Ansys Mechanical Linear and Nonlinear Dynamics

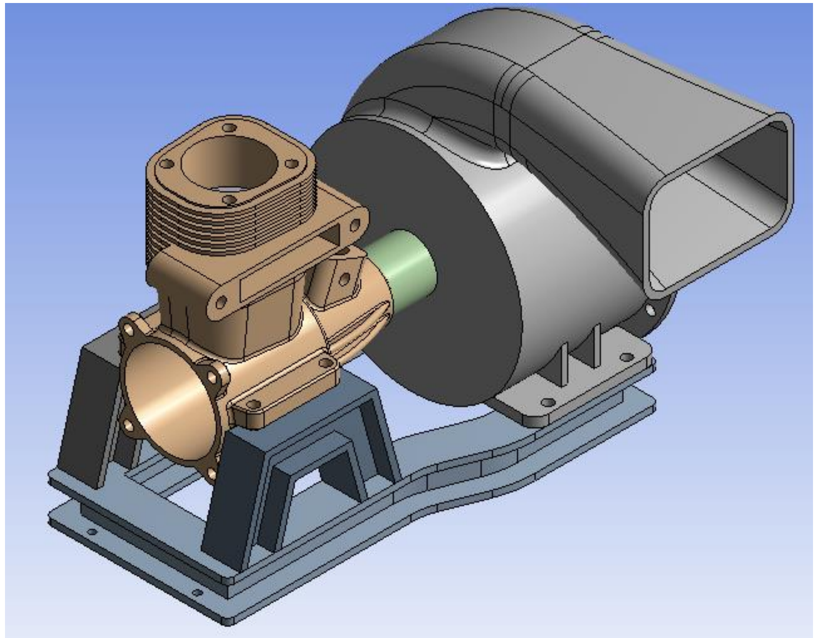
WS 10.1: Blower Frame CMS

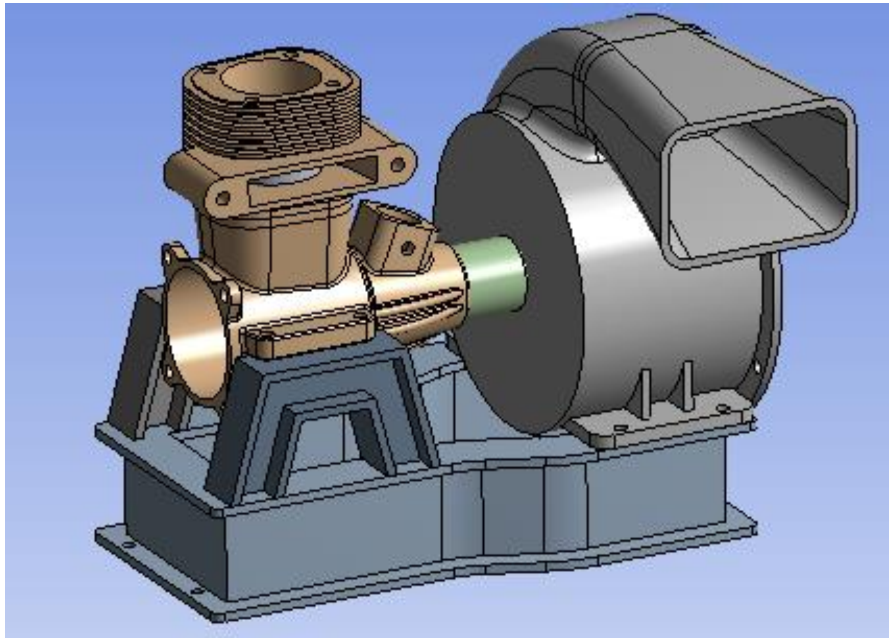
Release 2022 R2

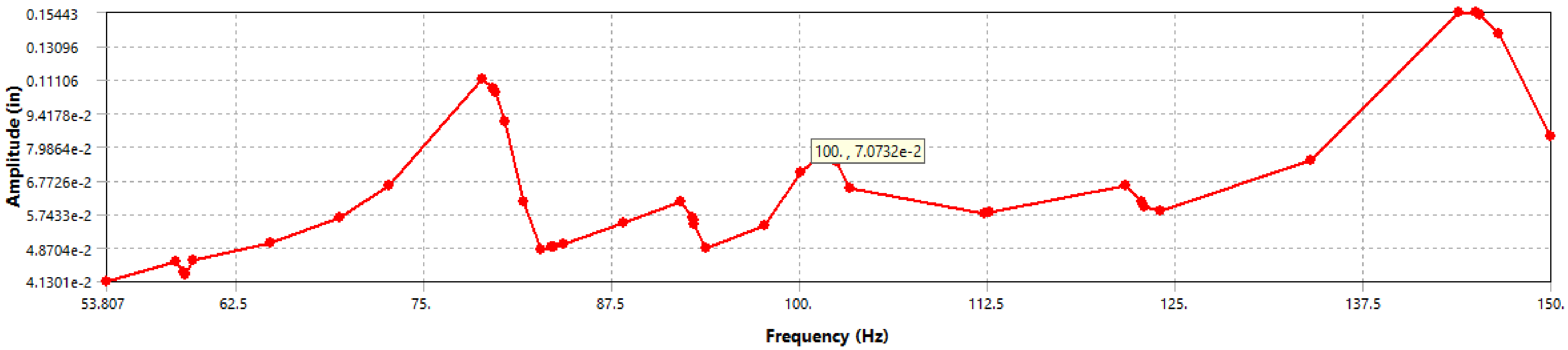
Please note:
- These training materials were developed and tested in Ansys Release 2022 R2. Although they are expected to behave similarly in later releases, this has not been tested and is not guaranteed.
- The screen images included with these training materials may vary from the visual appearance of a local software session.
- Although some workshop files may open successfully in previous releases, backward compatibility is somewhat unlikely and is not guaranteed.

Ansys

Workshop 10.1: Blower Frame Component Mode Synthesis





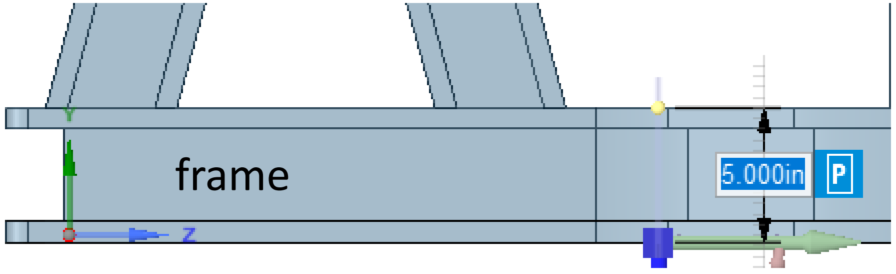


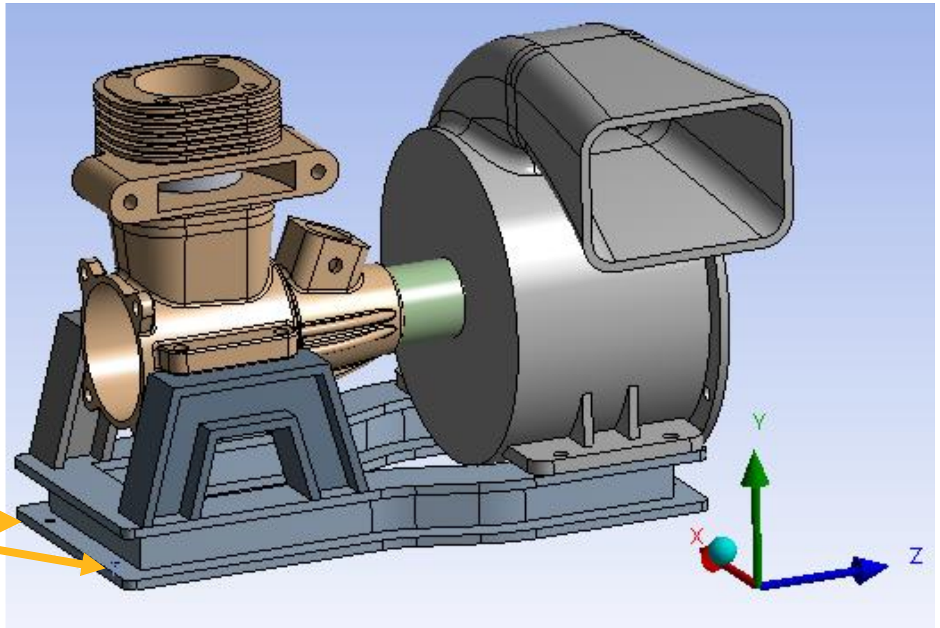
Workshop 10.1 - Goals

- Our goal is to use Component Mode Synthesis (CMS) while studying the harmonic response of a Blower Frame to a base excitation displacement of 0.030” at 100 Hz frequency.
  - Establish a baseline harmonic solution of the full model to be used to validate the CMS approach
  - Replicate the full model solution using condensed parts representing all but the frame part
  - Vary the height of the frame attempting to reduce the stress in the frame at the 100 Hz excitation frequency
    - Achieve a stress less than 20,000 psi in the top flange of the frame
    - Reduce solution time during the design iterations by using CMS

Workshop 10.1 - Model Description

- The blower frame assembly consists of a frame support structure, 5” high, mounted to a structure (not shown) that vibrates at a constant 0.030” amplitude at 100Hz in the Y direction.
  - The model file is supplied as *WS10.1 – Blower_Frame.wbpz*



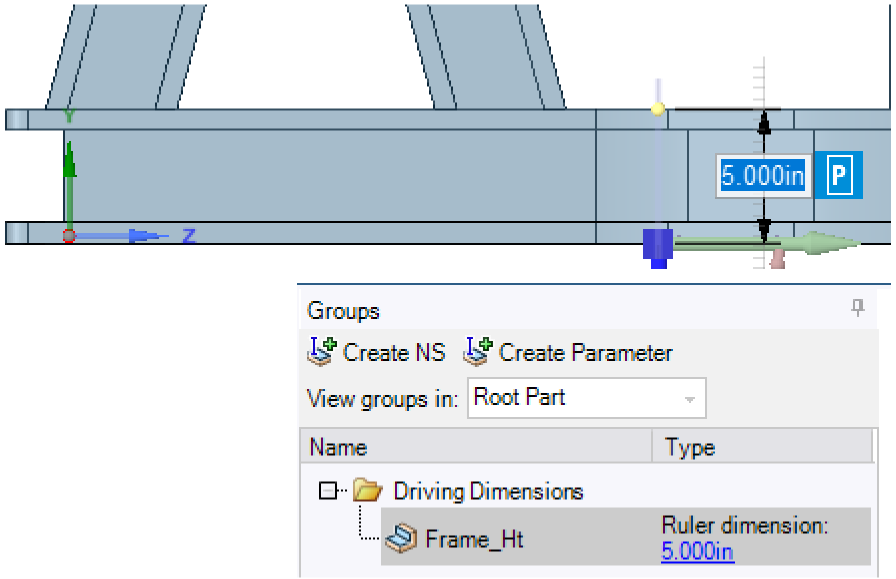


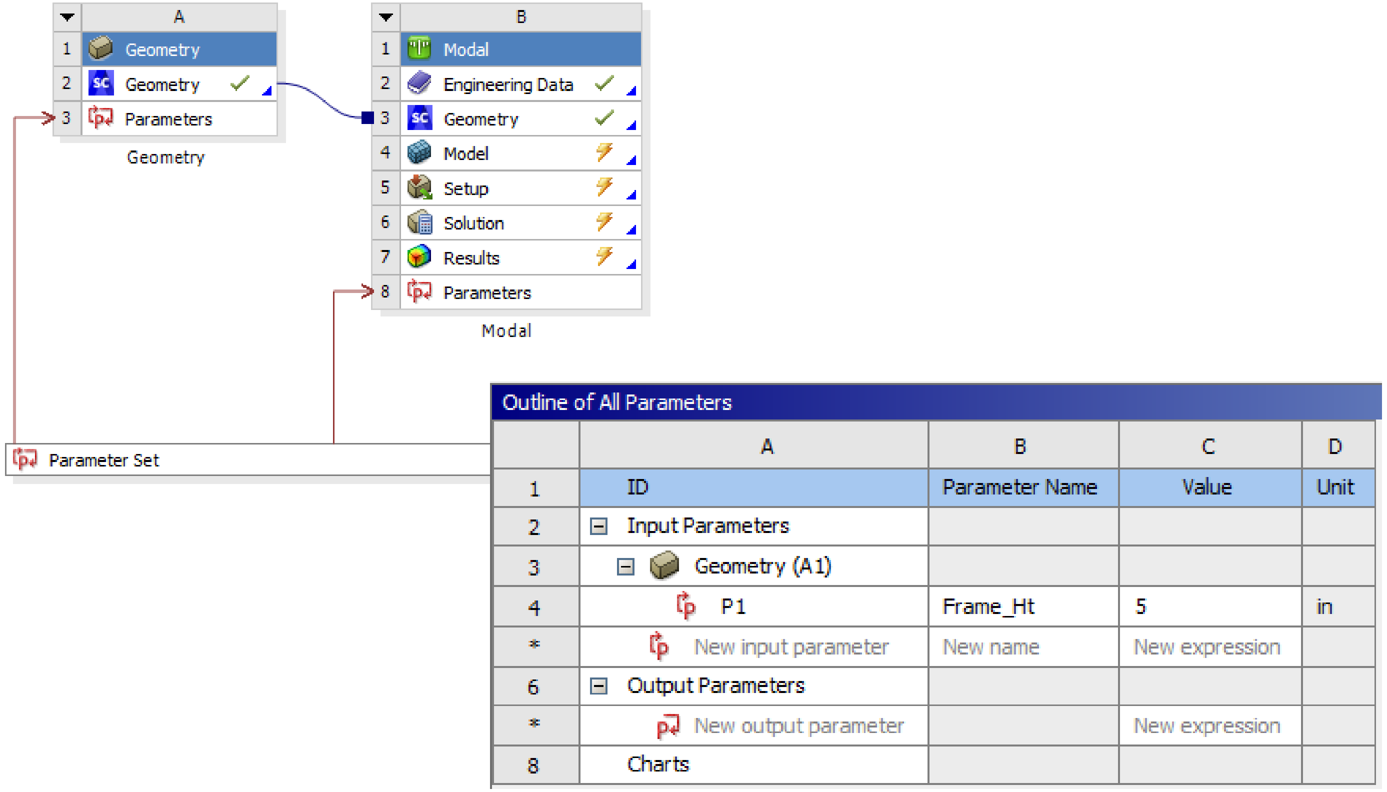
Frame mounts, each end

Ansys

Workshop 10.1 - Model Description

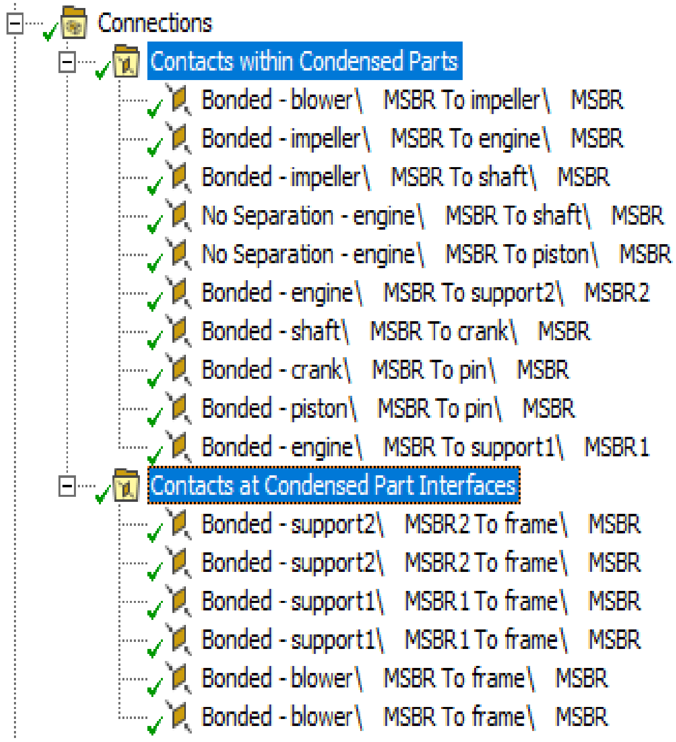
- The frame height is defined as a driving dimension in SpaceClaim, and thus appears as an input parameter in the Parameter Set of the Project Schematic.
  - *This workshop requires a license of Ansys SpaceClaim in order to complete the design iterations*

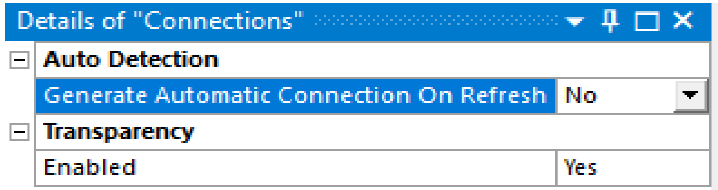




Workshop 10.1 - Model Description

- The Connections branch contains two Contact definition folders.
  - Contacts Within Condensed Parts
    - These contacts will be completely within condensed parts.
  - Contacts at Condensed Part Interfaces
    - These contacts will be used to “join” condensed parts to the frame structure.
    - *Note: For best solution performance when generating condensed parts (Generation Pass), it is recommended to use Fixed Joints at all condensed part interfaces; In this case, the number of masters resulting from bonded contact will be minimal and will have little impact on solution time during the generation pass.*
  - The Auto Detection setting in the Details of the Connections branch has been set to “No” in order to prevent additional contacts from being generated upon design updates of the frame body.





Ansys

Workshop 10.1 – Engineering Challenge

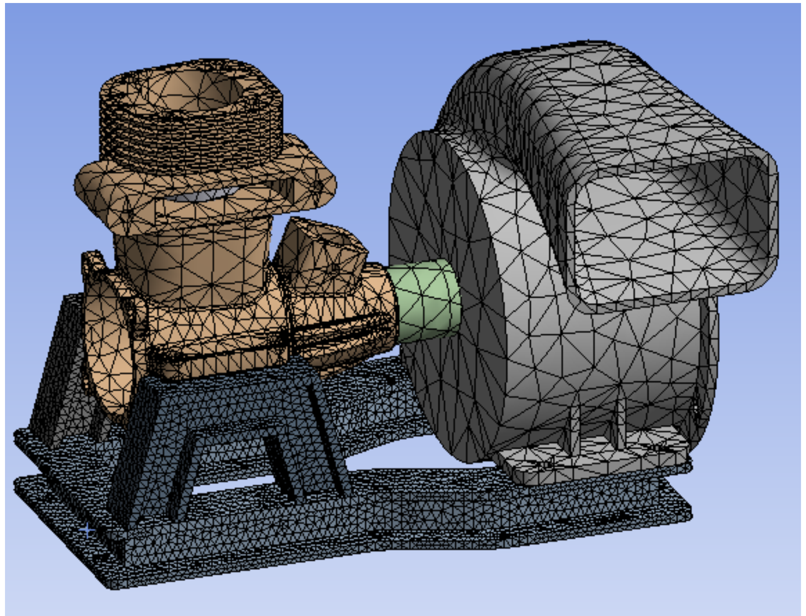
- With the blower frame assembly subjected to a constant harmonic excitation at its supports, there is a concern that modes at or near the excitation frequency of 100 Hz will be excited and thus cause serious structural damage to the frame.
- Perform a modal analysis to determine the presence of frequencies at or near 100 Hz.
- Perform a harmonic analysis and evaluate the stress in the flanges of the frame at the 100 Hz excitation frequency.
- Modify the frame height in order to shift frame frequencies further away from the 100 Hz excitation.
- Perform design iterations on the frame height until the stress in the top flange of the frame falls below 20,000 psi.

Workshop 10.1 – General Workflow

- Open the supplied *WS10.1 – Blower_Frame.wbpz* archive
- This workshop will be completed in three phases
  1. Baseline modal and harmonic solutions of the full model
  2. Baseline CMS modal and harmonic solutions using condensed parts representing all but the frame body
     - Natural frequencies of this model should match those of the baseline full model solution
  3. Design iterations of the frame using CMS to produce stress in the top flange less than 20,000 psi.
     - Frame stock is available in standard height dimensions of 5”, 8”, 10” and 12”.

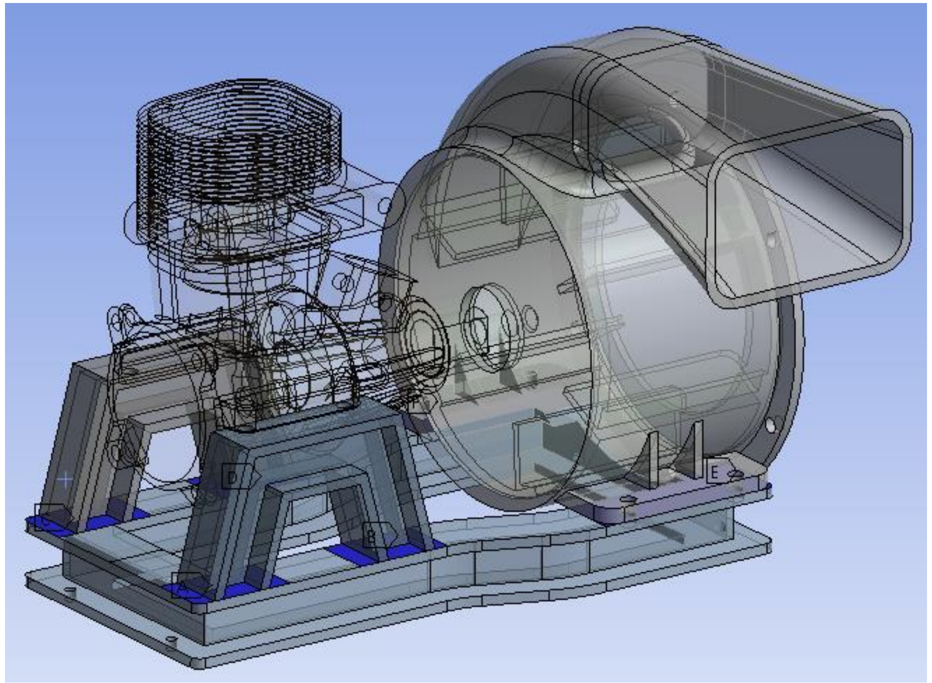
Workshop 10.1 – General Workflow – Baseline *Full Model* Solution

- Set up a Mode Superposition Harmonic analysis using the supplied Modal analysis already defined.
- Enter Mechanical and assign mesh size controls to the frame body (0.75”) and the two support bodies (0.75”).
  - It’s a good idea to create two separate size controls, as the support bodies will eventually be within a Condensed Part while the frame will not.
- Add mesh size control to the blower body(3”).

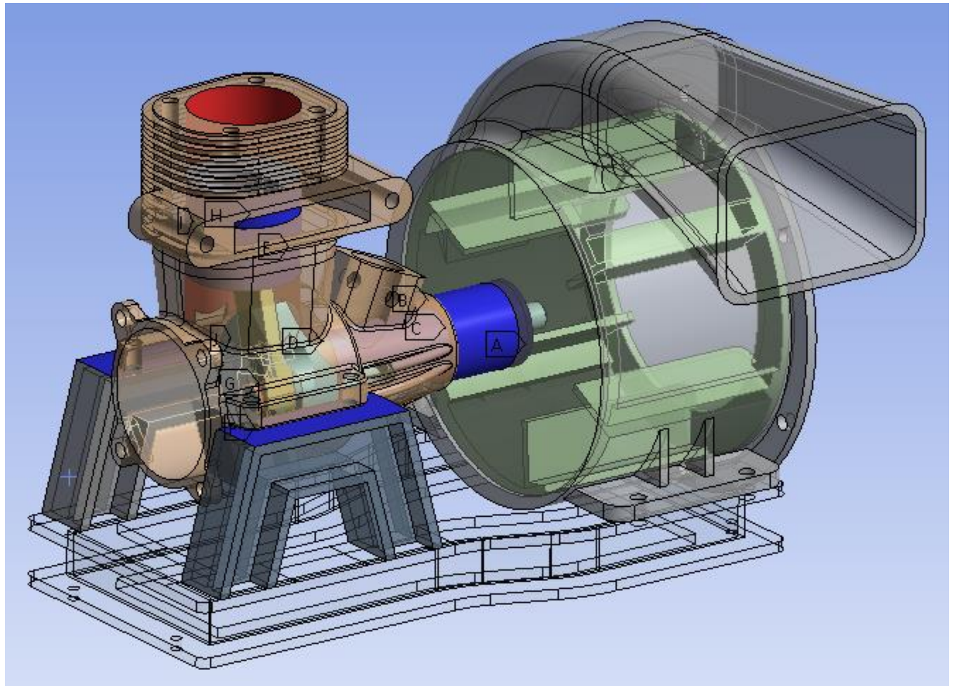


Workshop 10.1 – General Workflow – Baseline *Full Model* Solution

- Contact between:
  - All bodies touching the frame

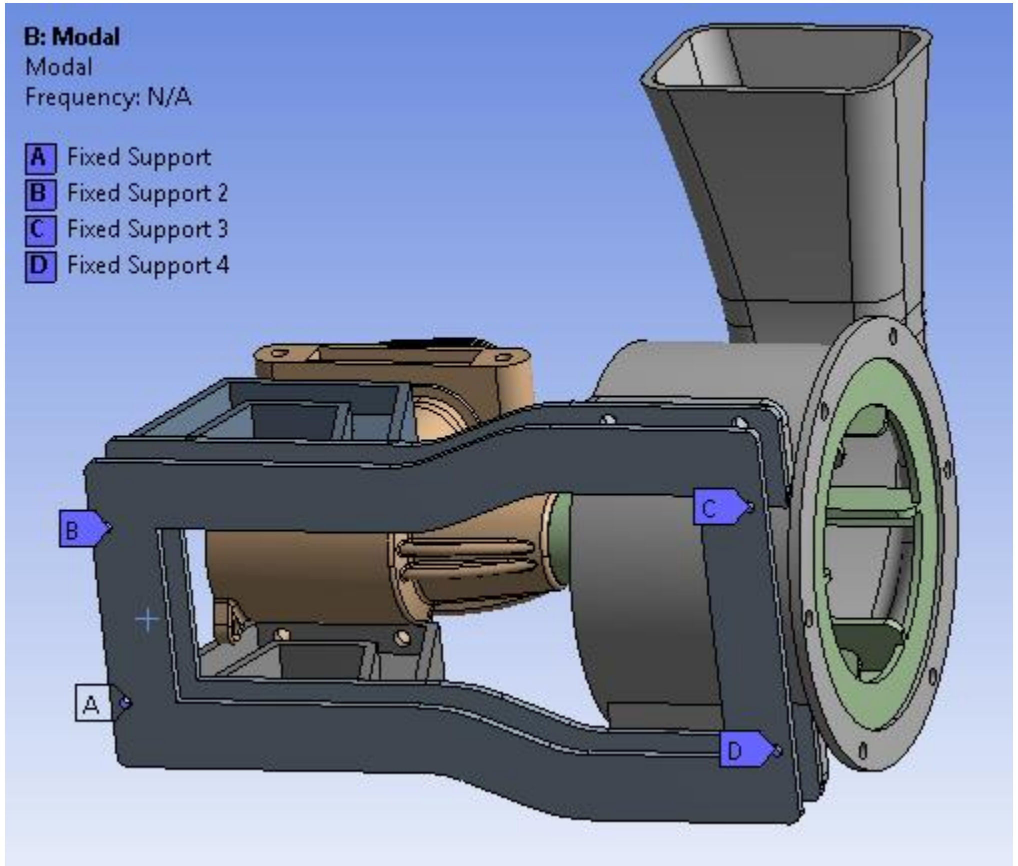


- Contact between:
  - All bodies except the frame



Workshop 10.1 – General Workflow – Baseline *Full Model* Solution

- Define a fixed support at each of the frame mounting holes.
  - Scoping each hole individually allows for the base excitation loading to be in-phase or out-of-phase with one another, if desired.



Ansys

Workshop 10.1 – General Workflow – Baseline *Full Model* Solution

- Modal Analysis Solution
  - The modal analysis should capture modes up to 1.5X the excitation frequency, or 150 Hz.
  - Start by extracting 12 modes during the modal analysis.
- Generate and review mode shape results and think about these questions:
  - Are there natural frequencies at/near the 100 Hz excitation frequency?
  - Did the modal analysis find sufficient modes to encompass 1.5X the excitation frequency?
  - Review the Participation Factor Summary
    - What mode(s) do you expect to be excited by the 100 Hz base excitation in the Y direction?
    - What mode(s) will be critical to stress in the frame?
    - What's the Ratio of Effective Mass to Total Mass in the Y direction?

Workshop 10.1 – General Workflow – Baseline *Full Model* Solution

Note: your result magnitudes may vary slightly throughout this workshop due to mesh and software release differences

- Modal Analysis Results

Tabular Data

	Mode	Frequency [Hz]
1	1.	59.009
2	2.	79.638
3	3.	83.451
4	4.	92.862
5	5.	102.33
6	6.	122.88
7	7.	145.17
8	8.	182.04
9	9.	184.96
10	10.	207.32
11	11.	230.5
12	12.	259.61

Participation Factor

Mode	Frequency [Hz]	X Direction	Y Direction	Z Direction
1	59.009	1.7186	0.13117	5.258e-002
2	79.638	-0.21254	0.77944	1.077e-002
3	83.451	9.6945e-002	-8.3557e-002	4.236e-002
4	92.862	8.6582e-002	0.59745	-0.76271
5	102.33	8.6327e-002	-0.39335	1.2754
6	122.88	-0.39501	0.42825	0.52318
7	145.17	5.9822e-002	-0.82114	-0.6962
8	182.04	-0.6084	-0.89617	-0.15495
9	184.96	0.31619	-0.79842	-1.1093e-002
10	207.32	-0.28015	0.41066	-0.33267
11	230.5	0.12118	-0.18009	-0.55664
12	259.61	-7.6174e-002	0.17477	8.1785e-002

Ratio of Effective Mass to Total Mass

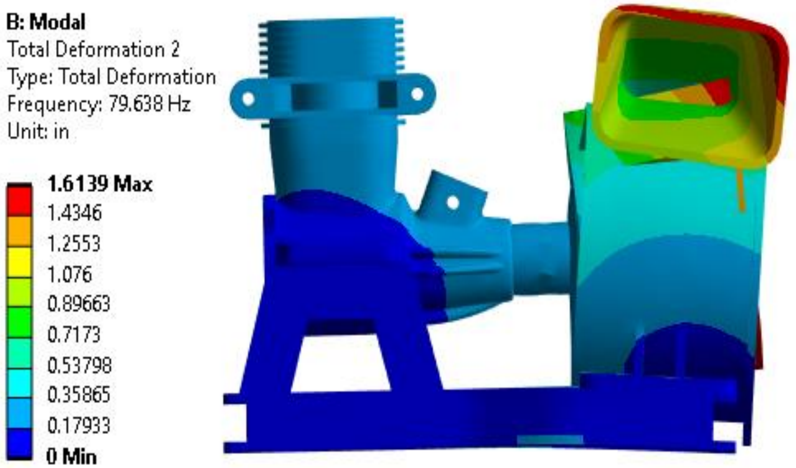
Mode	Frequency [Hz]	X Direction	Y Direction	Z Direction
1	59.009	0.65888	3.8381e-003	6.167e-004
2	79.638	1.0077e-002	0.13552	2.5875e-005
3	83.451	2.0965e-003	1.5574e-003	4.0026e-004
4	92.862	1.6722e-003	7.9624e-002	0.12976
5	102.33	1.6624e-003	3.4514e-002	0.36284
6	122.88	3.4807e-002	4.091e-002	6.1058e-002
7	145.17	7.9829e-004	0.15041	0.10812
8	182.04	8.2568e-002	0.17915	5.3557e-003
9	184.96	2.2301e-002	0.1422	2.7447e-005
10	207.32	1.7507e-002	3.7618e-002	2.4687e-002
11	230.5	3.2757e-003	7.2345e-003	6.9116e-002
12	259.61	1.2943e-003	6.8136e-003	1.4921e-003
Sum		0.83694	0.81938	0.7635

Workshop 10.1 – General Workflow – Baseline Full Model Solution

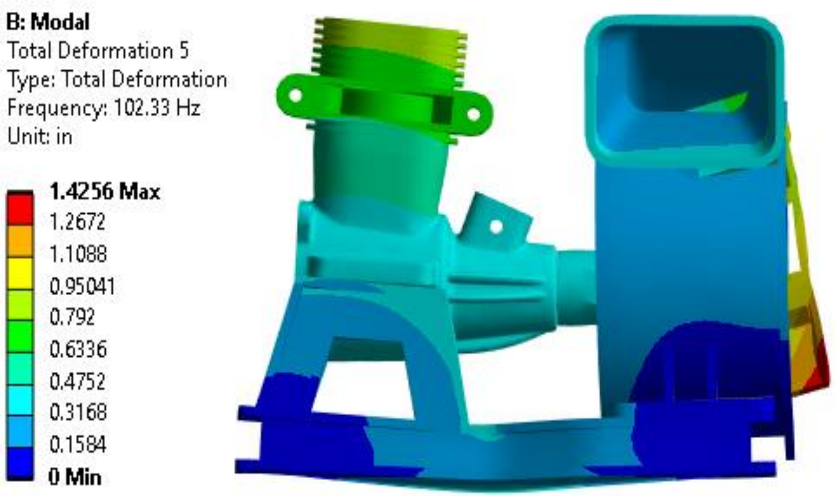
Note: your result magnitudes may vary slightly throughout this workshop due to mesh and software release differences

- Modal Analysis Results
  - Modes 2, 4, 5, and 7-9 all have high participation factors in the Y direction.
  - Modes 7-9 are likely far enough away from the 100 Hz excitation frequency.
  - Modes 2 and 4 exhibit very little frame deformation.
  - Y Deformation of the frame structure is most prevalent in mode 5 and this mode is very near the excitation frequency.

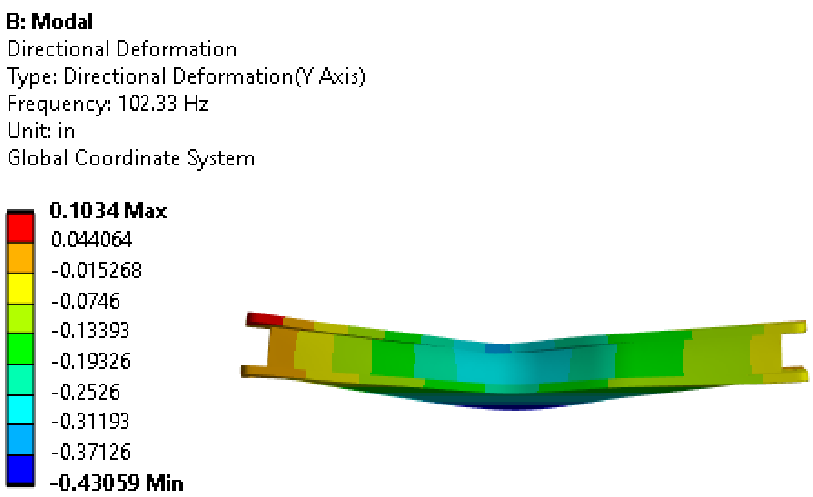
Mode 2



Mode 5



Mode 5 frame Y deformation



Ansys

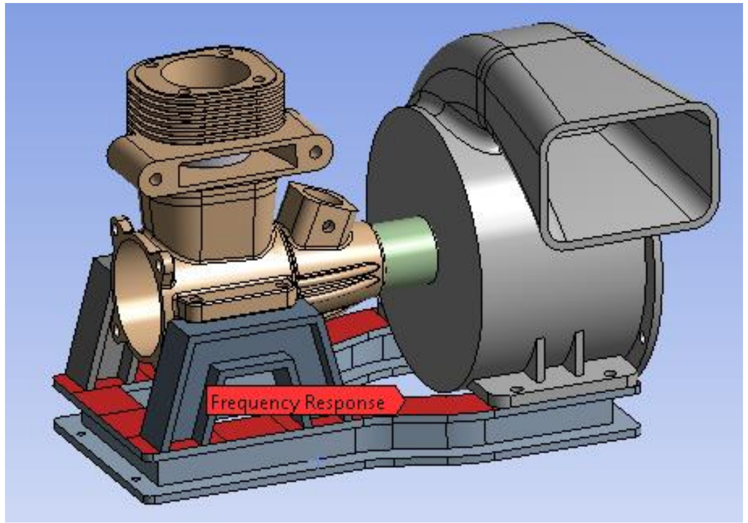
Workshop 10.1 – General Workflow – Baseline *Full Model* Solution

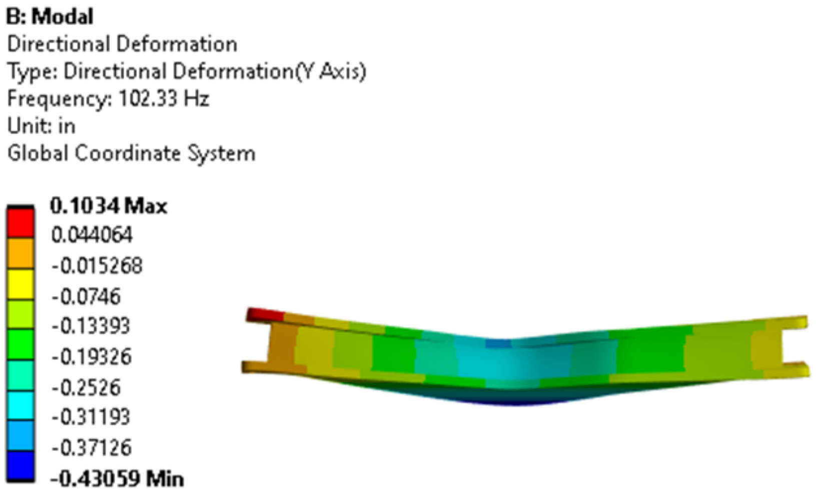
- The Harmonic Solution is performed as a Mode-Superposition solution.
  - Run the harmonic solution from 0 Hz to 150 Hz
  - The solution can be run at discrete solution intervals of interest, or it can be run by clustering results around natural frequencies.
    - The cluster option provides peak results at all natural frequencies within the harmonic excitation range.
  - In addition to the cluster option, User-Defined Frequencies can be requested to provide results at discrete frequencies of interest.
    - Define a User-Defined Frequency at 100 Hz, the frequency of the base excitation load
  - Assume a global damping ratio of 3% for this solution
  - Define the base excitation load of 0.03” acting in the Y direction at all support locations
    - Don’t forget to activate the Base Excitation option on the displacement loading in order to fully validate the loading
  - Solve

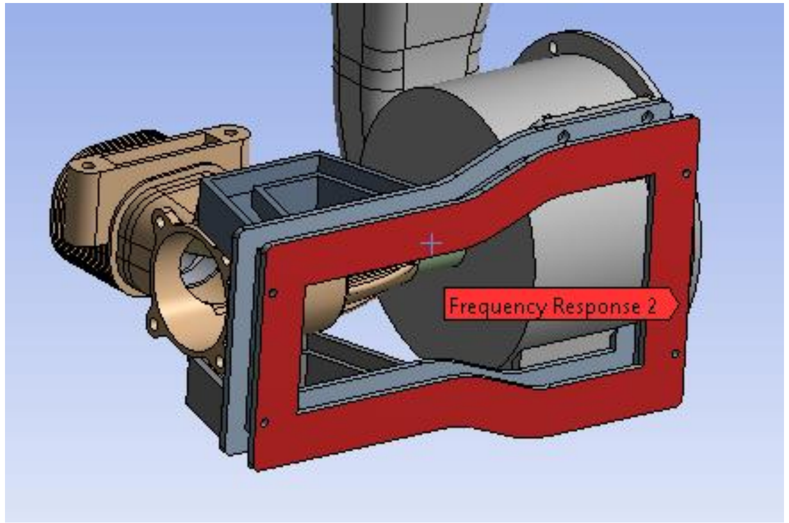
Workshop 10.1 – General Workflow – Baseline *Full Model* Solution

Note: your result magnitudes may vary slightly throughout this workshop due to mesh and software release differences

- Harmonic Analysis Results
  - Mode 5 is a primary bending mode of the frame. The top and bottom flanges will be placed in tension/compression.
  - Insert two Frequency Response Deformation objects using the top and bottom frame faces
    - Monitor maximum amplitude in Y direction







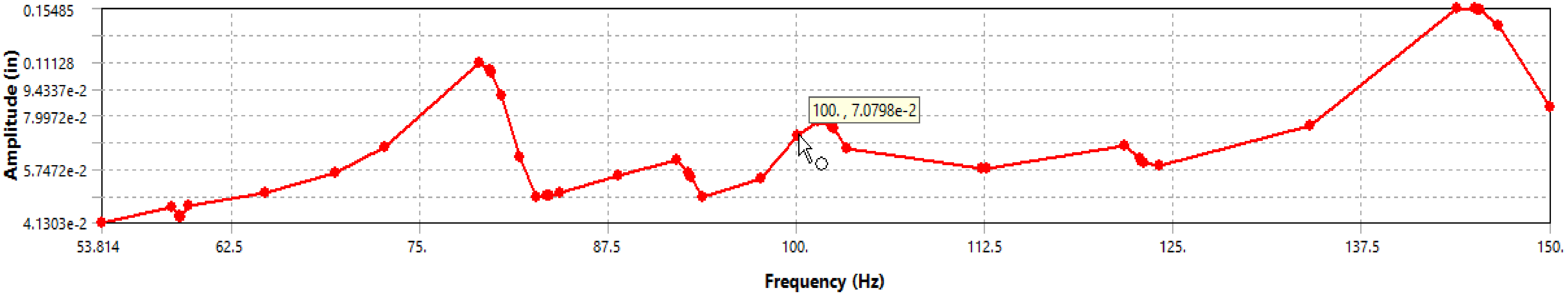
Workshop 10.1 – General Workflow – Baseline *Full Model* Solution

Note: your result magnitudes may vary slightly throughout this workshop due to mesh and software release differences

- Harmonic Analysis Results
  - Ctrl-select the data point on the curve at 100 Hz, or find it in the tabular data to see amplitude/phase angle information
  - The response at 100 Hz is close enough to a natural frequency to cause concern
  - Frequency response at top flange of frame:

Tabular Data

	Frequency [Hz]	Amplitude [in]	Phase Angle [°]
25	92.945	5.467e-002	-49.158
26	93.727	4.8537e-002	-39.024
27	97.596	5.4206e-002	-28.975
28	100.	7.0798e-002	-40.664



Ansys

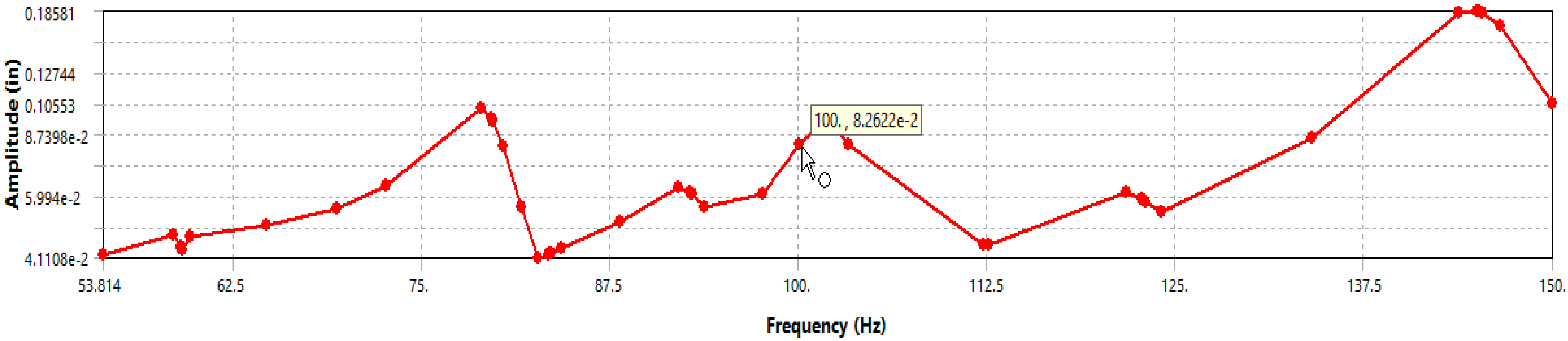
Workshop 10.1 – General Workflow – Baseline *Full Model* Solution

Note: your result magnitudes may vary slightly throughout this workshop due to mesh and software release differences

- Harmonic Analysis Results
  - Frequency response at bottom flange of frame:

Tabular Data

	Frequency [Hz]	Amplitude [in]	Phase Angle [°]
25	92.945	6.0708e-002	-42.184
26	93.727	5.592e-002	-44.571
27	97.596	6.0756e-002	-33.529
28	100.	8.2622e-002	-45.092



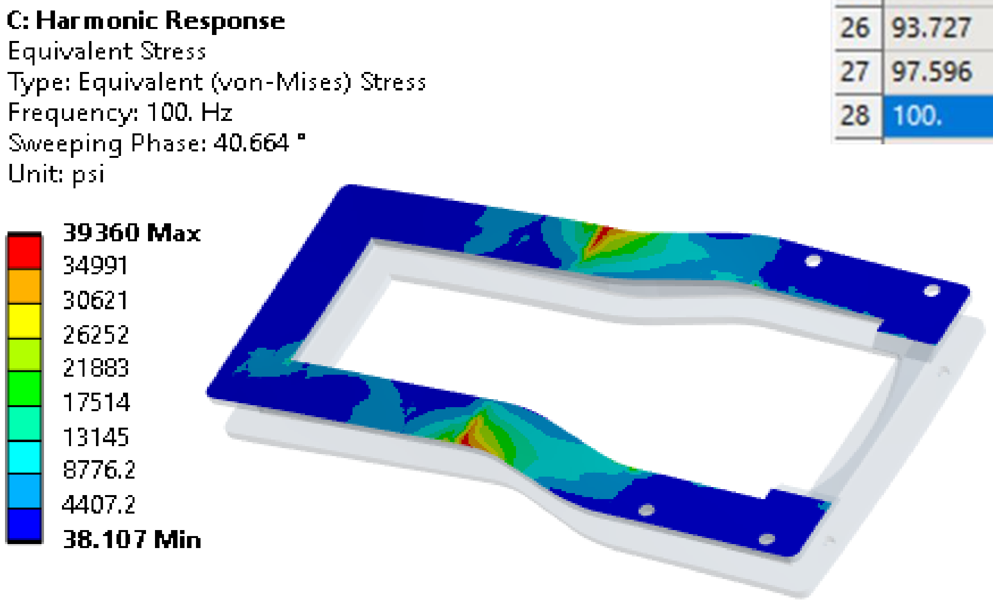
Workshop 10.1 – General Workflow – Baseline *Full Model* Solution

Note: your result magnitudes may vary slightly throughout this workshop due to mesh and software release differences

- Harmonic Analysis Results
  - Evaluate stress in the frame flanges at the 100 Hz frequency, using the phase angle obtained at that same frequency
  - Don’t forget to change the sign on the phase angle
  - Top Flange Stress:

Tabular Data

	Frequency [Hz]	Amplitude [in]	Phase Angle [°]
25	92.945	5.467e-002	-49.158
26	93.727	4.8537e-002	-39.024
27	97.596	5.4206e-002	-28.975
28	100.	7.0798e-002	-40.664



Solution (C6)
- Solution Information
- Equivalent Stress
- Equivalent Stress 2
- Frequency Response
- Frequency Response 2

Details of "Equivalent Stress"

Scope	
Scoping Method	Geometry Selection
Geometry	12 Faces
Definition	
Type	Equivalent (von-Mises) Stress
By	Frequency
Frequency	100. Hz
Amplitude	No
Sweeping Phase	40.664 °
Identifier	
Suppressed	No

Ansys

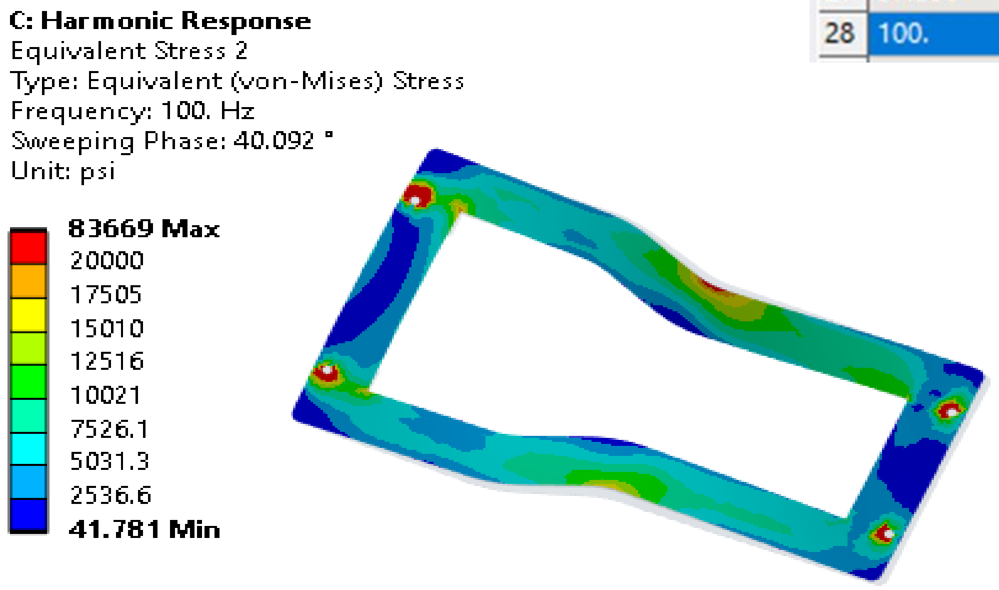
Workshop 10.1 – General Workflow – Baseline *Full Model* Solution

Note: your result magnitudes may vary slightly throughout this workshop due to mesh and software release differences

- Harmonic Analysis Results
  - Bottom Flange Stress: (contours re-scaled to 20,000 psi for better resolution away from singularities)

Tabular Data

	Frequency [Hz]	☑ Amplitude [in]	☑ Phase Angle [°]
25	92.945	6.0708e-002	-42.184
26	93.727	5.592e-002	-44.571
27	97.596	6.0756e-002	-33.529
28	100.	8.2622e-002	-45.092



- Solution (C6)
  - Solution Information
  - Equivalent Stress
  - Equivalent Stress 2
  - Frequency Response
  - Frequency Response 2

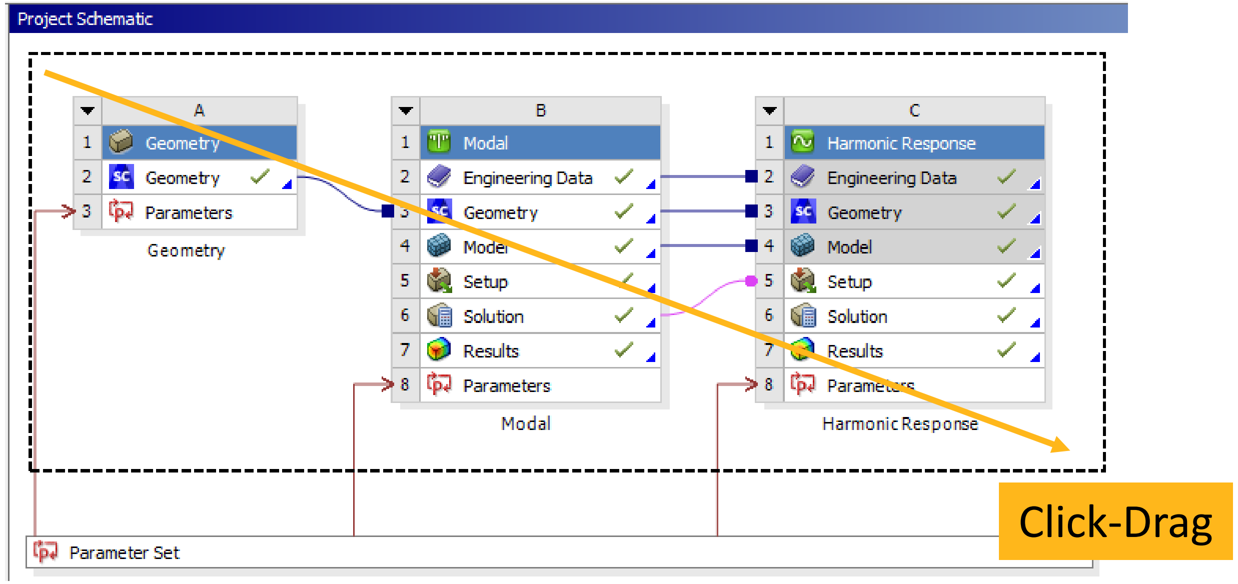
Details of "Equivalent Stress 2"

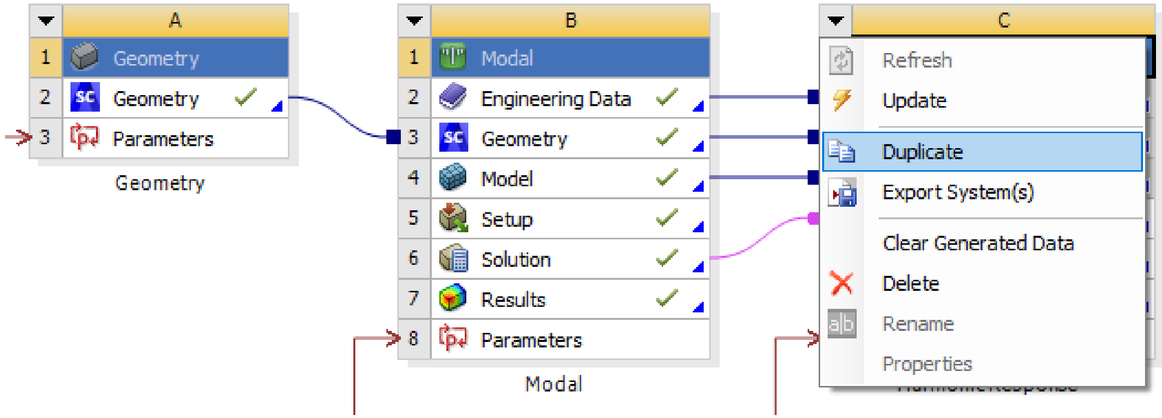
Scope	
Scoping Method	Geometry Selection
Geometry	1 Face
Definition	
Type	Equivalent (von-Mises) Stress
By	Frequency
☐ Frequency	100. Hz
Amplitude	No
Sweeping Phase	40.092 °
Identifier	
Suppressed	No
Integration Point Results	
Display Option	Averaged
Average Across Bodies	No

Ansys

Workshop 10.1 – General Workflow – Baseline *CMS Model* Solution

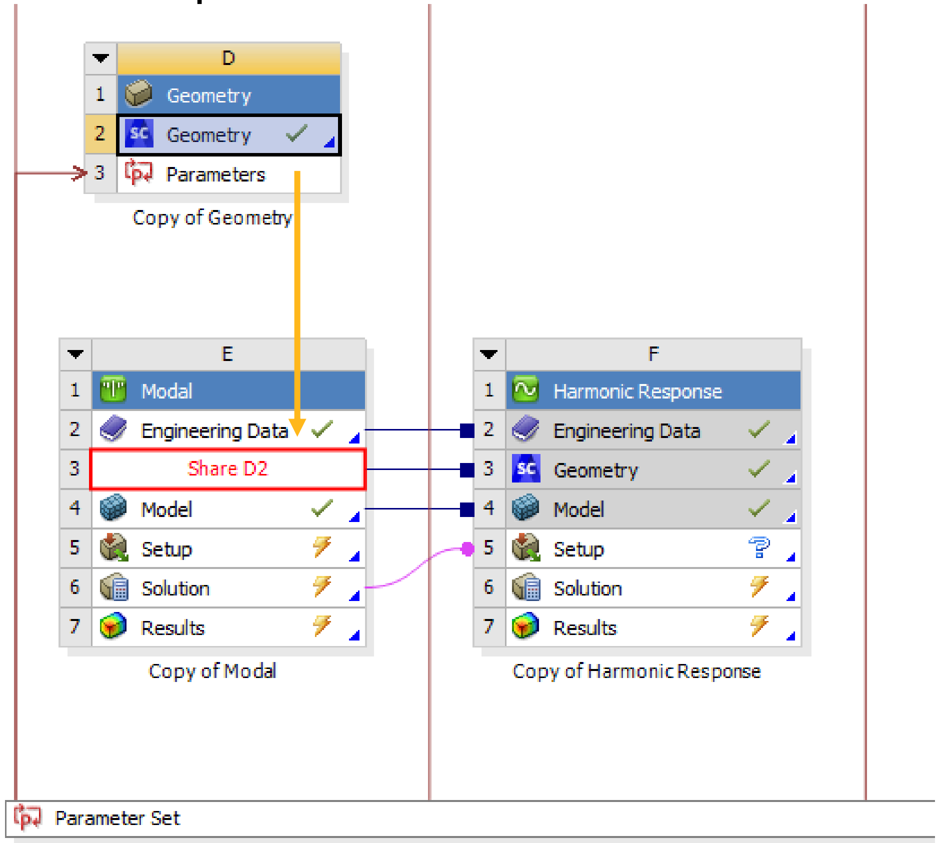
- The next phase of this analysis involves validating the CMS approach against the solution of the full model that has just been completed.
  - To preserve the full model solution:
    - From the Project application, click-drag a selection box surrounding the Geometry, Modal and Harmonic Analysis systems
    - With the three analysis systems selected, use the pull-down menu on the Harmonic system to Duplicate

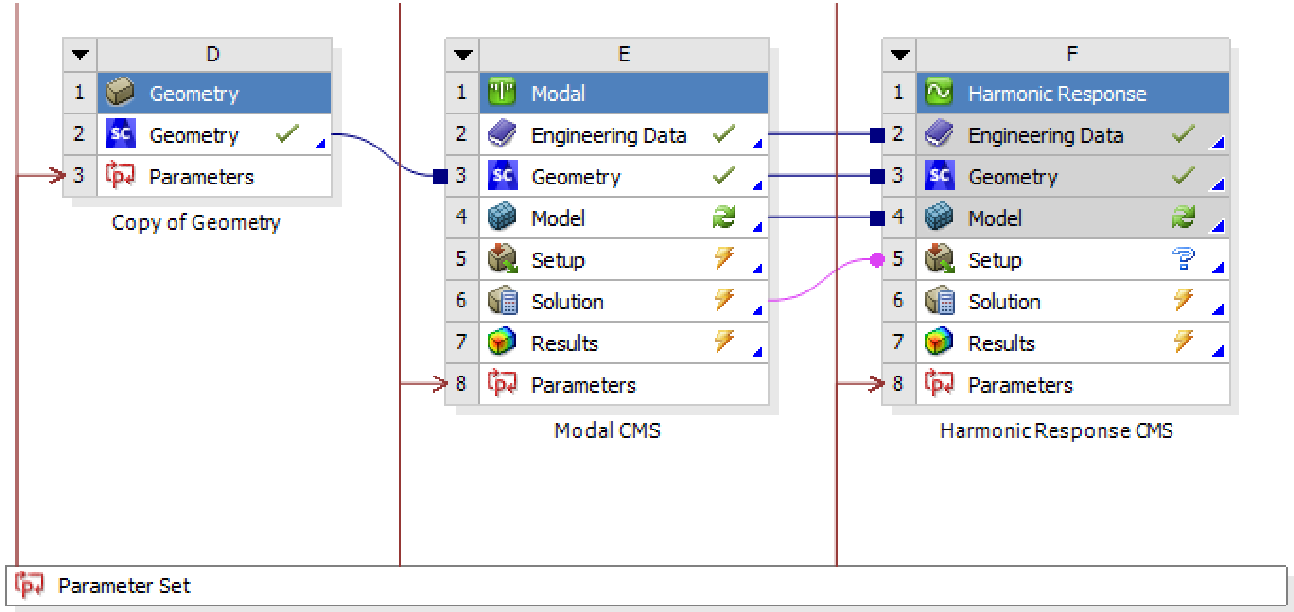




Workshop 10.1 – General Workflow – Baseline *CMS Model* Solution

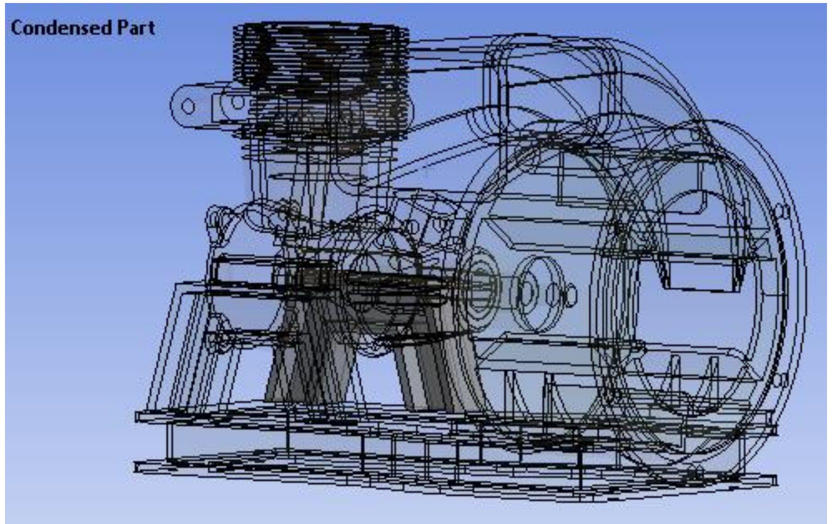
- To preserve the full model solution:
  - Share the new Geometry Cell, D, with the Geometry of the new Modal analysis system, E
  - Rename systems E and F to "Modal CMS" and "Harmonic Response CMS", below right
  - Open Mechanical from the Modal analysis, system E

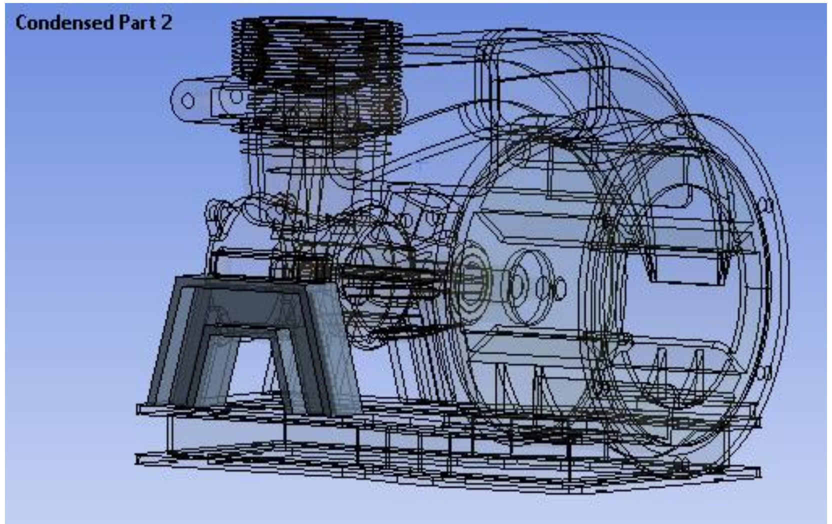


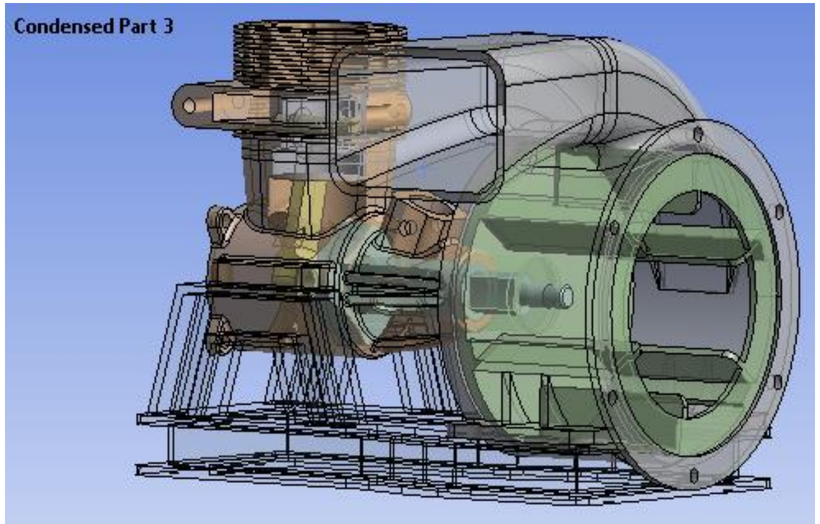


Workshop 10.1 – General Workflow – Baseline *CMS Model* Solution

- Define three condensed parts, consisting of:
  - support1
  - support2
  - All bodies except support1, support 2 and frame
  - We're defining 3 separate condensed parts to allow flexibility in how we may want to review results within the condensed parts
    - We might want to review complete displacement/stress in the support bodies, while only reviewing displacement in the other engine/blower bodies

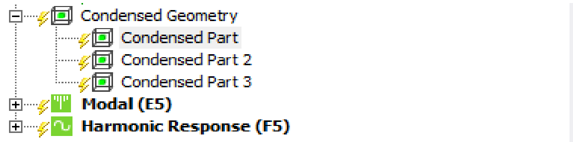






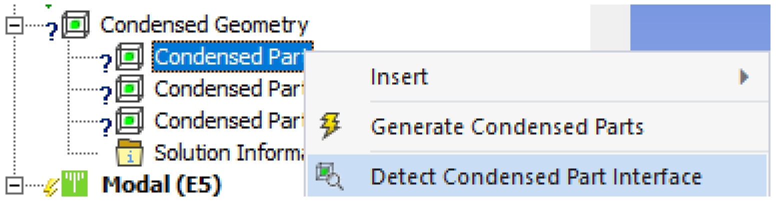
Workshop 10.1 – General Workflow – Baseline *CMS Model* Solution

- After meshing the model, Detect Interfaces on each of the three condensed parts
  - Each condensed part should have interfaces consisting of several Bonded contacts
  - Note the number of master nodes in each
  - Generate the Condensed Parts using the default Number of Modes (6) for each



Details of "Condensed Part"

Scope	
Scoping Method	Geometry Selection
Geometry	1 Body
Definition	
Scope Mode	Manual
Suppressed	No
ID (Beta)	403
Environment Temperature	22. °C
Physics Type	Structural
Matrix Reduction Method	Component Mode Synthesis
Interface Method	Fixed
Number Of Modes To Use	6.
Limit Search to Range	No
Solver Type	Program Controlled
Lumped Mass Formulation	Program Controlled
Added Mass Treatment	On Interface
Generate Damping Matrix	Program Controlled
Future Expansion (Beta)	Program Controlled
Keep Files For	MAPDL Expansion
Interfaces	
Number of Interfaces	3.
Number of Master Nodes	769.
Automatic	Bonded - engine\ MSBR To support2\ MSB...
Automatic	Bonded - support2\ MSBR2 To frame\ MSBR
Automatic	Bonded - support2\ MSBR2 To frame\ MSBR
Analysis Data Management	



Condensed Part

Clear

Interfaces

Name	Scope Method	Environment Name	Source	Type	Condition	Side
Bonded - engine\ MSBR To support1\ MSBR1	Geometry Selection	N/A	Automatic	General	Contact Region	Target
Bonded - support1\ MSBR1 To frame\ MSBR	Geometry Selection	N/A	Automatic	General	Contact Region	Contact
Bonded - support1\ MSBR1 To frame\ MSBR	Geometry Selection	N/A	Automatic	General	Contact Region	Contact

Workshop 10.1 – General Workflow – Baseline *CMS Model* Solution

- Modal Analysis Solution
  - The modal analysis is run using the same settings as the full model.
- Review results from the Modal analysis
  - Compare the frequencies from the CMS model to those of the baseline Full Model
  - Good agreement for first 3 modes, but higher modes begin to deviate

CMS Model

Tabular Data

	Mode	Frequency [Hz]
1	1.	59.383
2	2.	79.911
3	3.	83.783
4	4.	93.112
5	5.	106.42
6	6.	124.44
7	7.	148.56
8	8.	188.69
9	9.	193.38
10	10.	224.4
11	11.	268.73
12	12.	317.69

Full Model

Tabular Data

	Mode	Frequency [Hz]
1	1.	59.009
2	2.	79.638
3	3.	83.451
4	4.	92.862
5	5.	102.33
6	6.	122.88
7	7.	145.17
8	8.	182.04
9	9.	184.96
10	10.	207.32
11	11.	230.5
12	12.	259.61

Note: your result magnitudes may vary slightly throughout this workshop due to mesh and software release differences

Workshop 10.1 – General Workflow – Baseline *CMS Model* Solution

- To achieve better correlation between the CMS model and the Full model, increase the Number of Modes to Use in each Condensed Part to 12
- Re-generate the condensed parts and rerun the modal solution
  - Correlation is much better now

Condensed Geometry
- Condensed Part
- Condensed Part 2
- Condensed Part 3

Details of "Condensed Part"

Scope	
Definition	
Scope Mode	Manual
Suppressed	No
Environment Temperature	71.6 °F
Physics Type	Structural
Matrix Reduction Method	Component Mode Synthesis
Interface Method	Fixed
Number Of Modes To Use	12.
Limit Search to Range	No
Solver Type	Program Controlled
Lumped Mass Formulation	Program Controlled
Added Mass Treatment	On Interface

CMS Model

Tabular Data

	Mode	Frequency [Hz]
1	1.	61.989
2	2.	83.619
3	3.	84.587
4	4.	92.886
5	5.	109.94
6	6.	125.2
7	7.	151.54
8	8.	185.09
9	9.	196.75
10	10.	210.65
11	11.	238.8
12	12.	261.64

Full Model

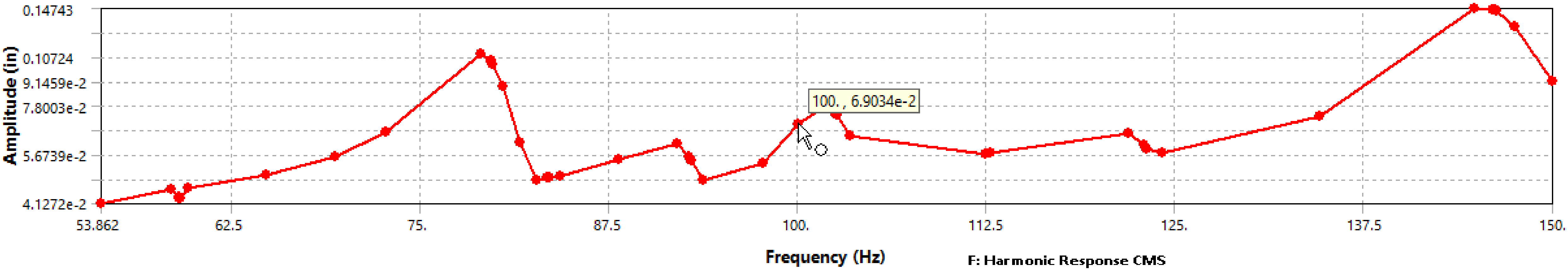
Tabular Data

	Mode	Frequency [Hz]
1	1.	59.009
2	2.	79.638
3	3.	83.451
4	4.	92.862
5	5.	102.33
6	6.	122.88
7	7.	145.17
8	8.	182.04
9	9.	184.96
10	10.	207.32
11	11.	230.5
12	12.	259.61

Note: your result magnitudes may vary slightly throughout this workshop due to mesh and software release differences

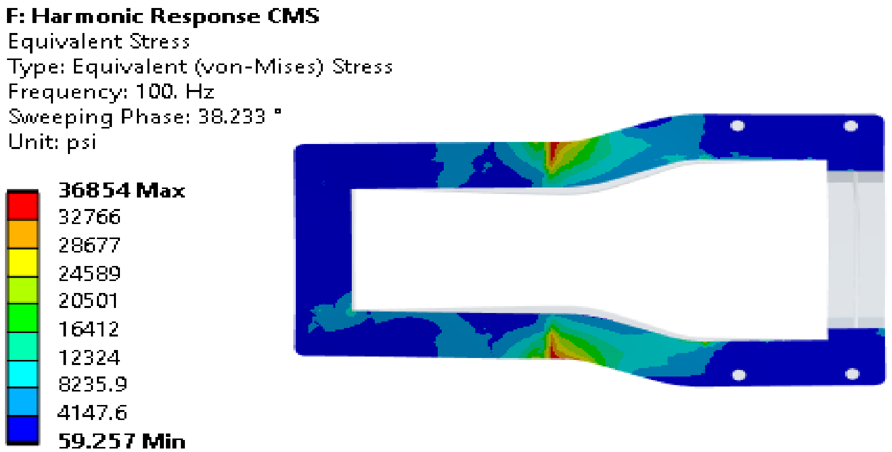
Workshop 10.1 – General Workflow – Baseline *CMS Model* Solution

- With good correlation now from the Modal analysis, solve the Harmonic analysis.
  - The phase angle at 100 Hz is likely to change slightly; make sure the new phase angle information is used to evaluate the stress at 100 Hz
  - Results shown for top flange, as that was the worst case



Tabular Data

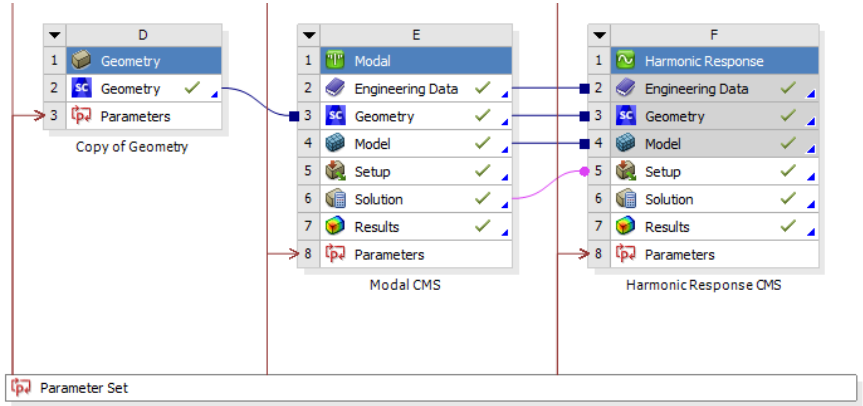
	Frequency [Hz]	Amplitude [in]	Phase Angle [°]
25	92.941	5.4433e-002	-49.098
26	93.723	4.8001e-002	-38.633
27	97.697	5.3606e-002	-27.996
28	100.	6.9034e-002	-38.323



Note: your result magnitudes may vary slightly throughout this workshop due to mesh and software release differences

Workshop 10.1 – General Workflow – Frame Design Iterations

- It's evident that the 100 Hz excitation is too close to a frame natural frequency and it's causing excessive stress in the frame support structure.
- Redesign the frame by evaluating several stock sizes of frame material
  - Existing design: 5" Height
  - Proposed designs: 8", 10", or 12" Height
- New frame height can be specified in the Parameter Set on the Project Schematic
  - Make sure you set the parameter value associated with Geometry from System D

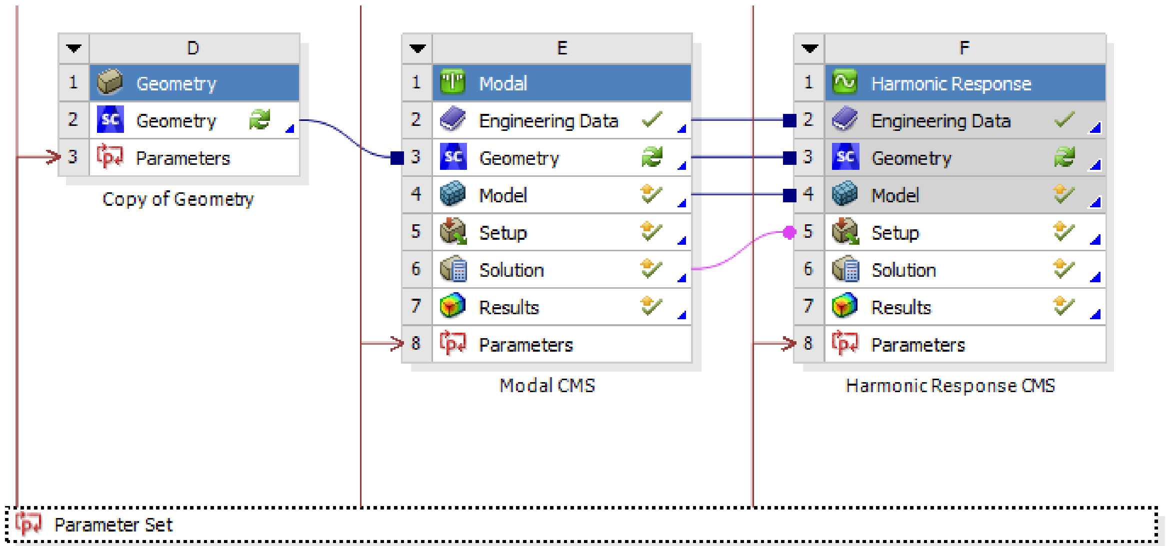


Outline of All Parameters

	A	B	C	D
1	ID	Parameter Name	Value	Unit
2	Input Parameters			
3	Geometry (A1)			
4	P1	Frame_Ht	5	in
5	Copy of Geometry (D1)			
6	P2	Frame_Ht	5	in
*	New input parameter	New name	New expression	
8	Output Parameters			
*	New output parameter		New expression	
10	Charts			

Workshop 10.1 – General Workflow – Frame Design Iterations

- Design Iteration 1
  - Use a frame height = 8”
  - Close the Parameter Set and Refresh the Project



Outline of All Parameters

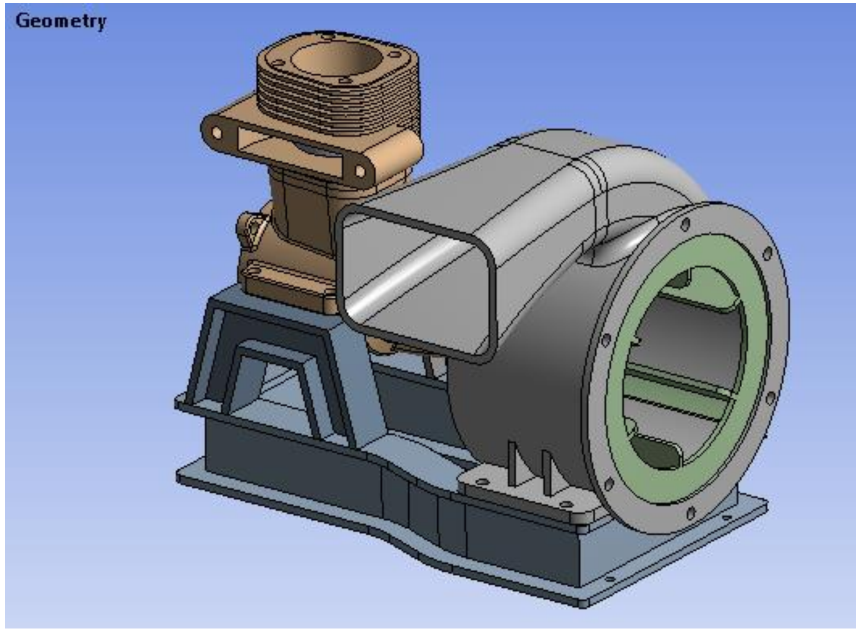
	A	B	C	D
1	ID	Parameter Name	Value	Unit
2	Input Parameters			
3	Geometry (A1)			
4	P1	Frame_Ht	5	in
5	Copy of Geometry (D1)			
6	P2	Frame_Ht	8	in
*	New input parameter	New name	New expression	
8	Output Parameters			
*	New output parameter		New expression	
10	Charts			

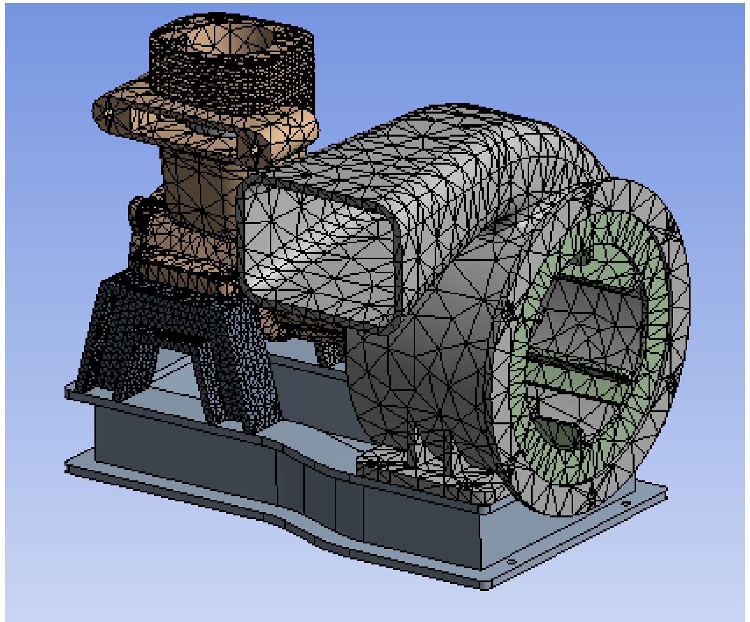
Note: Geometry updates will require access to a license of Ansys SpaceClaim

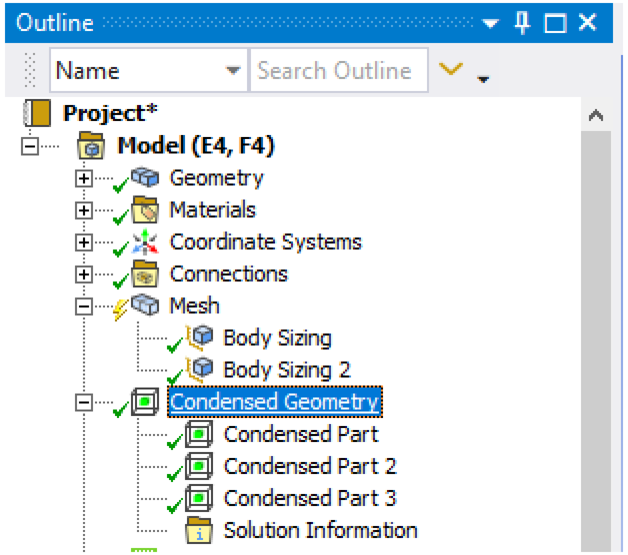
Ansys

Workshop 10.1 – General Workflow – Frame Design Iterations

- Design Iteration 1
  - In Mechanical, note the updated Geometry with new frame height
  - Note the mesh is persistent on all parts that haven't been updated
  - Note the Condensed Geometry is still up-to-date!
    - No need to Re-generate the Condensed Parts, thus saving solution time for the Generation Pass

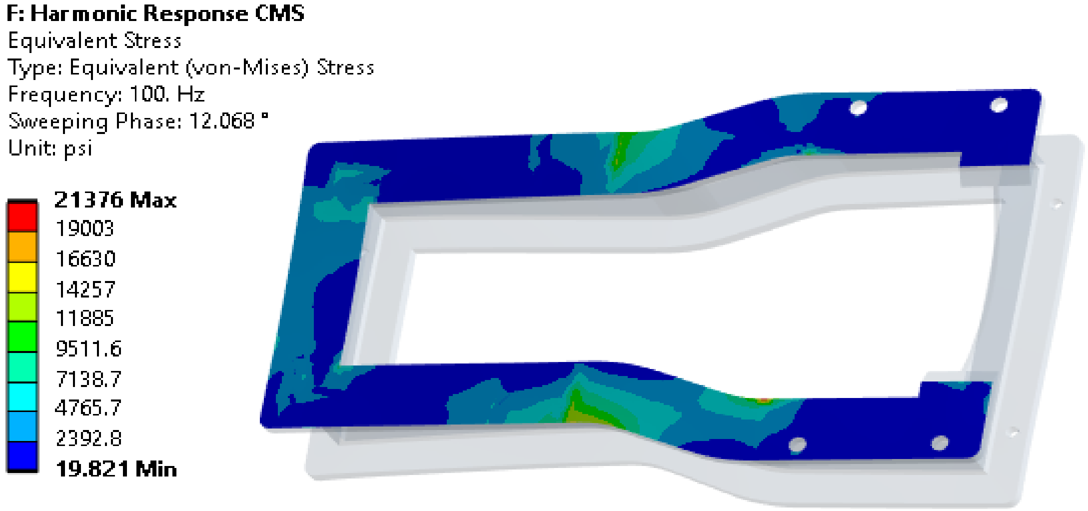






Workshop 10.1 – General Workflow – Frame Design Iterations

- Design Iteration 1, 8” Frame Height
  - Solve the Harmonic analysis
    - Mesh will update, then Modal analysis will be completed, then Harmonic will be completed

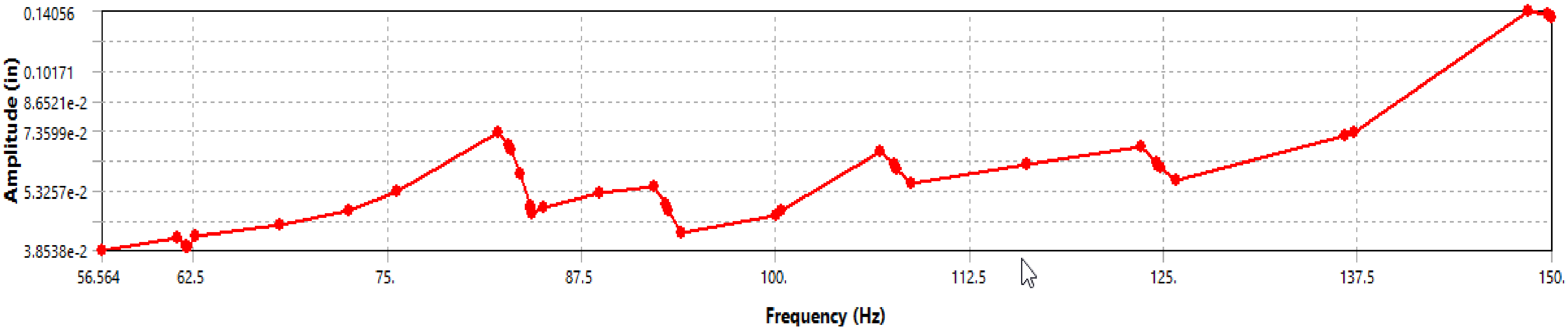


Tabular Data

	Frequency [Hz]	Amplitude [in]	Phase Angle [°]
22	93.009	4.8733e-002	-41.428
23	93.092	4.7995e-002	-42.244
24	93.876	4.2523e-002	-28.467
25	100.	4.6603e-002	-12.068

Tabular Data

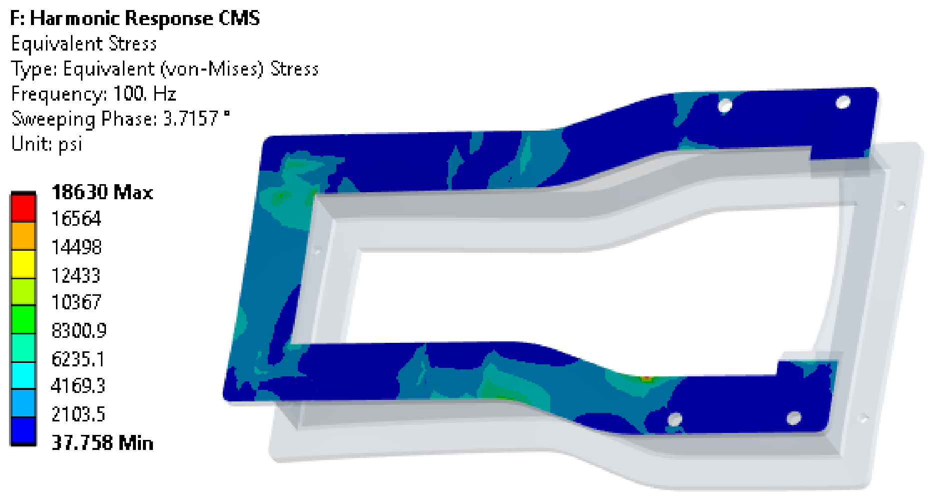
	Mode	Frequency [Hz]
1	1.	62.026
2	2.	82.886
3	3.	84.233
4	4.	93.009
5	5.	107.75
6	6.	124.66
7	7.	149.88
8	8.	185.05
9	9.	193.72
10	10.	209.72
11	11.	238.37
12	12.	263.19



Note: your result magnitudes may vary slightly throughout this workshop due to mesh and software release differences

Workshop 10.1 – General Workflow – Frame Design Iterations

- Design Iteration 2, 10” Frame Height
  - Repeat the steps from the previous three slides to evaluate stress in the top flange of a 10” frame height
  - The 10” frame height meets our design goal!

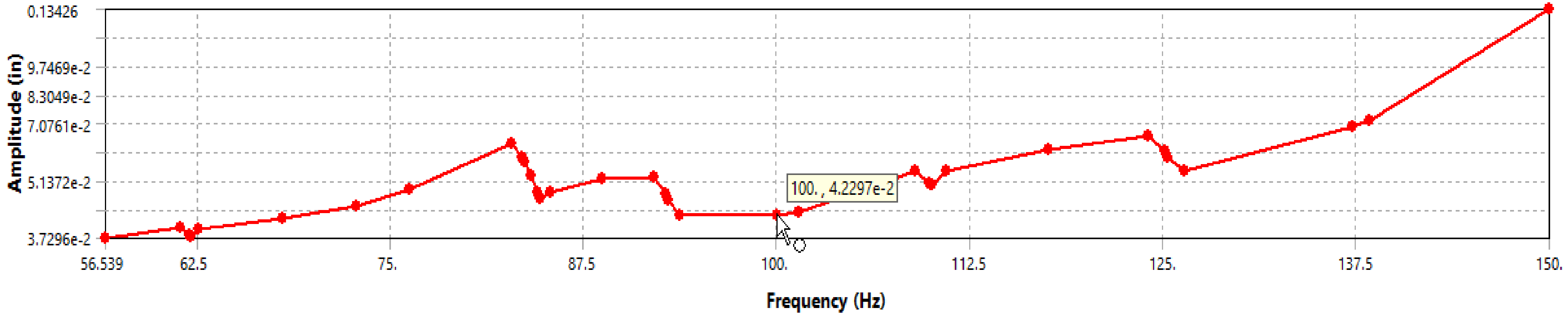


Tabular Data

	Mode	Frequency [Hz]
1	1.	61.998
2	2.	83.62
3	3.	84.587
4	4.	92.889
5	5.	109.95
6	6.	125.21
7	7.	151.54
8	8.	185.09
9	9.	196.78
10	10.	210.65
11	11.	238.8
12	12.	261.65

Tabular Data

	Frequency [Hz]	Amplitude [in]	Phase Angle [°]
21	92.805	4.7697e-002	-38.642
22	92.889	4.7004e-002	-39.446
23	92.972	4.6284e-002	-40.221
24	93.754	4.2464e-002	21.298
25	100.	4.2297e-002	3.7157

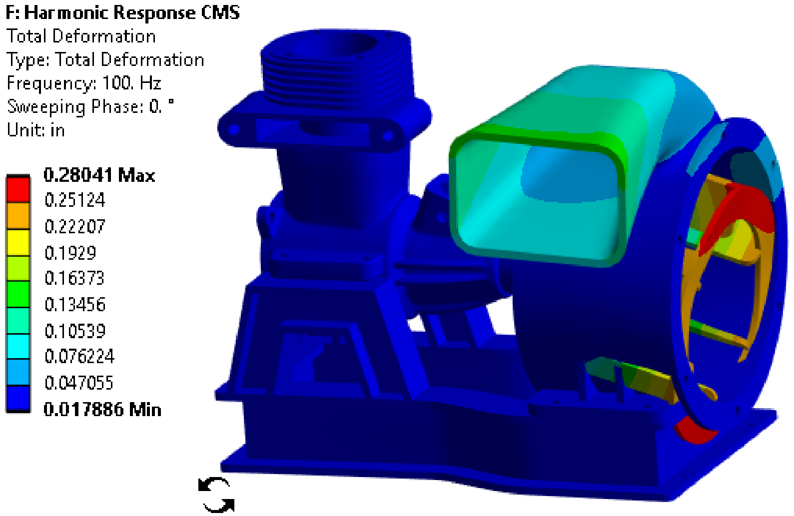


Note: your result magnitudes may vary slightly throughout this workshop due to mesh and software release differences

Workshop 10.1 – General Workflow – Frame Design Iterations

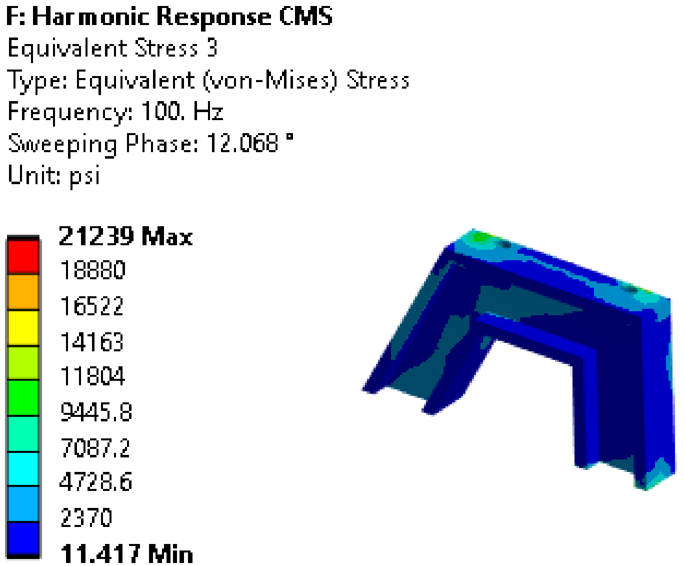
- Expanded Harmonic Results within Condensed Parts
  - Lastly, expand the displacements throughout all condensed parts along with stress in support 1
  - Plot Deformation and Stress at the 100 Hz excitation frequency

Harmonic Response (F5)
- Modal (Modal)
- Analysis Settings
- Displacement
- Solution (F6)
  - Solution Information
  - Expansion Settings



Expansion Settings

	Condensed Part	All Results	Displacement
	Condensed Part	☑	☑
	Condensed Part 2	☐	☑
	Condensed Part 3	☐	☑



Note: your result magnitudes may vary slightly throughout this workshop due to mesh and software release differences

Ansys

End of presentation