Tutorial

MDESIGN 2012

Introduction of MDESIGN

– a family of software components and digital libraries for mechanical design and product development

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Preamble

This document shows how to use the calculation tools of MDESIGN for dimensioning and optimizing machine elements during the engineering and designing process.

The introduction will show a comparison of manual and software-based calculation of machine elements giving the advantages and disadvantages of both methods. The following chapters will give general information about MDESIGN, mainly focusing on the calculation tool which is the main part of the MDESIGN software components. Moreover there will be information about new components of the MDESIGN software family mostly dealing with the gathering of information. The databases containing the engineer standards and the comprehensive information system show the extensive possibilities of MDESIGN in general and standardized calculations in special.

The following calculation examples provide the opportunity to improve as well your knowledge about the mechanical element calculation as the handling of the MDESIGN software.

Another key aspect of the calculation examples is to demonstrate the easy and fast documentation of the machine elements during the calculation process.

Objectives

The purpose of this tutorial is to provide the basics of the calculation software MDESIGN.

The focus lies on:

- Calculation options in MDESIGN
  (Calculation modules - implemented engineer standards)
- Handling of the program (user interface)
- Process of a machine element calculation
  (Gathering of information – verification of range of validity - calculation - documentation)
- Calculation examples

The tutorial gives detailed step to step information about the calculations of machine elements. Working on the calculation examples gives the opportunity to follow and understand the single steps. It is possible to follow the examples by reading the corresponding chapter but it is recommended to additionally work on the exercises using the calculation program. This enables the user to fully understand the process and the single steps of the calculation.

1 Introduction

1.1 Calculation of machine elements – manually and software-based

A machine element is the smallest single unit of a machine that can be used as a construction element for other technical applications with none or small alterations of its form. Due to the huge range of applications for identical or similar elements standard committees started to standardize many machine parts at the beginning of the 20th century. These standards are still valid and are regularly updated. Not only the single parts but also the methods of calculation have been standardized to ensure the compliance with safety standards.

The calculation routines are part of the education at the universities and of the extensive technical literature dealing with machine element calculation.

The calculation can be performed manually by following the standardized calculation methods or by using calculation programs with implemented calculation routines. The user must be aware of the advantages and disadvantages of both methods to minimize the risk of error.

Manual calculation:

Manual calculation

The big advantage of the manual calculation lies in the in-depth knowledge both of the thematical field and of the calculation routine that is needed to set up the algorithm.

This minimizes the failures when simplifications and assumptions are made in order to convert a real machine element and its surrounding system to an abstract mathematical model.

The disadvantage of the manual calculation is the complex progress of setting up the algorithm for the calculation. There is a risk of errors during this progress and of type errors during the calculation.

CAE-calculation:

CAE - calculation

The disadvantage of the manual calculation is the advantage of the CAE calculation. The calculation algorithm is already implemented in the calculation program and does not need to be set up. It is guaranteed that the exact same routine is used for every single calculation.

This minimizes the risks of inaccuracies and offers enormous time-savings.

The possibility to perform time saving calculations might lead to problems if the user is not aware about the simplifications and abstractions the program makes to generate an analogous model for the calculation.

The software package MDESIGN offers comprehensive information (text and graphic help) to prevent such problems.

Conclusion:

CAE-Software can be a big advantage for the calculation of machine elements, but there is the risk that the user is not fully involved in the thematical field.

This might lead to wrong results or false interpretations even though the calculation was performed according to the correct algorithms.

1.2 What is MDESIGN

MDESIGN is a group of technical software components and applications for mechanical engineering including an information, calculation and database system.

1.2.1 Calculation of machine elements

Calculating using MDESIGN

There are standardized calculation routines for a huge number of standardized machine elements. These are mostly calculation standards that have been defined by the German Institute for Standardization (Deutsches Institut für Normung e.V.), so called DIN standards. The other important group of calculation standards contains the VDI standards that have been generated by the Association of German Engineers (Verein Deutscher Ingenieure e.V.)

MDESIGN mechanical is a calculation library for mechanical engineering that contains almost all standard issues and offers a software-based construction in accordance with DIN, VDI and EN regulations.

For some machine elements there do not exist comprehensive calculation standards. These elements can be calculated by using the methods described in the technical literature for calculation of machine elements. MDESIGN works closely with the technical book “Roloff/Matek Maschinenelemete”, which is the top-selling book about calculation of machine elements in Germany.

For more information about the implementation of the technical standards in the modules of the calculation software MDESIGN please see chapter 1.4.

1.3 Objectives and requirements

The purpose of this tutorial is to enable the user to competently apply the MDESIGN calculation modules.

To fulfill this purpose an intensive engagement with the basics of the calculation of machine elements is absolutely required. Especially the knowledge about the coverage of the calculation standards is essential for a correct calculation.

1.4 Engineer Standards

Machine element	Standard	MDESIGN-Module
Shaft	DIN 743	MDESIGN shaft
Shaft-Hub Connections Parallel Key Con. Cylindr. Press-Fit Con. Polygonprofile P3G Polygonprofile P4C	 DIN 6892 DIN 7190 DIN 32711 DIN 32712	MDESIGN mechanical Shaft-Hub Connections
Screw Connections	VDI 2230	MDESIGN bolt
Gears Spur Gear Bevel Gear Worm Gear	 DIN 3960 DIN 3991 DIN 3996	MDESIGN mechanical Gears
Belt- Chain drives Normal V-belt Narrow V-belt Roller Chains	 DIN2218 DIN7753 DIN ISO 10823	MDESIGN mechanical Belt-, Chain drives
Roller Bearing	DIN ISO 281	MDESIGN mechanical Roller Bearing
Journals Axial Journals Radial Journals	 DIN 31654 DIN 31652	MDESIGN mechanical Journals
Elastic Springs Tension/Compr. Springs Belleville Springs Torsion Springs Torsion Bar Springs	 DIN EN 13906 DIN 2092 DIN 2288 DIN 2091	MDESIGN mechanical Elastic Springs
Fit ISO Fit System	 DIN 286	Tables and Databases Tolerances and fit
Welded Connections	DS 952 01 DVS 0705	MDESIGN mechanical Welded Connections

Table 1-1: Engineer standards

2 MDESIGN explorer – User interface

MDESIGN explorer is a graphical user interface for engineers for the purposes of development, construction and production. MDESIGN explorer is especially tailor-made for calculations, intelligent catalogue functions and for access to databases and technical documents. Indeed, MDESIGN explorer's most exceptional feature is its ability to offer and perform calculation and selection procedures in consideration of any information sources available in the network.

This chapter will show the layout of the MDESIGN explorer user interface. The interface layout is based on the windows explorer so that the menu bar, tool bar and the explorer bar will look very familiar. The MDESIGN specific components of the user interface will be explained on the following pages.

The general layout concept of the interface is the same throughout all MDESIGN programs and modules and is shown in Figure 2-1.

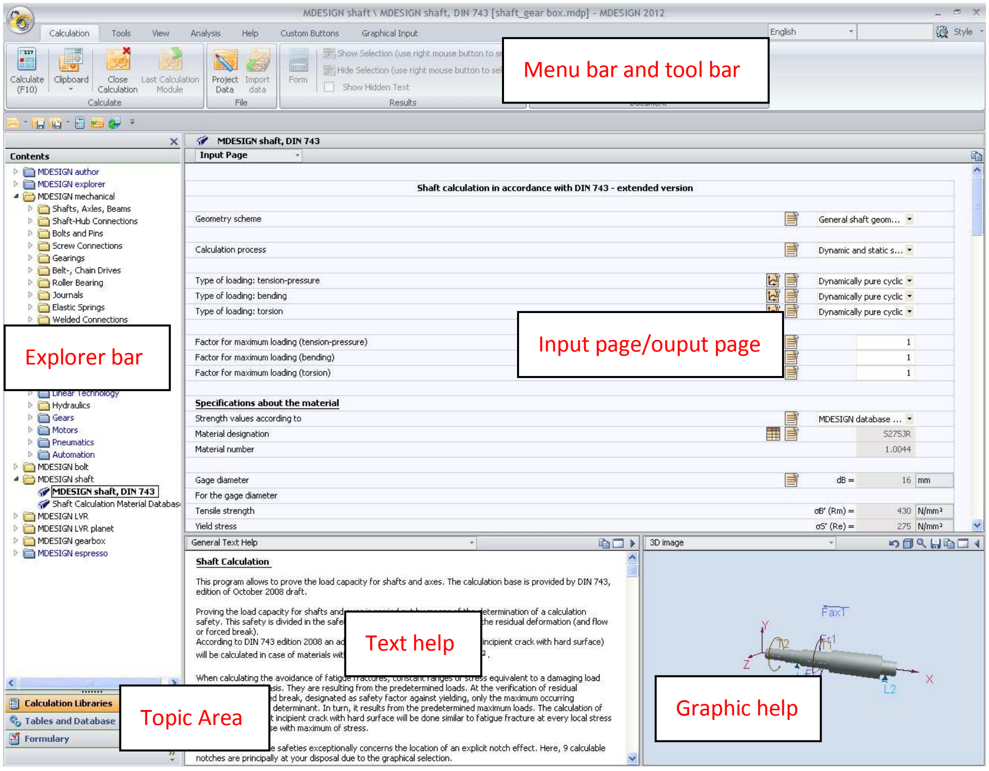


Figure 2-1: MDESIGN layout

Components of the program

The interface consists of the following elements:

- Menu bar and tool bar
- Topic Area
- Explorer bar
- Information page (see 2.1)
- Input page/output page (output page available after calculation)
- Text help
- Graphic help

2.1 Information pages

MDESIGN offers an information page for each group of the topic area “Calculation libraries”. The information page appears after double-clicking on the group in the explorer bar.

It shows general information about the selected group and the corresponding standards. The information pages also contain information about technical literature, contact persons and manufacture information as well as additional information about MDESIGN content, corresponding internet links and general information.

You can also use the information page as a browser to surf the Internet. All links on the information page connect either to other information pages or to the Internet.

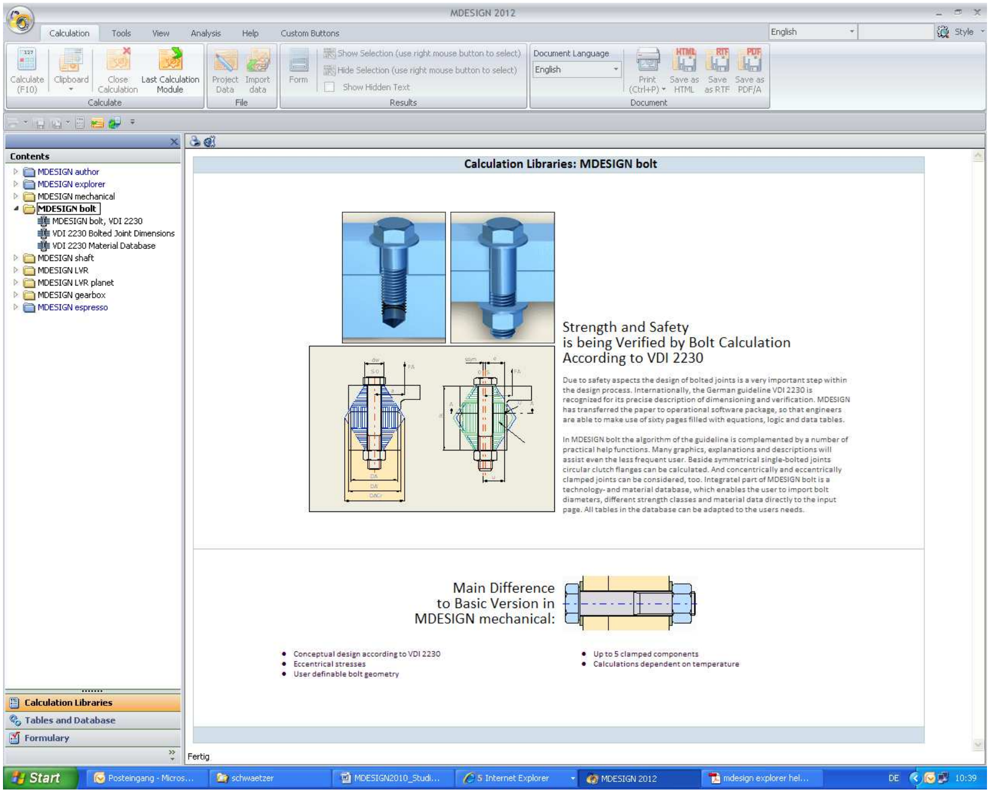


Figure 2-2: Information page MDESIGN bolt

Figure 2-2 shows the information page of the group “MDESIGN bolt”.

2.2 Multi function bar (Ribbon)

Figure 2-3 shows the MDESIGN multi function bar. The fuctions will be explained in the following.

Compatible with Windows applications

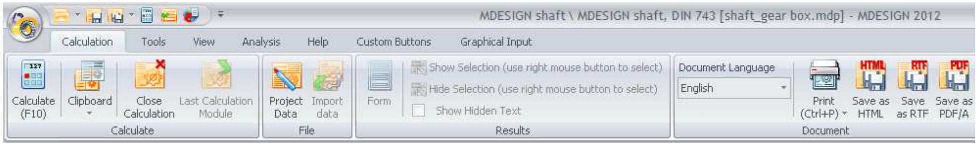


Figure 2-3: Multi function bar in MDESIGN 2012

MDESIGN Command button:

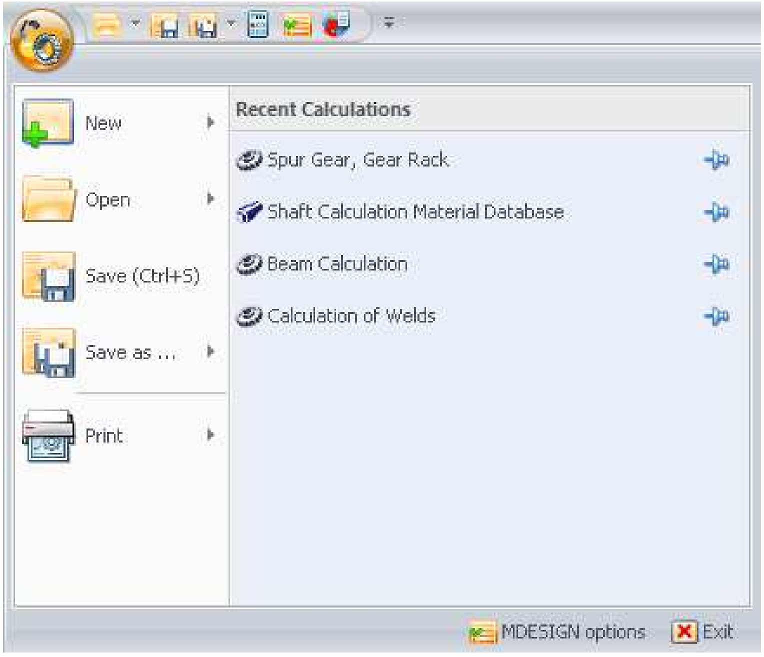


Figure 2-4: Main button in MDESIGN 2012

The Command button contains the following options (similar to Windows applications)

- New/Open
- Save/Save as …
- Print

With one click you will also be able to see a list of recent Modules on the right side of the menu. Click on an entry to load the corresponding module.

Tab “Calculation”:

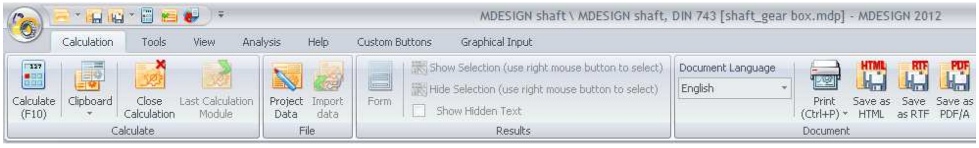


Figure 2-5: Tab „Calculation” in the Multi function bar

The tab Calculation contains the following commands:

- Calculate
  Starting a calculation according to the data and parameters in the input page

- Clipboard
  Defining which data, results and graphics shall be saved in the clipboard to be available for pasting in Windows programs that support the clip-board function

- Close Calculation
  Closing the ongoing calculation and resetting MDESING to start mode

- Last Calculation Module
  Starting the most recent calculation module of the ongoing session

- Project Data
  Entering the project data for the documentation

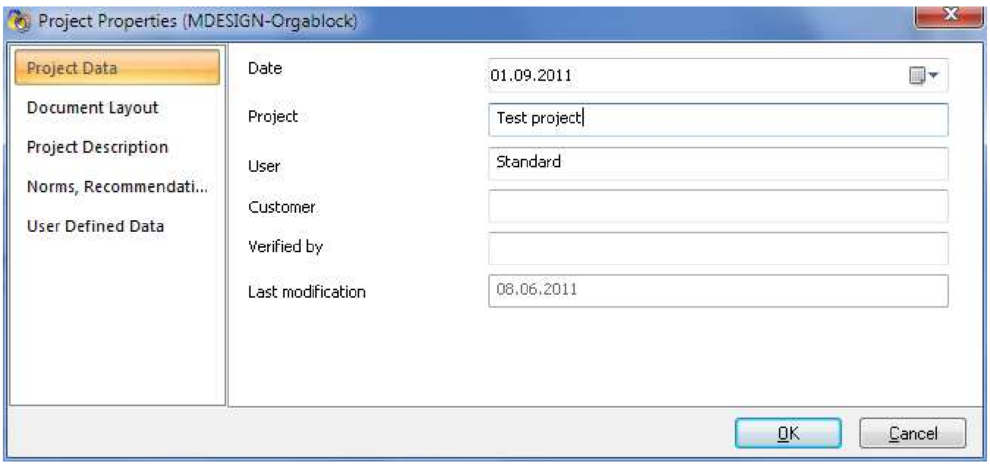


Figure 2-6: Entering the project data

- Import Data
  Importing data to make them available to other MDESIGN calculations (see command “Module Relationships” in menu „Tools“)

- Form
  For special applications only

- Show/Hide Selection/ Show hidden text
  Available after calculation only

  It is possible to hide single values on the output page temporarily. Hidden results will not be displayed in the documentation. This way the documentation can be customized to only the parameters that are of interest for the user.

- Document language
  The documentation is available in German, English, French and Italian.
  The setting of the language for the user interface is independent of the document language and can be modified above the multi function bar on the right side.

- Print
  MDESING offers the common commands for Print, Quick Print, Printer Settings and Print preview.
  Additionally it is possible to select a layout template for the printed document.

- Save as HTML
  Saving the results as a HTLM file that can be viewed by a compatible web browser

- Save as RTF
  Saving the results as a RTF file (Rich Text Format) that can be edited by MS-Word

- Save as PDF/A
  Saving the results as a PDF/A file

Menu Tools

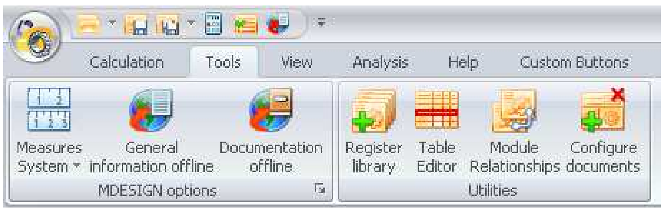


Figure 2-7: Menu Tools

- Measures System
  Selecting the measurement systems “Metric System”, “US system” or “All systems”
  The selection will convert the values of all calculation parameters into the selected system of measurement if the calculation is loaded at the time of the selection. All calculations from here on will also use the selected measurement system.

- General Information Offline / Online
  Determining the status of the Information pages
  In the online mode the Information page gives information that is always accessed directly from the internet and displayed live. This mode is preferable as the page content is always up to date. If no internet connection is available the information page is offline and will show the information of the product CD.

- Documenatation Offline/ Online
  Determining the status of the documentation
  In the online mode the User Guide and technical and calculation documentation is accessed from the internet or the manufacturer server. This consequently ensures that the information is always up to date.

- Register Library (Administrator rights required)
  Administration of MDESING libraries in networks

- Table Editor (Administrator rights required)
  Editing data records in database

- Module Relationships
  Linking calculation modules to make input or output parameters available to both modules

- Configure Documents
  Managing Documents in the explorer bar
  It is possible to add documents to the explorer bar to make them easily accessable during the MDESIGN operation. These documents might e.g. be PDF files of manufacturer catalogues, engineer standards or designing guidelines.

Menu View

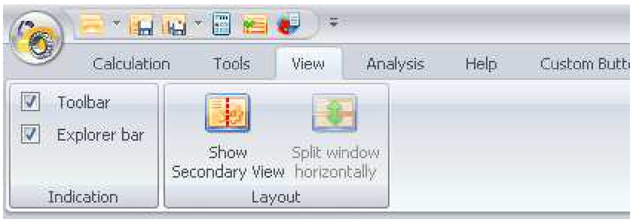


Figure 2-8: Menu View

This menu allows you to manage the layout of the MDESIGN interface elements and the layout of the windows. You can choose whether to view or hide the Ribbon toolbar and the explorer bar.

- Show/Hide Secondary View
  Showing or hiding the output page manually

- Split window horizontally/vertically
  Arranging the input and output pages horizontally or vertically

Menu Analysis

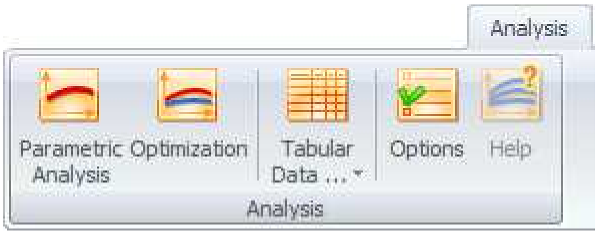


Figure 2-9: Menu Analysis

- Parametric Analysis

  Automatically performing a calculation with different predefined input parameters in a specific value range and analysing the results

- Optimization (only activated after successful parametric analysis)

  Giving the value of the output parameter that has reached the maximum and showing the corresponding input values

- Tabular Data
  Displaying the tables that contain the data of the parametrical analysis

- Options
  Configuring parametric analysis settings

Menu Help

The handling of MDESIGN is based on an effective help system. You will find all Help and Support topics at your disposal via the “Help” tab on the Ribbon.

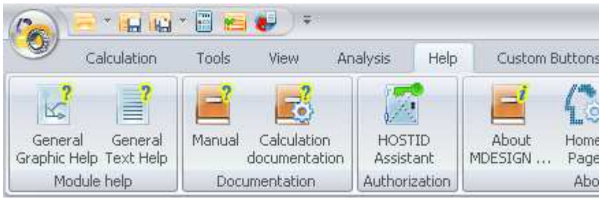


Figure 2-10: Menu Help

- General Graphic/Text Help

  Providing general graphic and text assistance on a currently open module If no module is active then these buttons will appear greyed out.

- Manual

  MDESIGN User´s Guide – MDESIGN explorer documentation
  Depending on the option Documentation Online / Offline, you can read the documentation either on the internet or offline in the MDESIGN target directory.

- Calculation Documentation

  (online) help on the currently active calculation module
  Depending on the option Documentation Online / Offline, you can read the documentation either on the internet or offline in the MDESIGN target directory.

- HostID Assistant

  Giving you the option to authorize the program with FLEXlm
  Administrator rights are required to do this. Please refer to authorization instructions

- About MDESIGN…
  Giving detailed information about the program
  The user obtains precise and current information about the version status of the programme being used. The current status of the calculation libraries and the respective authorisations will also be shown here. This information is very useful if the user wishes to contact the Hotline or to reorder.

2.3 Topic Area and Explorer bar

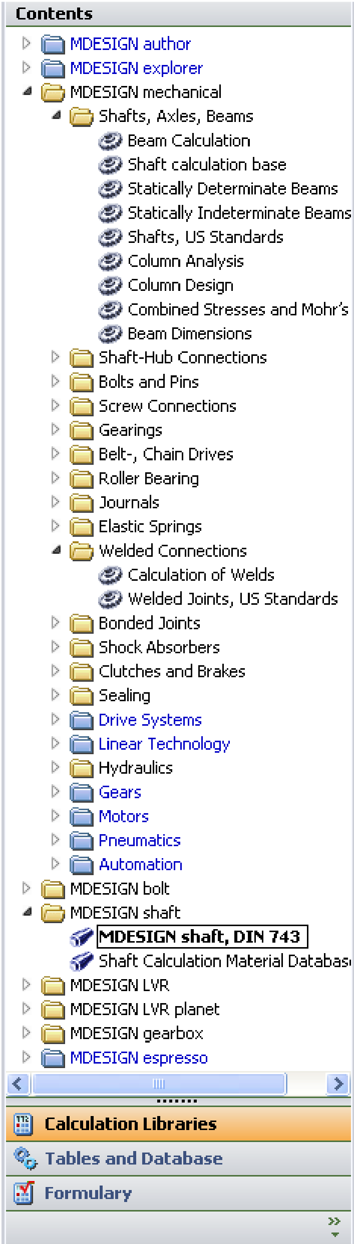


Figure 2-11: Topic Area and explorer bar

The structure of the Explorer bar is based on the look and feel of MS Outlook and displays the entire content of your installed version of MSDESIGN. With the help of the Explorer bar, all installed and licenced modules, documents, additional information pages and information sources are at your disposal.

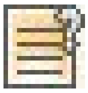
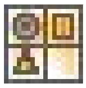
- Calculation Libraries
  Core element of MDESIGN that contains various calculation modules based on engineer standards, technical guidelines, technical literature and manufacturer´s information

- Tables and Database/Formulary
  Userful reference and design modules about subjects like materials, geometry, physics, mechanics and hydraulics

2.4 Input Page

After loading a calculation or formulary module the input page is displayed.

The help buttons next to some of the input fields give useful information about the input parameter. The following buttons are available on the MDESIGN input page:

- Text Help 
- Graphic Help 
- Choice of Graphics 
- Graphical Input Assistant 
- Database 

For more information about these input help buttons please see chapter 3.2.

2.5 Output Page

The output page is displayed after a successful calculation. The view can be split to show the output page as well as the input page simultaneously. The output page lists all results of the calculation.

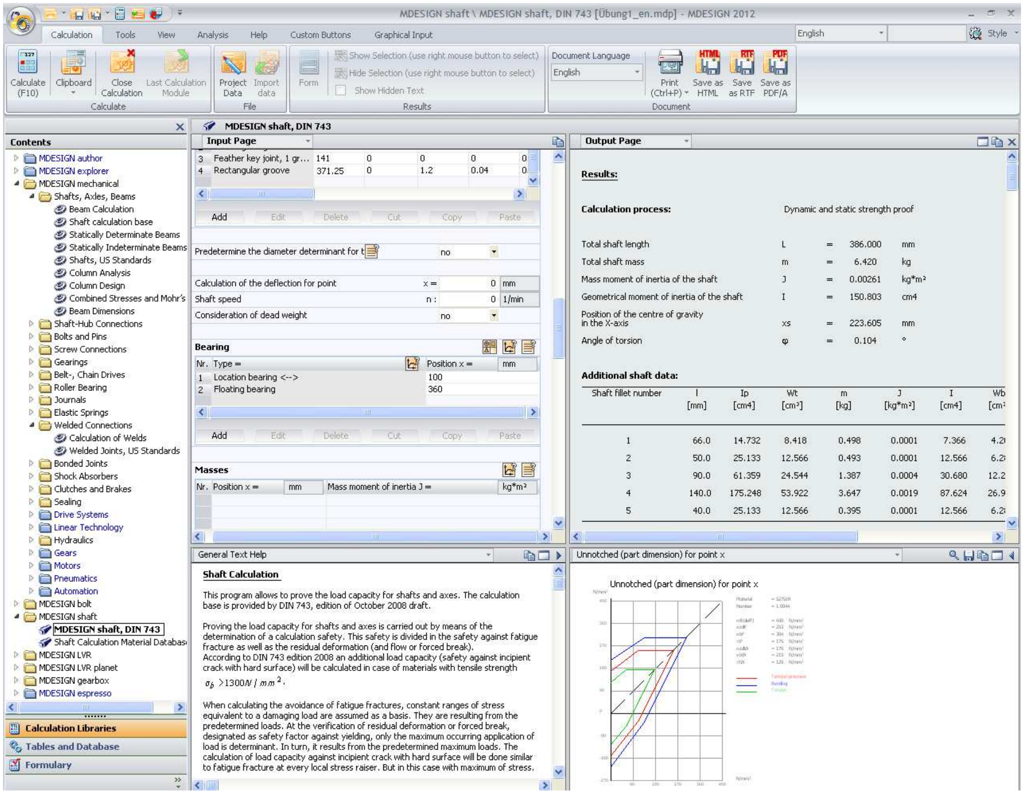


Figure 2-12: User interface after calculation

3 Performing a calculation

3.1 Procedure

Performing a calculation is the most important procedure in MDESIGN. To perform a calculation please select and load a calculation module from the calculation libraries or the formulary. The calculation libraries and the formulary are located in the topic area.
Double-clicking on a module will load its data and algorithms into MDESIGN explorer. Only one module can be loaded at a time. If available the corresponding record data of the calculation module will be loaded as well. Before starting the calculation it is required to fill in all necessary data and parameter.
All results will be displayed on the output page after the successful calculation. The graphic help window will show additional graphic results if available. All input data, results and result graphics can be implemented in the calculation documentation (see chapter 3.4).

3.2 Input and Input help

It is recommended to enter the data according to the order on the input page. Some of the inputs and select options are very specific and need additional informatin to be understood properly. Mostly these inputs are related to the corresponding calculation standard of the active calculation module.

MDESIGN offers additional input help for these inputs to ensure the correct input of all parameters.

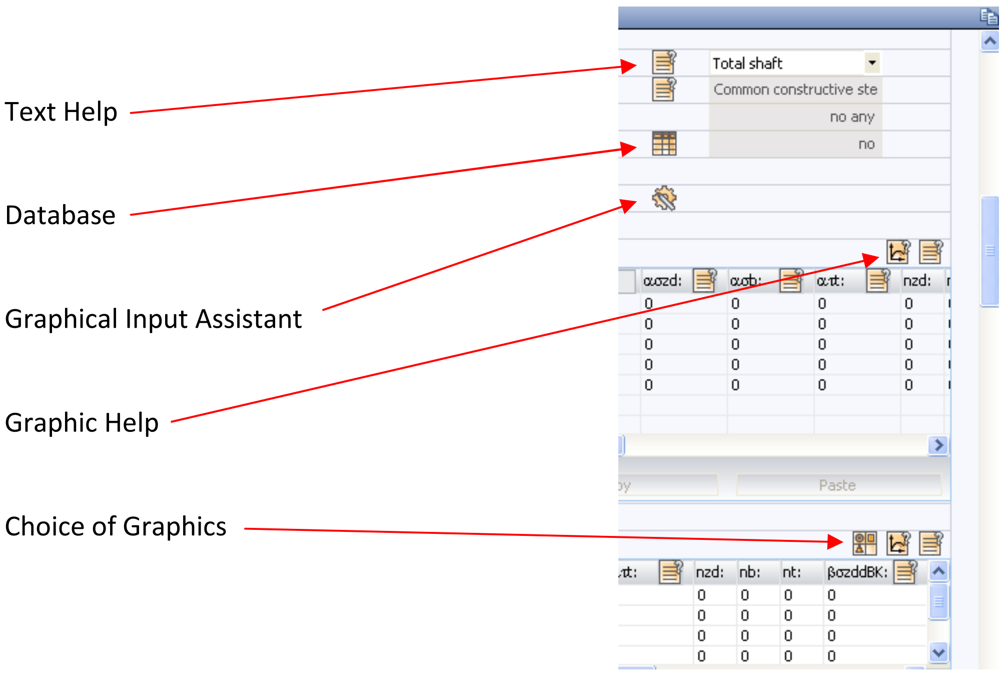


Figure 3-1: Input Help buttons

3.2.1 Text Help

Text help window

The Text Help offers any available assistance in text form for the input parameters of each module. The text help window contains significant details for understanding the entire calculation module and its individual parameters (please see Figure 3-2).

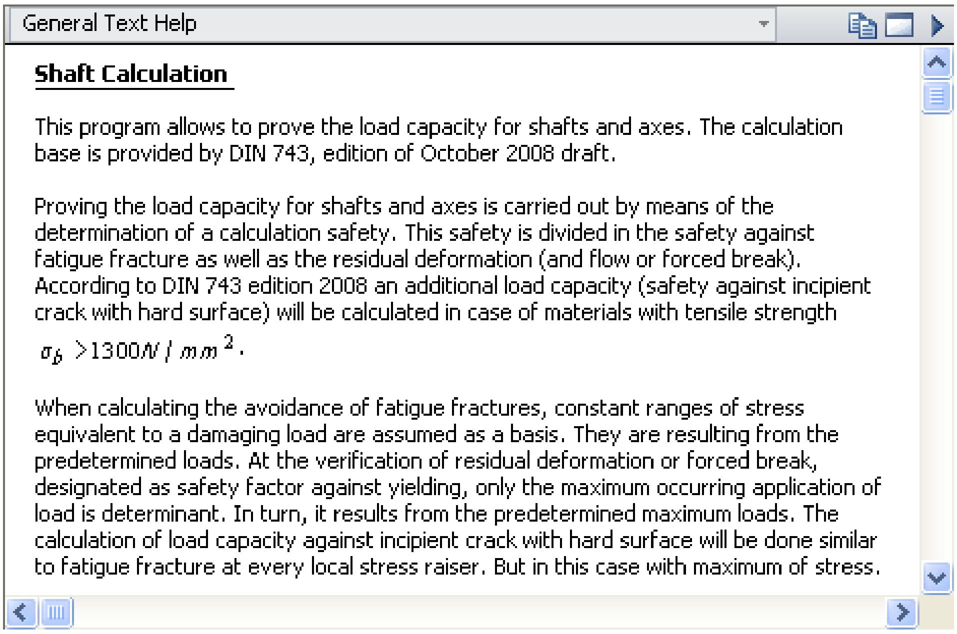


Figure 3-2: Text help example

The button allows you to open the window in the largest possible view. Pressing the button transfers the text from the window to the clipboard to make it available to other text processing programs (e.g. MS Word).

3.2.2 Graphic Help

This window contains graphical information (diagrams, grid, drawings, images and other types of visual representations), which are of importance for understanding the entire calculation module or its individual parameters. The graphical results of a calculation are also illustrated in this window.

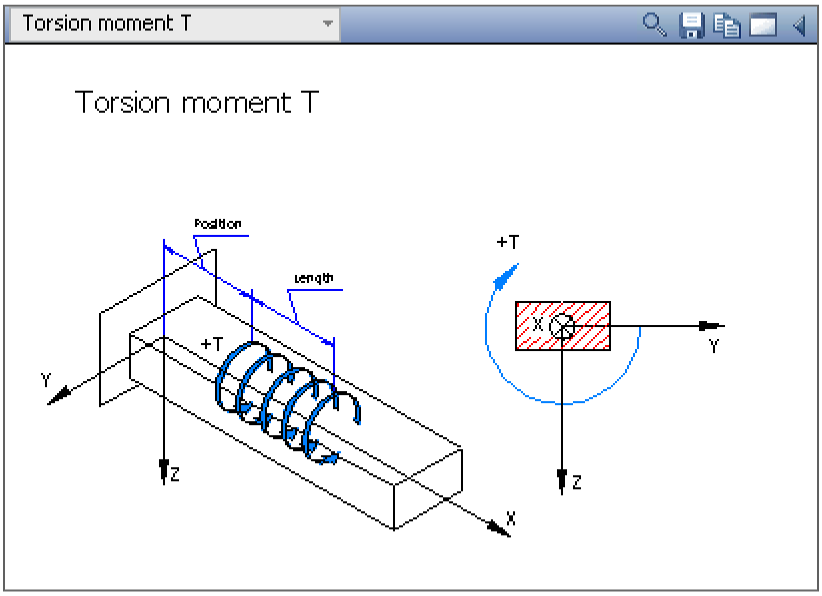


Figure 3-3: Graphic Help example

The button allows you to open the window in the largest possible view. Pressing the button transfers the text and graphics from the window to the clipboard to make it available to other text processing programs (see Text Help window).

The button enables you to save the graphics in a file. Different file types are offered according to the type of graphics: Bitmap (bmp) and DXF or DirectX (x) (for 3D graphics).

Using the button activates the zoom function (enlarge \ minimize) for the image without changing the size of the window.

For viewing one of the result graphics after a calculation please select an item from the list in the graphic help window.

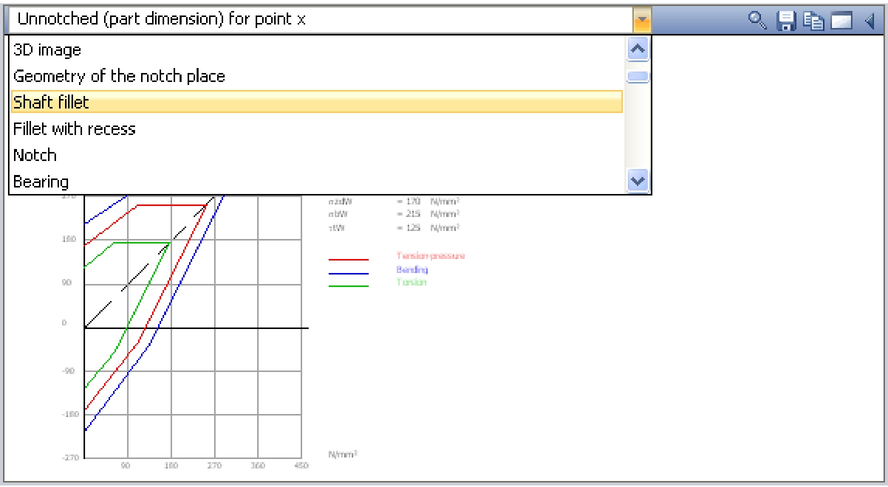


Figure 3-4: Result graphics

In this list you will find all graphical help items relating to the calculation (general graphical help for the entire calculation and graphical help for individual parameters), as well as the graphical results. After selecting one of the rows in the list, the corresponding graphic will appear.

3.2.3 Using Input Help functions

For some parameter the table based input on the input page is not functional. For these parameters the Input Help functions facilitate the input of geometrical parameters. The buttons displayed in Figure 3.1 indicate the Input Help functions.

The Input Help functions can be used as a choice function (button ) as displayed in Figure 2-1.

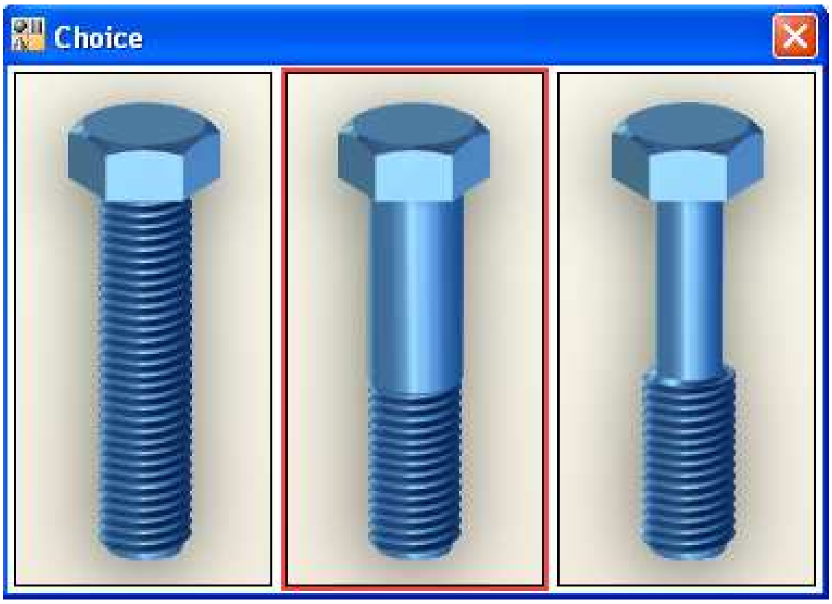


Figure 3-5: Selection of a bolt

Moreover the graphical assistants give the opportunity to enter complex structures and geometry in an easy way. It is for example possible to define the complete geometry of a shaft including bearings and loads in the graphical input page shown in Figure 3-6.

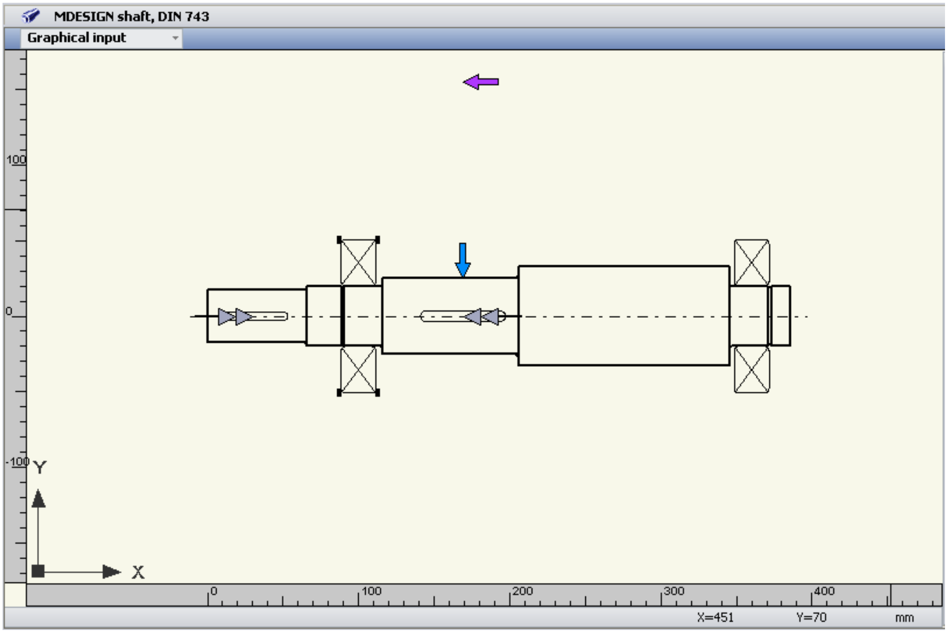
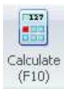


Figure 3-6: Graphical Input Assistant (shaft)

The calculation example 1 deals with the assembling of a shaft and the functionalities of the Graphic Input page in detail.

3.3 Calculation and Output Page

After completing all necessary inputs the calculation can be performed. There are two ways to start the calculation:

- Toolbar - Symbol: 

- Key F10 - Shortcut F10

The program will first check if all input data are complete and plausible before performing the calculation.

If the program detects any missing or inconsistent data it will abort the calculation and will show an error message. The corresponding input field will be activated so that the error can be corrected.

If all input data are complete and plausible, the program will perform the calculation and open the output page with all results.

It is possible to hide the output parameters by selecting the responding parameter and pressing “delete”. This way the user can customize the output page according to his requirements. The hiding function is also available for the result documentation (see next chapter).

3.4 Documentation

As mentioned in chapter 1.1 the documentation of a strength proof is of immense importance for the calculation of machine elements. One big benefit of the MDESIGN calculation software is the automatic generation of the documentation. This chapter will show how to perform this automatic documentation and how to customize the calculation documentation if necessary.

Language setting

The setting of the documentation language can be changed independently of the program language. The language setting for the documentation is located in the menu “calculation”.

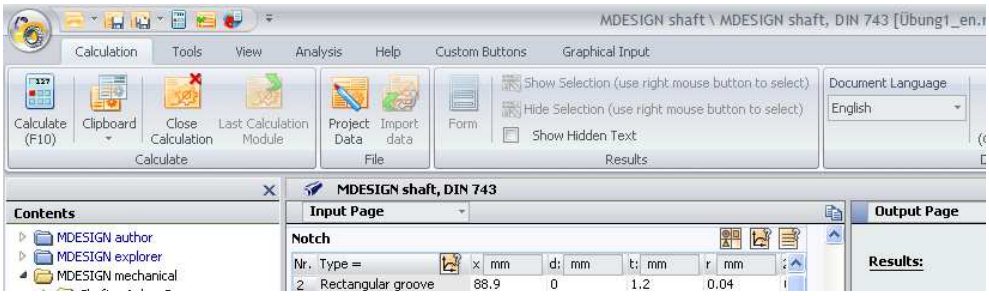
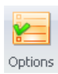


Figure 3-7: Document language setting

Customizing the documentation

To choose which result graphics and help graphics shall be part of the documentation please press the MDESIGN options button 

in the toolbar. The register “Output” will show a list of all available graphics that can be displayed in the documentation.

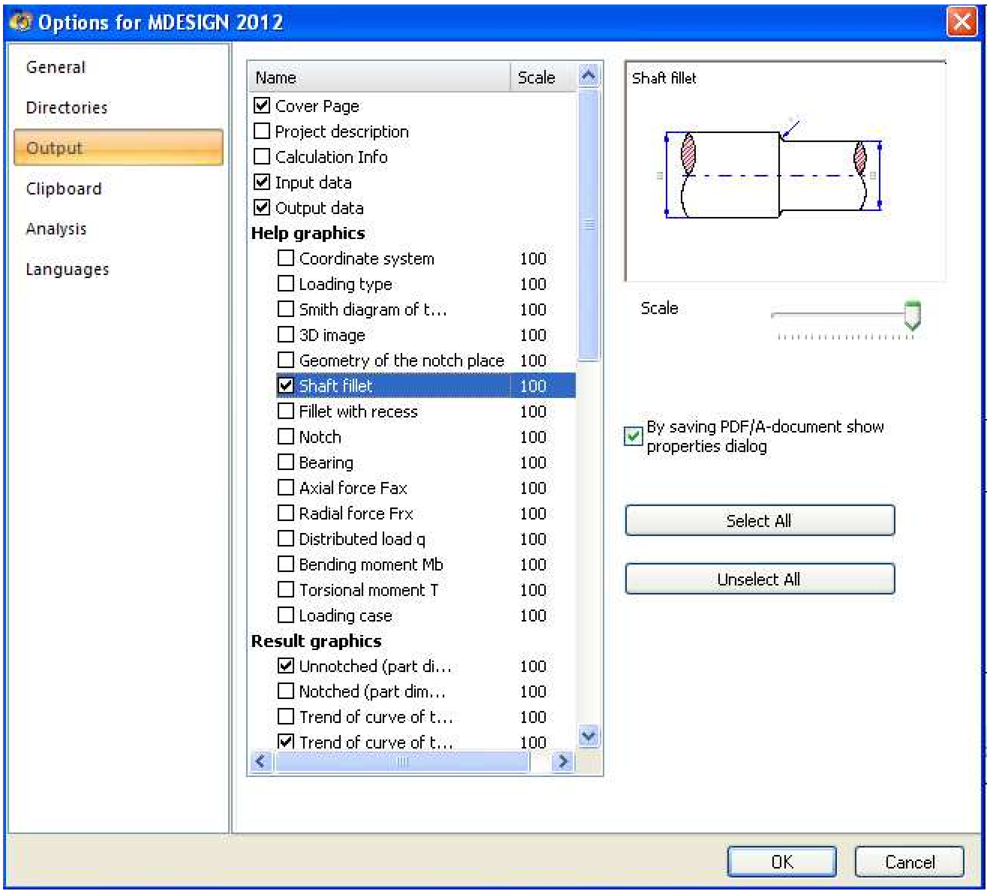


Figure 3-8: Register „Output“ in the MDESIGN Options window

All selected graphics as well as all input and output parameters (as long as they are not hidden) will be transferred to the documentation. Hidden parameters will not be part of the document.

To create your own calculation documentation please use the fuction „clipboard“ that is available for the windows of the input page, output page, text help and graphic help. This function allows you to add all results and parameters to a text processing program where you can assemble your own documentation.

4 Calculation examples

4.1 Exercise 1 – Calculation of a Shaft according to DIN 743

Task

This example will show step by step how to perform a calculation using MDESIGN mechanical.

The task in this example is to calculate a gearbox output shaft. Before starting the calculation it is necessary to abstract the shaft. The geometry of the shaft and additional notches shall be adopted from the drawing. The following table shows the relevant parameters of this example.

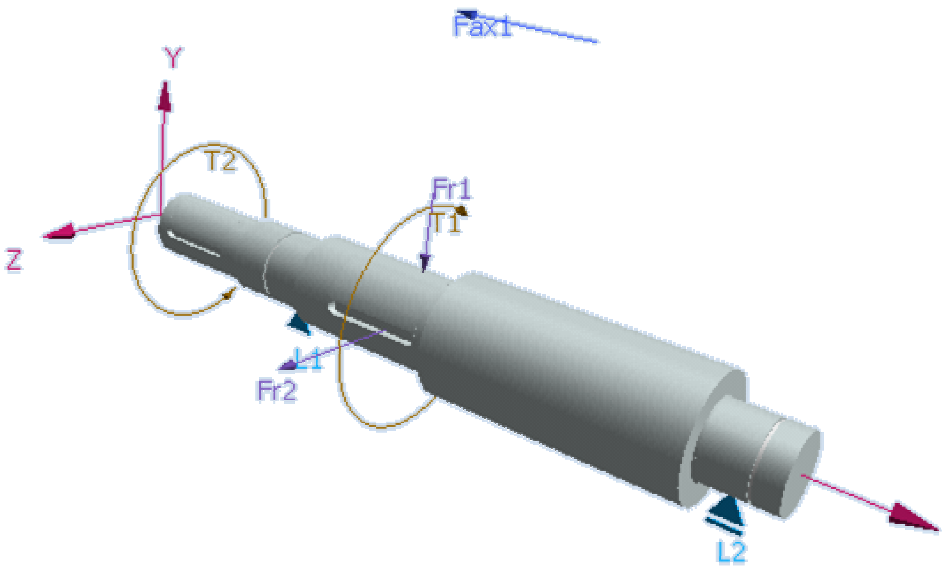


Figure 4-1: Gearbox output shaft

Parameters

Geometry of the shaft:

Sections of the shaft:

Section	d [mm]	l [mm]	Transition radius [mm]	Rz [µm]
1	35	66	1.5	6.3
2	40	50	1	6.3
3	50	90	3	6.3
4	65	140	1	6.3
5	40	40	0	6.3

Table 4-1: Sections of the shaft

The numbering of the sections follows the x-axis as shown in Figure 4-1. The Transition radius is the radius to the adjacent section. According to this there is no transistion radius for the last section.

According to DIN 743 the notch effect of the shaft shoulders have to be taken into account in the proof of safety. Furthermore the DIN 743 defines additional notches. For our example of the gearbox output shaft we find the following additional notches:

Types of notches:

Section	Notch	Parameters [mm]
1	Parallel Key Connection	Position: x = 8 Length: l = 45
2	Square Groove	Position: x = 88.9 Depth: t = 1.2 Width: m = 1.85 Radius: r = 0.04
3	Parallel Key Connection	Position: x = 141 Length: l = 56
5	Square Groove	Position: x = 371.25 Depth: t = 1.2 Width: m = 1.85 Radius: r = 0.04

Table 4-2: Notches

Bearing:

The bearing of the shaft is a tycical fixed and floating bearing arrangement.

Section	Bearing	Position [mm]
2	Fixed bearing	x = 100
4	Floating bearing	x = 360

Table 4-3: Bearing

Material of the shaft: S275JR

Loads:

The output torque M= 286.5 Nm is applied to the shaft by a helical spur gear. It is transmitted by the parallel key connection in section 3.

Due to the tooth forces there are additional loads transmitted to the shaft that need to be considered. The tangential force at the engagement acts as a radial force in two directions of the coordinate system. The helix angle of the gear causes an additional axial force acting on the shaft.

Gear parameters:

Radius of pitch circle: rw = 154.6 mm

Pressure angle: $\alpha = 25°$

Helix angle : $\beta = 20°$

Step 1- Starting the shaft calculation module

Starting MDESIGN shaft

The shaft calculation according to DIN 743 is realized in the MDESIGN module MDESIGN shaft. To start this application you need to choose the theme “Calculation Libaries”. The explorer will now show all available calculation modules.

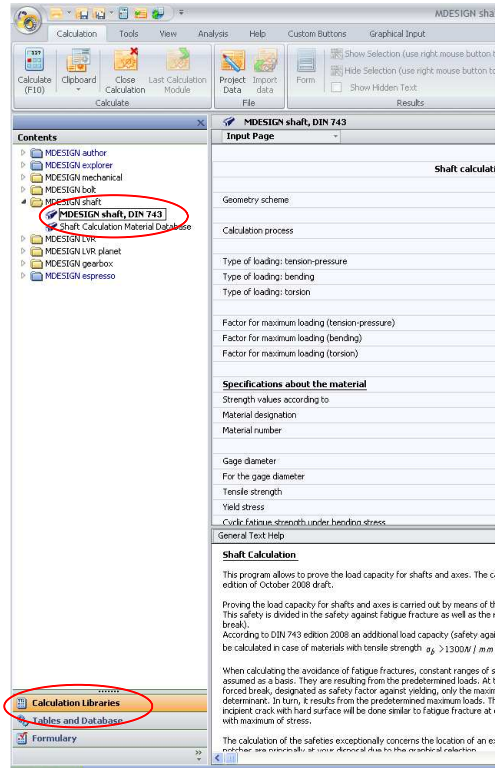


Figure 4-2: Starting MDESING shaft in the explorer bar

Step 2 – Entering the parameters

After starting the MDESIGN shaft module the program will show the data input page of the module. Below the input page you can find the windows for the text and graphic help. After starting a module the text help window will always show the general text help of the selected module.

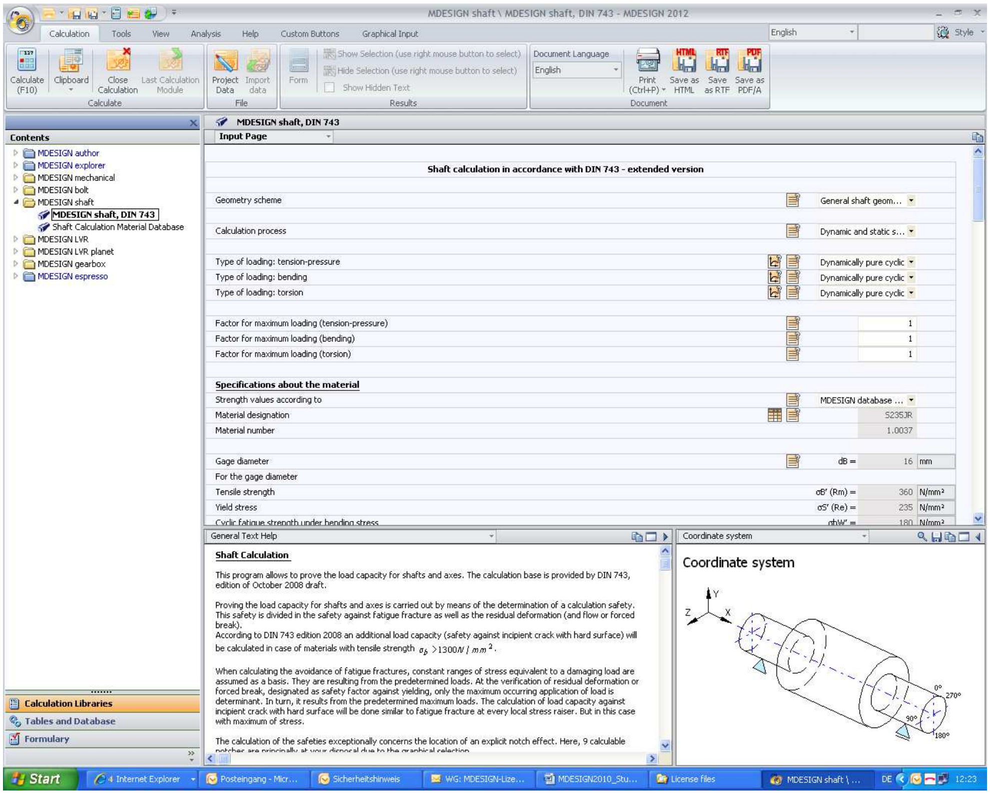


Figure 4-3 Input page of the shaft calculation

Please fill in all necessary parameters on the input page. It is recommended to enter the data according to the order on the input page.

There is an input assistance for most of the parameters that can be very helpful, especially when you are just starting to use the program.

Geometry scheme: 1. Single notch point

Implementing the DIN 743 → calculation of safeties for a single notch point of the shaft

2. General shaft geometry

In addition to a calculation according to DIN 743 it is possible to calculate a complete shaft. In this case the program will first determine the bending moments and stresses acting on the shaft based on the supporting forces. Then it will calculate the safeties for all notches.

→ Please choose "General shaft geometry" for the example exercise.

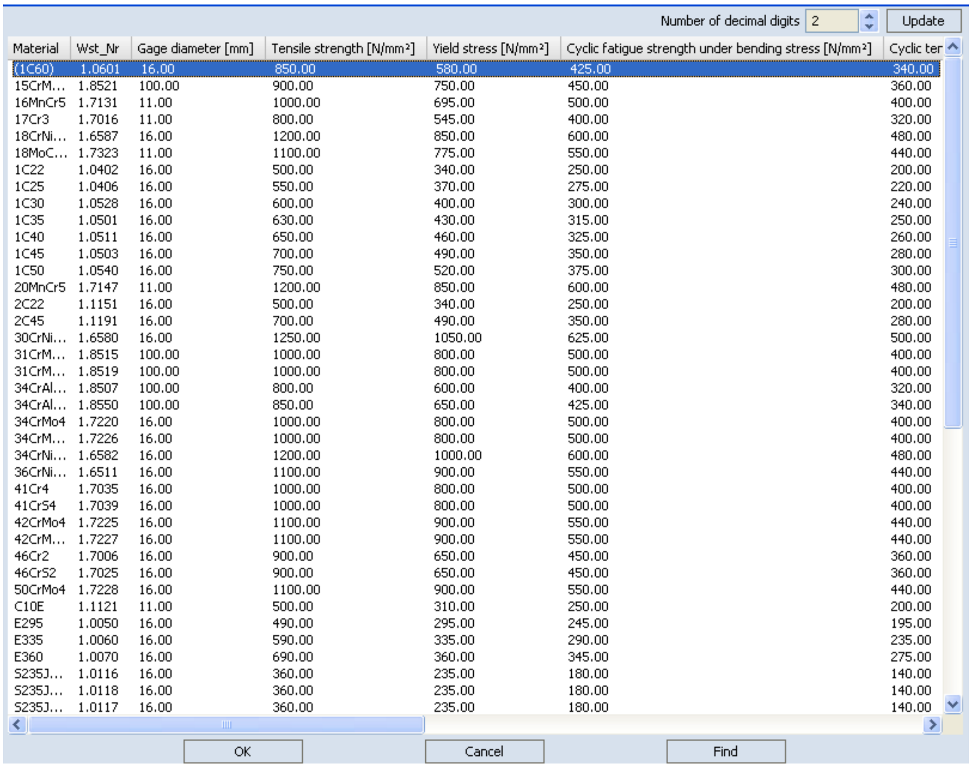
Calculation process: 1. Dynamic and static strength proof

2. Static strength proof only

→ Though we find a static load in our example it is however necessary to calculate the dynamic strength proof as well. Due to the rotation of the shaft the static load acts as dynamic stress (rotating bending).

Material designation:

Please use the symbol to open the material database and select the material.



Number of decimal digits 2 Update

Material	Wst_Nr	Gage diameter [mm]	Tensile strength [N/mm²]	Yield stress [N/mm²]	Cyclic fatigue strength under bending stress [N/mm²]	Cyclic ter
(1C60)	1.0601	16.00	850.00	580.00	425.00	340.00
15CrM...	1.8521	100.00	900.00	750.00	450.00	360.00
16MnCr5	1.7131	11.00	1000.00	695.00	500.00	400.00
17Cr3	1.7016	11.00	800.00	545.00	400.00	320.00
18CrNi...	1.6587	16.00	1200.00	850.00	600.00	480.00
18MoC...	1.7323	11.00	1100.00	775.00	550.00	440.00
1C22	1.0402	16.00	500.00	340.00	250.00	200.00
1C25	1.0406	16.00	550.00	370.00	275.00	220.00
1C30	1.0528	16.00	600.00	400.00	300.00	240.00
1C35	1.0501	16.00	630.00	430.00	315.00	250.00
1C40	1.0511	16.00	650.00	460.00	325.00	260.00
1C45	1.0503	16.00	700.00	490.00	350.00	280.00
1C50	1.0540	16.00	750.00	520.00	375.00	300.00
20MnCr5	1.7147	11.00	1200.00	850.00	600.00	480.00
2C22	1.1151	16.00	500.00	340.00	250.00	200.00
2C45	1.1191	16.00	700.00	490.00	350.00	280.00
30CrNi...	1.6580	16.00	1250.00	1050.00	625.00	500.00
31CrM...	1.8515	100.00	1000.00	800.00	500.00	400.00
31CrM...	1.8519	100.00	1000.00	800.00	500.00	400.00
34CrAl...	1.8507	100.00	800.00	600.00	400.00	320.00
34CrAl...	1.8550	100.00	850.00	650.00	425.00	340.00
34CrMo4	1.7220	16.00	1000.00	800.00	500.00	400.00
34CrM...	1.7226	16.00	1000.00	800.00	500.00	400.00
34CrNi...	1.6582	16.00	1200.00	1000.00	600.00	480.00
36CrNi...	1.6511	16.00	1100.00	900.00	550.00	440.00
41Cr4	1.7035	16.00	1000.00	800.00	500.00	400.00
41CrS4	1.7039	16.00	1000.00	800.00	500.00	400.00
42CrMo4	1.7225	16.00	1100.00	900.00	550.00	440.00
42CrM...	1.7227	16.00	1100.00	900.00	550.00	440.00
46Cr2	1.7006	16.00	900.00	650.00	450.00	360.00
46CrS2	1.7025	16.00	900.00	650.00	450.00	360.00
50CrMo4	1.7228	16.00	1100.00	900.00	550.00	440.00
C10E	1.1121	11.00	500.00	310.00	250.00	200.00
E295	1.0050	16.00	490.00	295.00	245.00	195.00
E335	1.0060	16.00	590.00	335.00	290.00	235.00
E360	1.0070	16.00	690.00	360.00	345.00	275.00
S235J...	1.0116	16.00	360.00	235.00	180.00	140.00
S235J...	1.0118	16.00	360.00	235.00	180.00	140.00
S235J...	1.0117	16.00	360.00	235.00	180.00	140.00

OK Cancel Find

Figure 4-4: Material database

After selecting the material all relevant material properties will be automatically transfered to the input page. These properties cannot be edited because they depend on the selected material. If you need to assign your own material parameters please select “strength values according to” “own assignment”.

→ The material of the shaft in our example is: S275JR

Definition of the shaft, shaft geometry:

Before the calculation can be started you need to define the geometry of the shaft. Please enter all dimensions, additional notch points, bearings and loads in the tables on the input page. Alternatively it is possible to use the graphic input assistent for the definition of the shaft to mininmize the risk of type errors. Pressing the symbol above the shaft geometry table will start the assistant and an empty window will appear. Figure 4-5 shows the graphical input window after defining the complete shaft.

The assembling of the shaft is done by dragging the elements, shaft sections, bearings and loads from the graphic input explorer on the right and dropping them in the graphic input screen. The element parameters can be edited in the table on the left side of the graphic input screen.

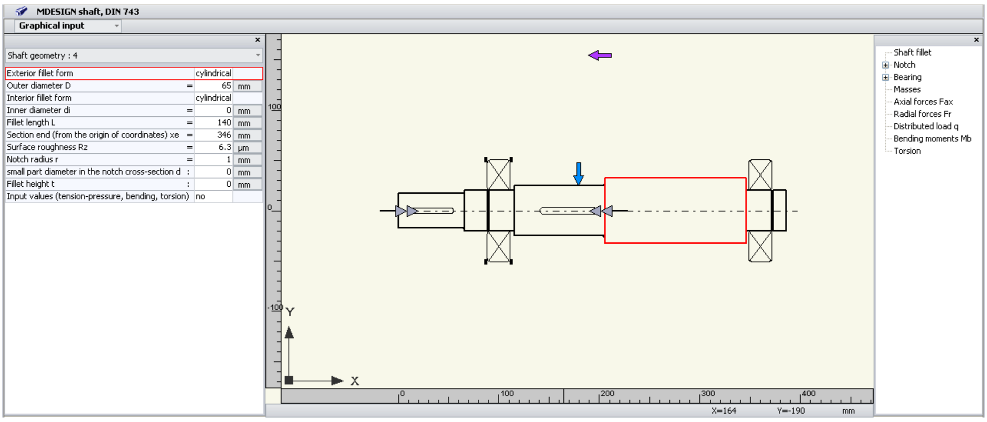


Figure 4-5: graphic input assistant

In our example we define the shaft sections step by step according to Table 4-1, starting with section 1 on the left. After completing the shaft sections we add the notch points by dragging the parallel key connections and square gooves from the explorer, dropping them at their location and editing the exact parameters according to Table 4-2.

In the next step we define the bearing of the shaft in the same way. We choose the bearings according to Table 4-3 and determine the position in the input sreen on the left.

Loads:

In the last step we add the loads that act on the shaft. An output torque is applied to the shaft and results in additional forces as stated in the task description.

The determination of the loads is not part of the DIN 743 and even MDESIGN contains only the calculation of the bearing forces and bending moments. The calculation of the tooth forces can therefore not be performed by the program but need to be done by the user.

Tangential force:

$$F_t := \frac{M_t}{r_w} \qquad F_t := \frac{286.5\,\mathrm{N \cdot m}}{0.1546\,\mathrm{m}} \qquad F_t = 1.853 \times 10^3\,\mathrm{N}$$

Normal force:

$$F_r := F_t \cdot \tan(\alpha) \qquad F_r = 864.147\,\mathrm{N}$$

Axial force:

$$F_a := F_t \cdot \tan(\beta) \qquad F_a = 674.499\,\mathrm{N}$$

The input of the loads is also done by drag and drop as described above.

The tangential force and the normal force act radially on the shaft, they need to be applied as radial forces in y and z direction. The axial force caused by the helical gearing is acting in x direction. It is important to notice that the axial force is acting excentrically so that the lever arm generates an additional bending moment. This can be taken account of in the program by defining the excentricity. In the example, the axial force acts in the gear with the radius of the pitch circle as excentricity.

Note:

All parameters of the shaft sections, notch points, bearings and loads can be edited at any time. Just mark the element and alter the values in the table left to the graphic input page.

Step 3 – Verification and calculation

The first way to control the inputs is the drawing in the graphical input screen. It enables the user to see and control the alterations in the geometry during the dimensioning process.

Another possibility to verify the inputs is the 3D-drawing of the shaft with all loads in the graphic help window. It is recommended to especially check the positions and directions of the forces.

Furthermore the program detects missing or inconsistent data and does not generate a 3D-drawing of the shaft in this case.

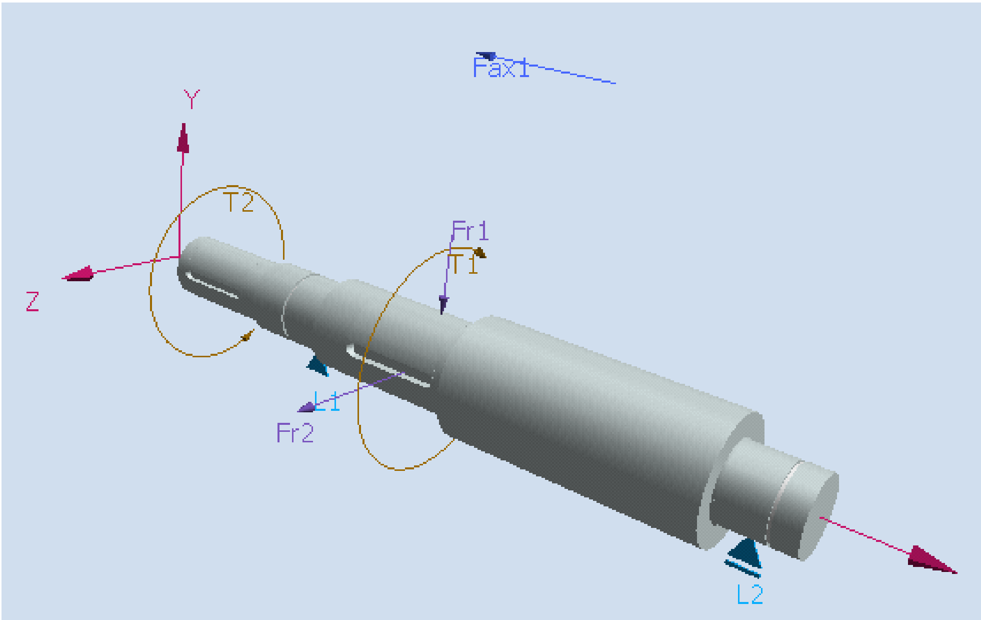


Figure 4-6: 3D-drawing of the shaft

When you have verified that all inputs are correct, please start the calculation by pressing the  button in the toolbar.

The program will first check if all input data are complete and plausible and will then perform the calculation.

Step 4- Results and Documentation

After finishing the calculation the program will display all results on the output page. The most important results are:

- Basic data of the shaft (mass, centre of gravity, mass moment of inertia)
- Sections of shaft (geometrical moments of intertia and section moduli)
- Supporting forces
- Intermediate results (stresses, notch factors, factors of influence)
- Static safety
- Dynamic safety

The presentation of the results (especially of the shaft calculation) does also contain diagrams. These are displayed in the graphic help window.

- Smith-Diagram of the fatigue strength
- Trend of curve of the transverse force
- Trend of curve of the bending moment
- Trend of curve of the torsional moment
- Distributions of stress (Tensile, compressive, bending and equivalent stress)
- Deflection of the shaft
- Saftety against yielding and fatigue fracture

Results graphic

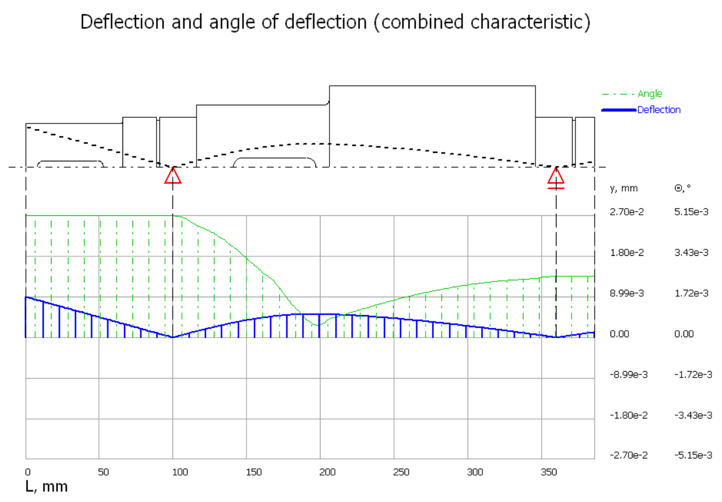


Figure 4-7: Deflection of the shaft

Documentation

We will now perform a documention of the calculation for our example as described in chapter 3.4. The first step is to determine the complexity of the output document. Please press the MDESIGN options button in the toolbar to open the following window. After pressing the button “Output” you can define which result graphics or help graphics will be displayed in the documentation.

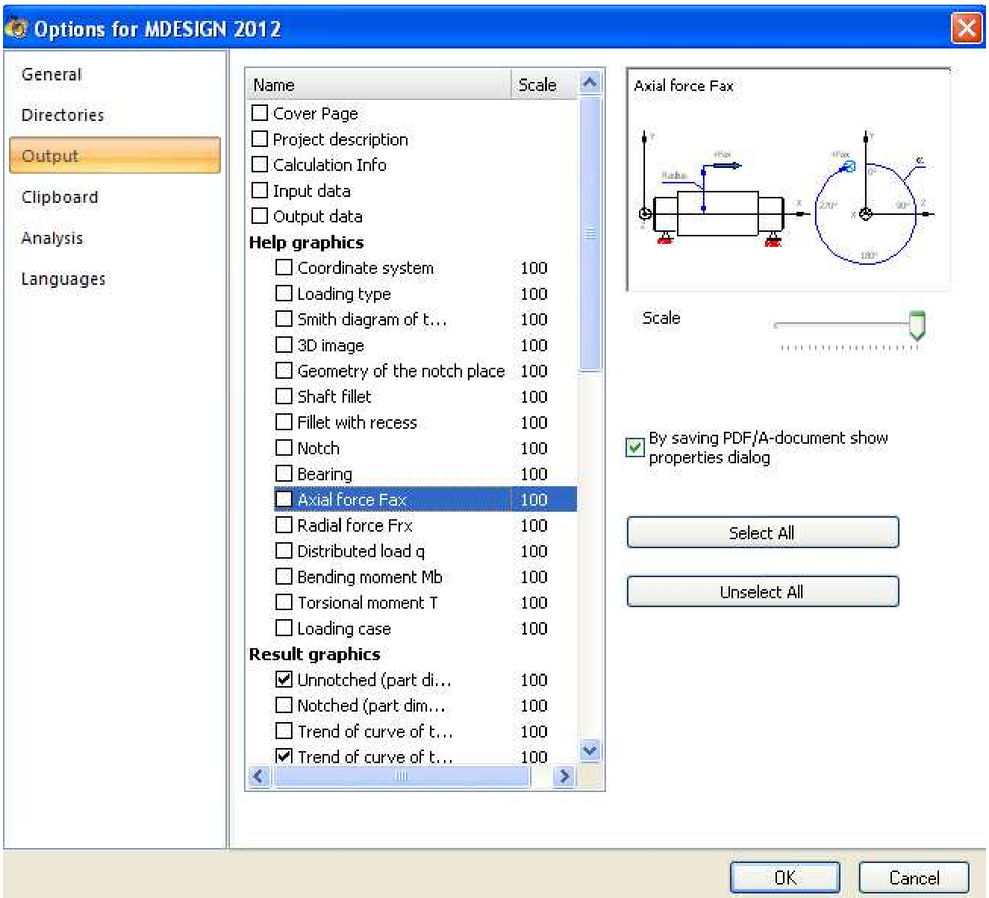


Figure 4-8: Defining the extend of the output document

Please confirm your settings by pressing “OK”. The documentation is available in English, Italian and German and can be saved as HTML, RTF or PDF/A. Please select the document language and press one of the “save as” buttons. The document will be saved including all selected graphs.

Figure 4-9: Saving the documentation

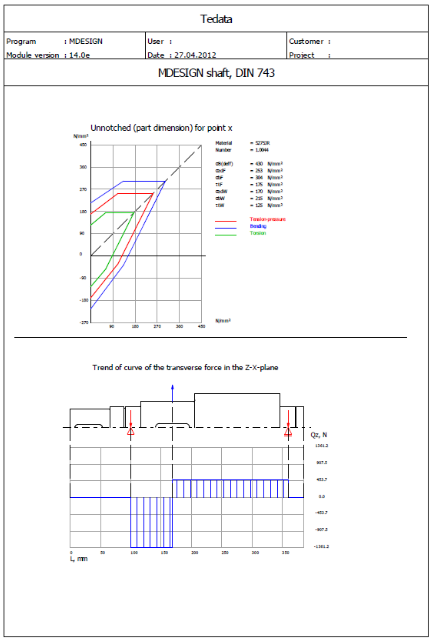


Figure 4-10: example documentation

4.2 Exercise 2 – Calculation of Welds

Task

The task in this example is to calculate the welded connection of a girder. The girder is a standardized I-beam that is welded to a panel assumed to be rigid. There is a transverse force acting on the end of the girder.

The following parameters are predefined:

- Girder:

  I-beam, according to DIN 1025-1, letter symbol: I300

  Dimensions: Height: 300 mm, Width: 125mm, Length: 1000mm

  Web thickness: 10.8 mm, Flange thickness: 16.2 mm

- Weld:

  Fillet weld, weld thickness: 7 mm

  Circumfirential

- Load:

  Shear load: 50 kN (tumescent)

- Material: S 235 JR

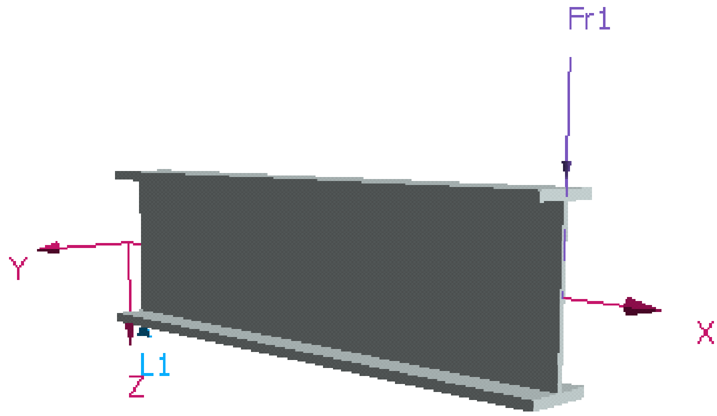


Figure 4-11: Girder with shear load

Step 1- Starting the weld calculation module

There are two different calculation standards for the calculation of welding connections. The standards are DS 952 01 (Welding of metals on railway vehicles and machine technic facilities) on the one hand and the Instruction sheet DVS 0705 (Recommendations for the choice of assessment groups according to DIN EN 25 817 and ISO 5817- butt welds and fillet welds on steel) on the other hand. Our example shall be calculated according to the Instruction sheet DVS 0705. In MDESIGN both standards are combined in one module. The selection of the calculation method will be done on the input page.

Please choose the theme “Calculation Libraries”. After opening “MDESIGN mechanical” you will find the module “Welded connections” that contains the calculation module “Calculation of Welds”.

Starting the welds calculation module

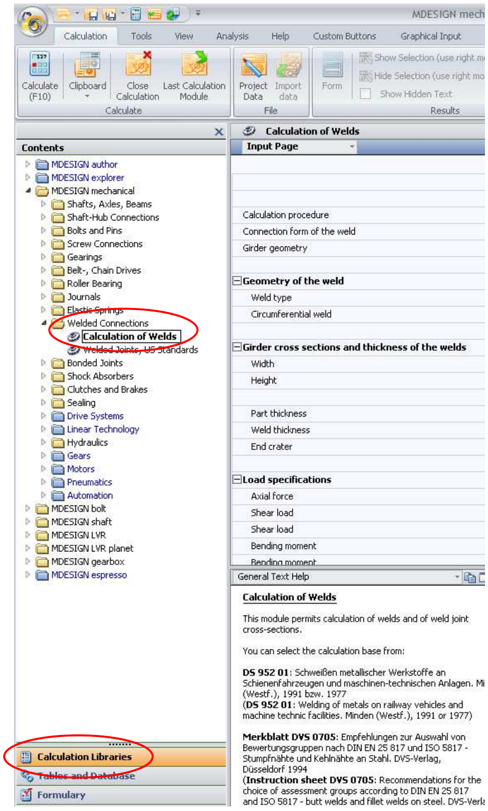


Figure 4-12: Selecting the module "Calculation of Welds" in the explorer bar

Step 2 – Entering the parameters

After starting the Calculation of Welds module the program will show the data input page of the module. Below the input page you can find the windows for the text and graphic help. The text help window will show the general text help of this module. You can find information about the calculation standard DS 952 01 and the instruction sheet DVS 0705 here.

Input page

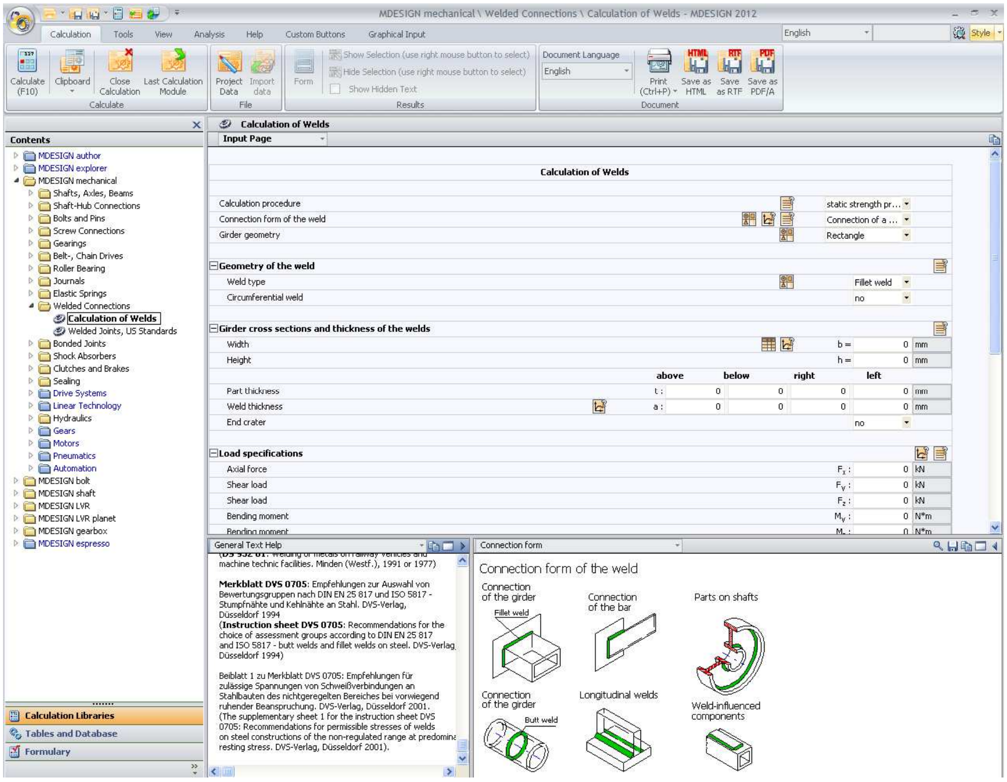


Figure 4-13: Input Page of the module "Calculation of Welds"

On the input page you will be asked to enter the following parameters:

Calculation procedure: 1. Static strength proof

2. Static and dynamic strength proof

Please choose "Static and dynamic strength proof" for our example.

Connection form of the weld:

There are many different ways to assemble and connect the welded parts. MDESIGN offers six different connection forms of the welds as shown in Figure 4-15. This diagram can be opened by pressing the "Selection" button on the input page.

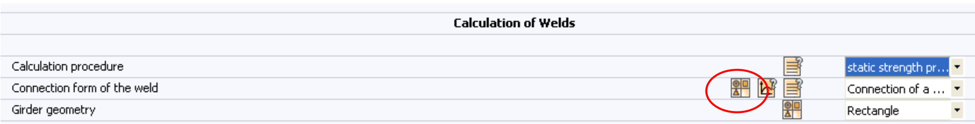


Figure 4-14: Opening the "connection forms" window

It might be necessary to reduce other geometrical types of assembly to comply with one of the connection forms. The selection of a connection form affects the parameters that are required for the calculation so that the layout of the input page changes according to the selected connection form.

Please select the connection form “Connection of the girder” for our example.

Selection of connection form

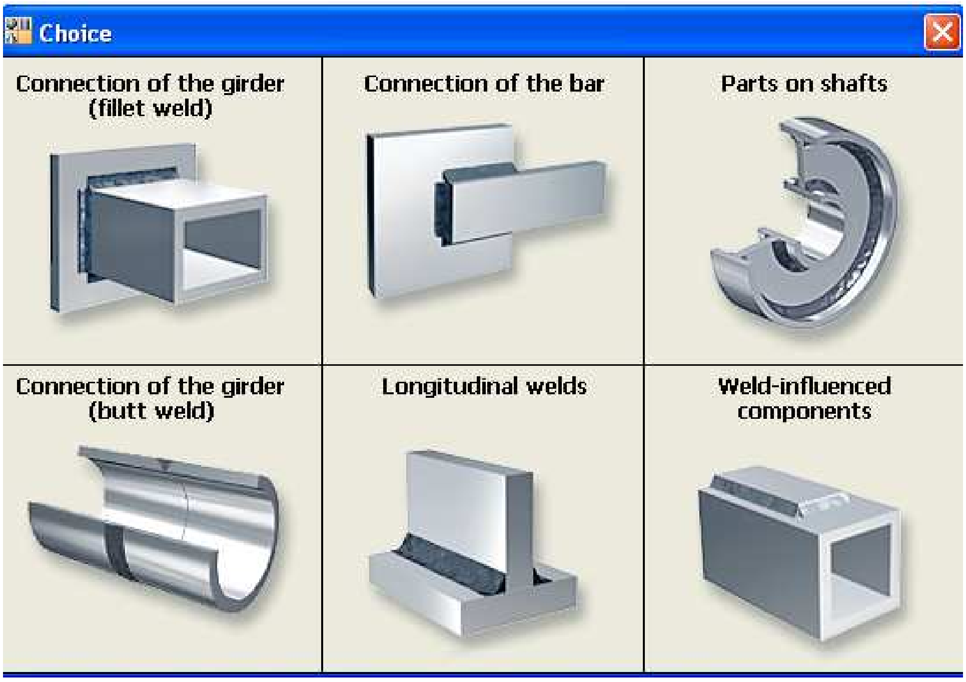


Figure 4-15: Connection forms of the welds

Geometry of the girder:

The task defines that the girder is a standardized I-beam, so please select “Standard profiles”.

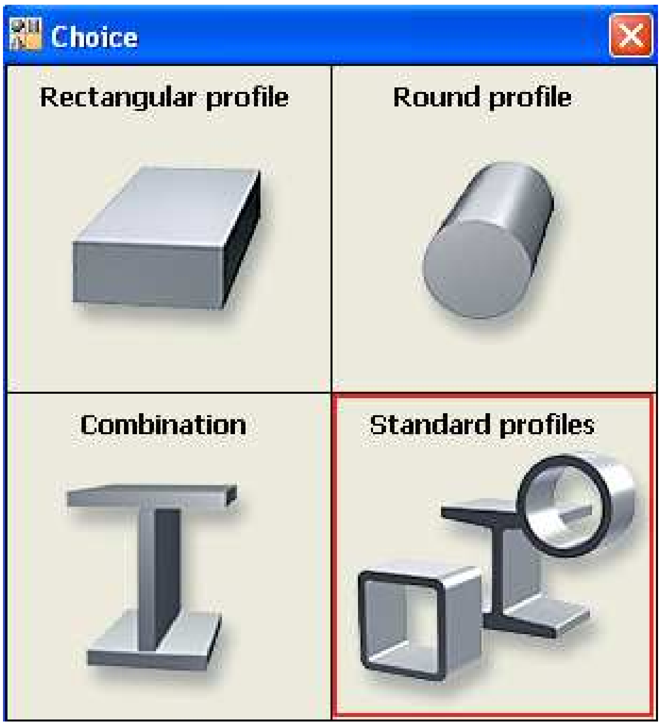


Figure 4-16: Selection of girder

Standard profile database

After this selection the following window will appear:

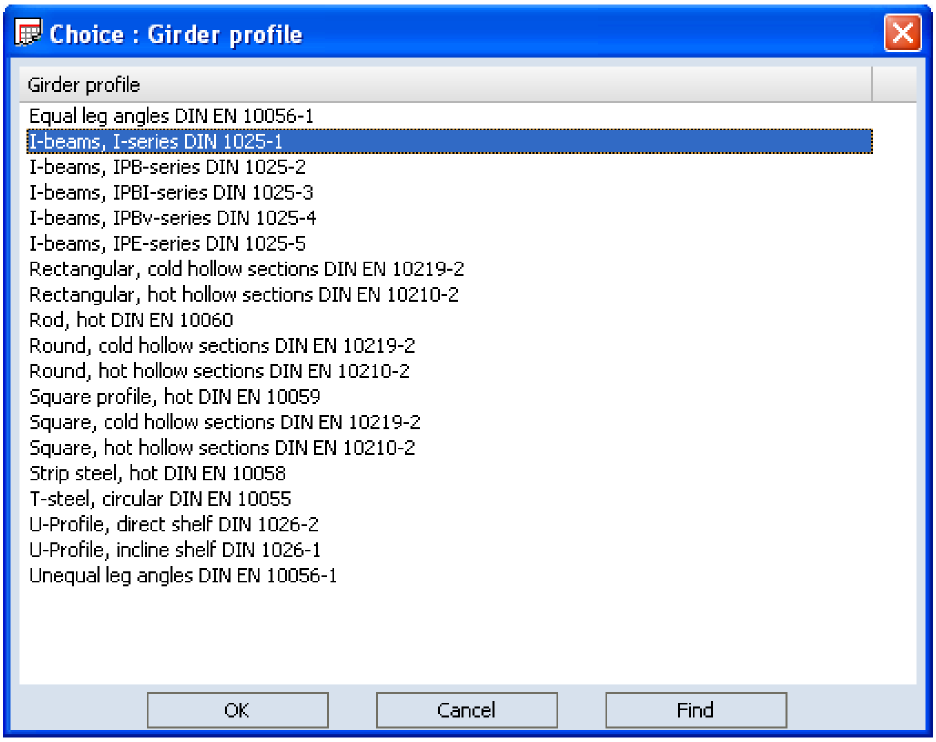
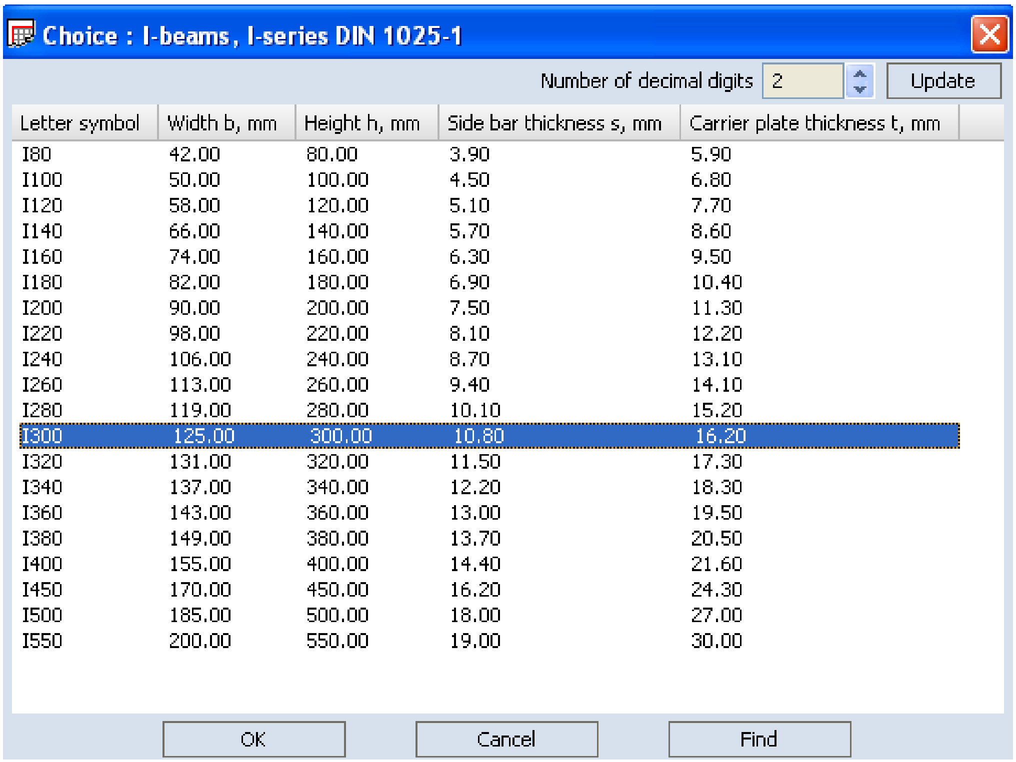


Figure 4-17: Selection of standard profile

Please select the profile for our example (I-beams, I-series DIN 1025-1). Please confirm your selection by pressing “OK”. The following window shows all available girder profiles of this series:



Letter symbol	Width b, mm	Height h, mm	Side bar thickness s, mm	Carrier plate thickness t, mm
I80	42.00	80.00	3.90	5.90
I100	50.00	100.00	4.50	6.80
I120	58.00	120.00	5.10	7.70
I140	66.00	140.00	5.70	8.60
I160	74.00	160.00	6.30	9.50
I180	82.00	180.00	6.90	10.40
I200	90.00	200.00	7.50	11.30
I220	98.00	220.00	8.10	12.20
I240	106.00	240.00	8.70	13.10
I260	113.00	260.00	9.40	14.10
I280	119.00	280.00	10.10	15.20
I300	125.00	300.00	10.80	16.20
I320	131.00	320.00	11.50	17.30
I340	137.00	340.00	12.20	18.30
I360	143.00	360.00	13.00	19.50
I380	149.00	380.00	13.70	20.50
I400	155.00	400.00	14.40	21.60
I450	170.00	450.00	16.20	24.30
I500	185.00	500.00	18.00	27.00
I550	200.00	550.00	19.00	30.00

Figure 4-18: Selection of girder profile

Please select the girder profile I300. The corresponding values for the width, height, web thickness (side bar) and flange thickness (carrier plate) of the girder will be automatically transferred to the input page.

The other selections for the girder geometry are rectangular profile, round profile and combination. Choosing “Combination” enables you to generate the following combination types:

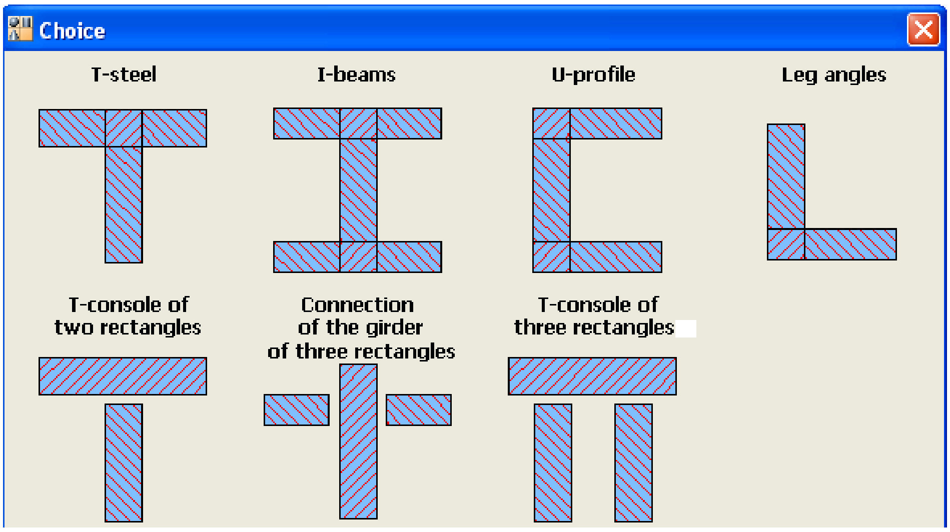


Figure 4-19: Combination types

Geometry of the Weld:

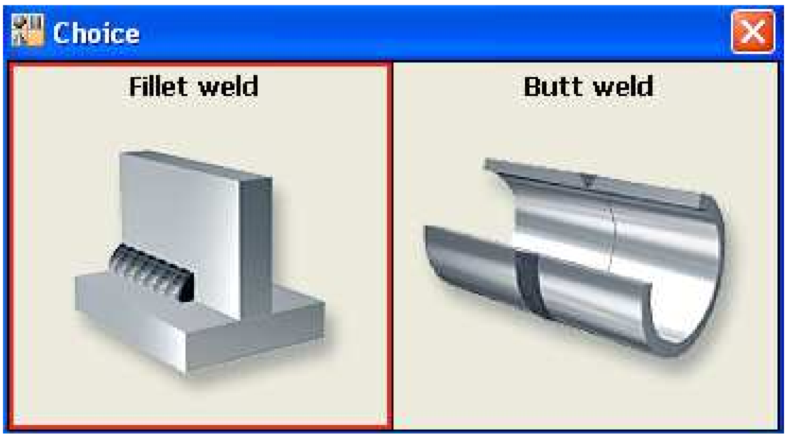


Figure 4-20: Selection of weld type

Weld types: 1. Fillet weld

2. Butt weld

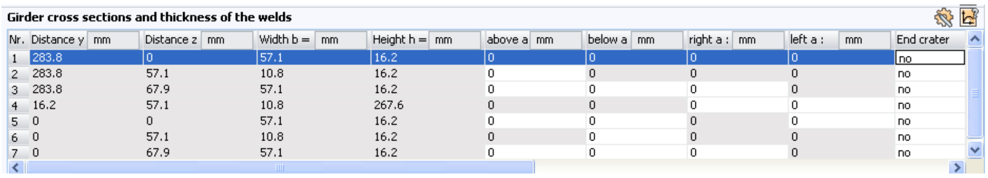
Please choose fillet weld for our example.

Circumfiential weld: yes/no

Please choose “yes” for our example.

If you choose “no” for this parameter, please be sure to specify if there are end craters that need to be taken acount of. This entry can be done in the process of the weld defininition which is the next step.

Defining the welds can be done either by entering the parameters in the following table or as it is recommened by using the graphical input assistant. The graphic input button is located above the table on the right side.


Girder cross sections and thickness of the welds

Nr.	Distance y mm	Distance z mm	Width b = mm	Height h = mm	above a mm	below a mm	right a : mm	left a : mm	End crater
1	283.8	0	57.1	16.2	0	0	0	0	no
2	283.8	57.1	10.8	16.2	0	0	0	0	no
3	283.8	67.9	57.1	16.2	0	0	0	0	no
4	16.2	57.1	10.8	267.6	0	0	0	0	no
5	0	0	57.1	16.2	0	0	0	0	no
6	0	57.1	10.8	16.2	0	0	0	0	no
7	0	67.9	57.1	16.2	0	0	0	0	no

Figure 4-21: Definition of welds

The layout of the graphical input assistant for defining the welds is similar to the one we used for the shaft calculation.

After starting the assistant it will show a cross section of the selected standard profile.

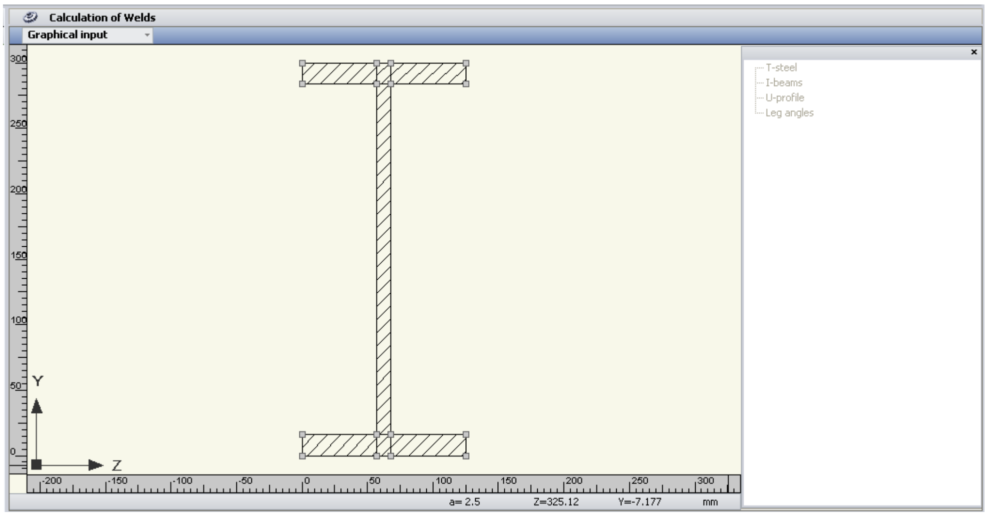


Figure 4-22: Graphical input assistant calculation of welds, cross section

You can add welds to the profile by using the mouse. Please select one of the highlighted points and keep the left mouse button pressed while you move the cursor to the next point. If the input was successful a green line will appear, representing the weld.

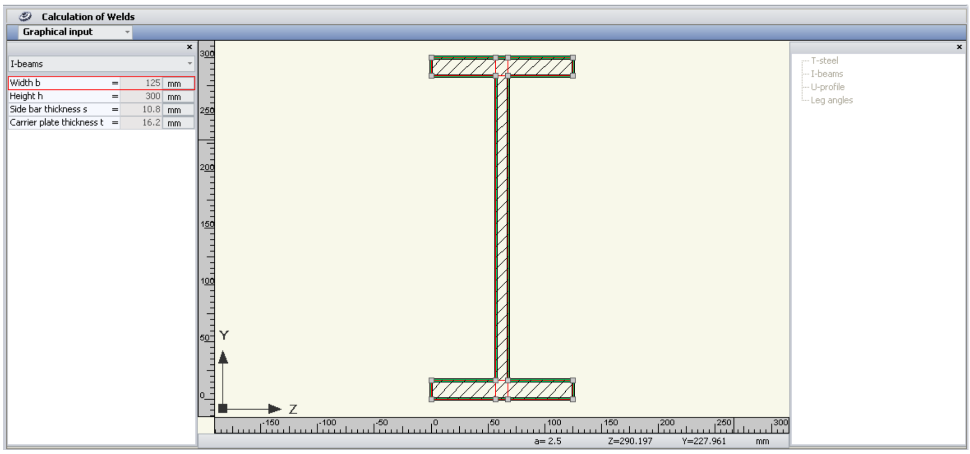


Figure 4-23: Graphic input assistant – cross section with welds

Figure 4-23 shows the girder of our example with a circumfiential weld according to the task.

The weld data are automatically transferred to the table on the input page. Only the thickness a=7mm needs to be enterend manually for each weld.

Load specifications:

When you enter the load specifications please keep in mind that all parameters are internal forces in the plane of the weld cross section (see text help "Load specifications").

The internal forces need to be calculated manually according to the balance of forces or by using the MDESIGN module "Beam calculation" which is the way we choose for this example.

To calculate the internal forces please start the „Beam calculation" module and enter all girder characteristics and load parameters. The standard profile database is available in this module also so that the girder can be directly selected without the need to enter all parameters manually.

Please define the shear load at the end of the girder in the table for the radial forces. The bearing is a rigid clamping (fixing) located at x=0.

The calculation yields the following results as loads for the welds:

Results of girder calculation

The force balance results in a shear force Fz=-50000N.

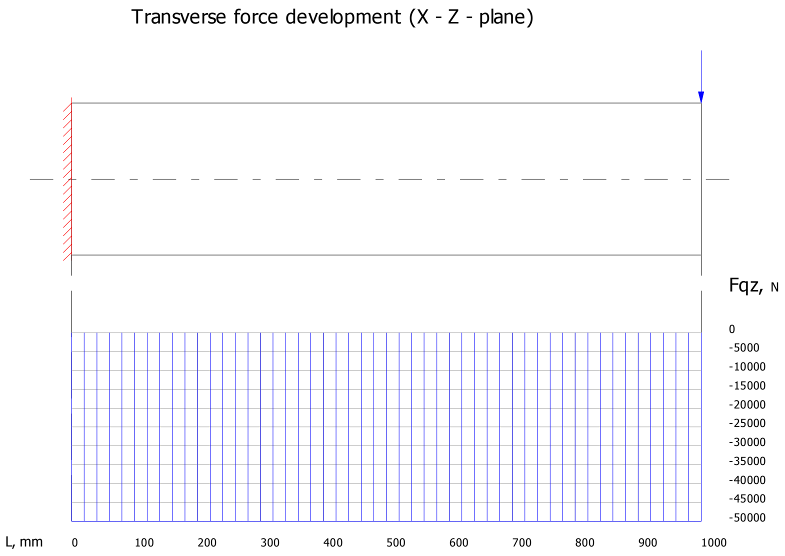


Figure 4-24: Transverse force development

The bending moment developement shows the bending moment in the plane of the weld cross section.

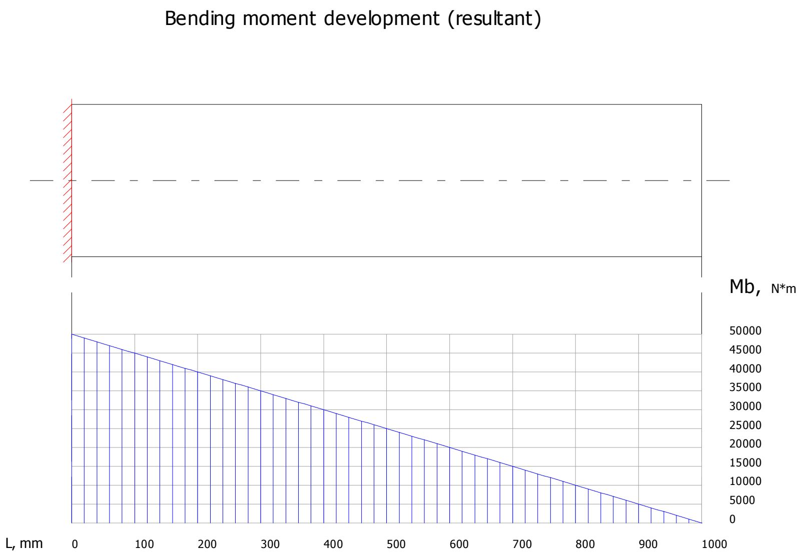


Figure 4-25: Bending moment development

So there are the following loads in the plane of the weld cross section:

Shear load: F_z = -50000 N

Bending moment: Mb_y = 50000 Nm

When you enter these loads in the input page of the weld calculation, please note that the coordinate system is different to the one in the girder calculation.

Loads

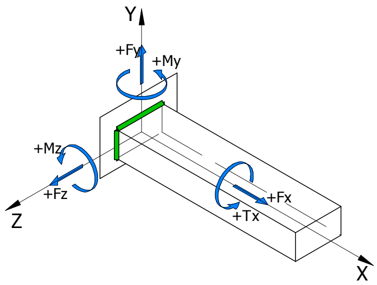


Figure 4-26: Definition of loads for the weld calculation

Loads according to the weld calculation coordinate system:

Shear load: F_y = 50000 N

Bending moment: Mb_z = 50000 Nm

Factors for maximum load:

It is possible to add a factor for maximum load to each force or moment to include infrequent overloads. These factors do only affect the static strength proof. Frequent overloads (N>1000) need to be entered as loads. They are part of the dynamic strength proof. For our example we do not enter any maximum loads.

Calculation method:

The calculation shall be performed according to instruction sheet DVS 0705.

Internal stresses:

There are no internal stresses that need to be considered.

Number of load changes (cycles):

The weld connection shall be rated for endurance strength so that the number of cycles shall be 2*10^6.

Type of stress (load):

There is a pulsating load for the normal stress as well as for the shear stress, so it is required to choose “dynamic pulsating” in both cases.

Vibration strength class (FAT):

For the safety analysis (strength proof) according to instruction sheet DVS 0705 it is required to specify the component classes (the so called vibration strength class

FAT). Please find the worksheets of the standard in MDESIGN by pressing the FAT text help button. These worksheets help to specify the right FATs.

These are the FATs for our example:

Normal stress: FAT 90

Shear stress: FAT 80

Maximum part thickness at the weld:

The maximum thickness of the component is required for the strength proof. In our example this is the flange thickness (carrier plate thickness).

Material specifications:

Please select a material, the material parameters will be filled in automatically.

Step 3- Results and documentation

Please press the "Calculate" button to start the calculation.

After finishing the calculation successfully the program will display all results on the output page.

The first results are intermediate results that are required for the calculation.

Results of the weld calculation

Welds- cross-section values

Rectangle No.	**Area Aw** mm²	**Moment of gyration, y-axis, Iw** cm4	**Moment of gyration, z-axis, Iw** cm4
1	912.800	158.202	1843.798
2	75.600	0.073	170.131
3	912.800	158.202	1843.798
4	3746.400	12.454	2235.657
5	912.800	158.202	1843.798
6	75.600	0.073	170.131
7	912.800	158.202	1843.798

Total area of the welds: Aw ges = 7548.800 mm²

Total moment of gyration, y-axis Iw ges = 645.409 cm^4

Total moment of gyratioin, z-axis Iw ges = 9951.110 cm^4

The next results are the stresses in the welds.

Stresses in the welds

	Des.	**Amplitude** N/mm²	**Mean value** N/mm²	**Upper load** N/mm²	**Maximum load** N/mm²
Stresses caused by axial force F_x	$\sigma_\perp$	0.000	0.000	0.000	0.000
Stresses caused by shear force F_y	$\tau\|\|$	-5.952	-5.952	-11.905	-11.905
Stresses caused by shear force F_z	$\tau\|\|$	0.000	0.000	0.000	0.000
Stresses caused by bending moment M_y	$\sigma_\perp$	0.000	0.000	0.000	0.000
Stresses caused by bending moment M_z	$\sigma_\perp$	37.684	37.684	75.368	75.368

And the end of the output page you can find the strength proof. Contrary to the classic strength proof where a value of >1 indicates a sufficient strength a value of <1 varifies the sufficient dimensioning in a weld strength proof.

Static strength proof:	5.130e-1 < 1
Dynamic strength proof:	9.377e-1 < 1

Both values are <1 for our example. The weld seam connection is sufficiently dimensioned.

The graphic help window shows the cross section of the weld as a result graphic.

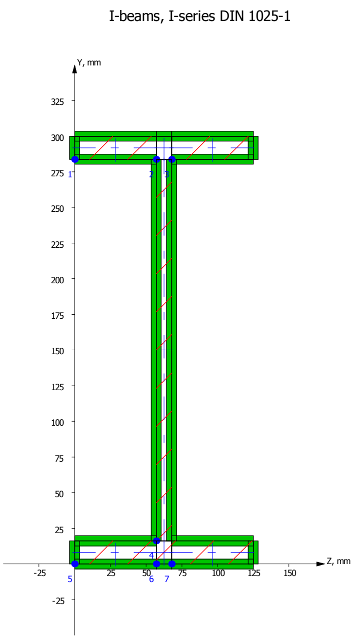


Figure 4-27: Result graphic

5 Summary

The introduction of this tutorial presents the advantages and disadvantages of the manual and software based calculation of machine elements.

The emphasis is put on the risks of automatic simplifications and abstraction the calculation program performs during the calculation. An intensive engagement with the basics of the calculation standards is absolutely required also for the use of an approved calculation program.

There are however significant advantages of the usage of CAE-software. One of the key advantages is that MDESIGN offers a consistent and comprehensive documentation with mimimum effort to comply the quality assurance requirements.

At first the tutorial gives an overview about the general functions of MDESIGN. Later on these functions and their handling are explained step by step. Some special functions are module specific and cannot be explained in detail, but as all functions work in a similar way, it is possible to transfer the general handling to the specific functions also.

At the end of the turorial the calculation examples give the opportunity to reproduce the handling of the program. It is possible to understand the examples by theoretically working on them but this can not replace the practical experience. It is highly recommended to work on the program practically as well.