.0	57932	4096205	-4096205	57932	4960	-4034	4034	4960	0.0000	0.0000
31	11311.1	62914	4539140	-4539140	62914	4836	-3816	3816	4836	0.0000	0.0000
32	12422.2	67896	4982075	-4982075	67896	4712	-3597	3597	4712	0.0000	0.0000

XLHoneycomb



XLHoneycomb is applicable to both honeycomb and hole pattern seals.

Seal Rotor Diameter

Diameter of shaft journal within the seal.

Seal Length

Axial length of seal from entrance to exit of the seal land.

Entrance and Exit Seal Radial Clearance

These are radial clearances at the entrance and exit of the seal land. Normally these would be equal. If different, the clearance follows a linear taper. When subjected to high pressure, the stators of some seals can deform to result in converging or diverging taper.

Effective Cell Depth

This is the ratio of total volume of all cells to the total surface area of the seal between inlet and exit.

Fluid Properties

Absolute Viscosity

See the description given for XLGasLaby

Gas Constant

See the description given for XLGasLaby

Reservoir Temperature

This would generally be the supply temperature. XLHoneycomb does its calculation assuming isothermal conditions. As the gas expands through the seal, its temperature would tend to decrease, but friction losses tend to heat the gas. If you have actual data for entrance and exit gas temperature, input their average.

Preswirl Ratio

This specifies the circumferential velocity of the gas at the seal entrance as a fraction of the surface velocity of the seal journal. Typical value would be 0.5. If a swirl brake or shunt injection is employed, inlet swirl could be as little as zero, or even negative. This input value can strongly influence cross coupled stiffness.

Whirl Ratio

Refer to the descriptions below for ***Number of Force Coefficients*** and ***Frequencies***.

Inlet and Exit Pressures

Enter absolute pressure. Not gage pressure.

Rotor and Stator Roughness Coefficients

These are Blasius friction-factor coefficients which are defined by the following friction factor model equation: $f=n(Re)^m$ where Re is the circumferential Reynolds number based on the circumferential fluid velocity relative to the rotor and the hydraulic diameter of the flow passage.

For a smooth rotor and typical honeycomb stator, Hirs suggests the following values:

Stator: ns=0.0785 and ms=-0.1101

Rotor: nr=0.0586 and mr=-0.217

Use these values unless you have empirical data for your particular seal.

Entrance Loss Coefficient

Typical values, x_i = 0 to 0.1. Accounts for pressure drop at seal entrance as gas abruptly accelerates from zero axial velocity.

$$\Delta P_{inlet} = \frac{1}{2}\rho_{inlet} V_{inlet}^2 (1 + x_i)$$

Exit Recover Factor

Accounts for pressure recovery as gas decelerates in exit chamber. Typical value, x_e=1.0 for no exit recovery.

$$\Delta P_{exit} = \frac{1}{2}\rho_{exit} V_{exit}^2 (1 - x_e)$$

Number of Grid Points

Number of Grid Points	100
Number of Frequencies	1
Number of Force Coefficients	[K,k,C,c]

This is the number of calculation points along the length of the seal. An input of 100 points is usually sufficient to get a fully accurate solution. To verify that 100 is or is not sufficient, run a case with 200, and if results do not change significantly, then 100 is sufficient.

If you receive a message that the flow rate could not be calculated, try increasing the number of grid points.

Number of Force Coefficients

This is the number of linearized force coefficients to output for the seal at each value of operating speed. Make your selection from a Drop Down list in the cell. There are presently four chioces for this option, which are:

[Kk]	K=direct stiffness, k=cross coupled stiffness
[KkCc]	C=direct damping, c=cross coupled damping
[KkCcM]	M=direct inertia
[KkCcMm]	m=cross coupled inertia

[Kk] - This selection essentially means the program will output the real part of the Radial Impedance times minus one (-Re{Ir}) in the Kxx column (and Kyy=Kxx), and it will output the imaginary part of the Tangential Impedance (Im{It}) in the Kxy column (and Kyx=-Kxy). This option can be used to generate data for plots of the impedance functions versus whirl frequency, for a given operating speed, by running a series of cases with the **Whirl_Ratio** input varied across the range of interest, say -2 to +2, or similar. When the **[Kk]** choice is selected, the input for **Number of Frequencies** must be 1 (the program will check this).

[KkCc] - This selection means the program will curve fit straight lines to the Re{Ir} and Im{It}, and the coefficients of the curve fit become the force coefficients as follows:

Re{Ir} = -K + c*f

Im{It} = k - C*f

Where f = whirl orbit frequency in radians per second.

[KkCcM] - This selection means the program will curve fit a quadratic function to the Re{Ir} and a straight line to Im{It}, and the coefficients of the curve fits become the force coefficients as follows. This option requires that the input for **Number of Frequencies** be 2 or more.

Re{Ir} = -K + c*f + M*f^2

Im{It} = k - C*f

[KkCcMm] - This selection means the program will curve fit a quadratic function to the Re{Ir} and a quadratic to Im{It}, and the coefficients of the curve fits become the force coefficients as follows. This option requires that the input for **Number of Frequencies** be 2 or more.

Re{Ir} = -K + c*f + M*f^2

Im{It} = k - C*f – m*f^2

Number of Frequencies

For each input rpm, the program calculates radial and tangential force impedances for a range of circular whirl orbit frequencies as dictated by this input, and these impedances are used to determine the linearized force coefficients output by the program.

When Number of Frequencies=1, the program will compute impedances at the following two frequencies:

0 and

1*Whirl_Ratio*Speed

When Number of Frequencies=2, the program will compute impedances at the following three frequencies. This choice optimizes the force coefficients about a frequency equal to Whirl_Ratio*Speed. For example, when doing a stability analysis of the first mode of a multi-stage centrifugal compressor with a first mode near 40% of operating speed, enter Speed=operating speed, Whirl_Ratio=0.4 and Number of Frequencies=2.

0.8*Whirl_Ratio*Speed

1.0*Whirl_Ratio*Speed

1.2*Whirl_Ratio*Speed

When Number of Frequencies=3, the program will compute impedances at the following four frequencies.

0.000*Whirl_Ratio*Speed

0.333*Whirl_Ratio*Speed

0.667*Whirl_Ratio*Speed

1.000*Whirl_Ratio*Speed

An input of Number of Frequencies>3 (call this N) will subdivide the range from 0 to 1*Whirl_Ratio into N equal increments.

XLHydroDyn.XLS Template File

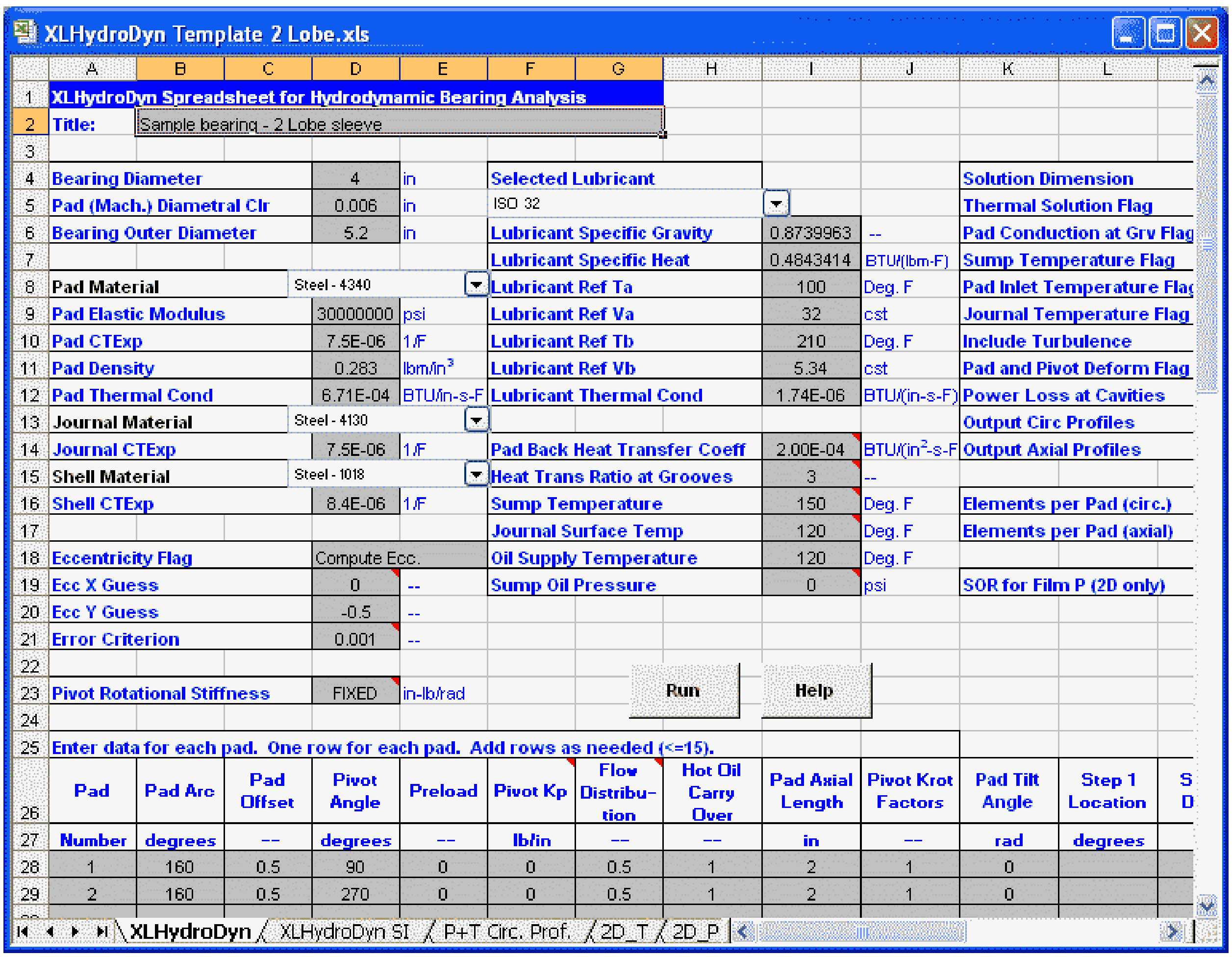
In-Depth Design Analysis for Hydrodynamic Bearings

See also

- Bearing Template Files
- XLJrnl Template File
- XLThrustBearing File
- Brg's Worksheet

To open a sample workbook, look in the XLRotor Templates folder.

XLHydrodyn is not included in a standard license of XLRotor. For information on how obtain this module, contact support@xlrotor.com. XLHydrodyn is used for design and analysis of both fixed geometry and tilting pad oil film bearings. A wide variety of bearings can be analyzed; multi-groove sleeve, tilting pad, pressure dam, taper land, deflection pad, and more.



XLHydroDyn Template 2 Lobe.xls

Row	A–C	D	E	F–G	I	J	K–L
1	XLHydroDyn Spreadsheet for Hydrodynamic Bearing Analysis						
2	Title:	Sample bearing - 2 Lobe sleeve					
3							
4	Bearing Diameter	4	in	Selected Lubricant			Solution Dimension
5	Pad (Mach.) Diametral Clr	0.006	in	ISO 32			Thermal Solution Flag
6	Bearing Outer Diameter	5.2	in	Lubricant Specific Gravity	0.8739963	--	Pad Conduction at Grv Flag
7				Lubricant Specific Heat	0.4843414	BTU/(lbm-F)	Sump Temperature Flag
8	Pad Material	Steel - 4340		Lubricant Ref Ta	100	Deg. F	Pad Inlet Temperature Flag
9	Pad Elastic Modulus	30000000	psi	Lubricant Ref Va	32	cst	Journal Temperature Flag
10	Pad CTExp	7.5E-06	1/F	Lubricant Ref Tb	210	Deg. F	Include Turbulence
11	Pad Density	0.283	lbm/in^3	Lubricant Ref Vb	5.34	cst	Pad and Pivot Deform Flag
12	Pad Thermal Cond	6.71E-04	BTU/in-s-F	Lubricant Thermal Cond	1.74E-06	BTU/(in-s-F)	Power Loss at Cavities
13	Journal Material	Steel - 4130					Output Circ Profiles
14	Journal CTExp	7.5E-06	1/F	Pad Back Heat Transfer Coeff	2.00E-04	BTU/(in^2-s-F	Output Axial Profiles
15	Shell Material	Steel - 1018		Heat Trans Ratio at Grooves	3	--	
16	Shell CTExp	8.4E-06	1/F	Sump Temperature	150	Deg. F	Elements per Pad (circ.)
17				Journal Surface Temp	120	Deg. F	Elements per Pad (axial)
18	Eccentricity Flag	Compute Ecc.		Oil Supply Temperature	120	Deg. F	
19	Ecc X Guess	0	--	Sump Oil Pressure	0	psi	SOR for Film P (2D only)
20	Ecc Y Guess	-0.5	--				
21	Error Criterion	0.001	--				
22							
23	Pivot Rotational Stiffness	FIXED	in-lb/rad	Run	Help		
24							
25	Enter data for each pad. One row for each pad. Add rows as needed (<=15).						

Row	Pad	Pad Arc	Pad Offset	Pivot Angle	Preload	Pivot Kp	Flow Distribu-tion	Hot Oil Carry Over	Pad Axial Length	Pivot Krot Factors	Pad Tilt Angle	Step 1 Location	S D
27	Number	degrees	--	degrees	--	lb/in	--	--	in	--	rad	degrees	
28	1	160	0.5	90	0	0	0.5	1	2	1	0		
29	2	160	0.5	270	0	0	0.5	1	2	1	0		

XLHydroDyn / XLHydroDyn SI / P+T Circ. Prof. / 2D_T / 2D_P

Running the XLHydroDyn Worksheet

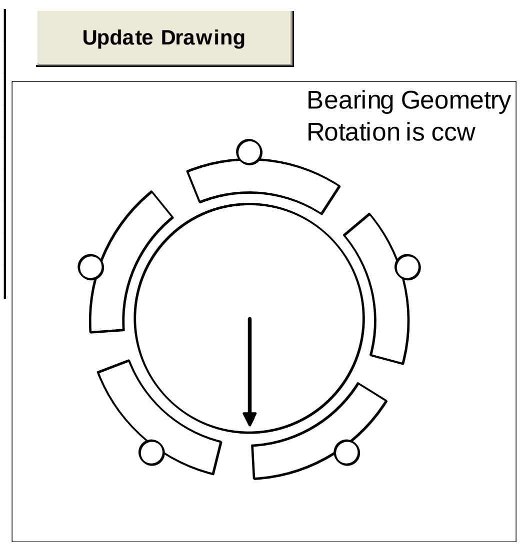
You run an analysis by doing any of the following:

- Click the ***Run*** button to execute the analysis on the currently active worksheet.
- Use the ***Shift*** and ***Control*** keys to select multiple worksheet tabs, then clicking the ***Run*** button will run the analysis on all the selected worksheets. Any of the selected sheets that are not XLHydroDyn sheets will be skipped.
- Hold the Shift key down and click the ***Run*** button, then all worksheets from the current worksheet to the end of the file will be run.

To execute an analysis from your own Excel macro, use the following Visual Basic statement:

```
Application.Run “hydrodyn.xla!RunXLHydroDyn” [,True/False]
```

The second argument is optional and True means don’t show any prompts or messages. The default is False which means messages and prompts will be displayed.



The geometry of the pad arrangement can be drawn automatically by clicking the ***Update Drawing*** button. Tilting pad bearings are drawn with circles depicting the locations of the pivots. Fixed geometry bearings are drawn with small dots at the pivots. The sample drawing here shows a 5 pad tilting-pad bearing in what is typically called a load between pad configuration. The load vector(s) is also depicted on the chart. The clearance of the bearing is amplified by a factor of 30 for display purposes (and so is the pad tilt angle), but all other geometric properties of the bearing are displayed approximately to scale. If you add your own annotations to the chart, they will remain on the chart after subsequent updates. You can also move and resize the chart. Subsequent updates will draw the bearing toward the left side of the chart. If the chart is deleted, it will be recreated the next time the button is clicked.

Analysis Options

The following options are selected from drop down lists which are activated when you click in one of the gray cells.

Eccentricity Flag	Compute Ecc.
Solution Dimension	1D for P & 1D for T
Thermal Solution Flag	Adiabatic Solution
Pad Conduction at Grv Flag	Grv T is Tsump
Sump Temperature Flag	Tsump Computed
Pad Inlet Temperature Flag	Tin Comp. w/ T_cav
Journal Temperature Flag	Average of Film T
Turbulence Flag	Turbulence Allowed
Pad and Pivot Deform Flag	All 3 Def's
Power Loss In Cavities	Do not include
Output Circ Profiles	Yes
Output Axial Profiles	No

Eccentricity Flag

For a given eccentricity the program can compute the journal load very quickly. For a given journal load the program iterates to find the eccentricity that produces the given load.

Compute Ecc. – (normal option) Here you specify the journal load and the program will iterate to find the eccentricity. In general, a reasonably good initial guess for eccentricity is required, otherwise the iteration may not converge to a solution. Depending on your choice of thermal solution options, the program also has to iteratively find temperatures and oil viscosity.

Specify Ecc. – When the eccentricity is given, the program only has to iterate to find the thermal solution (when requested).

Solution Dimension

This option controls how the pressure and temperature of the lubricant film are modeled in the axial and circumferential directions. In the cross film direction, pressure is always constant, and the modeling of temperature is dictated by the Thermal Solution Flag discussed below. One of the 2D options must be used when the input value for Sump Oil Pressure is not zero.

1D for P & T – (normal option) Pressure and temperature will vary circumferentially and be computed for each mesh point. Axial pressure variation will be according to an analytical expression and is a function of the L/D ratio of the pad (Ettles, 1980). Temperature is assumed to be constant in the axial direction.

2D for P, 1D for T – Pressure is computed on both circ and axial mesh points. Temperature is constant in the axial direction. This option will take significantly more time to run than using the Ettles expression. The effect on results is often small.

2D for P & T – Pressure and temperature are each computed on both circumferential and axial mesh points. This option increases the time even more. Temperature variation in the axial direction is often found to be quite small.

If you're specifying a nonzero value for Sump Pressure, you also must select one of these 2D solution options. A 2D option must also be selected if a Step Width has been specified that is shorter than the axial length of a pad.

Thermal Solution Flag

The Adiabatic option will almost always produce higher film temperatures than the Solve for Conduction option, in which case Adiabatic can be considered as conservative for design purposes (note this option ignores possible heating by a hot shaft). In tilting pad bearings with highly conductive pads like Copper, the Solve for Conductive option should be used.

Adiabatic – (normal option, particularly for fixed pad bearings) This means all heat generated in the oil is absorbed by the oil in the film and none is conducted to either the shaft or pads. This also means the temperature (and viscosity, too) will be constant across the lubricant film, although it can still vary in the circumferential and axial directions.

Solve for Conduction – Heat is allowed to conduct to or from the shaft and pads. This option is required for temperature (and viscosity) to be able to vary across the fluid film.

Isothermal – The oil throughout the bearing will be constant at the supply temperature input value. Therefore, the oil will also be isoviscous throughout the bearing. This option would not normally be used for most bearing analysis.

Pad Conduction at Groove Flag

Heat transfer from the end faces of each pad is modeled as convection using your input value for Pad Back Heat Transfer Coeff. Your selection for this option designates what temperature to use as the ambient temperature.

Groove T is Tsump – (normal option) Use the temperature ***Tsump*** in the grooves for convective heat transfer from the ends of each pad.

Groove T is Tmix - Use the temperature ***Tmix*** in the grooves for convective heat transfer from the ends of each pad. ***Tmix*** is defined below.

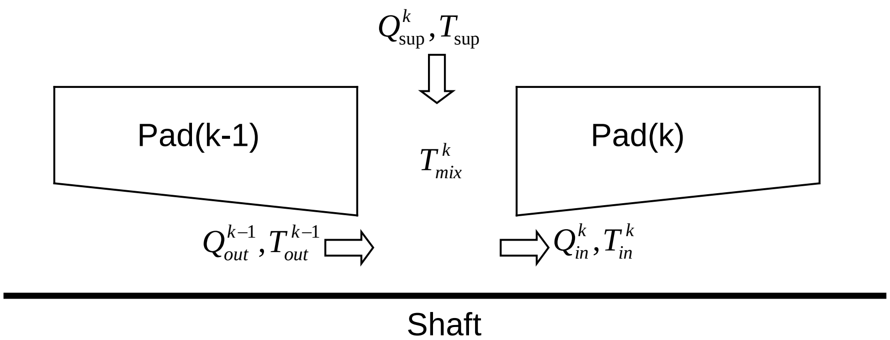
Sump Temperature Flag

Unless an adiabatic or isothermal option has been selected, heat conducts radially through the pad, and a convective heat transfer model is used to model heat leaving the back of the pad. The ambient temperature surrounding the pad is Tsump. Heat transfer from the back of the pad will be convective using your input value for Pad Back Heat Transfer Coeff.

> ***Tsump Fixed by User*** – The sump temperature is fixed at the value you input for Tsump. The heat flowing through the pad will be strongly governed by this temperature.
>
> ***Tsump Computed*** – (normal option) The sump temperature is calculated as part of the overall thermal solution. This is done by converting 100% of all power loss to heat, which heats the total oil flow of Qin at Tin to Tsump.

Pad Inlet Temperature Flag

This is among the most important options to be selected. The temperature of the oil entering each pad at its leading edge is an extremely important value in determining bearing performance. Referring to the following figure, this temperature can be determined in several ways:



$$T^k_{in} = \frac{Q^{k-1}_{out} T^{k-1}_{out} + (Q^k_{in} - Q^{k-1}_{out}) T^*}{Q^k_{in}}$$

All hot oil Qout exiting the trailing edge of the upstream pad is assumed to enter the next pad (although this can be modified with the Hot Oil Carry Over input). Qout is usually smaller than Qin for the next pad. The temperature T* of oil that is mixed with Qout can be dictated by your choice among the following options. The program always operates on the presumption that Qin will be available in some fashion to avoid starvation at the leading edge of each pad. It is recommended to check the pad flows output by the program so that you will know whether or not Qsup is sufficient.

> ***Tin is Tsupply*** – The oil temperature entering a pad at its leading (upstream) edge is set equal to your input value for supply temperature. This is the option to use when you want to specify exactly the oil temperature entering each pad's leading edge. A possible example would be an LEG (leading edge groove) bearing.
>
> ***Tin is Tmix*** – Tmix is simply an ideal mixing of supply oil (Qsup at Tsup) with oil exiting the upstream pad (Qout at Tout).

Tin is Tsump – Tsump is computed by assuming that all of the calculated power loss goes into heating all of the supplied oil.

Tin computed w/ Tsup – If Qout>Qin, then Tin=Tout. If Qout<Qin, the equation given above is utilized with T* being equal to Tsup regardless of whether or not Qsup is sufficient. This option is appropriate for sleeve bearings with pressurized grooves, but you should still check that the oil supply is sufficient to avoid starvation.

Tin computed w/ Tsump – Same as above except extra oil is at Tsump instead of Tsup. This option is appropriate for tilting pad bearings with a single inlet at the bottom and drain at the top.

Tin computed w/ Tcav - If Qout>Qin, then Tin=Tout. If Qout<Qin, the equation given above is utilized with T* being equal to Tsup if Qsup is sufficient (i.e. [Qout+Qsup>Qin). If Qsup is not sufficient, then additional required oil is at Tsump. This option is appropriate for tilting pad bearings with direct nozzles at each pad.

Journal Temperature Flag

Unless an adiabatic or isothermal option has been selected, the shaft can either take or give heat from the oil. The shaft temperature can be specified as a known value, or calculated by the program.

Fixed by User – The temperature of the shaft is fixed at the value you enter for the Journal Surface Temperature.

Average of Film T – (normal option) The temperature at each circ mesh point is averaged to get the shaft temperature. This may result in nonzero net heat flow to or from the shaft to the oil.

No Heat to Shaft – A constant journal surface temperature is calculated such that no net heat is gained or lost to the shaft. This is not the same thing as a purely adiabatic calculation. There is heat flowing to and from the shaft, but the net is zero.

Turbulence Flag

Laminar Solution – The solution to Reynolds equation is assumed to be laminar throughout the bearing.

Turbulence Allowed – (normal option) Turbulence correction factors (which are analytical functions of local Re number) are computed and applied independently in the axial and circ directions. This is much like turbulence correction factors being applied to the viscosity.

Pad & Pivot Deform Flag

This option controls how to account for the effect on pad preload and clearance of three things; 1) pivot deformation, 2) pad elastic deformations and 3) pad thermal deformations. The three different contributors can be selected in any combination. The influences can cause the apparent pad-bore clearance and/or apparent set-bore clearance to change, and thereby cause the apparent preload to change. Program execution time will generally increase modestly when including pad deformations.

No Pad or Pivot Deformation – (normal option) This corresponds to a rigid pad and rigid pivot, which means the preload and clearance of the pad will not change from your input values.

Pivot Def. – Enables the effect of pivot compliance on the preload of loaded pads. This effect causes the apparent set-bore clearance to increase but doesn’t change the apparent pad-bore clearance.

Pad-Thrm – Enables the effect of pad thermal deformations. This can change both the thickness (i.e. set-bore clearance) and curvature (i.e. pad-bore clearance) of the pad. The journal diameter, pad outer diameter and bearing shell diameter also can change. These effects can cause both apparent pad-bore and set-bore clearances to change at each pad. So the resultant preload of a pad could increase or decrease.

Pivot + Pad-Thrm – Both Pivot Deformation and Pad Thermal deformations are included.

Pad-Mech – Enables the effect of mechanical deformations. The hydrodynamic pressure acting on the pad causes the pad curvature to open up a small amount. This will tend to cause the apparent pad-bore clearance to increase while the apparent set-bore clearance remains unchanged. Thus preload will tend to increase.

Pivot + Pad-Mech

Pad-Thrm + Pad-Mech

All 3 Def's

Be aware that a finite compliance of the pivot reduces the stiffness of the bearing (see Pivot Kp), but that effect is separate from this.

Also be aware that if you select a choice that includes pivot deformation, then none of the pads will be permitted to have a completely rigid pivot (i.e., Pivot Kp=0).

Power Loss in Cavities

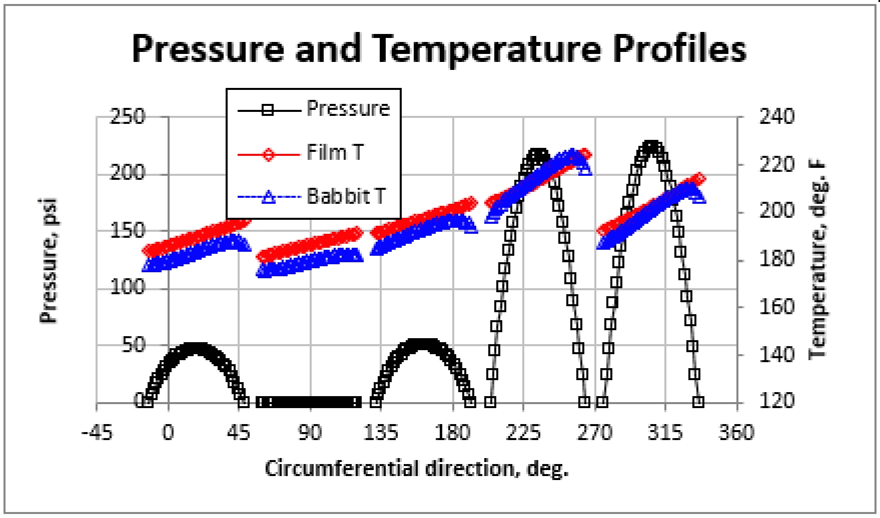
The total power loss of a bearing is often calculated only from the viscous shearing action within the fluid film. Power loss due to churning action in the grooves can be significant, especially at higher speeds. Turning this option on or off will directly affect the predicted power loss and sump temperature. It will normally have little, if any, influence on other outputs.

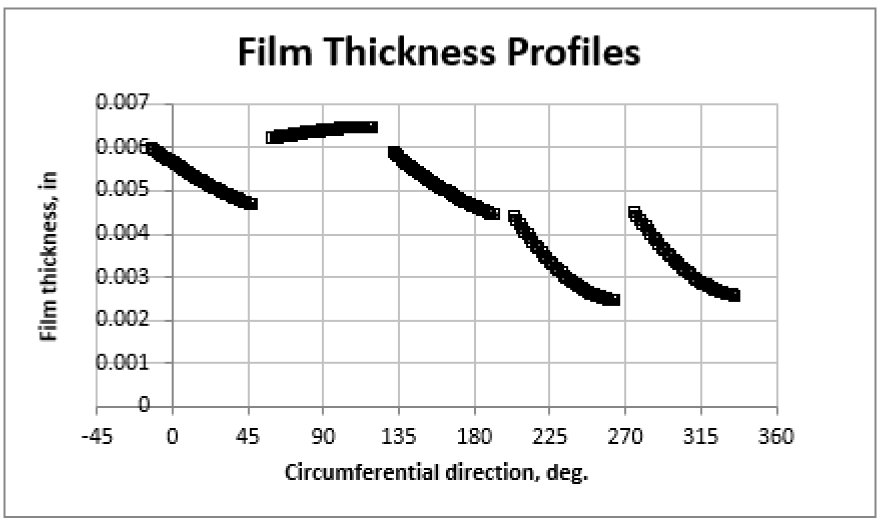
Do Not Include Power Loss (normal option)

Include Power Loss

Output Circumferential Profiles

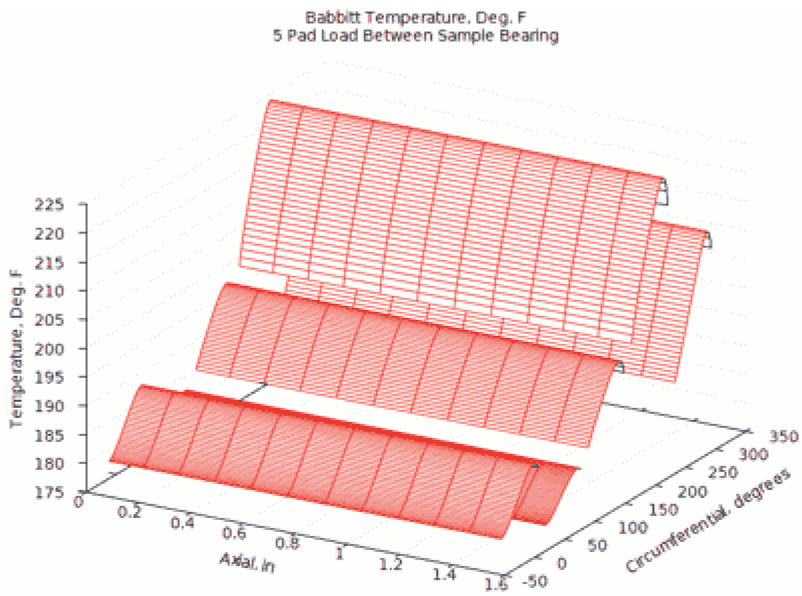
Temperature, pressure and film thickness profiles in the circumferential coordinate at the midplane of the bearing can be written to a separate worksheet named “P+T Circ. Prof.”. The worksheet will be created if needed, or else overwritten. Maximum values of pressure and temperature will always be in the midplane. The following example plot is of a 5-pad tilting-pad bearing. In this example pad 2 has zero pressure which means it is fully cavitated (note that its film thickness is fully divergent). From the plots it is evident that the load is applied between pads 4 and 5.

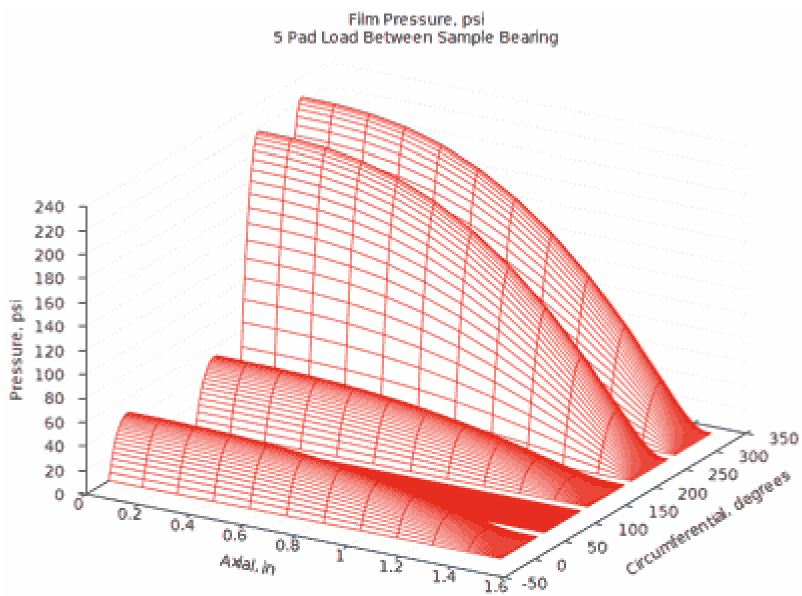




Output Axial Profiles

This option will output full 2 dimensional maps of temperature and pressure. Pressure data is written to a worksheet named “2D_P”, and temperature to a worksheet named “2D_T”. These worksheets will be created if needed, or else overwritten. The 3D plots are created with the Gnuplot.





Analysis Parameters

Ecc X & Ecc Y Guesses

These are starting guesses when the program is finding eccentricity for a specified journal load. Otherwise, these become the specified eccentricity for which the journal load will be calculated (see Eccentricity Flag). These inputs are dimensionless with respect to the pad clearance. An input value of zero signifies the geometric center of the bearing (but don't use 0 & 0 as an initial guess). For bearings with zero preload, an input value of 1 corresponds to being close to rubbing. When preload m is not zero, an input value close to (1-m) corresponds to being close to rubbing. Therefore, for preloaded bearings be sure that your initial guess is <(1-m).

Error Criterion

(normal value 0.001) The iterative search for static eccentricity position continues until the error is smaller than this value. A value of 0.001 means error will be less than 0.1%. This is the recommended value which should provide satisfactory results in nearly all situations. If this value is too small, the calculation will not converge due to the discreet nature of the mesh. If you are running a case that is having trouble converging, double check all inputs very carefully before increasing this value. Usually, convergence problems are due to unrealistic conditions resulting from an improper input (like a clearance that is far too large or too small). This can easily happen when creating an input file by editing an existing file, and not changing everything that needs to be changed. The program also has some internal limits on how many iterations it will perform before aborting. See Tips on Program Use.

Pivot Rotational Stiffness

This is a rotational stiffness value which resists tilting motion of a pad. For tilting pad bearings this value should be zero. For fixed geometry bearings, like sleeve bearings, enter the word FIXED. For deflection pad bearings enter a positive value that is normally determined via structural analysis of the pad's support post.

When this input is not zero, there can be multiple solutions for static eccentricity that produce a specified load. This is normal, but it can cause the overall bearing solution, when viewed as a function of speed and load, to be discontinuous. In cases where two solutions are very close together, this can interfere with (i.e. prevent) convergence to a single solution.

Pad Back Heat Transfer Coef

This is a convective heat transfer coefficient to use on the back and sides of the pad (but see next input). Typical values might be in the range 1.7E-05 to 2.04E-04 BTU/[in^2-s-F] (50 to 600 W/m^2 C)

Heat Transfer Ratio at Grooves

(normal value 3) The convective heat transfer coefficient in the grooves will be equal to that of the pad back multiplied by this ratio.

Sump Temperature

This is the sump temperature Tsump. This input value will be used as the initial guess for calculating Tsump from the given flow rate and total calculated power loss. Or, if you've opted to specify Tsump directly, this input value with be used for Tsump.

Journal Surface Temperature

This input value will be used as the initial guess for calculating Tshaft. Or, if you've opted to specify Tshaft directly, this input value will be used for Tshaft. In machines with a very hot shaft, like steam turbines, this allows you to specify the shaft temperature directly.

Oil Supply Temperature

(normal value about 120F or 50C) This is the temperature of all fresh oil supplied to the bearing at the input value of flow rate of Qsup.

Sump Oil Pressure

(normal value 0) Set this equal to the pressure (gage) in the bearing cavity. This pressure value is used as a boundary condition along all edges of each pad. The normal input value would be zero. It cannot be negative. An input greater than zero requires the selection of one of the 2D "Solution Dimension" options. The sump oil pressure input can decrease the amount of cavitation predicted within the bearing film.

SOR for Film P for 2-D

(normal value 1.65) This value is used to accelerate the iterative solution for film pressure, and is only used with a 2D film pressure solution. A value of 1 means no acceleration. This value should ordinarily be between 1.5 and 1.75. The recommended value is 1.65.

Elements per Pad (circ.)

(normal value is one element about every 2 degrees) This is the number of elements to use in the circumferential direction, for each pad. The higher the number, the longer the calculation time. Sometimes convergence difficulties can be solved by increasing the number of mesh points. Must be less than or equal to 250. See Tips on Program Use.

Elements per Pad (axial)

(normal value about 10 to 15) This is the number of elements to use in the axial direction, for each pad. This is only used when one of the 2D solution options has been selected. Must be less than or equal to 25. The axial mesh actually covers one half of the bearing; from midplane to the outer edge. The bearing solution is always assumed to be perfectly symmetric about the midplane.

Pad Material

Select a pad material from the drop down list of materials. This will cause the properties for that material to be placed in the various cells. Or you can select USER DEFINED for the material and enter your own values. Which, if any, of these properties will be utilized in the analysis depends on your choices of various analysis options. It could range from none to all.

Pad Elastic Modulus – this is Young's modulus, psi or Pa.

Pad CTExp – coefficient of thermal expansion

Pad Density – lbm/in3 on an English unit worksheet, and kg/m3 on SI sheets

Pad Thermal Cond – BTU/(s-in-F) or W/(m-C)

The CTE input is only used when Pad Thermal Deformations are being included.

The available materials in the drop down list are read from a file named MATERIAL.XLS. This file should be located in: for Windows Vista and later **C:\ProgramData\XLRotor**, or for Windows XP **C:\Documents and Settings\All Users\Application Data\XLRotor.** There is also a backup copy in the XLRotor installation folder. You can edit this file to modify, add or remove materials.

Journal Material

Thermal growth of the shaft is accounted for in the analysis only when Pad Thermal Deformations are being included.

Journal CTExp

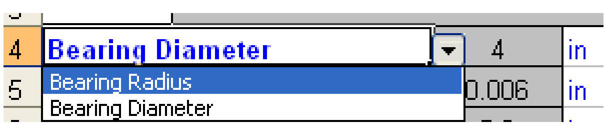
Shell Material

Thermal growth of the bearing shell is accounted for in the analysis only when Pad Thermal Deformations are being included. The temperature of the shell is assumed to be the sump temperature Tsump.

Shell CTExp

Bearing Diameter

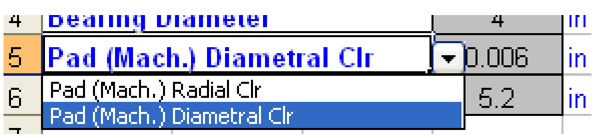
This is the diameter of the journal. To input a radius instead of diameter, select the radius option from a drop down list to the left of the input cell.



On SI unit worksheets you can change the units in the cell to the right of the value to either **meters** or **mm**.

Pad (Mach.) Diametral Clearance

This is the pad-bore clearance, and it must be the same for each pad. If the pads are preloaded, that is specified elsewhere. The effect of thermal growth on clearance is accounted for in the analysis when Pad Thermal Deformations are being included. To input a radius instead of diameter, select the radius option from a drop down list to the left of the input cell.



On SI unit worksheets you can change the units in the cell to the right of the value to either **meters** or **mm**.

Bearing Outer Diameter

In a tilting pad bearing this is the outer diameter of the pads, and is used to account for elastic and thermal effects. To input a radius instead of diameter, select the radius option from a drop down list to the left of the input cell.

On SI unit worksheets you can change the units in the cell to the right of the value to either **meters** or **mm**.

Selected Lubricant

Select a lubricant from the drop down list. This will cause the properties for that lubricant to be placed in the various cells. Or you can select USER DEFINED and enter your own values. The worksheet cell that is behind the drop down will contain the name of the selected lubricant. This is so you can refer to this cell value elsewhere (e.g., in the Title cell). The temperature dependency of viscosity is specified via two temperature/viscosity points – designated points "a" and "b".

Lubricant Specific Gravity – this value is dimensionless, and would be the same value on both English and SI worksheets.

Lubricant Spec Heat – BTU/(lbm-F) on English sheets, and J/(kg-C) on SI sheets

Lubricant Ref Ta – temperature of point "a". In degrees F on English sheets and degrees C on SI sheets

Lubricant Ref Va - viscosity of point "a". Always in cst (centistokes).

Lubricant Ref Tb – temperature of point "b". In degrees F on English sheets and degrees C on SI sheets

Lubricant Ref Vb - viscosity of point "b". Always in cst (centistokes).

Lubricant Thermal Cond – BTU/(s-in-F) or W/(m-C)

Internally the program determines viscosity as a function of temperature with the following relationship:

$$\mu(T) = \mu_a e^{\frac{\ln(\mu_b/\mu_a)}{T_b - T_a}(T - T_a)}$$

Pad Input Table

Pad	Pad Arc	Pad Offset	Pivot Angle	Preload	Pivot Kp	Flow Distribu-tion	Hot Oil Carry Over	Pad Axial Length	Pivot Krot Factors	Pad Tilt Angle
Number	degrees	--	degrees	--	lb/in	--	--	in	--	rad
1	160	0.5	90	0	0	0.5	0.5	2	1	0
2	160	0.5	270	0	0	0.5	0.5	2	1	0

Pad Number

Enter sequential numbers 1,2,3... for however many pads are in the bearing. The maximum number of pads permitted is 15.

Pad Arc

This is the angular extent of each pad in degrees. For example, a typical five pad bearing often has 60 degree pads. Pads must not touch or overlap each other.

Pad Offset

(normal value 0.5) This locates the pivot relative to the pad's leading edge. An offset of 0 places the pivot at the leading edge. An offset of 1 places the pivot at the trailing edge. Typically the pivot is centered, in which case the offset is 0.5 and would be referred to as a pad that is not offset, or centrally pivoted. A common design for an offset pivot is 0.55 to 0.6 which means the pivot is 55% to 60% of the Pad Arc from the leading edge (note that angles and shaft rotation are measured counterclockwise). Tilting pad bearings frequently have an offset of 0.5 to accommodate shaft rotation in either direction. An offset of less than 0.5 is to be avoided.

For fixed pad bearings the pad offset does not matter unless the pad is also preloaded. When a fixed pad has a nonzero preload, the pad is moved toward the shaft at the location of the pivot. So an offset of 0.5 would generally be used.

Pivot Angle

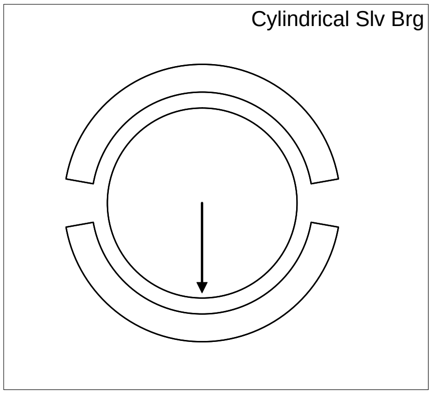
The pivot angle, in degrees, locates the pivot for each pad. Even for fixed geometry bearings (see Pivot Rotational Stiffness) a pivot location must be specified. Pivot angles must be entered in increasing order. Any nonzero preload specified for the pad is applied at the pivot location.

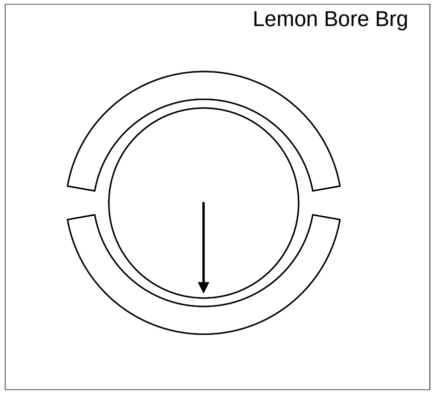
Note: The Pad Arc, Pad Offset and Pivot Angle collectively specify the size and circumferential location of each pad. Pads are not permitted to overlap or touch.

Preload

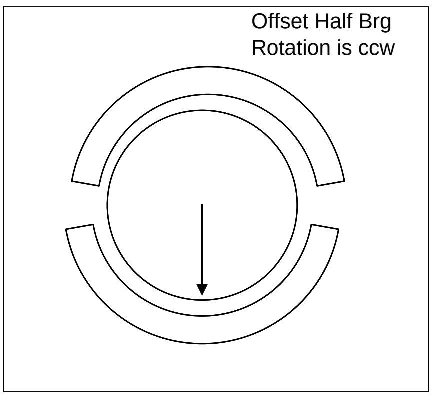
(normal value between 0 and 0.8) Preloading a pad moves the pad closer to the shaft from the "machined" pad-bore clearance circle. The preload specifies the distance the pad is moved as a fraction of the pad-bore clearance, resulting in what is referred as the set-bore clearance, or simply "bearing clearance" or "assembled clearance." For example, if the pad-bore clearance is 10 mils and the preload is 0.2, the set-bore clearance is 10*(1-0.2) = 8 mils. Preloading a 2 lobe cylindrical sleeve bearing, for example, creates a lemon bore bearing. Tilting pad bearings are quite often preloaded (helps prevent pad flutter among other things).

Nonzero preload can be specified for fixed pad bearings just as for tilting pad bearings. For example, a preload of 0.6 in a two lobe sleeve bearing (pivot offset must be 0.5) produces what is often called a lemon bore bearing (also known as an elliptic bearing).





If the pivot offset is not 0.5 then preloading the pad also moves it laterally. For example, this can be used to create what is called an "offset half" bearing. In the following example both pads have 160 degree arc length. The top pad has a pivot location at 180 degrees, pad offset of 1.0625 (to center the pad about the y axis), and a preload of 0.4. These inputs move the top pad to the right a distance 40% of the radial clearance.



Note that preload is a radially inward movement applied at the pivot location. So to combine a typical preload normally associated with a centered pivot, along with lateral offset, input a pivot location and preload amount corresponding to the vector addition of the normal and lateral preloads.

Pivot Kp

(normal input 0) This is the stiffness of the pivot in a compressive sense. A value of zero signifies a rigid pivot. A finite value means the pivot will compress under load, which means the pivot deflection will be non-zero. Pivot deflections may cause the stiffness and damping coefficients to decrease, but not always.

Pivot deflection can also cause the preload of loaded pads to decrease. However, for this effect to be included, an option for Pad & Pivot Deform Flag to include pivot deformations must be selected. You can see the result of this after the analysis is complete in the Resultant Preload column on the worksheet.

Flow Distribution

(normal value 1/#pads) These values specify how much of the supply flow goes to each pad. The values must sum to one. For most bearings the values will all be equal. For example, they will all be 0.25 for a 4 pad bearing.

Hot Oil Carry Over

(normal value 1) In determining the oil inlet temperature for each pad, this specifies the portion of oil from the trailing edge of the upstream pad that is used in the groove mixing analysis to determine the oil temperature at the inlet edge of the pad. These values should generally be between 0.5 and 1. A value of 1 means all the oil from the upstream pad's trailing edge is used in the groove mixing analysis. If unsure what to use, 1 would be conservative since that results in higher oil temperatures.

Pad Axial Length

(normal value about 1/2 of the journal diameter) This specifies the active axial length of each pad. For most applications they will all be the same.

On SI unit worksheets you can change the units in the cell above the column of values to either **meters** or **mm**.

Pivot Krot Factor

(normal value 1) This input allows you to specify a different rotational stiffness for each pad. This input only matters when Pivot Rotational Stiffness input is a nonzero value because they are multiplied times the Pivot Rotational Stiffness. Usually each of these values would be one. A value of zero for any pad means that pad has no pivot rotational stiffness regardless of the input value for Pivot Rotational Stiffness.

Pad Tilt Angle

(normal value 0) This allows you to specify a pad tilt angle, in radians counter clockwise, for each pad. When the pivot rotational stiffness is zero this input has no effect. When the pivot rotational stiffness is rigid, this value specifies a fixed (or manufactured) angle for each pad which allows one to define a "tapered pad" geometry. When not zero, typical values will be on the order of a few milliradians. Tapered pad (also known as tapered land) bearings can be defined this way, or by using the Step inputs described next.

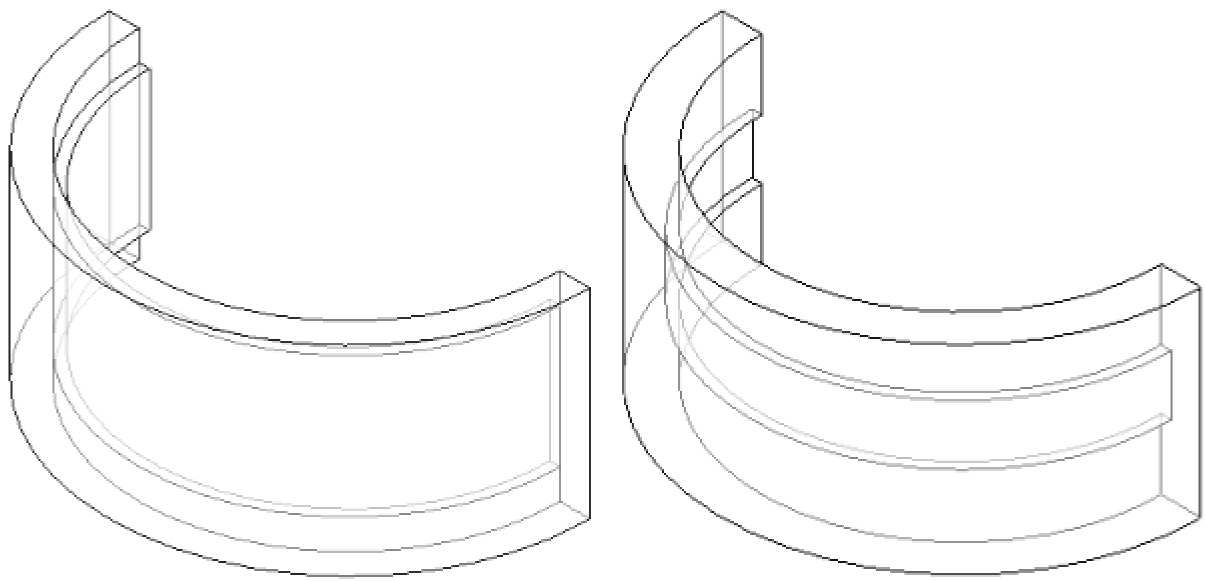
Step 1 Location & Depth
Step 2 Location & Depth
Step Width

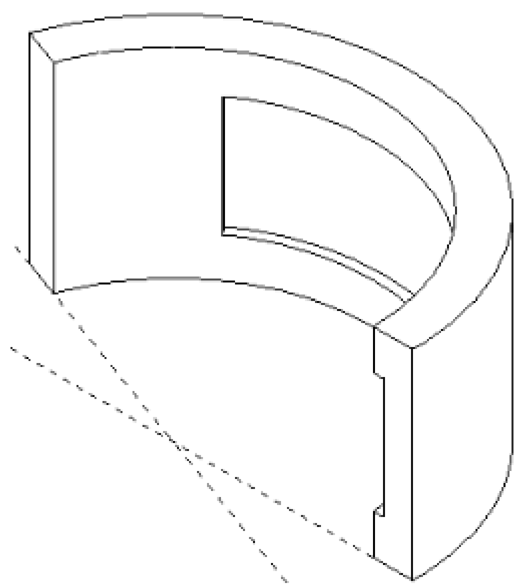
On SI unit worksheets you can change the units in the cells above the columns of values to either **meters** or **mm**.

These inputs are used to specify a rectangular region with an increased clearance. The rectangular region is centered at the bearing midplane. It can extend all or part of the pad axial width. This enables modeling many different types of bearing geometries. Examples are the recess in the top pad of a pressure dam bearing or a leading edge taper in tilting pad bearings.

Location 1 & 2 specify angles in degrees measured from the leading edge of the pad to the leading and trailing limits of the step. The **Depth 1 & 2** values specify the depth of the step at the leading and trailing edges (measured radially, and linearly tapered between if the depths are not equal). The **Step Width** specifies the axial extent of the step. The **Step Width** must be less than or equal to the full axial width of the pad. The step will be centrally located between the inboard and outboard edges of the pad.

For a <u>Pressure Dam Bearing</u> the “step” typically in the top pad is sometimes also referred to as a “relief” or “pocket.” The step generally will start at the leading edge of the top pad and extend about 125 degrees around the pad in the direction of rotation. **Location 2** where the step ends is sometimes called a “dam” because when oil flowing along the step encounters the trailing edge of the step, this causes a localized pressure buildup that in effect pushes the shaft downward like an artificial gravity load. The third image below shows an example of a top pad with 160 degree arc length and a 125 degree step. The depth of the step is often around 2 to 3 times the radial clearance. Typical pressure dam bearings will have a bottom pad with an axial length smaller than the upper pad. The artificial load, together with the reduced axial length of the bottom pad, results in a larger static operating eccentricity which often means the bearing will have improved rotordynamic stability characteristics from the standpoint of oil whirl. There are two methods of reducing the axial length of the bottom pad used by different bearing manufacturers. The first image below shows the land being trimmed equally at the inboard and outboard ends. This configuration would be modeled by simply inputting a shorter axial length for the bottom pad. The second image below shows a deep groove having been machined in the center (axially) of the pad. This configuration would be modeled by defining the **Step 1 & 2 Locations** at the leading and trailing edges of the bottom pad (i.e. the entire pad), and the **Step Width** would be the axial width of the deep groove. This groove should be very deep, typically around 10 times the bearing clearance, so that it does not generate a significant pressure on the shaft.





For additional information on the design and application of pressure dam bearings, see the following reference:

Nicholas. J., and Allaire, P., “Analysis of Step Journal Bearings - Finite Length, Stability,” ASLE Transactions, 57 (4), 197-207, 1980.

These inputs can be used to specify a tapered scallop at the leading edge of a pad. In this case **Location 1** would be zero and **Depth 1** would be the depth of the scallop at the leading edge, for example 0.020 inches. **Location 2** would be the length of the scallop from the leading edge, for example 10 or 15 degrees, and **Depth 2** would be zero. After an analysis has been run the presence of the scallop will be evident in the plot of film thickness.

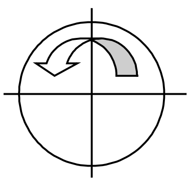
To define a tapered land bearing **Location 1** is zero and **Depth 1** is a value corresponding to how much taper is desired. **Location 2** is equal to the Pad Arc and

Step 2 is zero. The clearance of the pad then tapers from **C+Depth 1** at the leading edge, to **C** at the trailing edge (C is the input value for pad clearance, radial).

Speed and Load Input Table

There is no limit to the number load cases that can be in this table. Add or insert additional rows as needed. Or delete rows no longer needed. When the analysis is run, the program will continue down the table until encountering a blank cell in the Speed column.

-X Load	-Y Load	Whirl Ratio	Pos. Rel. Factor	Oil Flow	Piv. Def. Factor	Speed
lbf	lbf	--	--	cips	--	rpm
0	1000	1	1	10	0	1000
0	1000	1	1	10	0	2000



-X Load & -Y Load

These specify the x and y components of static load applied to the shaft and therefore reacted by the bearing. For example, entering zero for ***–X Load*** and +1000 for ***–Y Load*** means the shaft is loaded downward with a load of 1000 lbf.

Whirl Ratio

(normal value 1) This specifies what whirl speed to use to determine stiffness and damping coefficients. A value of 1 means use the journal speed as the whirl speed. A value of 0.5 use a whirl speed of one-half of shaft speed.

Pos. Rel. Factor

(normal value 1) This is the Position Relaxation Factor which is used to help the program successfully converge to a solution for static eccentricity. This value should always be less than or equal to one. Use 1 unless convergence fails, in which case try values like 0.75 or 0.5. If it's too small convergence will still fail. See Tips on Program Use.

Oil Flow

This is total flow rate of oil being supplied to the bearing at a temperature equal to Oil Supply Temperature. Increasing the flow rate usually results in lower film temperatures. A common way to determine a suitable value for this input is to adjust it so that the temperature rise from T Supply to T Sump is about 30 degrees F.

On US unit worksheets you can change the units in the cell above the column of values to either **cips** or **gpm**.

On SI unit worksheets you can change the units in the cell above the column of values to either **m^3/s**, **liter/s** or **liter/min**.

The input for Sump Oil Pressure described earlier is the pressure inside the bearing housing and is the boundary condition around the edges of each pad. The relationship between oil supply pressure and oil flow into the bearing housing is a function of the plumbing system that supplies oil to the bearing. The XLHydrodyn input for ***Oil Flow*** would typically be adjusted to achieve a suitable temperature rise through the bearing, for example 30F or 17C. Then the plumbing system would be designed to provide this flow to the housing.

Piv. Def. Factor

This input is used only when the option for Pad & Pivot Deform Flag allows the pads to deform. A good overall choice for this value is 0.5. It should always be less than or equal to 1. If a case fails to converge, try a different value for this input, either smaller or larger. See Tips on Program Use.

Speed

This is the speed of the journal in rpm. Sometimes the program performs better when speed cases are in increasing order, and sometimes better when in decreasing order. When linking this worksheet to a shaft model, the order of the speeds does not matter to XLRotor. The direction of rotation is counter clockwise (i.e. from the +x axis to the +y axis).

Output Table for Load Cases

Speed	Inlet Somm.	Ecc X	Ecc Y	Power	P Max	Film T Max	Babbit T Max	Babbit T at 75%	H Min	Sump T	Shaft T	WFR
rpm	--	--	--	hp	psi	Deg. F	Deg. F	Deg. F	in	Deg. F	Deg. F	--
1000	0.173594	0.437435	-0.5861	0.18751	408.23	147.06	147.06	139.86	0.0008061	120.87	130.32	0.4665038
2000	0.347189	0.434835	-0.446371	0.60148	350.33	151.64	151.64	142.24	0.0011319	122.78	134.49	0.4784513
3000	0.520783	0.4174	-0.360662	1.1898	322.29	155.67	155.67	145.04	0.0013465	125.5	138.25	0.4844707

All program output cells have been formatted to have red lettering. However, you can change the cell formats to suit your preference. The table above summarizes the results of each load case specified in the table of load cases.

Inlet Somm.

This is the Sommerfeld number and is a dimensionless value computed with the following expression where the absolute viscosity is evaluated at supply temperature. N is the journal speed in rpm. L is the axial length. D is the journal diameter. W is the load. R is the journal radius, and C is pad bore radial clearance. Note that preload, if any, is not included in this value.

$$S = \frac{\mu NLD}{60W}\left(\frac{R}{C}\right)^2$$

When comparing this Sommerfeld number to values from other sources, be aware that viscosity might be evaluated at a different temperature, and the clearance might be bearing clearance instead of pad clearance. Also, an alternative expression for Sommerfeld number often used in Europe is:

$$S_{alt} = \frac{W}{\frac{\pi}{30} N\mu LD}\left(\frac{C}{R}\right)^2$$

Ecc X & Ecc Y

These specify the static eccentricity components calculated for the journal center. These are dimensionless where a value of 1 corresponds to the pad bore clearance. Note that for a bearing with a preload of 0.4, an operating eccentricity approaching 0.6 means the journal is close to touching the pads.

Power

This is the total power loss due to viscous shear in the bearing (plus parasitic losses if the Power Loss in Cavities option is turned on). This power loss value equates to the loss implied by your input value of flow rate together with the total calculated temperature rise (Tsump-Tsupply).

On SI unit worksheets you can change the units in the cell above the column of values to either **Watts** or **kW**.

P Max

This is the maximum value of oil film pressure anywhere in the bearing. Excessive oil film pressure combined with excessive babbitt temperature can lead to creep of the babbitt material.

Film T Max

This is the maximum value of mean oil film temperature anywhere in the bearing. Typically this will be in the most heavily loaded pad. Be aware that the temperature of the oil film varies across the film throughout the bearing, and this output value is the maximum mean value. The actual peak oil temperature could be higher.

Babbitt T Max

This is the maximum value of babbitt temperature. This temperature will be different than the maximum oil film temperature only when the ***Thermal Solution Flag*** is set to

Solve for Conduction. Excessive oil film pressure combined with excessive babbitt temperature can lead to creep of the babbitt material.

Babbitt T at 75%

This is the midline temperature at a location 75% of the way from the leading to the trailing edge for the most heavily loaded pad. This is a location where some API specifications require that pad temperature be measured.

H Min

This is the minimum oil film thickness value anywhere in the bearing. There is a limit to how small this can be. The program will likely encounter convergence problems when the minimum film thickness is less than 0.5 mils (i.e., less than about 13 microns). See Tips on Program Use.

On SI unit worksheets you can change the units in the cell above the column of values to either **meters**, **mm** or **microns**.

When it is necessary to run cases with extremely small film thickness, selecting the ***Isoviscous*** thermal solution option should work, but the viscosity will be set corresponding to the input value for oil supply temperature Tsup.

Sump T

The sump temperature is the same as the oil exit temperature. The Sump Temperature Flag described earlier directs the program to either set the ***Sump T*** equal to your input value, or to calculate it from the thermal solution of the bearing. The ***Sump T*** is closely related to the power loss of the bearing.

Shaft T

Depending on your selection for the Journal Temperature Flag, this is the shaft temperature determined as part of the heat transfer analysis.

WFR

This is the Whirl Frequency Ratio of the bearing. It is a commonly used indicator of stability for fluid film bearings and also annular seals. It is computed directly from the stiffness and damping coefficients with the following expression:

$$WFR = \frac{K_{xy} - K_{yx}}{\omega(C_{xx} + C_{yy})}$$

Omega is the shaft speed in radians/second.

Output Table for Pads

Pad Number	Pad Rotation	Pad Load Normal	Pad Load Tang.	Resultant Preload	Diam Pad Cp	Diam Pad Cb	Pad Inlet T	Pad Inlet Flow	Pad Outlet T	Pad Outlet Flow	Groove T
--	rad	N	N	--	mm	mm	Deg. C	liter/min	Deg. C	liter/min	Deg. C
1	0	101.4817	99.13693	0.5	0.3048	0.1524	54.3	5.848	55.9	5.781	53.2
2	0	2320.953	-101.4029	0	0.3048	0.3048	55.6	6.068	62.2	2.046	53.0

As the series of specified load cases are calculated one at a time, the contents of this table can be seen to change as each load case is calculated. After all load cases have been completed, this table will contain the results of the last load case. The cell above the table documents which speed case is in the table.

If you want a speed other than the last speed to be the final output to this table, then create a cell comment on one the cells in the input column of Speed values containing the words "Pad Table" (not case sensitive). To create a cell comment, right click the cell and look for Insert Comment in the popup menu.

Pad Rotation

This output is primarily for tilting pad bearings. It gives the final rotational deflection (counter clockwise) of each pad in radians. In a fixed geometry bearing, this output will always be equal to the input values for Pad Tilt Angle.

Pad Load

This gives the load reacted by each individual pad. Components are normal and tangential to the pivot. A vector addition of all pad loads will equal the applied load. For tilting pad bearings the tangential component should be negligible compared to the normal component.

Resultant Preload

The preload of each pad is subject to change depending on the selection for Pad & Pivot Deform Flag***.*** This column lists the final operating preload of each pad.

Diametral Pad Cp

This lists the diametral pad-bore clearance of each pad during operation at speed and load conditions. The values output here will only be different from the input value of ***Pad (Mach.) Diametral Clearance*** if pad deformations are being included (see ***Pad and Pivot Deform Flag***).

On SI unit worksheets you can change the units in the cell above the column of values to either **meters** or **mm**.

Diametral Pad Cb

This lists the diametral set-bore clearance of each pad. These values are equal to (1-preload)*pad-bore clearance.

On SI unit worksheets you can change the units in the cell above the column of values to either **meters** or **mm**.

Pad Inlet T & Exit T

These are the temperatures of the oil entering the leading edge of the pad and leaving the trailing edge of the pad. The leading edge inlet temperature is very important for determining bearing performance, and is determined according to your selection for Pad Inlet Temperature Flag*.*

Pad Inlet & Exit Flow

These are the flow rates of oil entering the leading edge and leaving the trailing edge of the pad. The difference between these two values is equal to the side flow of oil exiting the pad out the sides (equal on both sides).

On US unit worksheets you can change the units in the cell above the column of values to either **cips** or **gpm**.

On SI unit worksheets you can change the units in the cell above the column of values to either **m^3/s**, **liter/s** or **liter/min**.

Groove T

This is the temperature of the oil in the groove on the upstream end of the pad (Tmix), and is the result of ideal mixing of supply oil and hot oil leaving the trailing edge of the upstream pad (see Pad Inlet Temperature Flag).

Tips on Program Use

The bearing solution is a highly nonlinear and iterative calculation. Convergence to a suitable result can sometimes be difficult, particularly at the extremes (high or low) of operating speed and/or load. When the program displays a message that convergence has failed, try some of the following.

> The first thing to do is double check that all inputs are as you intended. Quite often entering an incorrect input value will cause convergence to fail. It is very easy for this to happen when creating new files by modifying old ones.
>
> Make sure the bearing is receiving enough flow. Too little oil flow will lead to temperatures that are too high.
>
> Check that the conditions of speed and load are not leading to a minimum film thickness less than about 0.5 mils (13 microns).
>
> Make sure you have enough grid points per pad. Usually one point every 2 degrees of pad arc is adequate, but sometimes increasing the number of grid points can remedy convergence problems.
>
> Try adjusting the initial shaft eccentricity guesses. A starting position that is too far off can cause convergence to fail.
>
> Change the value of the position relaxation factor. Start at 0.75 and work down to 0.1.

Convergence problems become likely if the minimum operating film thickness becomes too small because either the speed is low, the load is high, or both. Introduce extra speed/load cases with less severe operating conditions. Another method sometimes used on heavily loaded applications is to gradually increase the load to full load.

Sometimes problems are due to pads on the top half of the bearing (tilting pad types) touching the shaft. If the above remedies do not work, try giving the pad(s) in question a small amount of offset or slightly increased preload.

As a last resort, increase the allowable error until convergence is attained.

XLThrustBearing.XLS Template File

Design Analysis for Hydrodynamic Thrust Bearings

See also

> Bearing Template Files - (all Xlrotor bearing types)
> XLHydrodyn Template File - (advanced analysis of radial bearings)

To open an XLThrustBearing template, look in the XLRotor Templates folder for versions in both US and SI units. The units of each template are fixed to US or SI systems, but for some inputs the units may be changed (see Alternate Units)

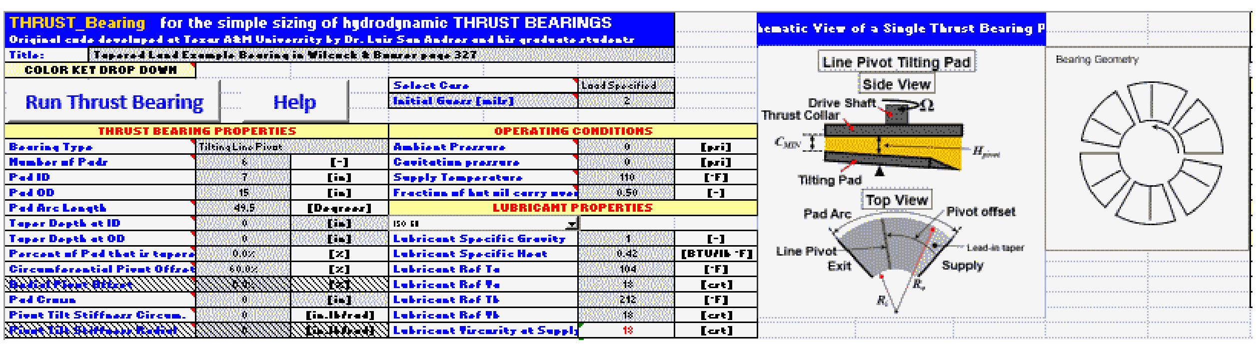
NOTE: XLThrustBearing is not included in a standard license of XLRotor. For information on how to obtain this module, contact support@xlrotor.com

XLThrustBearing is used for design and analysis of fixed geometry and pivoting pad oil film thrust bearings. (see Thrust Bearing Geometry). This includes:

- Fixed Pad Taper Land
- Line Pivot Tilting Pad
- Point Pivot Tilting Pad

Jump to XLThrustBearing INPUTS

Jump to XLThrustBearing OUTPUTS



Running the XLThrustBearing Worksheet

Note: The default input worksheet in an **XLThrustBearing** file is named **Thrust Bearing**. It is ok to change the name of this worksheet. It is also ok to have multiple copies of the sheet in one file. Any of the sheets may be run at any time. However, whichever was the last sheet to be run will have its outputs placed on the various plot output sheets (see below sections about plots).

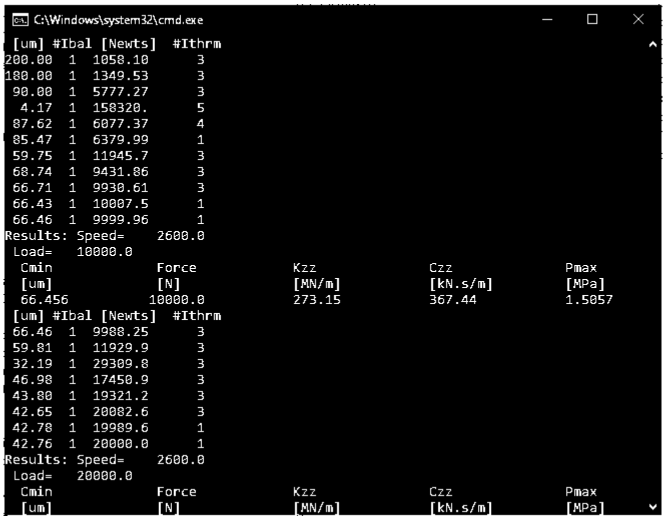
An analysis is run by doing either of the following:

1) Click the ***Run Thrust Bearing*** button to execute the analysis.

2) Execute an analysis from an Excel macro with the following Visual Basic statement:

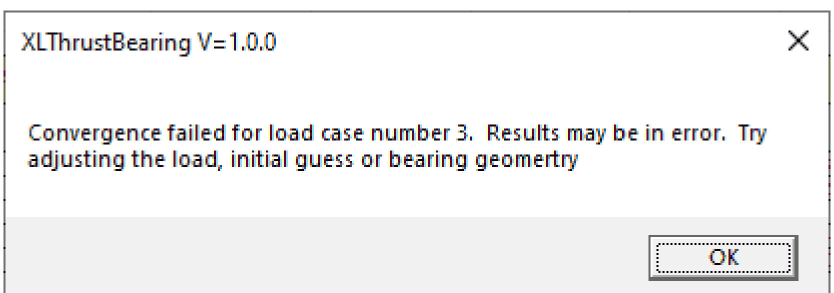
```
Application.Run “XLThrustBrg_addin.xla!RunThrustBearing”
```

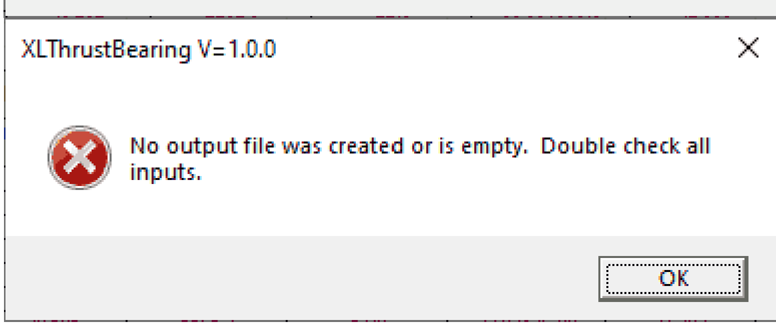
While the program executes, a Command Prompt window will be visible over the Excel window. Some calculation parameters (always in SI units) are printed to this window during the run. This window will automatically close when the run is finished.



```
C:\Windows\system32\cmd.exe
 [um] #Ibal [Newts]  #Ithrm
200.00  1  1058.10      3
180.00  1  1349.53      3
 90.00  1  5777.27      3
  4.17  1  158320.      5
 87.62  1  6077.37      4
 85.47  1  6379.99      1
 59.75  1  11945.7      3
 68.74  1  9431.86      3
 66.71  1  9930.61      3
 66.43  1  10007.5      1
 66.46  1  9999.96      1
Results: Speed=    2600.0
 Load=   10000.0
  Cmin             Force            Kzz              Czz              Pmax
  [um]             [N]              [MN/m]           [kN.s/m]         [MPa]
  66.456          10000.0           273.15           367.44           1.5057
 [um] #Ibal [Newts]  #Ithrm
 66.46  1  9988.25      3
 59.81  1  11929.9      3
 32.19  1  29309.8      3
 46.98  1  17450.9      3
 43.80  1  19321.2      3
 42.65  1  20082.6      3
 42.78  1  19989.6      1
 42.76  1  20000.0      1
Results: Speed=    2600.0
 Load=   20000.0
  Cmin             Force            Kzz              Czz              Pmax
  [um]             [N]              [MN/m]           [kN.s/m]         [MPa]
```

Successful runs will produce an output file at **C:\Users\{username}\AppData\Local\Temp\XLRotor\output.txt**, which is automatically read to populate the output portions of the worksheet. Unsuccessful runs may display messsages such as the following.





The last analysis can be rerun by double clicking the file **C:\Users\{username}\AppData\Local\Temp\XLRotor\debug.bat**. A similar Command Prompt window will appear, but will remain open so you may view its contents. This may help identify the cause of an unsuccessful run.

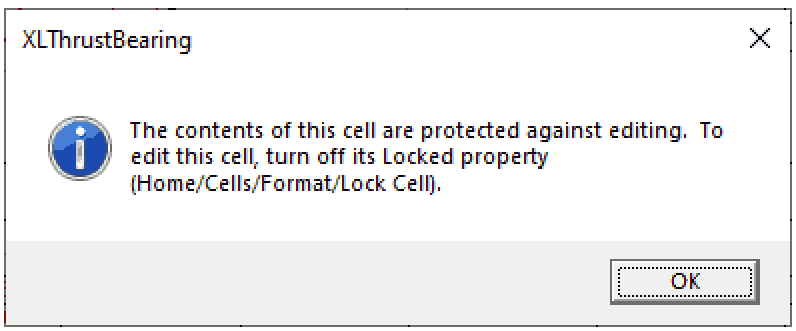
Depending on the specifics of a case, the program may need to iterate simultaneously in up to 3 ways.

1. Iterate to find clearance for a given load.
2. Iterate to find effective viscosity.
3. Iterate to balance moments for tilting pads.

The only case not requiring iteration is an isoviscous case for a specified clearance with rigid pads. The above sample image of a Command Prompt window displays the number of iterations taken during the run. Two load cases are shown. The first load case took 11 iterations to find the clearance, and the second load case took 8. This run was for rigid pads, so the number of moment balancing iterations (`#Ibal`) is always 1. The number of viscosity iterations (`#Ithrm`) varies from 1 to 5.

Locked Cells

Some cells in the worksheet are locked to prevent accidentally modifying their contents. Only cells which contain something that should not normally be edited are locked. For example, cell A10 contains the string *Number of Pads*. If this cell, or any other locked cell, is edited, the following message is displayed.



The cell can be edited by first turning off its **Locked** property. From the Excel ribbon do **Home/Cells/Format/Locked Cell**. Or right click the cell and select **Format Cells/Protection** and uncheck **Locked**.

Multiple cells, or even all cells, on the sheet may be unlocked in one step by selecting all cells and performing the unlock procedure just described.

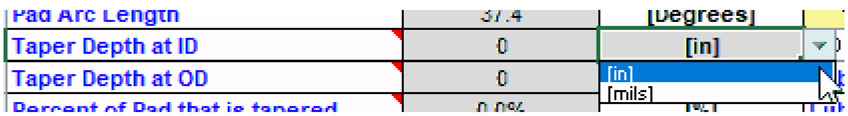
However, be aware that if cells are copied and pasted from another file, their "Locked" property is copied as well. If a "Locked" cell is pasted, that will trigger the above message, and thereby prevent the paste. The solution is to either uncheck the cell's Locked property before the copy/paste, or else paste only the values or formulas (in the ribbon click **Home/Paste...**).

XLThrustBearing Inputs

----All user inputs are shaded gray----

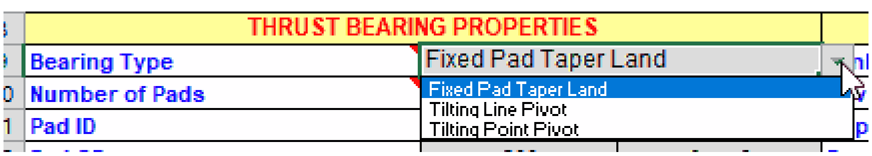
THRUST BEARING PROPERTIES		
Bearing Type	Tilting Point Pivot	
Number of Pads	6	[-]
Pad ID	7	[in]
Pad OD	15	[in]
Pad Arc Length	54.7	[Degrees]
Taper Depth at ID	0.007	[in]
Taper Depth at OD	0.004	[in]
Percent of Pad that is tapered	80.0%	[%]
Circumferential Pivot Offset	60.0%	[%]
Radial Pivot Offset	50.0%	[%]
Pad Crown	0	[in]
Pivot Tilt Stiffness Circum.	0.00E+00	[in.lb/rad]
Pivot Tilt Stiffness Radial	0.00E+00	[in.lb/rad]

Some entries permit a choice of Alternate Units as shown below, which can be selected from a dropdown list.

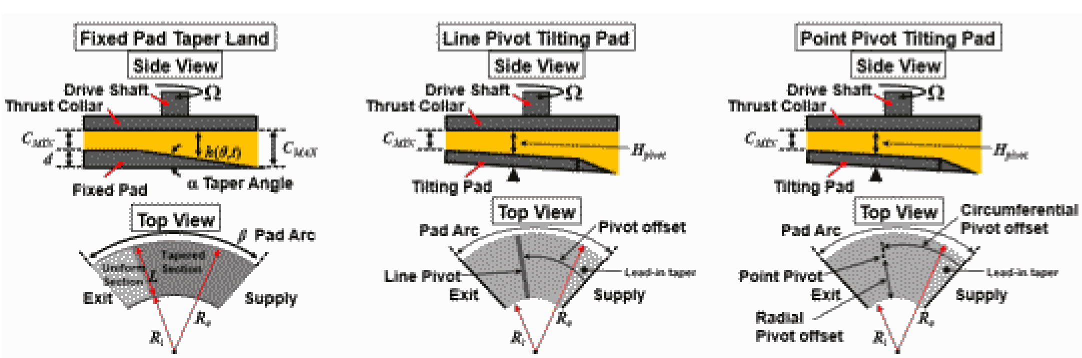


Thrust Bearing Geometry

Bearing Type

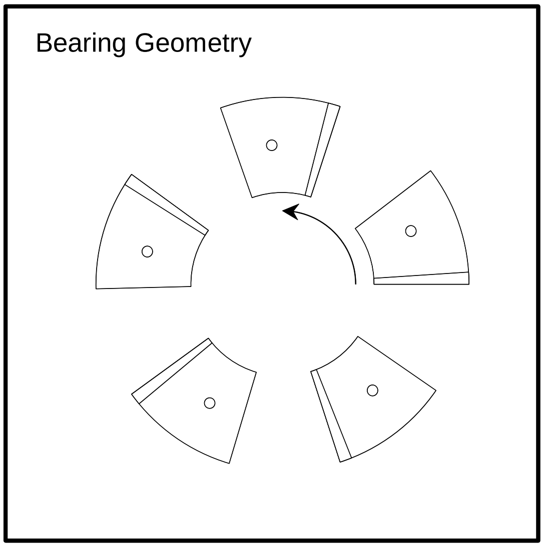


When the selected ***Bearing Type*** is changed, the generic descriptive image on the worksheet will change automatically, and some input fields (discussed later) will be enabled or disabled.



Note that both Fixed and Pivot type pads are permitted to have a tapered section. For fixed pad bearings, the tapered section is an essential feature. For tilting pad thrust bearings, there may be a lead-in taper, but it is not required. See also FE Mesh on handling the taper in the model.

For many of the bearing geometry items, the Bearing Geometry Schematic will automatically update as changes are entered into the worksheet cells.



This image shows (in scale) the pad shape, with location of pivot (point or line) and tapered section, if any. The image is an ordinary Excel Chart object, and may be moved or resized. If it is deleted, a new one will be created the next time a geometry input is changed.

Number of Pads

A whole number which defines the number of pads which make up an entire single side of the thrust bearing. The program analyzes a single pad, and then multiplies by the number of pads when presenting total bearing values such as load capacity.

Pad ID and OD

These values are the Inner Diameter (ID) and Outer Diameter (OD) of a single pad, as shown in the sample geometry. These may be any value as long as ID is less than OD. The pitch-line diameter of a bearing is the average of these two values.

Pad Arc Length

This defines the arc length of a single pad, in degrees. The Arc Length multiplied by the Number of Pads must be less than 360°. The pad arc length would generally be small enough to leave at least 5 degrees between adjacent pads, but more than that is common.

Taper Depth at ID and OD

The amount of taper is defined as the depth below the plane of the *untapered* portion. Units are user selectable between inches and mils for US units, and meters, millimeters and microns for SI units. Combined with Percent of Pad that is Tapered, this fully defines the taper. A different taper depth is permitted at the ID and OD, so the plane of the taper may or may not be aligned to the *untapered* surface. It is common to have this geometry due to the real-life machining of the pads. For the tapered section to be a truly flat plane, the ratio of OD Depth to ID Depth must equal the ratio of OD to ID. Otherwise the tapered section will be slightly warped (i.e. not perfectly flat), which can be seen in a 3D plot of film thickness discussed later..

Percent of Pad that is Tapered

Combined with Taper Depth at ID and OD, this fully defines the taper of the pad. This is expressed as a percent value from 0 to 100. The percent is in reference to the Pad Arc Length which is an angle, and always begins at the pad leading edge. This means the tapered section will be a section of a ring, like the entire pad.

For pads with no taper, this value will be 0%, and the meshing input for the tapered section must also be zero. See FE Mesh.

As examples, a tapered-land fixed-pad bearing would typically have a tapered section of 70% to 90%. Tilting pad bearings typically would not have a tapered part (i.e. 0%). However, for a tilting pad this feature could be used to define a short lead-in taper of perhaps 5% to 10%.

Note: The ***% Taper*** input cell is formatted by Excel to display the value as a percentage including a % symbol. To enter 70% in this cell, enter **70** and press **Enter**. Entering **.7** (i.e. not 0.7) will also produce 70%. To actually enter 0.7% one would enter **0.7**.

Circumferential Pivot Offset

For all types of tilting pads, the circumferential pivot location must be defined. For Line Pivot bearings, this single input fully defines the pivot location. For Point Pivot bearings, this input together with Radial Pivot Offset fully define the pivot location.

This is expressed as a percent value from 0 to 100. The percent is in reference to the Pad Arc Length which is an angle, and is always measured from the pad leading edge. Since it is referenced to the pad leading edge, pivot position is not affected by the presence of a tapered section.

Typical values are between 55% and 65%. Note that an offset such as this means the bearing is *not* bi-directional.

Radial Pivot Offset

For point pivot tilting pads only, the radial pivot location must be defined. The pivot location is fully defined when combined with Circumferential Pivot Offset.

This is expressed as a percent value from 0 to 100. The percent is in reference to the difference between ID and OD, which is a length, and begins at the pad interior edge.

Typical values are usually close to 50%.

Pad Crown

The geometric shape of a pad crown is spherical, and may be envisioned as material removed from an initially flat pad. Pad Crown is centered at the center of the pad (i.e. midway between the ID and OD, and midway between the leading and trailing edges of the *untapered* part of the pad). The input value for Pad Crown will be realized as crown depth at the corners of the outer edge. Due to the arc geometry of the pad shape, the inner edge will have slightly less crown depth at its corners than the outer edge. A 3D plot of film thickness will exhibit the Pad Crown graphically.

Pivot Tilt Stiffness, Circumferential & Radial

For tilting pads only, there may be a tilting stiffness at the pivot. This is expressed as a moment stiffness, and may be different in the circumferential and radial directions. The spring's equilibrium (i.e. unloaded) position is with the *untapered* section of the pad parallel to the runner. Note that the Radial stiffness only applies for a Point Pivot option.

Operating Conditions

OPERATING CONDITIONS		
	User Input	Units
Ambient Pressure	0	[Pa]
Cavitation pressure	0	[Pa]
Supply Temperature	50	[°C]
Fraction of hot oil carry over	0.50	[-]

Ambient Pressure

Normal value 0. Set this equal to the pressure (gauge) in the bearing cavity. This pressure value is used as a boundary condition along all edges of each pad and is also assumed present on the opposite side of the thrust runner for the purpose of determining the net axial load on the bearing. The normal input value would be zero. It cannot be negative. The main effect of an elevated ambient pressure is to decrease the amount of cavitation, if any, in the bearing film. In the absence of cavitation, the only effect of ambient pressure is it is added to the film pressure (i.e. clearances, loads, flows and temperatures are not affected).

Cavitation Pressure

Normal value 0. Set this equal to the pressure (gauge) below which cavitation will occur. In nearly any situation this input value should be zero.

Supply Temperature (Oil)

Normal value about 120F or 50C. This is the temperature of all fresh oil supplied to the bearing. Only the oil temperature is specified, and the program calculates viscosity from the temperature. The calculated viscsosity at the supply temperature is shown in the Lubricant Properties section of the worksheet.

Fraction of Hot Oil Carry Over

In determining the oil inlet temperature for each pad, this specifies the portion of oil from the trailing edge of the upstream pad that enters the next pad. This value should generally be between 0.5 and 1. A value of 1 means all oil from the upstream pad's trailing edge enters the next pad. If unsure what to use, 1 would be conservative since that usually results in higher oil temperatures. Since trailing edge flow rate is always less than leading edge flow rate, some oil at supply temperature must be part of the leading edge flow.

If desired, the temperature of oil entering the leading edge may be specified directly by entering ***Hot Oil Carry Over***=0. In which case all oil entering the leading edge is equal to supply temperature.

Lubricant Properties

LUBRICANT PROPERTIES		
ISO 32		
Lubricant Specific Gravity	0.873996294	[-]
Lubricant Specific Heat	0.484341433	[BTU/lb °F]
Lubricant Ref Ta	104	[°F]
Lubricant Ref Va	32	[cst]
Lubricant Ref Tb	210	[°F]
Lubricant Ref Vb	5.34	[cst]
Lubricant Viscosity at Supply T	28.91574528	[cst]

The pull down menu includes the many common lubricants. Selecting a different lubricant will populate the cells automatically. The user may enter custom values by selecting USER DEFINED in the pull down menu. Viscosity at supply temperature will be calculated automatically. Internally, the program will calculate an effective viscosity in the film land with an iterative process which utilizes the following viscosity-temperature relationship:

$$\mu_{eff} = \mu_{supply} + e^{-\gamma\left(T_{eff}-T_{supply}\right)}$$

$$\gamma = \ln\left(\frac{\mu_a}{\mu_b}\right)/(T_b - T_a)$$

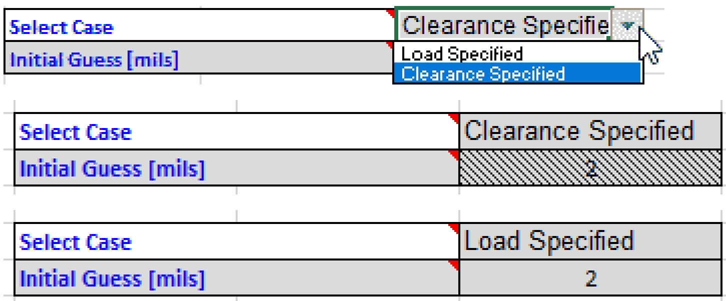
Where:

T: temperature

γ :	thermal viscosity coefficient
μ :	viscosity

Note: A case with a known constant viscosity can be run by selecting **User Defined** and entering the desired viscosity value for both **Va** and **Vb**.

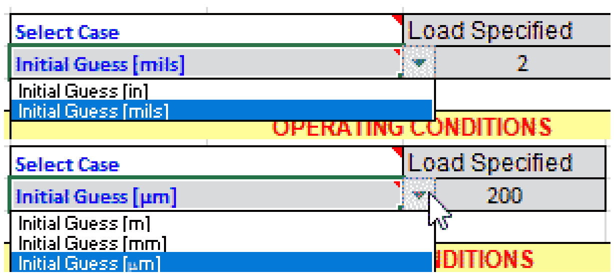
Thrust Bearing Loading



Select Case

This option permits selecting ***Load Specified*** or ***Clearance Specified*** from the dropdown list. For ***Clearance Specified*** , you define the minimum film clearance and the program will calculate the corresponding load. For ***Load Specified***, you define the applied load, and the program will determine the film clearance via an iterative search. For a fixed pad bearing, you specify the true minimum clearance. For a tilting pad bearing, you specify the clearance *at the pivot*.

Initial Guess (of clearance)



This input applies only for the ***Load Specified*** option. In general, a reasonably good initial guess for clearance is required, otherwise the iterative search for the clearance corresponding to the given load may not converge to a solution.

Use the dropdown list in the adjoining cell to select your preferance for units for this value.

Speed / Load / Minimum Clearance

This input table will take one of the following two forms, depending on the choice for ***Load Specified*** or ***Clearance Specified***.

Load Specified

Rotor Speed [rpm]	Axial Thrust Load [lbf]	Min Clearance [in]
3600	70000	0.001
3000	70000	0.001
2400	70000	0.001
1800	70000	0.001
1200	70000	0.001
600	70000	0.001

Clearance Specified

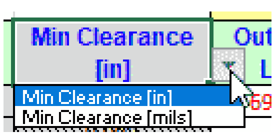
Rotor Speed [rpm]	Axial Thrust Load [lbf]	Min Clearance [in]
3600	70000	0.001
3000	70000	0.001
2400	70000	0.001
1800	70000	0.001
1200	70000	0.001
600	70000	0.001

When ***Load Specified*** is selected (upper image), complete this table with ***Rotor Speed*** and ***Axial Thrust***. ***Min Clearance*** will be grayed out, indicating no entries apply.

When ***Clearance Specified*** is selected (lower image), complete this table with ***Rotor Speed*** and ***Minimum Clearance***. Note that ***Minimum Clearance*** refers to pivot clearance in the case of pivot type bearings. ***Axial Thrust Load*** will be grayed out.

The program will analyze each load case sequentially until encountering a blank cell in the **Rotor Speed** column. Any entries below this are ignored. You may insert or delete rows from this table as needed. The maximum number of cases which can be analyzed in one run is 250.

Note that since the ***Min Clearance*** column heading has a gray background, it is an input cell with a dropdown allowing you to select units.



XLThrustBearing Outputs

Each run of the program creates a text output file at **C:\Users\{username}\AppData\Local\Temp\Xlrotor\output.txt**. The contents of that file are automatically read and summarized in two tables described as follows:

Primary Tabular Output

CALCULATION OUTPUTS														
Output Thrust Load [N]	Output Min Clr [µm]	Specific Load [MPa]	Leading Edge Temp. [°C]	Temperature Drain [°C]	Temperature Max [°C]	Power Loss [kW]	Lubricant Flow Rate [L/min]	Film Stiffness [MN/m]	Film Damping [kN.s/m]	Effective Viscosity [cst]	Max Pressure [MPa]	H Pivot [µm]	Circ Tilt [mrads]	Radial Tilt [mrads]
10000	66.456	0.521238717	51.085	53.523	56.679	2.557	26.659	273.15	367.44	30.40148269	1.5057	66.456	0	0
20000	42.762	1.042477435	51.456	55.558	62.652	3.5017	23.197	740.64	827.05	28.75413428	3.381	42.762	0	0
30000	31.702	1.563716152	51.676	57.309	69.517	4.2761	21.489	1359.5	1395.1	27.45618869	5.6018	31.702	0	0

A summary of output data is presented in tabular form. For each load condition, critical values are listed. All program output cells have been formatted to have red characters. However, you may change the cell formats to suit your preference. Note the data in this table is used to make plots, so do not change the numerical values.

- ***Output Thrust Load*** - the load of the *entire bearing* (i.e. all pads)***.*** For *load specified* cases conditions, this should closely match the input load values.

- ***Min Clearance*** - the minimum film clearance of a single pad. For clearance specified cases, this should match the input value for rigid pad bearings.

- ***Specific Load*** - the load per unit area, i.e. the total load divided by the total area of all pads.

- ***Leading Edge Temperature*** - temperature of oil entering the leading edge of a pad. If Hot Oil Carry Over is zero, this temperature will be equal to Supply Temperature.

- ***Temperature Drain*** - temperature of oil exiting the bearing. This is determined by ideal mixing of oil exiting the bearing; i.e. exiting the trailing, inner and outer edges of the pad.

- ***Temperature Max*** - the maximum temperature within the bearing film of a pad. This will often occur at the outer corner of the trailing edge.

- ***Power Loss*** - power loss of the *entire* bearing (i.e. all pads) due solely to viscous drag torque within the film land. Additional parasitic losses, if any, from oil on other parts of the thrust runner are not included.

- ***Lubricant Flow Rate*** - total flow rate of oil which should be supplied to the bearing. The flow rate of oil required at a pad's leading edge comes partly from hot oil carry over, and the rest from supply oil. This output value is the minimum amount of oil that should be supplied to the bearing (i.e. sum of all pads).

- ***Film Stiffness*** - total axial stiffness of the bearing oil film***.*** This stiffness value could be used, for example, in a calculation of *axial* natural frequencies. Thrust bearing stiffness normally is negligible in *lateral* rotordynamic analysis, but it could be included as a moment stiffness at the thrust runner calculated as $KR^2/2$, where K is the axial stiffness and R is the pitch-line radius. Typically only rotors with very stiff thrust bearings plus very short bearing spans will this be significant. An XLUserKC sheet can be used in a lateral model to add this stiffness.

- ***Film Damping*** - total damping of the bearing film***.***

- ***Effective Viscosity*** - effective viscosity of the lubricant. See Governing Equations.

- ***Max Pressure*** - maximum pressure within the film.

- ***H Pivot*** - film clearance at the pivot of a tilting pad.

- ***Circ Tilt*** - tilt of a pad in the circumfernetial direction about the pivot. Will be zero for rigid pads.

- ***Radial Tilt*** - tilt of a pad in the radial direction about the pivot. Will be zero for rigid pads and for line pivot pads.

Additional Tabular Output

Additional Results for Last Load Case (#4)		
Reynolds Number	282.38	
Leading Edge Flow	1.46094674	[gpm]
Trailing Edge Flow	0.96113318	[gpm]
Inner Edge Flow	0.097576986	[gpm]
Outer Edge Flow	0.40221808	[gpm]
Leading Edge Temp.	122.063	[°F]
Trailing Edge Temp.	126.2732	[°F]
Inner Edge Temp.	124.169	[°F]
Outer Edge Temp.	124.169	[°F]

Additional flows, temperatures, and the Reynolds Number are output for the last load case of the run. Note that load cases can be in any desired order, but the last case is always the one output here. Values for all load cases can be seen in the output file at **C:\Users\{username}\AppData\Local\Temp\Xlrotor\output.txt**

GNU (3D) Plots

GNUPLOT PLOTS	
Pressure (P)	Yes
Film Thick. (H)	No
Temperature (T)	No
Flow Rate (Q)	No

Select ***Yes*** or ***No*** from dropdown lists in the gray cells. ***Yes*** means the program will create a 3D plot of the corresponding quantity. Each plot is on a separate worksheet named P, H, T, or Q. If a sheet with the exact name does not exist, it will be created on the next run. The plots may be manipulated with the mouse to change point of view and scaling, and can be edited with gnuplot commands (www.gnuplot.info). Start by clicking on the plot, which launches the Gnuplot application and displays the plot in a separate window.

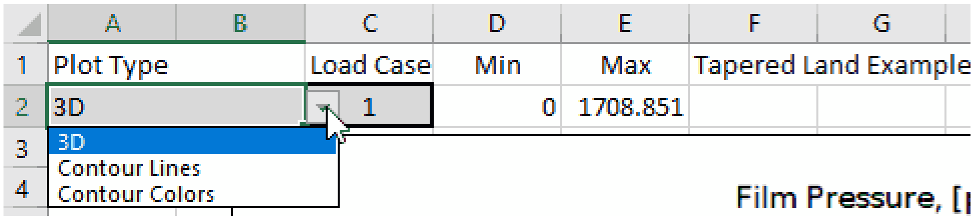
- **P** (Pressure) - presents pressure for a single pad.

- **H** (FilmThickness) - presents thickness of the bearing film for a single pad. If the pad has a tapered section or is crowned, these features will be evident in the plot.

- **T** (Film Temperature) - presents temperature of the bearing film for a single pad. Note that the program computes the film solution (i.e. Reynolds Equation) with an isothermal assumption. Temperature variation over the pad is determined via a post processing calculation which considers flow and power loss on an element-by-element basis.

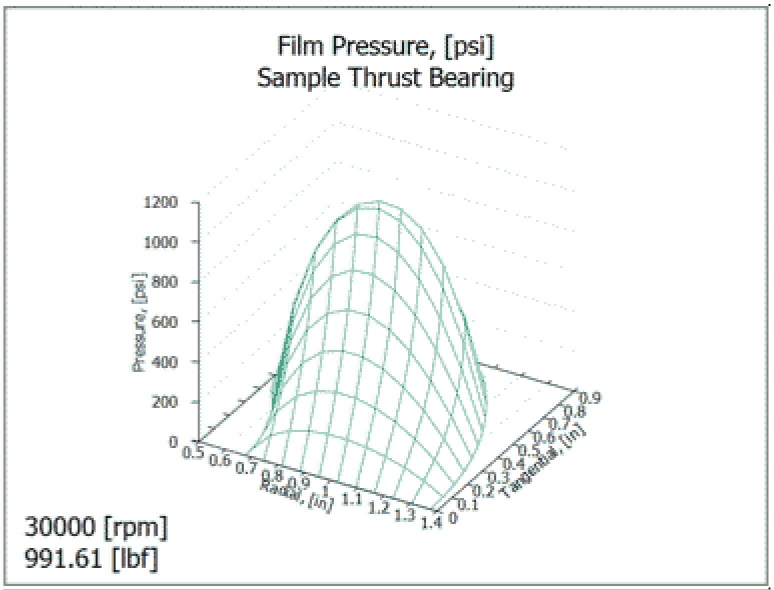
- **Q** (Flow) - presents oil flow rate (i.e. lpm or gpm) for a single pad.

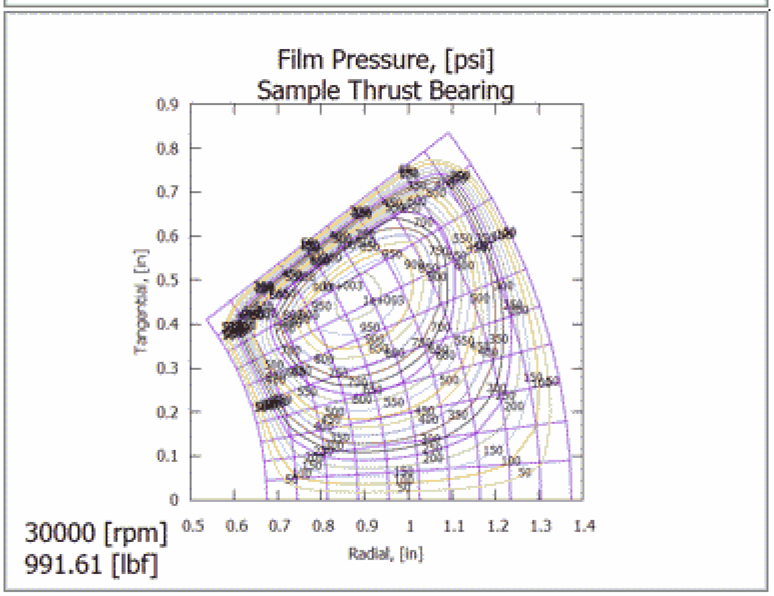
The plots of **P**, **H** and **T** can be in one of three formats; 3D, Contour and Color Map. Select the format from a dropdown list on each worksheet. These sheets also have a second dropdown for selecting which load case to plot if there are multiple load cases.

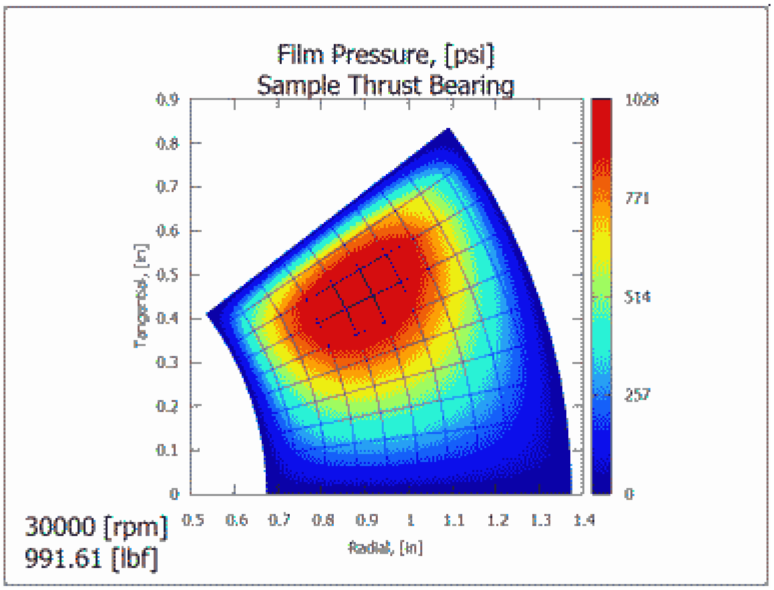


Cell **F1** contains a cell formula referencing the worksheet from which the plotted results were generated. When a file contains multiple input worksheets, this cell formula identifies which sheet generated the results.

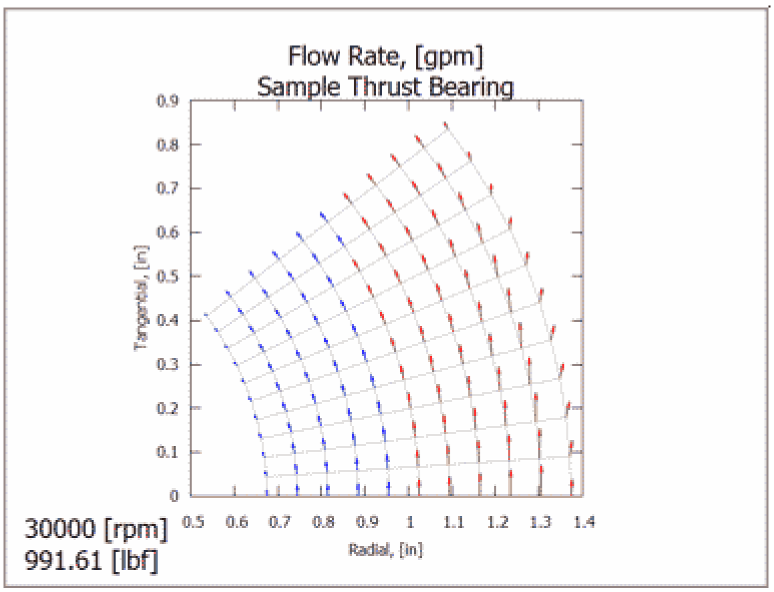
The plot format and/or load case can be changed after the run, and the plot will be updated.


Film Pressure, [psi]
Sample Thrust Bearing
Pressure, [psi]
Radial, [in]
Tangential, [in]
30000 [rpm]
991.61 [lbf]


Film Pressure, [psi]
Sample Thrust Bearing
Tangential, [in]
Radial, [in]
30000 [rpm]
991.61 [lbf]

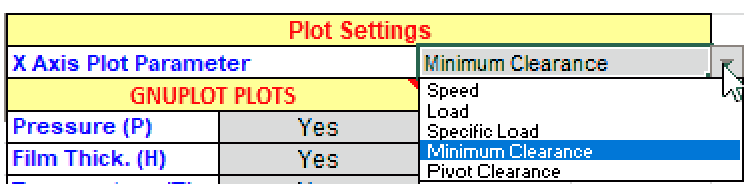


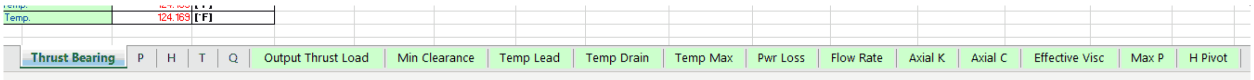
For the flow rate sheet, **Q**, an Arrow plot is the only option. The flow arrows depict flow rate magnitude and direction, and are colored red and blue to signify flow towards the outer and inner pad eges, respectively.



The data for each plot is read from text files created in **C:\Users\{username}\AppData\Local\Temp\Xlrotor**. The names of the files are; **Pressure.txt**, **Hfilm.txt**, **Temps.txt**, **Flows.txt**.

X Axis Plot Parameter

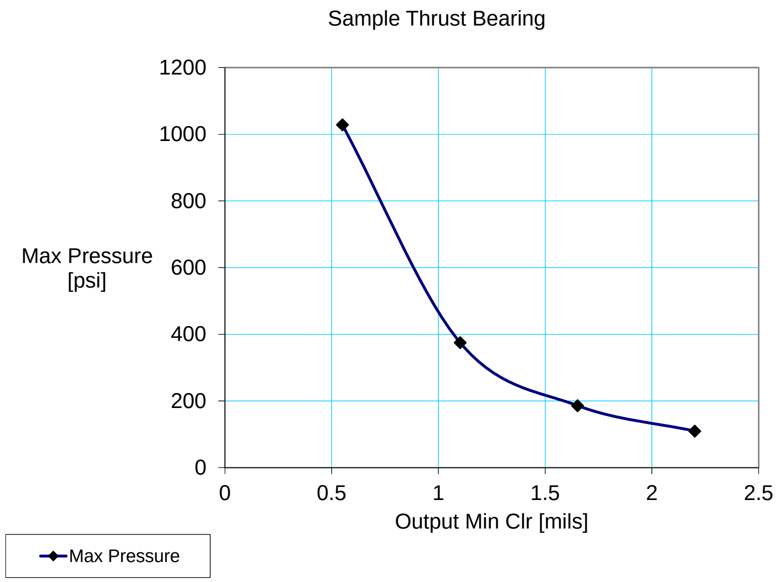


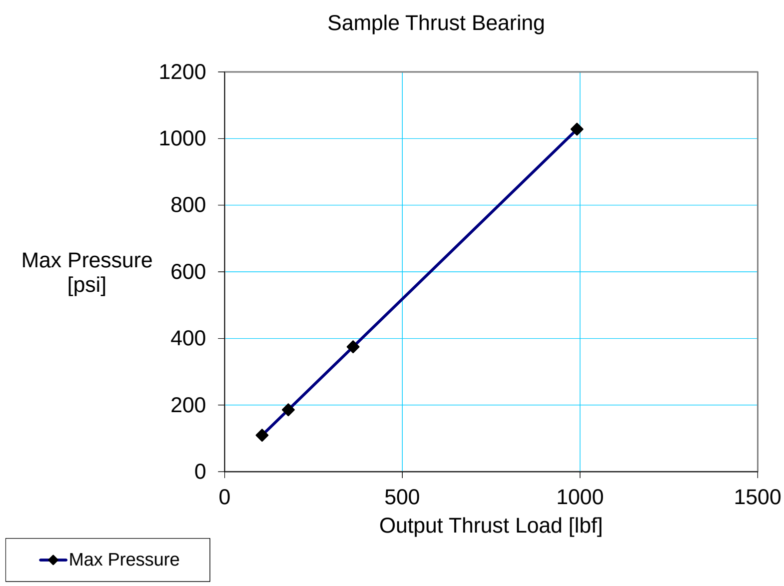


Most of the output quantities appearing in the Primary Output Table are also displayed in Excel XY scatter charts. Each of these charts appears on a separate chart sheet. The tab names are shown in the above image and must not be changed. However, these chart sheets are not required, and may be deleted from the file. The quantity used for x axis is selected from the dropdown list. Changing this selection will instantly change the X-axis of all plots without requiring a re-run. However, a press of F9 may be needed if Excel is in Manual Calculation mode.

When the file contains multiple input worksheets, click on the title at the top of the plot and examine the formula in the Excel formula bar to identify which sheet the plot results refer to. Each time the ***X Axis Plot Parameter*** dropdown on a particular sheet for is changed, the plots will be updated to display data from that sheet.

The following example is the plot of peak film pressure plotted against two choices of the x-axis variable; minimum clearance and thrust load.

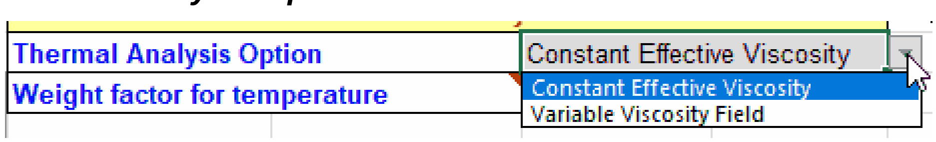




Other Input Fields

Thermal Analysis		
Thermal Analysis Option	Constant Effective Viscosity	
Weight factor for temperature	0.50	[-]

Thermal Analysis Option



There are two choices for the thermal analysis option.

Constant Effective Viscosity This selection means the viscosity in the film land will be a constant value corresponding to an "effective" temperature which is determined by balancing the heat generated in the film by viscous losses with heat removed by hot oil leaving the bearing and being replaced with new oil at supply temperature. The thermal heat balance analysis determines a unique combination of leading edge and trailing edge oil temperatures (T_{le} and T_{te}) which result in a balanced flow of heat through the bearing. The "effective" temperature is the numerical average of the leading and trailing edge temperatures. The heat balance analysis requires an additional assumption for the temperature of oil flowing out a pad's inner and outer edges.

The input value for ***Weight Factor for Temperature*** is used in the following relationships.

Weight factor for inner edge temperature: $T_{ie} = w*T_{te} + (1-w)T_{le}$

Weight factor for outer edge temperature: $T_{ie} = w*T_{te} + (1-w)T_{le}$

The recommended input value for the weight factor is 0.5.

Variable Viscosity Field This selection means the viscosity in the film land is determined separately for each finite element. The Weight Factor is not required, and thus the input cell for this value is disabled. If the program fails to converge to a solution for film thickness at a given load, a better initial guess for film thickness may help. Do a run with Constant Effective Viscosity to get an improved initial guess for film thickness.

FE Mesh & Convergence Criteria

FE MESH & CONVERGENCE CRITERIA	
FE Meshing Option	Auto-mesh Standard
# Circumferential elements in tapered section	10
# Circumferential elements in uniform section	3
# Radial Elements	13
Max iterations for load calculation	50
Max acceptable load difference [%]	0.01
Max iterations for temperature calculation	70
Max acceptable temperature difference [Deg]	0.1
Relaxation factor for load iteration	1

Accurate results can often be obtained with 10 to 15 elements in the radial and circumferential directions, with elements having close to square aspect ratio. Repeating a run with a greater number of elements is a good way to check if more elements are needed.

The maximum allowable number of elements in each direction is 50.

FE Meshing Option

Select one of the two options for automatically determining the mesh inputs, or select User Defined. Usually, increasing the number of elements will not affect results very much, but it will provide more points for the 3D plots of film pressure, etc.

Circumferential elements in tapered section

If the Percent of Pad that is Tapered is zero, then the number of elements in the tapered section must be zero.

Circumferential elements in uniform section

If the Percent of Pad that is Tapered is 100%, then the number of elements in the uniform (i.e. untapered) section must be zero.

Radial Elements

The number of elements in the radial direction should be chosen to achieve an element aspect ratio close to one.

Max iterations for load calculation

This input applies only when the Load Specified option has been selected. This sets an upper limit to the number of iterations used to search for the oil film clearance corresponding to an input value of load. Fifty is a good choice for most situations since most runs will converge in less than 10 or 20 iterations. A good input value for initial guess for clearance will minimize iterations.

Max acceptable load difference [%]

This input applies only when the Load Specified option has been selected. Recomended value is 0.01. Unlike other % inputs, this input cell is <u>not</u> formatted to display a % symbol. So 0.01 means one hundredth of one percent (i.e. 0.01%). If a case is taking a very large number of iterations to find a solution, increasing this input should help. If this input is too small, the program will not be able to converge to a solution.

Max iterations for temperature calculation

Every run requires iteration of the heat balance equations to find the lubricant viscosity and its corresponding temperature. The only exception to this requirement are runs which are forced to be isoviscous (see Lubricant Properties).

Max acceptable temperature difference [Deg]

Recomended value is 0.01 degrees for either Fahrenheit or Celsius.

Relaxation factor for load iteration

Recomended value is 1. This input applies only when the Load Specified option has been selected. If a case fails to converge to the given load within 50 iterations, setting this input to a value between 0.5 and 1.0 may help. Start with 0.9.

Governing Equations

XLThrustBearing solves the Reynolds equation for thin film flows. Laminar, inertialess flow with an incompressible, Newtonian fluid (Pinkus. 0., 1958, "Solution of the Tapered-Land Sector Thrust Bearing," *Transactions of the ASME,October* 1958. pp. 1510- 1516).

The program offers two modes of calculation for determining lubricant viscosity. *Constant* viscosity and *Variable* viscosity.

Constant viscosity is synonomous with isothermal. However, the inevitable rise in oil temperature is accounted for via an input-to-output energy balance. This is a global application of the energy equation. In other words, the program determines a constant viscosity value which results in the heat gain due to viscous losses being exactly equal to the heat removed by hot oil being continuously replaced by supply oil. This is an iterative calculation because viscous losses and flow rates are a function of viscosity. The energy balance analysis is adiabatic from the standpoint that no heat is gained or lost to the pad or runner, and all heat from viscous losses goes to heating the oil.

Variable viscosity means viscosity is determined separately for each element of the mesh. This is an element-by-element application of the energy equation.

$$\frac{1}{r}\frac{\partial}{\partial r}\left(r\frac{h^3}{12\mu_{eff}}\frac{\partial p}{\partial r}\right)+\frac{1}{r}\frac{\partial}{\partial \theta}\left(\frac{h^3}{12\mu_{eff}}\frac{\partial p}{r\partial \theta}\right)=\frac{\partial h}{\partial t}+\frac{\frac{\Omega}{2}\partial h}{\partial \theta}$$

Nomenclature

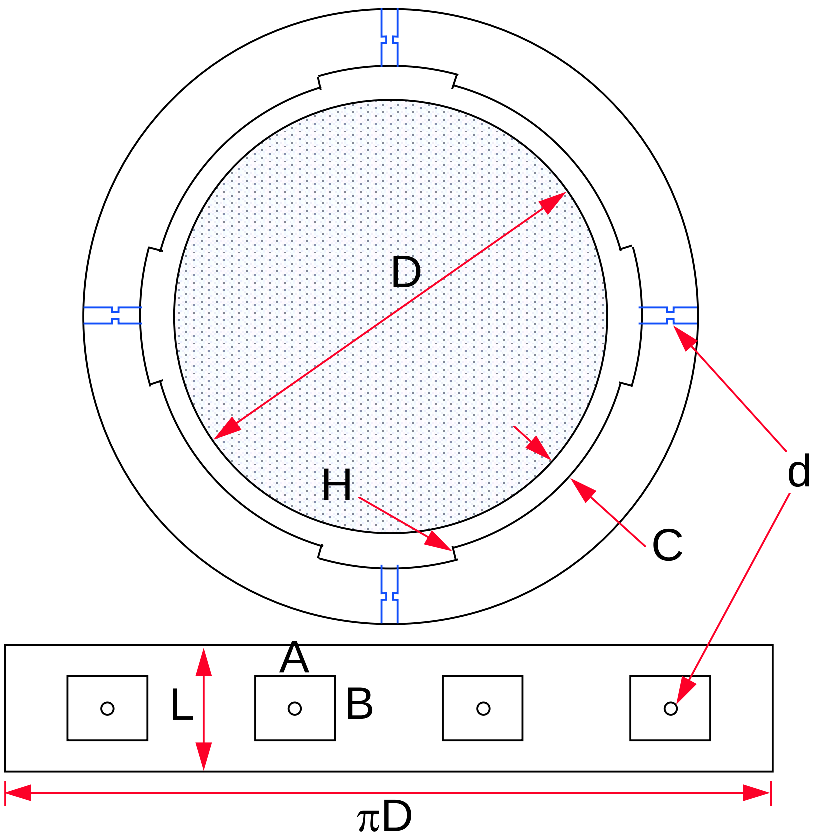
h	: film thickness
p	: film pressure
r	: radial coordinate
θ	: circumferential coordinate
μ_{eff}	: effective viscosity, function of T
Ω	: shaft rotational speed

XlHydst.XLS Hydrostatic Bearing Template File

See also

Bearing Template Files
Brg's Worksheet

The *XLHydst* module is used for analyzing laminar and turbulent incompressible flow hydrostatic journal bearings. Hydrostatic bearings generate their load carrying capacity from a high pressure supply of liquid. The liquid can be oil, or process fluid. In addition to rotordynamic coefficients, *XLHydst* calculates the flow rate, pocket pressure, and Reynolds numbers for the bearing as a function of shaft speed. By utilizing a high pressure supply, hydrostatic bearings have some attractive advantages over plain hydrodynamic bearings including; more load capacity, greater stiffness, less deflection under static load, and load support at zero speed.



Applications for hydrostatic bearings are numerous. In general hydrostatic bearings are applied where:

- The fluid used (available) has no lubricity (i.e. low viscosity).
- The applied loads exceed the capacity of hydrodynamic bearings (typ > 400 psi specific load).
- Low speed rotating machines.

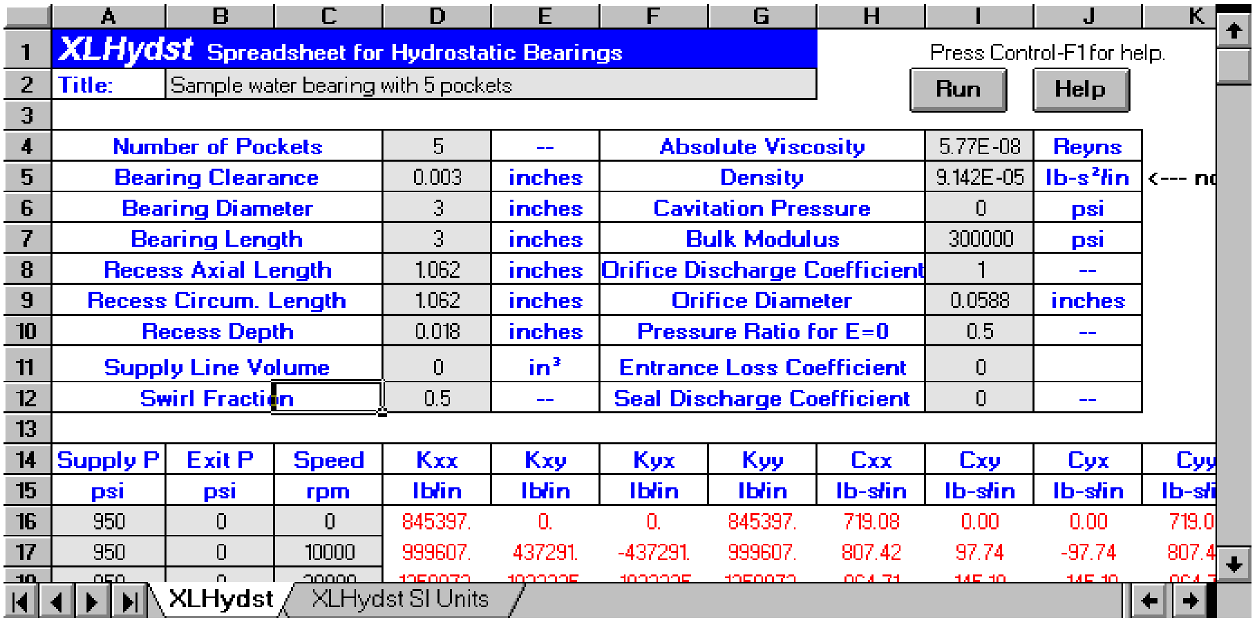
- Greater accuracy of positioning is needed.

Sample applications include:

- Cryogenic turbopumps.
- Submersible (liquefied natural gas) pumps.
- Nuclear reactor cooling pumps (liquid NA and water).
- Milling machines and high precision lathes.
- As hydraulic lifting jacks in large (heavily loaded) turbo-compressor generators.
- Low speed (huge) drums used in the sugar mill industry, and crushers.
- Cement plants.
- Petrochemical and medical centrifuges.
- Air HJB's used on the dentist drills (> 400,000 rpm).
- Air HJBs used on some diesel turbochargers.
- Air gyroscopes in navigation systems, etc.
- Refrigeration compressors using refrigerant in the bearing.
- Boiler feed pumps.
- Magnetic drive sealless process pumps.

In hydrostatic bearings fluid cleanliness is very important. Typically the bearing supply should be filtered. Generally the orifice diameter is larger than the radial clearance, so particle damage to the shaft is often more likely than a clogged orifice.

What follows are explanations of the inputs to the XLHydst module for analyzing hydrostatic bearings for incompressible fluids.



XLHydst Spreadsheet for Hydrostatic Bearings

Press Control-F1 for help.

Run | Help

Title: Sample water bearing with 5 pockets

Number of Pockets	5	--	Absolute Viscosity	5.77E-08	Reyns
Bearing Clearance	0.003	inches	Density	9.142E-05	lb-s²/in
Bearing Diameter	3	inches	Cavitation Pressure	0	psi
Bearing Length	3	inches	Bulk Modulus	300000	psi
Recess Axial Length	1.062	inches	Orifice Discharge Coefficient	1	--
Recess Circum. Length	1.062	inches	Orifice Diameter	0.0588	inches
Recess Depth	0.018	inches	Pressure Ratio for E=0	0.5	--
Supply Line Volume	0	in³	Entrance Loss Coefficient	0	
Swirl Fraction	0.5	--	Seal Discharge Coefficient	0	--

Supply P	Exit P	Speed	Kxx	Kxy	Kyx	Kyy	Cxx	Cxy	Cyx	Cyy
psi	psi	rpm	lb/in	lb/in	lb/in	lb/in	lb-s/in	lb-s/in	lb-s/in	lb-s/i
950	0	0	845397.	0.	0.	845397.	719.08	0.00	0.00	719.0
950	0	10000	999607.	437291.	-437291.	999607.	807.42	97.74	-97.74	807.4

XLHydst | XLHydst SI Units

Title

This is a descriptive title for the bearing being analyzed. When you Link an XLHydst file to an XLRotor rotor model file, your entry here will appear on the Brg's Worksheet.

BEARING DIMENSIONAL GEOMETRY

Number of Pockets (N)

The number of pressure pockets in the bearing. Each pocket must be rectangular, and are all in the same axial plane of the bearing, equally spaced around the circumference of the bearing. All pockets must be identical.

Radial Clearance (C)

This is the radial clearance of the bearing. It must be constant throughout the bearing, except at the pockets. In some exotic applications, it may be necessary to account for centrifugal and/or thermal growth of the shaft or bearing housing during operation.

Journal Diameter (D)

This is the diameter of the journal shaft.

Journal Length (L)

This is the full axial length of the bearing land. That is, the end to end length of the bearing, including the pockets.

Axial Length of Pocket (A)

This is the axial length of each pocket, and must be the same for each pocket.

Circumferential Length of Pocket (B)

This is the circumferential length of each pocket, and must be the same for each pocket.
.

B=[Pocket arc length (deg)] PI D / 360 (degs)

Pocket Depth (H)

This is the machined depth of each pocket.

Volume of Orifice Supply Line (Vsup)

This is the volume between the supply line orifice and the end of the supply line where it discharges into the pocket.

<u>FLUID PROPERTIES</u>

Absolute Viscosity (mu)

This is the absolute viscosity of the fluid used.

Density (rho)

This is the density of the fluid used in the bearing.

Cavitation Pressure (Pc)

This is a fluid property, and is the absolute pressure below which the fluid will cavitate (i.e. can not sustain tension).

Compressibility Parameter = 1/ Fluid Bulk Modulus

A fluid material property necessary to account for compressibility effects within the volume of the pocket. Fluid compressibility is only accounted for within the pocket volumes.

Typical values of Bulk modulus; water, 290 Kpsi, and oil, 350 kpsi

Journal Rotational Speed (RPM)

This is the rotor speed. You can enter as many values in the speed column as you wish, in any order you wish.

OPERATING PARAMETERS

Supply Pressure (Ps)

This is the absolute pressure on the upstream side of the supply line orifice.

External Pressure (Pa)

This is the absolute pressure in the discharge cavity (sump) of the bearing.

Orifice Diameter (d)

This is the diameter of the supply line orifice. Many hydrostatic bearings are designed to have about half of the bearing pressure drop occur across this orifice, and the other half in the lands and bearing exit (i.e. a pressure ratio = (Ppocket-Pa)/(Ps-Pa)=0.5. For turbulent flow applications a ratio = 0.6 usually results in the largest direct stiffness.

Orifice Discharge Coefficient (Cd)

This empirical coefficient defines the losses across the supply line orifice. Typical values range from 0.6 to 1.0, and it is defined in accordance with the following expression.

$$\dot{Q} = C_d \left(\frac{\pi d^2}{4} \right) \sqrt{2 \frac{P_{\text{supply}} - P_{\text{pocket}}}{\rho}}$$

Inertia Entrance Loss Coefficient (Xsi)

Non-isentropic entrance loss coefficient for flow from the pockets to the film lands. Used for high speed/high flow applications.

Typical value=0.25. The pressure drop occurring as the fluid leaves the pocket and enters the land is calculated as

$$\Delta P = \tfrac{1}{2}(1 + Xsi)\rho V^2$$

Exit Seal Discharge Coefficient (Cdis)

Defines an additional pressure loss at the bearing discharge plane. Used only for pure hydrostatic applications (RPM=0) when the bearing has some end-seals at the exit planes.

Typical values: 0, no seal, and 20, very tight end seal.

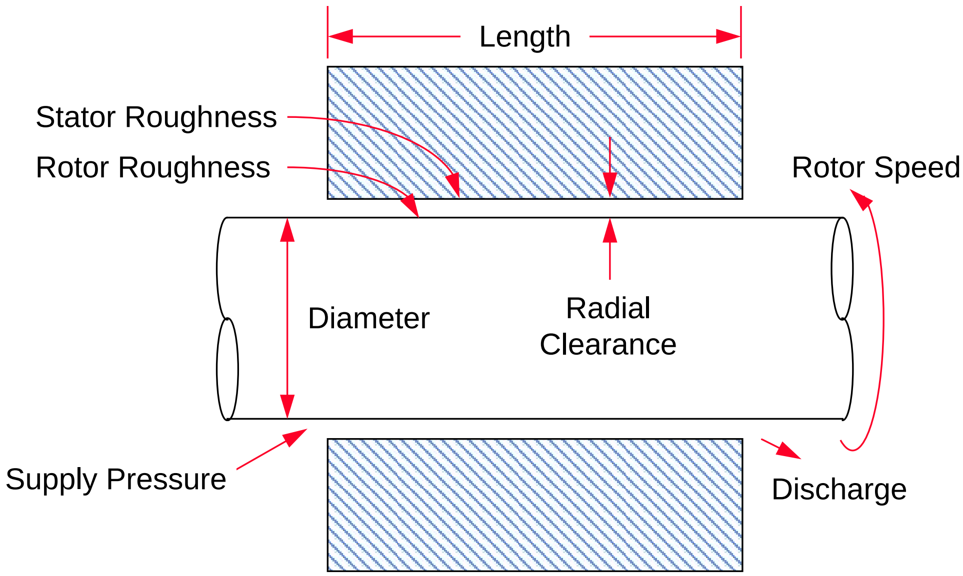
$$P_{\text{exit}} - P_{\text{a}} = \tfrac{1}{2} C_{\text{dis}} \rho V^2$$

P_{exit} is the pressure at the exiting edge of the land.

XLShSeal.XLS Short Annular Seal Template File

See also

- Bearing Template Files
- Brg's Worksheet
- XLAnnularSeal Template File



The *XLShSeal* module is used for analyzing laminar and turbulent flow incompressible **annular seals which have short axial length (L/D<0.5)**. For long seals, use the XLAnnularSeal module.

This type of seal is common in process pumps as wear rings seals, interstage seals, and balance piston seals. In high performance pumps the stiffness and damping properties of seals can exert a very strong influence on the rotordynamics. The stiffness and damping is roughly proportional to the pressure drop, and are strong functions of the length, diameter, and clearance.

Annular seals generate their stiffness and damping from both hydrostatic effects (i.e. the pressure drop), and hydrodynamic effects like regular sleeve bearings.. The liquid can be oil, water or any incompressible process fluid. In addition to rotordynamic coefficients, *XLShSeal* calculates the flow rate, power loss, and Reynolds numbers for the seal as a function of shaft speed.

XLShSeal allows for different surface roughness ratios for the rotor and stator. This permits analysis of damping seals which generally have knurled stators and smooth rotors.

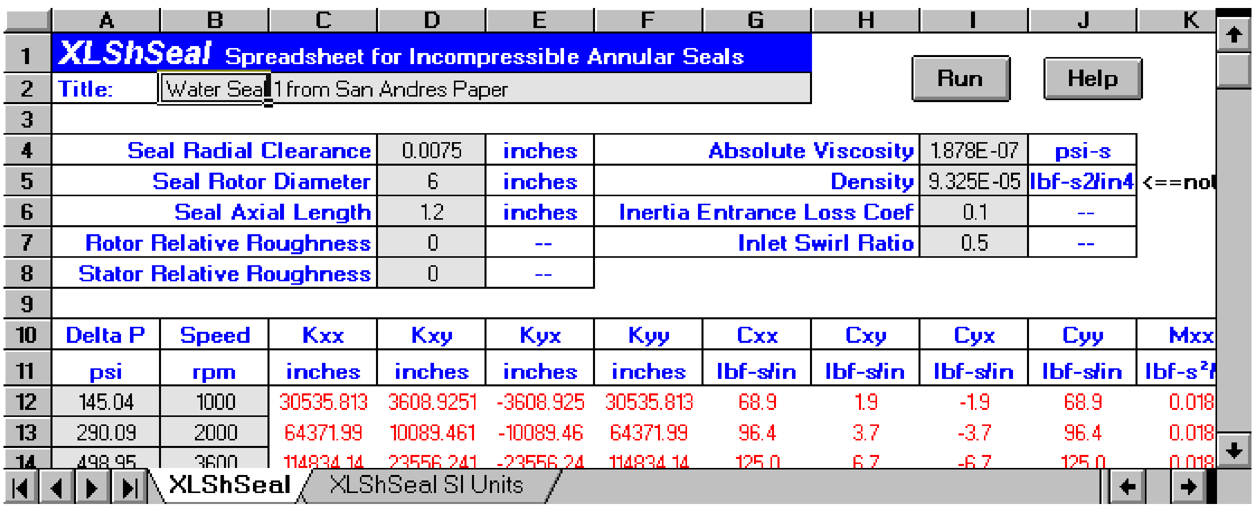
The analysis done by XLShSeal was devised by Dr. Luis San Andres of Texas A&M University. The following technical paper describes this analysis.

San Andres, L., "**Dynamic Force and Moment Coefficients for Short Length Annular Seals**, ASME Journal of Tribology, Vol. 115, 1, pp. 61-70, 1993. The abstract from this paper is reproduced here.

Abstract

Close form expressions for the dynamic force and moment coefficients in short length annular pressure seals operating at the concentric and aligned position are derived. The analysis considers fully developed turbulent flow within the seal and determines a set of ordinary differential equations for the bulk-flow field due to perturbations in rotor displacements and angular motions. The flow equations are solved exactly for seals of short length where dynamic variations in circumferential velocity are neglected. The analytical solution derived is simple and reasonably accurate for seals of length to diameter ratios (L/D) as large as 0.5 as comparisons with results from full-scale numerical solutions show. The formulae presented are practical for use in preliminary design stages and parametric studies of dynamic seal performance.

The *XLShSeal* analysis module can also be used for circumferentially grooved seals if the grooves are shallow and do not take up a large portion of the seal length. For deep grooves that do take up a substantial portion of seal length, the rotordynamic coefficients can be significantly reduced. See the book ***Turbomachinery Rotordynamics*** by Dara W. Childs, Wiley Interscience, 1993, for more information on this topic.



What follows are explanations of the inputs to the XLShSeal module for analyzing short annular seal with incompressible fluids.

Title

This is a descriptive title for the seal being analyzed. When you Link an XLShSeal file to an XLRotor rotor model file, your entry here will appear on the Brg's Worksheet.

SEAL DIMENSIONAL GEOMETRY

Seal Radial Clearance (C, inches or meters)

This is the radial clearance of the seal. It must be constant throughout the seal. Note that in some applications, it may be necessary to account for centrifugal and/or thermal growth of the shaft or housing during operation.

Seal Rotor Diameter (D, inches or meters)

This is the diameter of the shaft. The L/D ratio of the seal should not exceed 0.5.

Seal Axial Length (L, inches or meters)

This is the full axial length of the seal land. That is, the end to end length of the seal where the clearance is as specified above. The L/D ratio of the seal should not exceed 0.5. Use the XLAnnularSeal module for long seals.

Rotor Relative Roughness (dimensionless)

This is the ratio of mean surface roughness of the rotor to the seal radial clearance.

Stator Relative Roughness (dimensionless)

This is the ratio of mean surface roughness of the stator to the seal radial clearance.

FLUID PROPERTIES

Absolute Viscosity (mu, psi-s or Pa-s)

This is the absolute viscosity of the fluid used.

Density (rho, lbf-s2/in4 or kg/m3)

This is the density of the fluid.

Here are a few viscosity conversion factors which may be helpful:

1 cp = 0.001 Pa-s

1 cp = 1.45E-7 psi-s

1 cp = sg*(1 cst)   (in these units only)

Water at 68.4F is exactly 1 cp = 1E-3 Pa-s. This also happens to be equal to 1 cst since the specific gravity, sg, is 1 for water.

For density, here are some more:

1 lbm/in^3 = (lbf-s**2/in**4)/386.4

1 lbm/in^3 = (kg/m**3)*27680.

1 kg/m^3 = (lbf-s**2/in**4)*9.35E-8

The density of water at 68F is 999 kg/m^3 = 0.999 gm/cm^3 = 9.34E-5 lbf-s^2/in^4.

OPERATING PARAMETERS

Pressure Drop (Pd, psi or Pa)

This is the overall drop in pressure across the seal.

Inlet Swirl Ratio (alpha, dimensionless)

This is the circumferential velocity of the fluid entering the seal expressed as a fraction of shaft surface speed . For many seals this value is around 0.5. If an intentional swirl break is being used, then this value can be lower. This parameter effects primarily the cross coupled stiffness and cross coupled damping. The other dynamic coefficients are largely unaffected by changes in swirl ratio.

Inertia Entrance Loss Coefficient (Xsi)

Non-isentropic entrance loss coefficient for flow entering the seal land. Important in high speed/high flow applications.

Typical value=0.1. The pressure drop occurring as the fluid enters the seal land is calculated as

$$\Delta P = \tfrac{1}{2}\left(1 + Xsi\right)\rho V^2$$

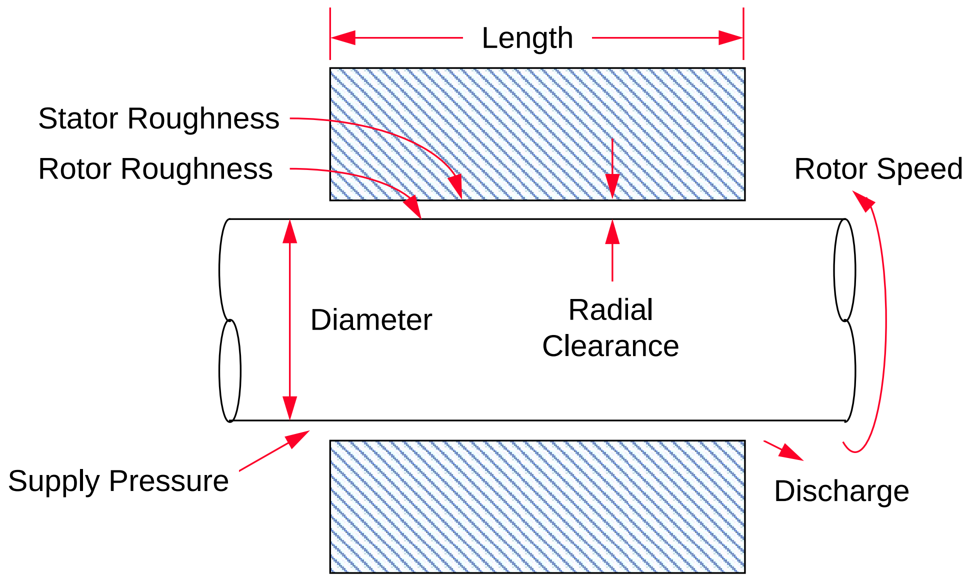
Journal Rotational Speed (RPM)

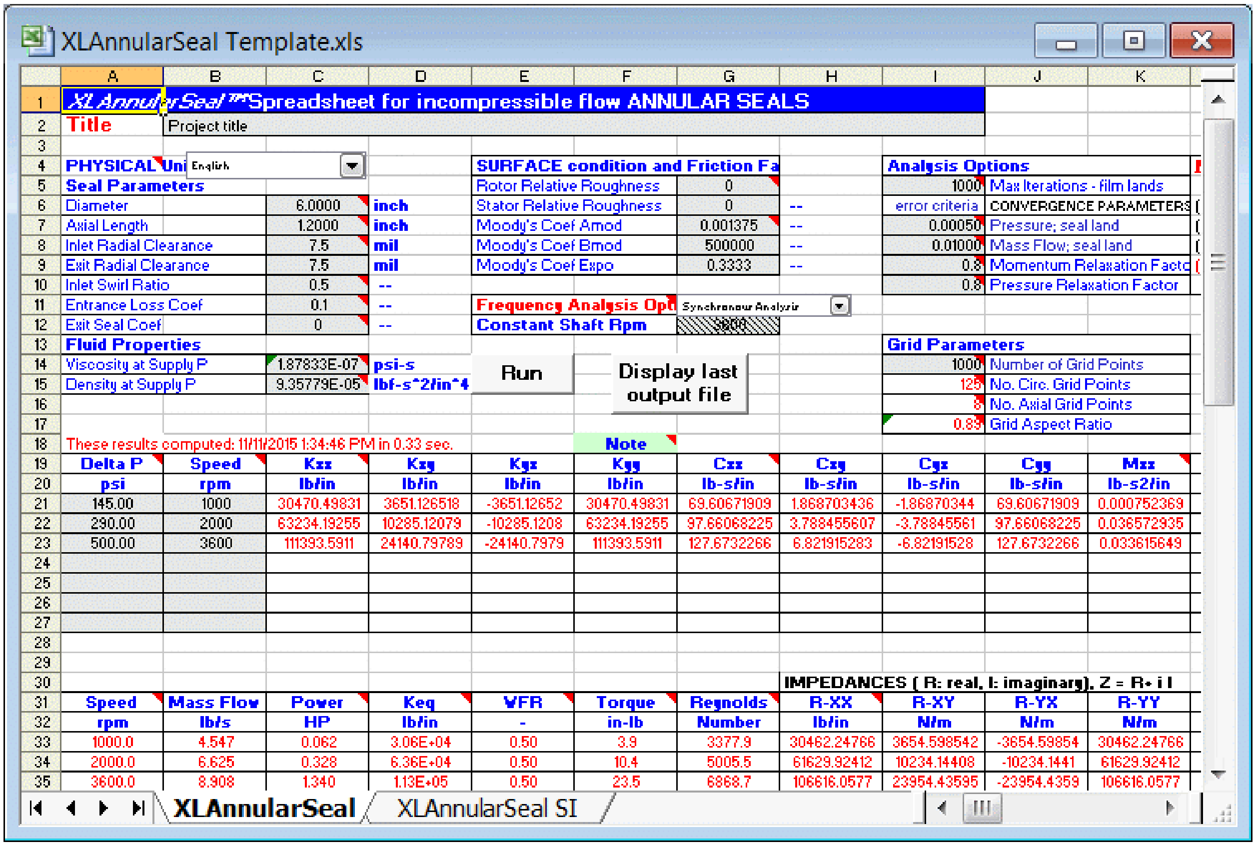
This is the rotor speed. You can enter as many values in the speed column as you wish, in any order you wish.

XLAnnularSeal.XLS Template File

See also

Bearing Template Files
Brg's Worksheet
XLHoneycomb Template File
XLSheal Template File





XLAnnularSeal Template.xls

XL AnnularSeal™ Spreadsheet for incompressible flow ANNULAR SEALS

Title: Project title

PHYSICAL Units	English		
Seal Parameters			
Diameter	6.0000	inch	
Axial Length	1.2000	inch	
Inlet Radial Clearance	7.5	mil	
Exit Radial Clearance	7.5	mil	
Inlet Swirl Ratio	0.5	--	
Entrance Loss Coef	0.1	--	
Exit Seal Coef	0	--	
Fluid Properties			
Viscosity at Supply P	1.87833E-07	psi-s	
Density at Supply P	9.35779E-05	lbf-s^2/in^4	

SURFACE condition and Friction Fa		
Rotor Relative Roughness	0	
Stator Relative Roughness	0	--
Moody's Coef Amod	0.001375	--
Moody's Coef Bmod	500000	--
Moody's Coef Expo	0.3333	--
Frequency Analysis Opt	Synchronous Analysis	
Constant Shaft Rpm	3600	

Run

Display last output file

Analysis Options	
1000	Max Iterations - film lands
error criteria	CONVERGENCE PARAMETERS
0.00050	Pressure; seal land
0.01000	Mass Flow; seal land
0.8	Momentum Relaxation Factor
0.8	Pressure Relaxation Factor
Grid Parameters	
1000	Number of Grid Points
125	No. Circ. Grid Points
8	No. Axial Grid Points
0.89	Grid Aspect Ratio

These results computed: 11/11/2015 1:34:46 PM in 0.33 sec.

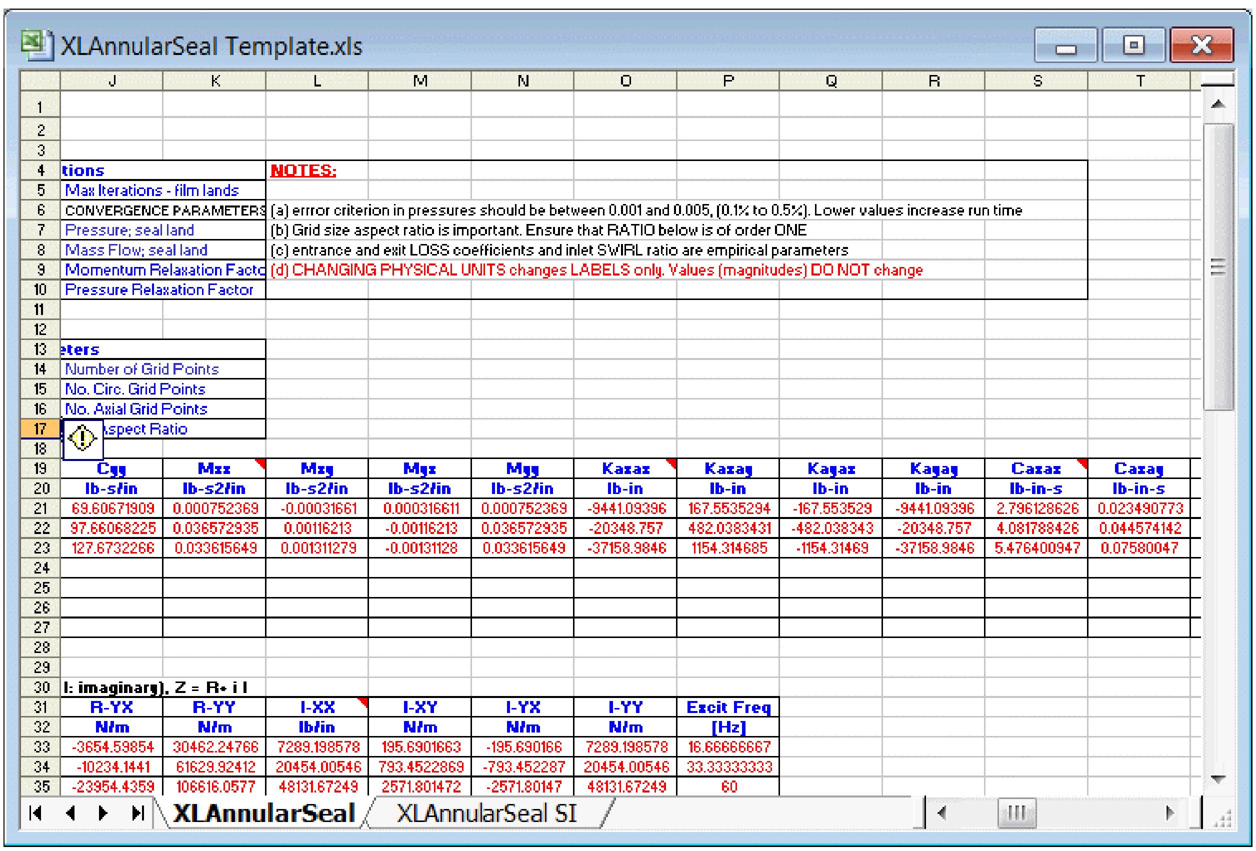
Note

Delta P	Speed	Kxx	Kxy	Kyx	Kyy	Cxx	Cxy	Cyx	Cyy	Mxx
psi	rpm	lb/in	lb/in	lb/in	lb/in	lb-s/in	lb-s/in	lb-s/in	lb-s/in	lb-s2/in
145.00	1000	30470.49831	3651.126518	-3651.12652	30470.49831	69.60671909	1.868703436	-1.86870344	69.60671909	0.000752369
290.00	2000	63234.19255	10285.12079	-10285.1208	63234.19255	97.66068225	3.788455607	-3.78845561	97.66068225	0.036572935
500.00	3600	111393.5911	24140.79789	-24140.7979	111393.5911	127.6732266	6.821915283	-6.82191528	127.6732266	0.033615649

IMPEDANCES (R: real, I: imaginary), Z = R+ i I

Speed	Mass Flow	Power	Keq	WFR	Torque	Reynolds	R-XX	R-XY	R-YX	R-YY
rpm	lb/s	HP	lb/in	-	in-lb	Number	lb/in	N/m	N/m	N/m
1000.0	4.547	0.062	3.06E+04	0.50	3.9	3377.9	30462.24766	3654.598542	-3654.59854	30462.24766
2000.0	6.625	0.328	6.36E+04	0.50	10.4	5005.5	61629.92412	10234.14408	-10234.1441	61629.92412
3600.0	8.908	1.340	1.13E+05	0.50	23.5	6868.7	106616.0577	23954.43595	-23954.4359	106616.0577

XLAnnularSeal | XLAnnularSeal SI



XLAnnularSeal Template.xls

NOTES:

(a) errror criterion in pressures should be between 0.001 and 0.005, (0.1% to 0.5%). Lower values increase run time

(b) Grid size aspect ratio is important. Ensure that RATIO below is of order ONE

(c) entrance and exit LOSS coefficients and inlet SWIRL ratio are empirical parameters

(d) CHANGING PHYSICAL UNITS changes LABELS only. Values (magnitudes) DO NOT change

Cyy	Mxx	Mxy	Myx	Myy	Kaxax	Kaxay	Kayax	Kayay	Caxax	Caxay
lb-s/in	lb-s2/in	lb-s2/in	lb-s2/in	lb-s2/in	lb-in	lb-in	lb-in	lb-in	lb-in-s	lb-in-s
69.60671909	0.000752369	-0.00031661	0.000316611	0.000752369	-9441.09396	167.5535294	-167.553529	-9441.09396	2.796128626	0.023490773
97.66068225	0.036572935	0.00116213	-0.00116213	0.036572935	-20348.757	482.0383431	-482.038343	-20348.757	4.081788426	0.044574142
127.6732266	0.033615649	0.001311279	-0.00131128	0.033615649	-37158.9846	1154.314685	-1154.31469	-37158.9846	5.476400947	0.07580047

I: imaginary), Z = R+ i I

R-YX	R-YY	I-XX	I-XY	I-YX	I-YY	Excit Freq
N/m	N/m	lb/in	N/m	N/m	N/m	[Hz]
-3654.59854	30462.24766	7289.198578	195.6901663	-195.690166	7289.198578	16.66666667
-10234.1441	61629.92412	20454.00546	793.4522869	-793.452287	20454.00546	33.33333333
-23954.4359	106616.0577	48131.67249	2571.801472	-2571.80147	48131.67249	60

XLAnnularSeal | XLAnnularSeal SI

The XLAnnularSeal worksheet is similar to the XLShSeal worksheet. The two sheets will give similar results for annular seals of ***short*** axial length (L/D<0.5). XLShSeal computes a purely analytical solution, and is very fast. XLAnnularSeal computes a numerical solution on a grid of calculation points, and takes longer to execute.

Refer to the many cell comments on the worksheet for details about the inputs and outputs.

REFERENCES:

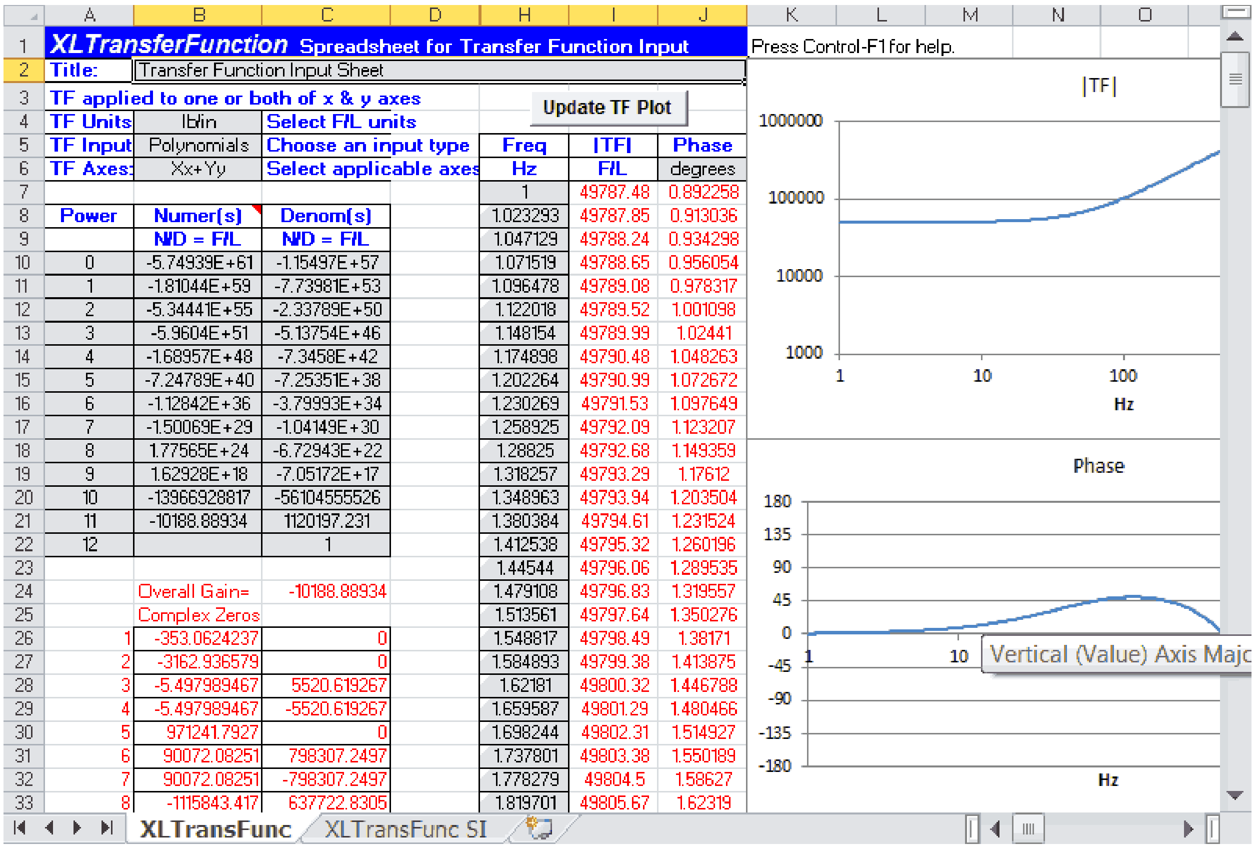
San Andres, L., 1993, "Effect of Shaft Misalignment on the Dynamic Force Response of Annular Pressure Seals," STLE Tribology Transactions, Vol. 36, No. 2, pp. 173 - 182.

Zirkelback, N. and L. San Andres, 1996, "Bulk Flow Model for the Transition to Turbulence Regime in Annular Pressure Seals," STLE Tribology Transactions, Vol. 39, No. 4, pp. 835 - 842.

XLTransferFunction Template File

See also

- Bearing Template Files
- Brg's Worksheet
- File Import Matlab TF
- API AMB Transfer Function Analysis
- MIMO Transfer Functions



	A	B	C	H	I	J
1	XLTransferFunction Spreadsheet for Transfer Function Input					
2	Title:	Transfer Function Input Sheet				
3	TF applied to one or both of x & y axes			Update TF Plot		
4	TF Units	lb/in	Select F/L units			
5	TF Input	Polynomials	Choose an input type	Freq	|TF|	Phase
6	TF Axes:	Xx+Yy	Select applicable axes	Hz	F/L	degrees
7				1	49787.48	0.892258
8	Power	Numer(s)	Denom(s)	1.023293	49787.85	0.913036
9		N/D = F/L	N/D = F/L	1.047129	49788.24	0.934298
10	0	-5.74939E+61	-1.15497E+57	1.071519	49788.65	0.956054
11	1	-1.81044E+59	-7.73981E+53	1.096478	49789.08	0.978317
12	2	-5.34441E+55	-2.33789E+50	1.122018	49789.52	1.001098
13	3	-5.9604E+51	-5.13754E+46	1.148154	49789.99	1.02441
14	4	-1.68957E+48	-7.3458E+42	1.174898	49790.48	1.048263
15	5	-7.24789E+40	-7.25351E+38	1.202264	49790.99	1.072672
16	6	-1.12842E+36	-3.79993E+34	1.230269	49791.53	1.097649
17	7	-1.50069E+29	-1.04149E+30	1.258925	49792.09	1.123207
18	8	1.77565E+24	-6.72943E+22	1.28825	49792.68	1.149359
19	9	1.62928E+18	-7.05172E+17	1.318257	49793.29	1.17612
20	10	-13966928817	-56104555526	1.348963	49793.94	1.203504
21	11	-10188.88934	1120197.231	1.380384	49794.61	1.231524
22	12		1	1.412538	49795.32	1.260196
23				1.44544	49796.06	1.289535
24		Overall Gain=	-10188.88934	1.479108	49796.83	1.319557
25		Complex Zeros		1.513561	49797.64	1.350276
26	1	-353.0624237	0	1.548817	49798.49	1.38171
27	2	-3162.936579	0	1.584893	49799.38	1.413875
28	3	-5.497989467	5520.619267	1.62181	49800.32	1.446788
29	4	-5.497989467	-5520.619267	1.659587	49801.29	1.480466
30	5	971241.7927	0	1.698244	49802.31	1.514927
31	6	90072.08251	798307.2497	1.737801	49803.38	1.550189
32	7	90072.08251	-798307.2497	1.778279	49804.5	1.58627
33	8	-1115843.417	637722.8305	1.819701	49805.67	1.62319

The XLTransferFunction worksheet is for using active magnetic bearings in your rotordynamic model. But it is not limited to just magnetic bearings. It can be used for any type of bearing or seal for which the transfer function of force to displacement is given. Once the transfer function has been input, this worksheet can be Linked to a rotor model on the Brg's Worksheet in exactly the same way as with other bearings.

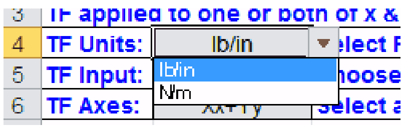
In many applications, transfer functions are ***strictly proper***, which means the degree of the numerator is less than the degree of the denominator. That ensures that the forces generated by the entity will tend to zero at infinite frequency. Actively controlled magnetic bearings generally satisfy that requirement. However, Xlrotor will allow the degree of the numerator to equal or exceed that of the denominator by up to 2 (see note at the end of this help page).

Note that in the image above, columns ***E***, ***F***, and ***G*** are hidden. This is explained below in the ***Mag+Phs Table*** description.

Title

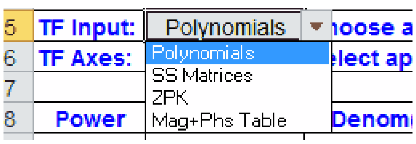
Enter a descriptive title into this cell. This title will appear within the XLRotor rotor model file(s) to which it is Linked. It will also be copied to any charts of bearing load created during a response analysis.

TF Units



The units of the transfer function must be either lbf/in or N/m. Select one of these from the drop down list. The units used here can be different than the units of the rotor model. XLRotor will convert units automatically when an analysis is run.

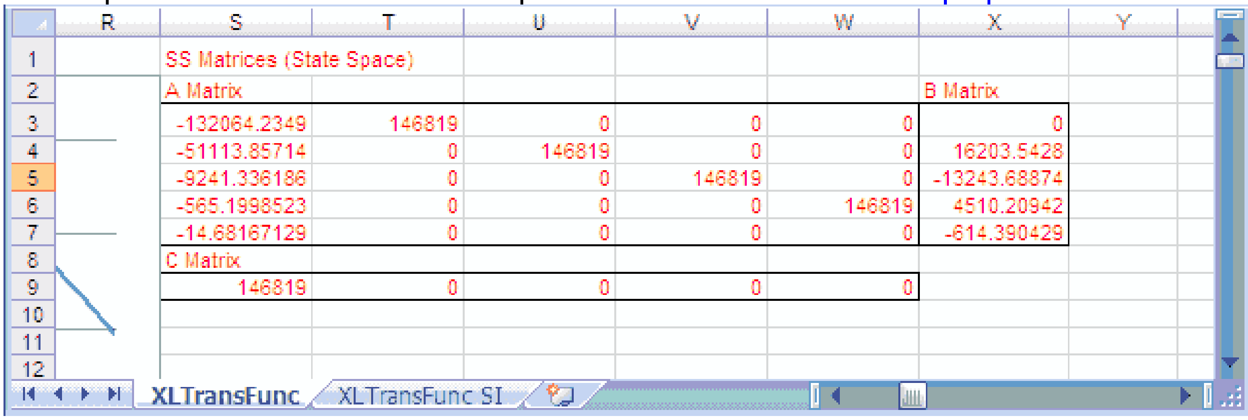
TF Input



There are 4 ways a transfer function can be input. Select from the dropdown list one of the following 4 options. Each time the selection is changed, the program will reformat the cell colors of the corresponding areas of the worksheet to make it more apparent which one will serve as input, and which are output.

1. When ***Polynomials*** is selected (N/D), input the coefficients of the numerator and denominator polynomials into the two corresponding columns. The zero power term must be first. The number of coefficients in the numerator column must not be more than m+2 where m is the number of coefficients in the denominator column.
2. When ***SS Matrices*** is selected (SS=State Space), enter the coefficients of these matrices into the cell areas to the right of the plots as in the following image. If the sizes of the matrices do not match your data, either too big or too small, you can resize them yourself manually or have the program resize them for you as follows: Change ***TF Input*** to ***Polynomials*** and put 1's in the denominator column to input a denominator polynomial with a degree equal to the size of your A matrix, and click the ***Update TF Plot*** button. This will resize the matrices. Then change ***TF Input*** back to ***SS Matrices***.

State space matrices can also be imported from Matlab. See File|Import Matlab TF.



	R	S	T	U	V	W	X	Y
1		SS Matrices (State Space)						
2		A Matrix					B Matrix	
3		-132064.2349	146819	0	0	0	0	
4		-51113.85714	0	146819	0	0	16203.5428	
5		-9241.336186	0	0	146819	0	-13243.68874	
6		-565.1998523	0	0	0	146819	4510.20942	
7		-14.68167129	0	0	0	0	-614.390429	
8		C Matrix						
9		146819	0	0	0	0		
10								
11								
12								

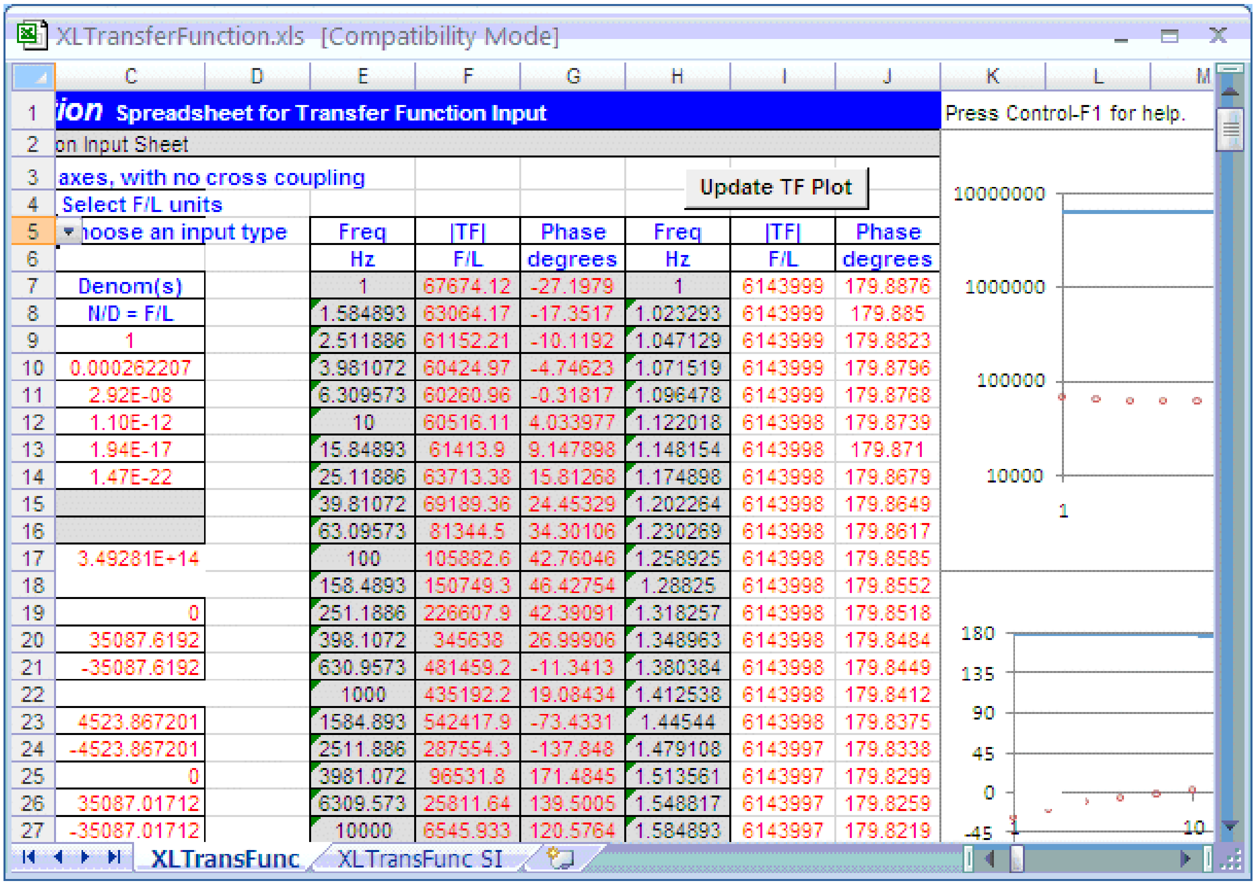
3. When ***ZPK*** is selected (ZPK=Zeros, Poles and Overall Gain), enter the overall gain, a list of complex zeros, and a list of complex poles. Enter these into the corresponding cell areas below the polynomials. You can add or remove zeros and poles from these lists using Excel's ***Edit/Delete/Cells*** menu command or on the ribbon use ***Home/Cells/Delete/Delete Cells***. Don't use the ***Insert/Delete Row*** because that will probably delete other data you don't want to delete.

4. When ***Mag+Phs Table*** is selected, worksheet columns ***E***, ***F***, and ***G*** are unhidden. In these three columns enter your data for Frequency, magnitude and phase angle. This data could be measured, or provided by a magnetic bearing vendor. When the ***Update TF Plot*** button is clicked, the data will be curve fit with numerator and denominator polynomials, and those polynomials will be output to the sheet (along with the ZPK and SS Matrices). The degrees of both polynomials will be equal to what is there when the button is clicked (i.e. the program will not change them). So preset the size of each polynomial by entering arbitrary nonzero values into the appropriate number of cells. Remember that the degree of the numerator must not exceed that of the denominator by more than 2.

   If the transfer function magnitude is increasing appreciably as frequency decreases toward zero, the transfer function probably includes an integrator, and the denominator will have a pole at the origin. This means the 0 order coefficient of the denominator will be exactly equal to zero. Putting a value of 0 in the cell for this coefficient will constrain the curve fit algorithm to include this root by forcing that coefficient to remain zero. If two poles are suspected at the origin, put 0 in the cells for the first two coefficients.

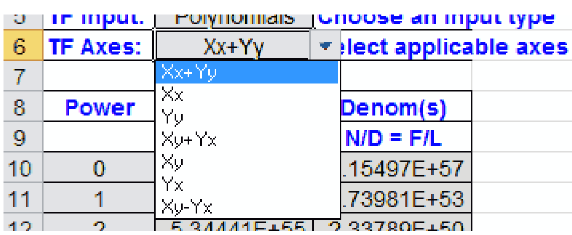
   Inevitably, the quality of the curve fit is judged by comparing in the plots the original data to the curve fit of the data. If the fit is not good, change the order of one or both of the polynomials and redo the calculation.

Note: Starting with XLRotor 5.61. XLRotor curve fits a transfer function with extended numerical precistion. Instead of the usual 15 digits of precision, a default of 30 digits of precision are used for the calculation (this can be changed by the end user).



	C	D	E	F	G	H	I	J
1	ion Spreadsheet for Transfer Function Input							
2	on Input Sheet							
3	axes, with no cross coupling							
4	Select F/L units							
5	hoose an input type		Freq	|TF|	Phase	Freq	|TF|	Phase
6			Hz	F/L	degrees	Hz	F/L	degrees
7	Denom(s)		1	67674.12	-27.1979	1	6143999	179.8876
8	N/D = F/L		1.584893	63064.17	-17.3517	1.023293	6143999	179.885
9	1		2.511886	61152.21	-10.1192	1.047129	6143999	179.8823
10	0.000262207		3.981072	60424.97	-4.74623	1.071519	6143999	179.8796
11	2.92E-08		6.309573	60260.96	-0.31817	1.096478	6143999	179.8768
12	1.10E-12		10	60516.11	4.033977	1.122018	6143998	179.8739
13	1.94E-17		15.84893	61413.9	9.147898	1.148154	6143998	179.871
14	1.47E-22		25.11886	63713.38	15.81268	1.174898	6143998	179.8679
15			39.81072	69189.36	24.45329	1.202264	6143998	179.8649
16			63.09573	81344.5	34.30106	1.230269	6143998	179.8617
17	3.49281E+14		100	105882.6	42.76046	1.258925	6143998	179.8585
18			158.4893	150749.3	46.42754	1.28825	6143998	179.8552
19	0		251.1886	226607.9	42.39091	1.318257	6143998	179.8518
20	35087.6192		398.1072	345638	26.99906	1.348963	6143998	179.8484
21	-35087.6192		630.9573	481459.2	-11.3413	1.380384	6143998	179.8449
22			1000	435192.2	19.08434	1.412538	6143998	179.8412
23	4523.867201		1584.893	542417.9	-73.4331	1.44544	6143998	179.8375
24	-4523.867201		2511.886	287554.3	-137.848	1.479108	6143997	179.8338
25	0		3981.072	96531.8	171.4845	1.513561	6143997	179.8299
26	35087.01712		6309.573	25811.64	139.5005	1.548817	6143997	179.8259
27	-35087.01712		10000	6545.933	120.5764	1.584893	6143997	179.8219

TF Axes



This option selects which coordinate axes to use for displacement and force. The normal option is Xx+Yy. Capital letters indicate the force coordinate, and lower case letters indicate the displacement coordinate.

1. ***Xx+Yy***. This is the normal option. It means the transfer function is applied identically in both x and y coordinates. Displacement in the x coordinate generates a force in the x direction, and similarly for y. The transfer function defined on the worksheet will be assembled twice into the system equations, once for x and again for y.

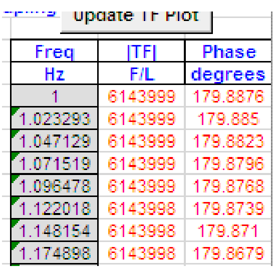
2. ***Xx***. This means the displacements are taken from the x coordinate, and the force acts in the x coordinate. The transfer function is applied <u>only</u> in the x coordinate (i.e. it is not applied in the y coordinate).

3. ***Yy***. This means the displacements are taken from the y coordinate, and the force acts in the y coordinate.
4. ***Xy+Yx***. This option is for specifying cross coupled transfer functions. Displacement and force are for orthogonal coordinate axes. The transfer function is applied identically for ***Xy*** and ***Yx*** (for a destabilizing cross coupled stiffness which has Kxy=-Kyx use the option number 7).
5. ***Xy***. This is for specifying a cross coupled transfer function where displacement is from the y coordinate, and the applied force is in the x coordinate.
6. ***Yx***. This is for specifying a cross coupled transfer function where displacement is from the x coordinate, and the applied force is in the y coordinate.
7. ***Xy-Yx***. This option is for specifying cross coupled transfer functions. Displacement and force are for orthogonal coordinate axes. The transfer function is applied exactly as input on the worksheet for ***Xy***, but for ***Yx*** its sign is reversed.

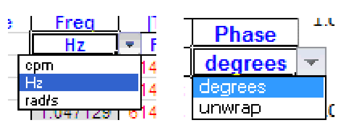
Important Note about SS Matrices

When the program outputs a set of SS Matrices (i.e. ABC), those matrices are not unique. The particular form output by XLRotor is a modifed version of Observable Canonical Form. This modified form performs well from a numerical standpoint. The set of ABC matrices shown earlier are an example. When an eigenvalue or response analysis is run, only the ABC matrices are used to form the system model. The polynomials and ZPK are not used. If you wish to use your own ABC matrices and not those output by XLRotor, use the ***TF Input/SS Matrices*** option described earlier.

Freq, |TF|, Phase



Freq	|TF|	Phase
Hz	F/L	degrees
1	6143999	179.8876
1.023293	6143999	179.885
1.047129	6143999	179.8823
1.071519	6143999	179.8796
1.096478	6143999	179.8768
1.122018	6143998	179.8739
1.148154	6143998	179.871
1.174898	6143998	179.8679



The ***Freq*** column is for inputting frequencies for the program to calculate and plot values for the given transfer function. There is a choice of three different units for frequency in the drop down list, and a choice of wrapped or unwrapped phase. The ***|TF|*** and ***Phase*** columns are filled by the program with calculated values when the ***Update TF Plot*** button is clicked. The list of frequency values appearing on this worksheet is also used by the API AMB analysis command.

Update TF Plot Button

When this button is clicked, the program converts whichever type of input has been selected, to the others. For instance, if ***Polynomials*** is selected, the zeros and poles (***ZPK***) will be calculated and output to the worksheet, and the ***SS Matrices*** will be formed and output to the worksheet. In addition, the data appearing in the columns of ***|TF|*** and ***Phase*** will be calculated and output.

In the special case of inputting a ***Mag+Phs Table***, all three of the other transfer function forms will be calculated and output.

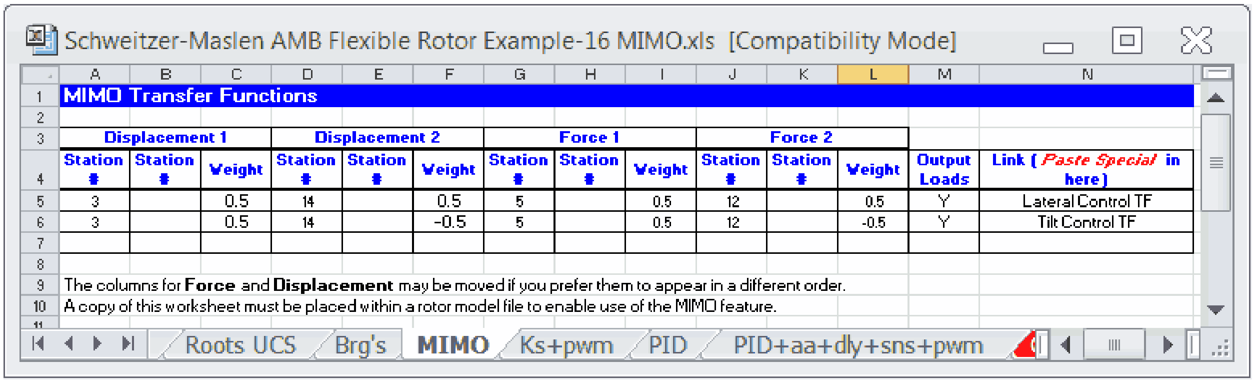
Improper Transfer Functions

When the numerator polynomial degree is not less than the denominator degree, the transfer function is not strictly proper. It is not considered "proper" because it would have infinite bandwidth, which is not considered physically realizable (i.e. not physically possible). The following example is equivalent to an entity which is a bearing with K=250000 lbf/in, C=250 lbf-s/in, and M=10 lbm=0.0259 lbf-s^2/in, and has a second order filter which limits its bandwidth to 1200 Hz. The poles and zeros are calculated and output in the normal way. The SS output of ABC matrices now includes a D matrix. In this example the D matrix has one element. The D matrix will have exactly one element when the numerator and denominator have the same degree. When the numerator degree is 1 greater than the denominator degree, the D matrix will have two elements, and it will have three elements when it is 2 greater.

TF applied to one or both of x & y axes		
TF Units:	lb/in	Select F/L unit
TF Input:	Polynomials	Choose an inp
TF Axes:	Xx+Yy	Select applicat
Power	Numer(s)	Denom(s)
--	N/D = F/L	N/D = F/L
0	250000	1
1	250	0.000212207
2	0.02590257	1.75905E-08
	Overall Gain=	1472533.153
	Complex Zeros	
1	-1133.004411	0
2	-8518.547616	0
	Complex Poles	
1	-6031.857895	4523.893421
2	-6031.857895	-4523.893421

SS Matrices (State Space)		
A Matrix		B Matrix
-12063.71579	47573	-74664
-1194.982897	0	-30708.7
C Matrix		
47573	0	
D Matrix		
1472533.153		

MIMO.xls Template File



MIMO Transfer Functions

Displacement 1			Displacement 2			Force 1			Force 2				
Station #	Station #	Weight	Station #	Station #	Weight	Station #	Station #	Weight	Station #	Station #	Weight	Output Loads	Link (*Paste Special* in here)
3		0.5	14		0.5	5		0.5	12		0.5	Y	Lateral Control TF
3		0.5	14		-0.5	5		0.5	12		-0.5	Y	Tilt Control TF

The columns for **Force** and **Displacement** may be moved if you prefer them to appear in a different order.
A copy of this worksheet must be placed within a rotor model file to enable use of the MIMO feature.

See also

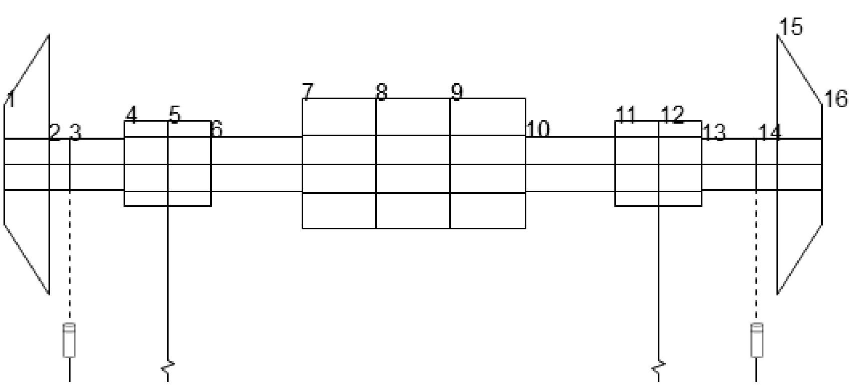
Brg's Worksheet
Bearing Template Files
XLTransferFunction Template File
Open Linked Bearing File

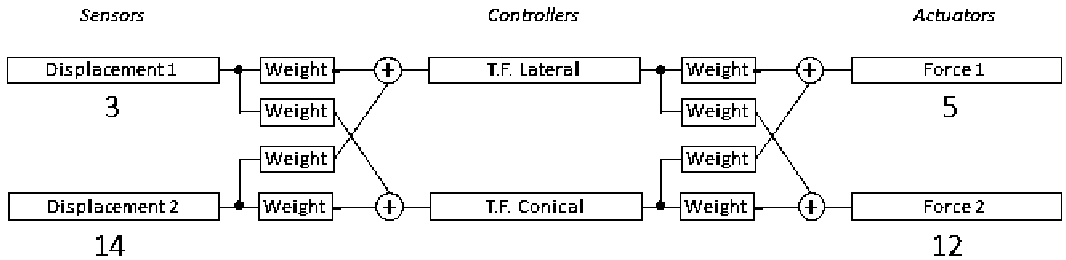
XLRotor allows transfer functions for magnetic bearings to be Single Input Single Output (SISO), or Multi Input Multi Output (MIMO). The normal option is SISO, for which transfer functions can be setup on the Brg's Worksheet. MIMO requires adding a special worksheet named MIMO to your XLRotor file.

SISO means a transfer function takes input from a single sensor, and outputs the force to a single actuator.

MIMO means the input comes from multiple sensors, and outputs the force to multiple actuators. XLRotor currently only allows specifying a maximum of two inputs and two outputs, but more are planned for the future.

A typical example of MIMO control is center-of-gravity control of rigid rotors as described on page 208 of *Magnetic Bearings*, by Schweitzer and Maslen, Springer-Verlag, 2009.





To add a MIMO worksheet to your file, use the Open Linked Bearing File command, or it can be done manually by copying a MIMO worksheet from any other workbook which has one.

Displacement 1 & Displacement 2

These columns are for specifying up to two sensor inputs. Each ***Displacement*** input allows for specifying *two* station numbers. The second **Station #** column is used when the sensor is measuring *relative* displacement *between* two stations, otherwise the cell in that column should be empty. The cells in the **Weight** columns should not be empty, and are for specifying in what proportion Displacements 1 and 2 are to be linearly combined to generate the input displacement for this transfer function.

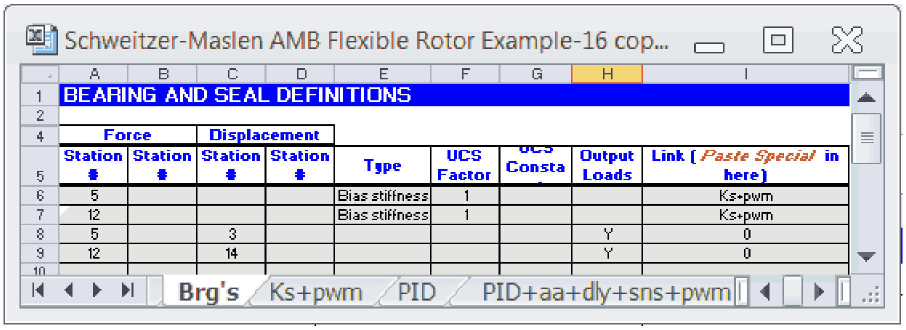
Force 1 & Force 2

These columns are for specifying up to two output actuators. The meaning of the two ***Station*** # columns and ***Weight*** column are analagous to those for ***Displacements 1 & 2***.

Output Loads

When doing a forced response calculation (i.e. Run|Response), entering *Y* or *Yes* in this column will cause the load generated by the transfer function to be output on the Resp Worksheet. Note that for a MIMO implementation, this load is apportioned to multiple actuators.

To get output of total load for individual actuators, on the Brg's Worksheet setup two bearings each with a stiffness of zero in the ***Link*** column, plus enter Y in the ***Output Loads*** column. The stations for these two bearings must match those of the MIMO connections. These two bearings must appear in the Brg's list together as a pair mirroring how they are listed on the MIMO sheet. As a bonus, these two bearings cause non-collocated sensors to be depicted on the Geo Plot. The following example corresponds to the sample MIMO worksheet shown above.



Force Station #	Station #	Displacement Station #	Station #	Type	UCS Factor	UCS Consta	Output Loads	Link (*Paste Special* in here)
5				Bias stiffness	1			Ks+pwm
12				Bias stiffness	1			Ks+pwm
5		3					Y	0
12		14					Y	0

Link

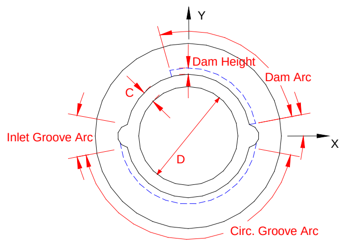
This column performs the same role as the ***Link*** column on the Brg's Worksheet. Each row of the MIMO input table specifies a transfer function which has been setup on a separate XLTransferFunction Worksheet.

XLUVA.XLS ROMAC Journal Bearing Drivers

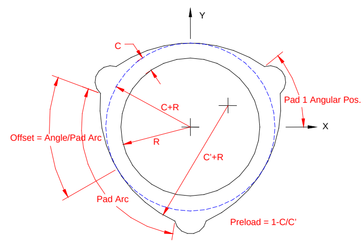
XLDambrg Worksheet	pressure dam bearings
XLThBrg Worksheet	fixed pad journal bearings
XLThPad Worksheet	tilting pad journal bearings
XLPdam2D Worksheet	multi-lobe dam bearings

Click on a picture or its title for more detail.

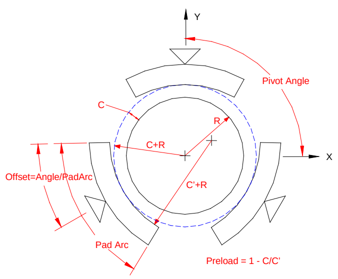
XLDambrg Pressure Dam



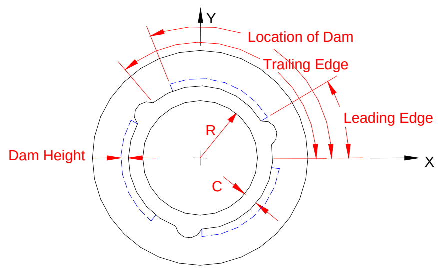
XLThBrg - Fixed Pad



XLThPad - Tilting Pad



XLPdam2D - Multi-Lobe Dam



The is a collection of 4 drivers which are used for executing the 4 legacy bearing analysis codes created by the University of Virginia ROMAC Laboratory. These drivers are not included with XLRotor. They are available for an extra cost option. Contact RMA INC if you whish to acquire any of these drivers.

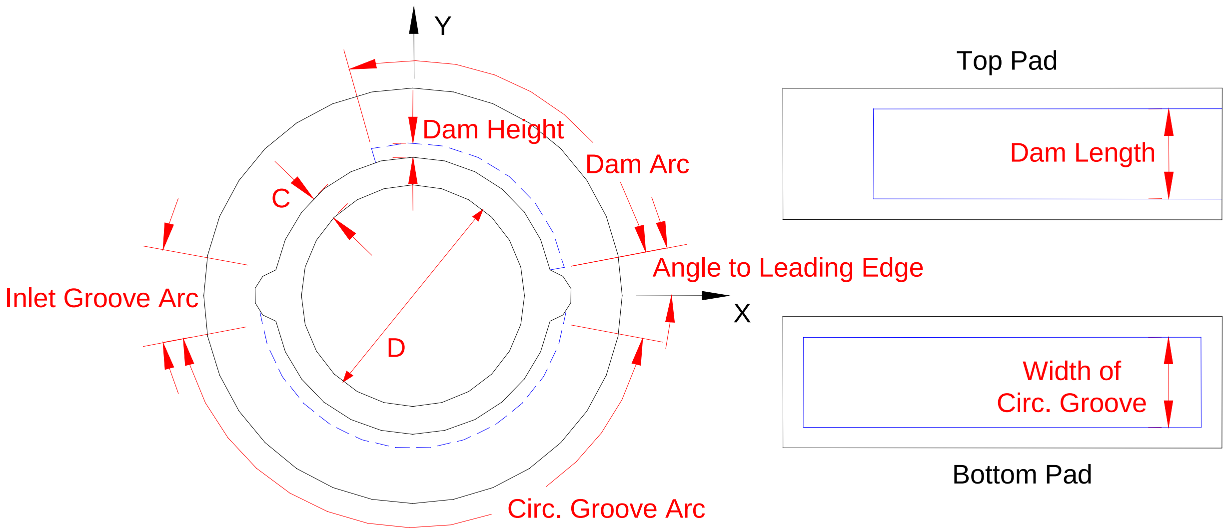
To utilize these drivers requires that you already have the executable files for each corresponding code. RMA INC does not distribute the executable codes.

XLDambrg Worksheet

See also

> XLUVA.XLS ROMAC Bearing Drivers
> XLThBrg fixed pad journal bearings
> XLThPad tilting pad journal bearings
> XLPdam2D multi-lobe dam bearings

Geometry definition for a pressure dam journal bearing.



The spreadsheet driver provides full access to all features of the bearing analysis code. When you click the RUN button, an input file is created in the format expected by the code, the code is executed on this input file, and the corresponding output file is scanned for the analysis results.

XLDamBrg **Spreadsheet for Pressure Dam Bearing Coefficients**

Run | Help | Import DamBrg File

Title:	
	Compressor Bearing
	ORIGINAL PRESSURE DAM BEARINGS
	sample case

Bearing Radius	2	in
Bearing Length	1.625	in
Bearing Radial Clr	0.0035	in
Bearing Load	1300	lbf
Lubricant Viscosity	2.76E-06	Reyns
Lubricant Density	8.16E-05	lbf-s2/in4
Number of Axial Nodes	6	--
Number of Circ Nodes	31	--
Include Turbulence	3 = Turbulence Allowe	
Max Iterations	12	--
Initial Ecc Guess Flag	1 = Use Input Values	
Ecc X Initial Guess	0.4	--
Ecc Y Initial Guess	-0.4	--

Selected Lubricant & Temperature		
ISO 32		
Lubricant Ref Ta	100	Deg. F
Lubricant Ref Va	3.99E-06	psi-s
Lubricant Ref Tb	210	Deg. F
Lubricant Ref Vb	6.19E-07	psi-s
Lubricant T	150	Deg. F
Viscosity at Lube T	1.71E-06	psi-s

These are not direct inputs to DAMBRG. Values are copied elsewhere

Inlet Grv Arc Length	30	degrees
Dam Axial Length	1	in
Dam Height	0.01	in
Land Arc Length	135	degrees
Theta Leading Edge	15	degrees
Circ Grv Axial Length	0	in
Circ Grv Arc Length	150	degrees

Ext X Load	Ext Y Load	Speed	Kxx	Kxy	Kyx	Kyy	Cxx	Cxy	Cyx	Cyy
lbf	lbf	rpm	lb/in	lb/in	lb/in	lb/in	lb-s/in	lb-s/in	lb-s/in	lb-s/in
0	0	3000	703187.5	-88156.3	-1710062.7	2015285	2029.9	-2739	-3298.5	9540.7
0	0	6000	854864.4	108317.3	-1700242.3	1361608	1581.6	-1644.2	-1804.1	4535.2
0	0	9000	1032178.6	233387	-1835517.8	1164166	1414.3	-1248.6	-1276.3	3109.7
0	0	12000	1194027.1	294156.2	-2029106.2	1140877	1261.9	-999.3	-978.4	2471.4

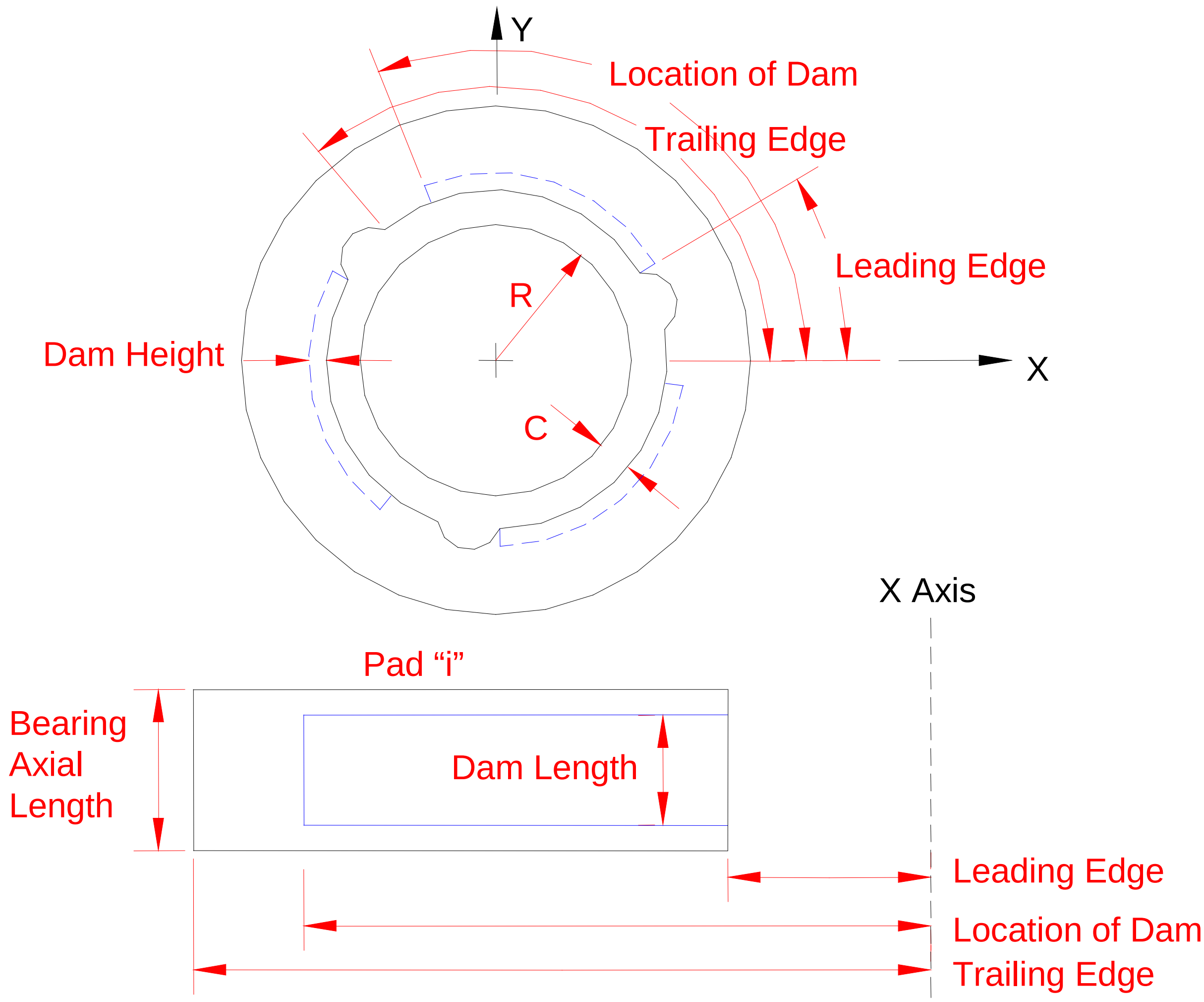
Somm.	Ecc X	Ecc Y	Power
--	--	--	hp
2.26E-01	0.459813	-0.57461	0.964
4.51E-01	0.45958	-0.41277	3.857
6.77E-01	0.444321	-0.30724	8.679
9.02E-01	0.429072	-0.23205	15.43

XLPdam2D Worksheet

See also

- XLUVA.XLS ROMAC Bearing Drivers
- XLDambrg Worksheet   pressure dam bearings
- XLThBrg Worksheet   fixed pad journal bearings
- XLThPad Worksheet   tilting pad journal bearings

Geometry definition for a multipad pressure dam journal bearing.



The spreadsheet driver provides full access to all features of the bearing analysis code. When you click the RUN button, an input file is created in the format expected by the code, the code is executed on this input file, and the corresponding output file is scanned for the analysis results.

***XLPDam2d* Spreadsheet for Pressure Dam Bearing Coefficients**

Run | Help | Import PDam2D File

Title:	PRESSURE DAM BEARING
	STABIILITY INVESTIGATION 11/85

Bearing Radius	9	in
Bearing Length	13	in
Lubricant Viscosity	2.93E-06	psi-s
Lubricant Density	8.18E-05	lbf-s2/in4
Bearing Load	36000	lbf
Load Direction	280	degrees
Weight per Bearing	36000	lbf
Bearing Radial Clr	0.0115	in
Bearing Preload	0.41	--

Selected Lubricant & Temperature			
SHELL TELLUS T 32			These are not direct inputs to PDAM2D. Use a cell reference to these.
Lubricant Ref Ta	104	Deg. F	
Lubricant Ref Va	3.95E-06	psi-s	
Lubricant Ref Tb	212	Deg. F	
Lubricant Ref Vb	7.86E-07	psi-s	
Lubricant T	150	Deg. F	
Viscosity at Lube T	1.99E-06	psi-s	

Include Turbulence	2 = Laminar Solution	
Ecc Initial Guess	0.4	--
Phi Initial Guess	270	degrees

Input data for each pad. One row for each pad. Add rows as needed (<=10).

Pad Number --	Dam Height inches	Axial Length inches	Leading Edge degrees	Location of Dam degrees	Trailing Edge degrees	Circumf Nodes --	Axial Nodes --
1	0.1	9.75	45	125	135	31	6
2	0	9.75	225	305	315	31	6

Speed rpm	Kxx lb/in	Kxy lb/in	Kyx lb/in	Kyy lb/in	Cxx lb-s/in	Cxy lb-s/in	Cyx lb-s/in	Cyy lb-s/in
3600	2485130	853348.9	-8717442	12908885	9362.3	1333.7	915	43704.7
2000	3046381	-2222568	-8628060	11237828	6734.3	-12246.3	-12246.5	59191.2
1000	3933036	-2989276	-1E+07	14306922	17340.3	-33469.7	-33466.7	138553.1

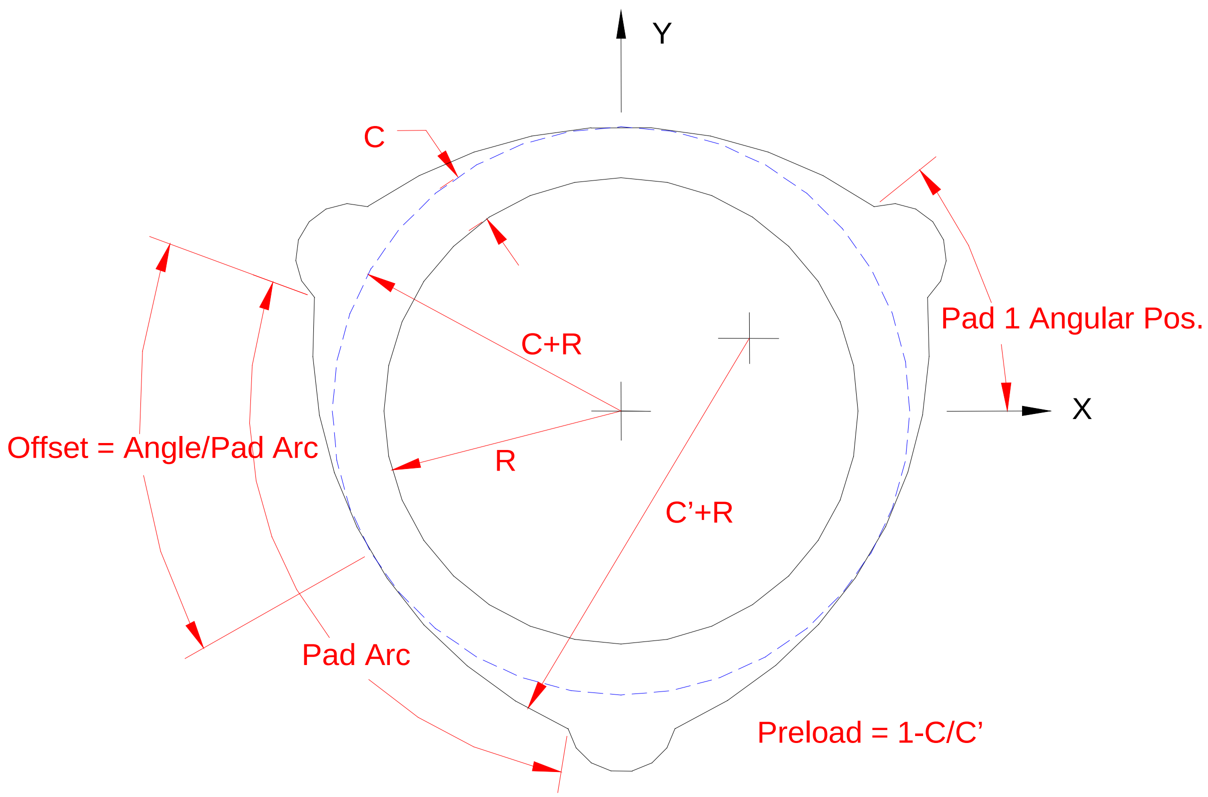
Somm. --	Ecc X	Ecc Y	Power
0.7006	0.5497	0.3289	
0.3892	0.5782	0.1843	
0.1946	0.5413	-0.0130	

XLThBrg Worksheet

See also

XLUVA.XLS ROMAC Bearing Drivers
XLDambrg Worksheet pressure dam bearings
XLThPad Worksheet tilting pad journal bearings
XLPdam2D Worksheet multi-lobe dam bearings

Geometry definition for a fixed pad journal bearing.



The spreadsheet driver provides full access to all features of the bearing analysis code. When you click the RUN button, an input file is created in the format expected by the code, the code is executed on this input file, and the corresponding output file is scanned for the analysis results.

XLTHBrg Spreadsheet for Fixed Pad Journal Bearing Coefficients

Run | Help | Import THBRG File

Title:	COMPRESSOR 3 Lobe bearing. arc radial offset=0.002
	WITH HEAT LOSS, CAVITATION, AND CROSS-FILM EFFECTS

Parameter	Value	Units
Bearing Radius	0.78	in
Bearing Radial Clr	0.00325	in
Bearing Outer Radius	1.1	in
Bearing Length	1.5	in
Axial Pressure Exp	2	--
Pad 1 Angular Pos.	5	degrees
Elements per Pad	20	--
Journal Weight Load	700	lbf

Selected Lubricant	USER DEFINED	
Lubricant Ref Ta	122	Deg. F
Lubricant Ref Va	2.65E-06	psi-s
Lubricant Ref Tb	194	Deg. F
Lubricant Ref Vb	8.14E-07	psi-s
Error Criterion	0.001	--
Ecc X Guess	0.13	--
Ecc Y Guess	-0.13	--

Parameter	Value	Units
Lubricant Density	8.00E-05	lbf-s2/in4
Lubricant Spec Heat	184	BTU-in/lb-s2
Oil Supply Temp	122	Deg. F
Oil Supply Pressure	20	psi
Outer Surf Temp	68	Deg. F
Journal Surf Temp	122	Deg. F
Lubricant Thrm Cond	2.00E-06	BTU/in-sF
Bearing Material	USER DEFINED	
Bearing Thrm Cond	6.70E-04	BTU/in-sF
Outer Surf Conv Coef	0.000016	BTU/s-in2F
Ratio Cav Thrm Cond	5	
Cav Latent Heat Ratio	0.25	BTU/s-in2F

Flag	Setting
Boundary Cond Flag	2 = Reynolds for Pressure
Include Turbulence	1 = Turbulence Allowed
Journal Temp Flag	0 = Average of Film T
Groove Temp Flag	0 = Solve for Grv T
Pressure Grad Flag	0 = Include in Energy Eqn.
Outer Temp Flag	0 = Outer Ambient T Given
Radial Cond Flag	1 = 2D Conduction in Shell
Adiabatic Soln Flag	0 = Solve for Conduction
Output Circ Profiles	1 = Print Circ. Profiles
Output Cross Films	1 = Print Cross Film Prof.
Include Cavitation	1 = Include Cavitation
Variable Visc Flag	1 = Variable Viscosity
Groove Cond Flag	0 = Grv Cond Set to Tin
Conv Profile Flag	0 = Constant Convection Coef

Input data for each pad. One row for each pad. Add rows as needed (<=10).

Pad Number	Preload --	Pad Arc degrees	Grv Arc degrees	Offset Fac --
1	0.6	110	10	0.5
2	0.6	110	10	0.5
3	0.6	110	10	0.5

Ext X Load lbf	Ext Y Load lbf	Speed rpm	Kxx lb/in	Kxy lb/in	Kyx lb/in	Kyy lb/in	Cxx lb-s/in	Cxy lb-s/in	Cyx lb-s/in	Cyy lb-s/in
0	0	10000	703561	-41863	-1602828	1982464	963	-739	-739	2551
0	0	20000	745336	57386	-1527558	1899072	562	-285	-283	1136
0	0	30000	860446	225688	-1589389	1683284	448	-245	-245	836
0	0	40000	905280	298499	-1596593	1689888	371	-174	-174	624

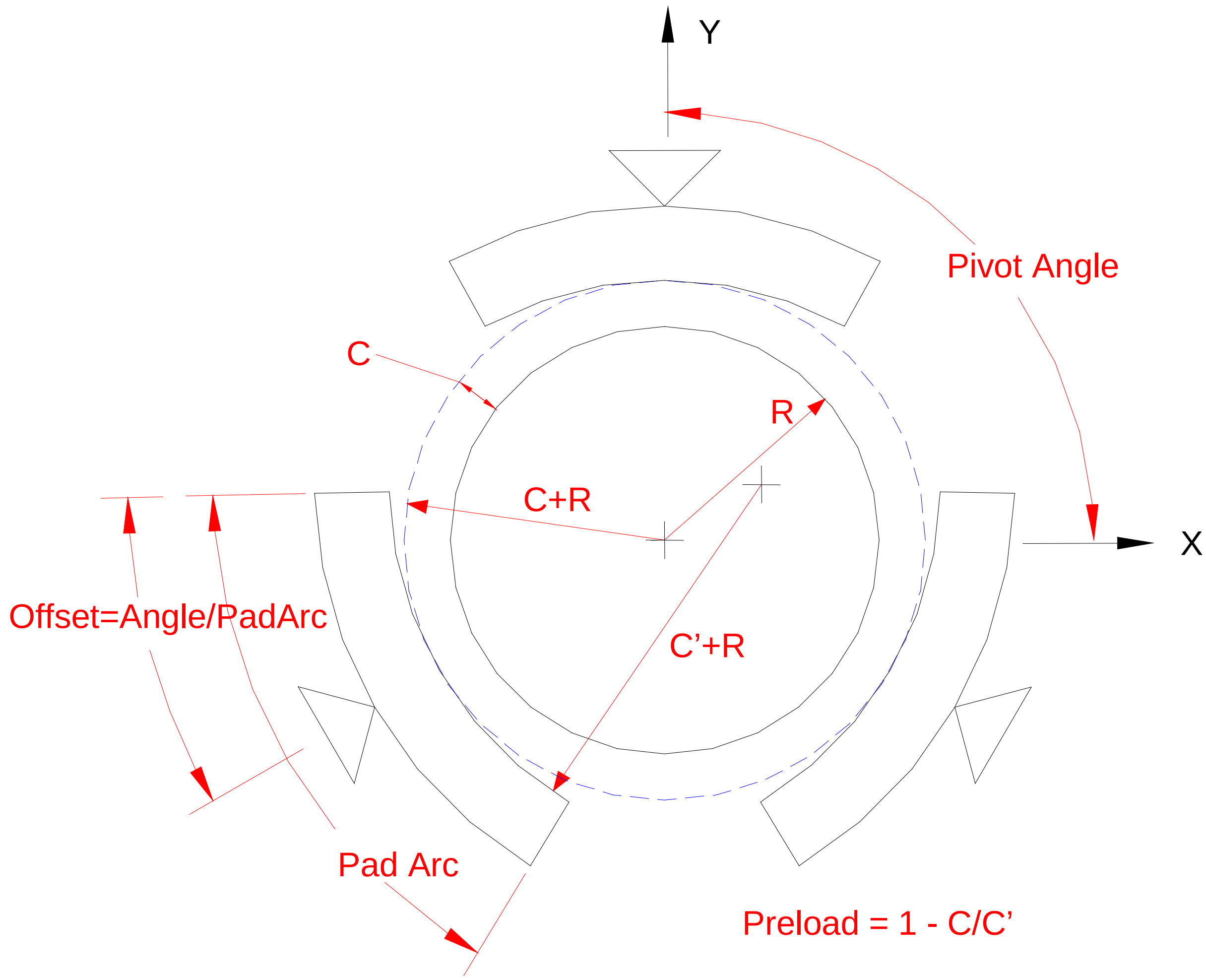
Somm. --	Ecc X --	Ecc Y --	Power hp	T Max deg F	P Max psi
8.50E-02	0.1275	-0.2163	1.057	162.21	1570.93
1.70E-01	0.1352	-0.1729	2.832	194.53	1523.86
2.55E-01	0.1345	-0.1501	4.913	213.87	1523.48
3.40E-01	0.1339	-0.1369	7.26	226.93	1530.38

XLThPad Worksheet

See also

XLUVA.XLS ROMAC Bearing Drivers
XLDambrg Worksheet pressure dam bearings
XLThBrg Worksheet fixed pad journal bearings
XLPdam2D Worksheet multi-lobe dam bearings

Geometry definition for a tilting pad journal bearing.



The spreadsheet driver provides full access to all features of the bearing analysis code. When you click the RUN button, an input file is created in the format expected by the code, the code is executed on this input file, and the corresponding output file is scanned for the analysis results.

XLTHPad Spreadsheet for Tilting Pad Journal Bearing Coefficients

Run | Help | Import THPad File

Title:	Sample tilting pad bearing analysis
	Load Between Pad Preload = 0.34 ISO 32

Bearing Radius	0.7854	in
Bearing Radial Clr	0.0031	in
Bearing Outer Radius	1.4127	in
Bearing Length	1.417	in
Pad Material	USER DEFINED	
Pad Elastic Modulus	30000000	psi
Pad CTExp	6.88E-06	1/F
Journal Material	USER DEFINED	
Journal CTExp	0	1/F
Shell Material	USER DEFINED	
Shell CTExp	0	1/F
Elements per Pad	35	--
Eccentricity Flag	0 = Compute Ecc.	

Whirl Ratio of Shaft	1	--
Non-Dim Factor	1	--
Oil Flow to Bearing	40	cips
Relax Factor for Pivot	0.7	--

Error Criterion	0.001	--
Ecc X Guess	-0.0077	--
Ecc Y Guess	-0.4174	--
Axial Pressure Exp	2	--
Position Perturbation	0	--

Journal Temp Flag	2 = No Heat to Shaft
Boundary Cond Flag	2 = Reynolds for Pressure
Include Turbulence	1 = Turbulence Allowed
Pad Conduction Flag	0 = 2D Cond. in Pad
Adiabatic Soln Flag	1 = Adiabatic Solution
Pad Back Temp Flag	1 = Pad T Fixed by User
Grv Temp Flag	0 = Solve for Grv T

Lubricant Thrm Cond	1.75E-06	BTU/in-sF
Pad Thrm Cond	5.60E-04	BTU/in-sF
Back of Pad Temp	120	Deg. F
Journal Surf Temp	120	Deg. F
Sump Oil Pressure	2	psi
Oil Supply Temp	120	Deg. F
Ratio Cav Thrm Cond	1	--
Cav Latent Heat Ratio	0	BTU/s-in2F

Output Circ Profiles	1 = Print Circ. Profiles
Output Cross Films	0 = Don't Prn Cross Films
Include Cavitation	1 = Include Cavitation
Variable Visc Flag	0 = Const Cross Film Visc.
Pad Pivot Deform Flag	0 = No Pad or Piv Def.
Pad Bending Type	0 = Curved Beam Anal.
Include Unloaded Pad	0 = Include Unloaded Pads
Sump Temp Flag	0 = T Sump = T Inlet

Selected Lubricant

USER DEFINED

Lubricant Density	7.99E-05	lbf-s2/in4
Lubricant Spec Heat	188	BTU-in/lb-s2
Lubricant Ref Ta	104	Deg. F
Lubricant Ref Va	3.75E-06	psi-s
Lubricant Ref Tb	210	Deg. F
Lubricant Ref Vb	6.35E-07	psi-s
Sump Heating Factor	1	--
Clearance Set Temp	0	Deg. F

Pivot Rotational K	1039	in-lb/rad
Pad Equilibrium Angle	0	degrees

						Insert Pad Formulas				
Enter data for each pad. One row for each pad. Add rows as needed (<=10).										
Pad Number	Pad Arc degrees	Offset Fac --	Preload --	Pivot Angle degrees	Pad Polar I lb-s2-in	Pivot K lb/in	Pad Mass lb-s2/in	Pad Bending I in4		
1	72	0.5	0.34	45	0	0	0	0		
2	72	0.5	0.34	135	0	0	0	0		
3	72	0.5	0.34	225	0	0	0	0		
4	72	0.5	0.34	315	0	0	0	0		

-X Load lbf	-Y Load lbf	Speed rpm	Kxx lb/in	Kxy lb/in	Kyx lb/in	Kyy lb/in	Cxx lb-s/in	Cxy lb-s/in	Cyx lb-s/in	Cyy lb-s/in
0	711	10000	1110894	-90788	-114675	1100137	762	-38	-26	767
0	711	20000	921368	-82905	-109306	909675	387	-32	-23	392
0	711	30000	850137	-87863	-114734	838813	263	-28	-21	267

Somm. --	Ecc X --	Ecc Y --	Power hp	P Max psi
9.61E-02	0.0312	-0.5779	0.816	1095.16
1.92E-01	0.0415	-0.4808	2.316	1032.45
2.88E-01	0.0494	-0.4259	4.228	1019.63

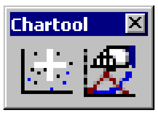
Chartool Toolbar

See also

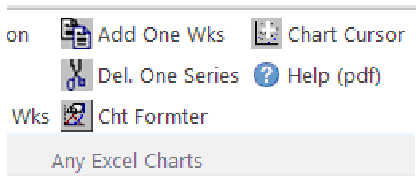
[XLRotor Tools Toolbar]

Chartool for Excel XY Scatter Charts

Custom toolbar



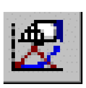
XLRotor Ribbon



Here's what Chartool does for Excel's xy scatter charts:

- Zoom & Pan With the Mouse or keyboard
- Versatile Cursor Readout using the Mouse
- Copy/Paste for Points and Axis Scales
- Label points with values & digitize point values to worksheet cells
- Edit chart series formats for all series in one or more charts
- Square up x and y axes (i.e. so a circle looks like a circle)

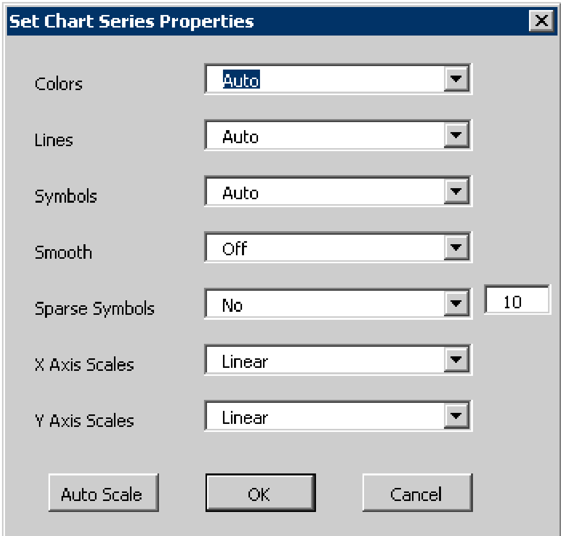
Once you become aware of what Chartool can do, using it should be intuitive.

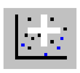


Set Chart Series Properties

This button displays a dialog for changing several chart formatting properties for one or more selected charts.

In addition, if the Shift key is held down when the button is clicked, the scaling properties of the Y axis are adjusted to make the X and Y axes have equal scales (so a circle looks like a circle). This is done separately for each chart which is selected, and no dialog box is displayed.



 ***Chartool Cursor Mode...is either "on" or "off".***

To start cursor mode, first select a chart, then do either of the following:

a) Click the Initialize button  on the Chartool toolbar, or

b) Use a right mouse click on either the ChartArea or PlotArea, and select the Chartool command (Excel 2003 only.   No right click menu in Excel 2007/2010).

The toolbar button becomes "pressed" when cursor mode is active, and Excel's status bar shows xy coordinates.

To stop cursor mode, do any of the following:

a) Repeat action a) or b) from above, or

b) Press Escape until the status bar display returns to normal, or

c) Deselect the chart, for example by clicking anywhere outside the chart.

The toolbar button becomes "unpressed" when cursor mode exits.

Using Cursor mode

When editing a chart in Excel, it is possible to have nothing selected inside the chart, or select one chart series, or select one point on a chart series.

Cursor Readout in the Status Bar.

a) **Free Mode** - If neither a Series nor single data point is selected, read out the location of the mouse pointer in chart units (see note below about precision errors).

b) **Series Mode** - With a <u>Series</u> selected, readout the coordinates of a tracking crosshair cursor that stays on the series.   This feature works with both straight lines between points and Excel's smooth curve option.

c) **Point Mode -** With a single data point selected, readout the xy values of the data point.

You can also use the keyboard to move from point to point along the selected series. Pressing one of the following keys will do this, and will switch from **Series Mode** to **Point Mode** if necessary.

Left/Right arrow keys	move one point at a time.
Shift+Left/Right	moves 3 points at a time
Shift+Control+Left/Right	moves 10 points at a time
Shift+Alt+Left/Right	moves 30 points at a time
Home/End	moves to the first/last points of the series
Control+Left/Right	moves to the next peak

Zoom/Pan Scale Control

a) **Zoom** – Click the mouse with Control held down to start drawing a "Zoom" rectangle, release the control key, click again when done sizing (in Excel 2007 only, press the Escape key to stop resizing the rectangle). Click on the rectangle with the left mouse button to show a popup menu with zoom commands, or press escape to cancel. To move or resize the rectangle after it is drawn, first right-click on it, then left-click on it.

b) **Pan -** Click the mouse once with Alt held down to start panning mode with the mouse. Click again to accept the pan, or press escape to cancel the pan. Panning can also be done using the combination Control-arrow keys (Control plus up/down/left/right arrow keys).

c) **Control-A** will autoscale either one or both axes, depending on what's selected.

d) **Control-Z** will undo the last zoom or pan scale operation.

e) **Z** and **z** will zoom in an out 50%, centered at the mouse pointer.

Copy/Paste

Copy (Control-C)

a) xy coordinates which are currently displayed in the statusbar (copied as text, x tab y).

b) All scale properties of the currently selected axis.

c) All scale properties of both axes whenever the PlotArea is selected.

Paste (Control-V)

a) paste xy coordinates as text in standard clipboard fashion.

b) when a single axis is selected and a single axis is on the clipboard, paste it.

c) when a single axis is selected but both x and y axes are on the clipboard, paste whichever matches the selection.

d) when the PlotArea is selected and a single axis is on the clipboard, paste it onto both axes.

e) when the PlotArea is selected and both x and y axes are on the clipboard, paste both (x to x, y to y).

Note: Axis properties consist of values for max & min for major & minor, and their autoscale settings.
Note: Chartool uses the windows clipboard for points, but it's own internal clipboard for axis scales.
Note: You can use the Copy/Paste feature to copy axis scales from one chart to another chart.

Labeling or Digitizing Chart Points

a) **Control-L** for labeling or digitizing points.
Point Mode - this hotkey will label the point first with its y value, then its x value, and then

both x,y values (i.e. like a toggle)
Free Mode - the x,y coordinates of the mouse will be placed in worksheet cells at the cell location indicated in the statusbar. The starting cell will be whatever worksheet cell was selected prior to entering Chartool.
Series Mode - the x,y coordinates of the crosshair will be placed in worksheet cells at the cell location indicated in the statusbar.

b) **Control-D** will clear the cell contents of the last digitized point.

Note about precision errors in mouse cursor coordinate readouts. Mouse resolution is always limited to the number of pixels used to display the chart. This places a limit on precision. Also, as strange as it may seem, Chartool is not always able to determine at exactly which pixels the chart axes are displayed. Most of the time it does, but being 1 pixel off is not uncommon, and being off by more than one pixel can also happen. This is due to limitations in Excel. Check the accuracy of the mouse cursor by positioning the mouse over each of the axes, and inspect the values displayed in the statusbar.

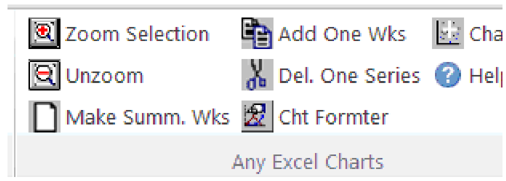
XLRotor Tools Toolbar

See also

Chartool Toolbar

Custom toolbar

XLRotor Ribbon

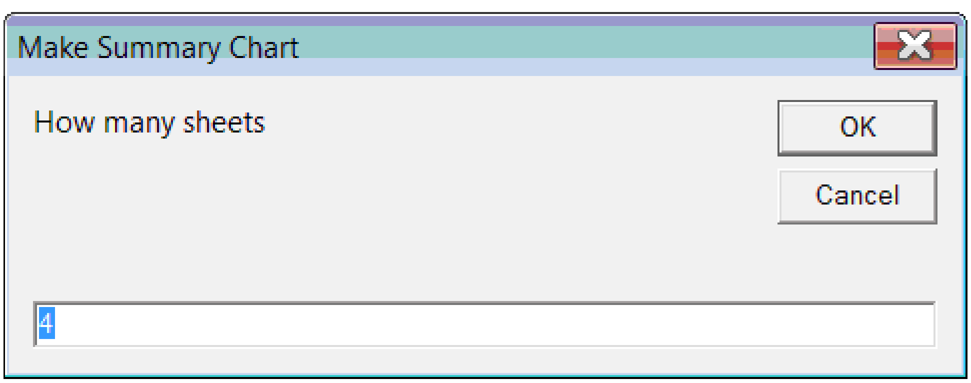


These are handy commands that can be used in any Excel file. These commands can be accessed from either the XLRotor Tools custom toolbar, or from the XLRotor Ribbon tab.

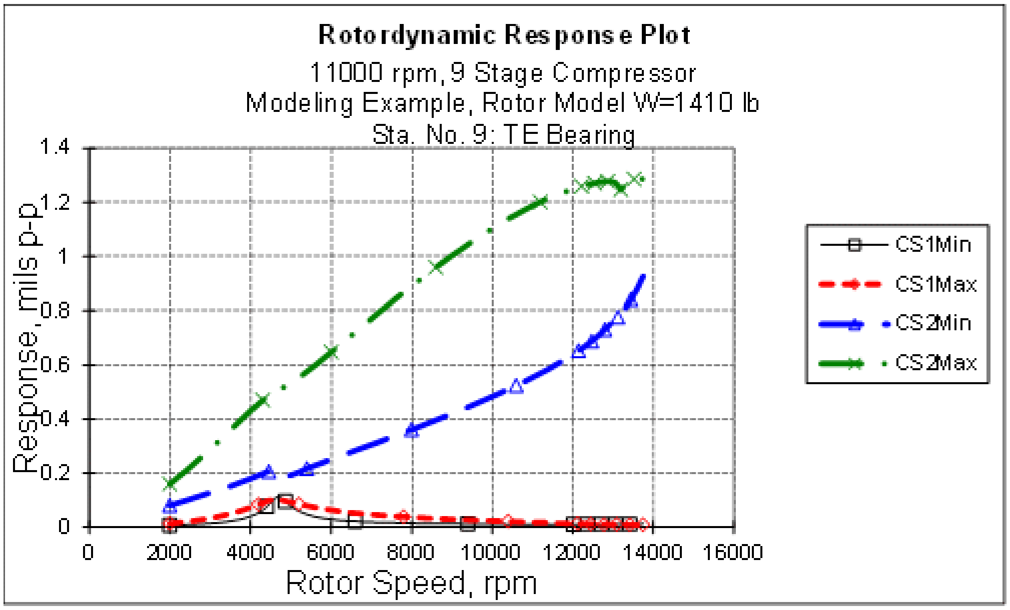
Make Summary Wks: Copy the selected charts on the current worksheet to a new worksheet and arrange them in a grid. You will be prompted for how many charts to place on each row of the grid. If no charts have been selected, all charts will be copied. This macro also gives you the option to delete all but the first data series from each copied chart, and make the legend entry for the remaining data series be linked to the name of the worksheet where it came from.

This command can also copy any group of selected charts to a new blank worksheet and arrange them in a grid.

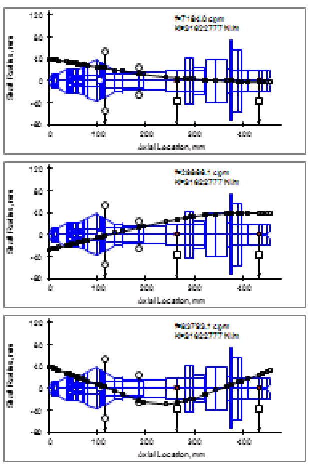
This command operates on the charts on the currently active worksheet. Adding additional data series from more worksheets is done one worksheet at a time using the next button on the toolbar (discussed below). However, if the ***shift key*** is held down when this button is clicked, you will be prompted for how many worksheets to process in a single operation.



The following example demonstrates combining results from 4 imbalance response worksheets. The 4 sheets are named in the chart legend.



The following example demonstrates assembling a set of mode shape charts copied from a Shapes worksheet into a convenient grid.



Add Current Wks: Copy the 1st chart series of each chart on a worksheet to charts on the preceding worksheet (i.e., to the first worksheet to the left). This command would normally be used to add data from additional worksheets to the charts made by the ***Make Summary Wks*** command described above***.*** However, most of the time you can avoid needing to use this command by using the Shift key feature with the ***Make Summary Wks*** button.

Delete one chart series: Delete one data series from a group of selected charts. You'll be prompted for which series to delete. If a chart is not currently selected, then all charts on the sheet will be processed.

This button also provides a handy way to quickly select ***all*** charts on a worksheet. With no charts selected, click this button and press the Escape key to dismiss the prompt asking for which series to delete.

Show/Hide most of Excel's interface elements to allow you to see more of your worksheet.

Compare 2 Worksheets: Compare two selected worksheets starting at the currently active cell.

Copy Current Wks: Make a duplicate copy of the current worksheet. For example, in Xlrotor this command could be used to make additional copies of bearing worksheets.

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