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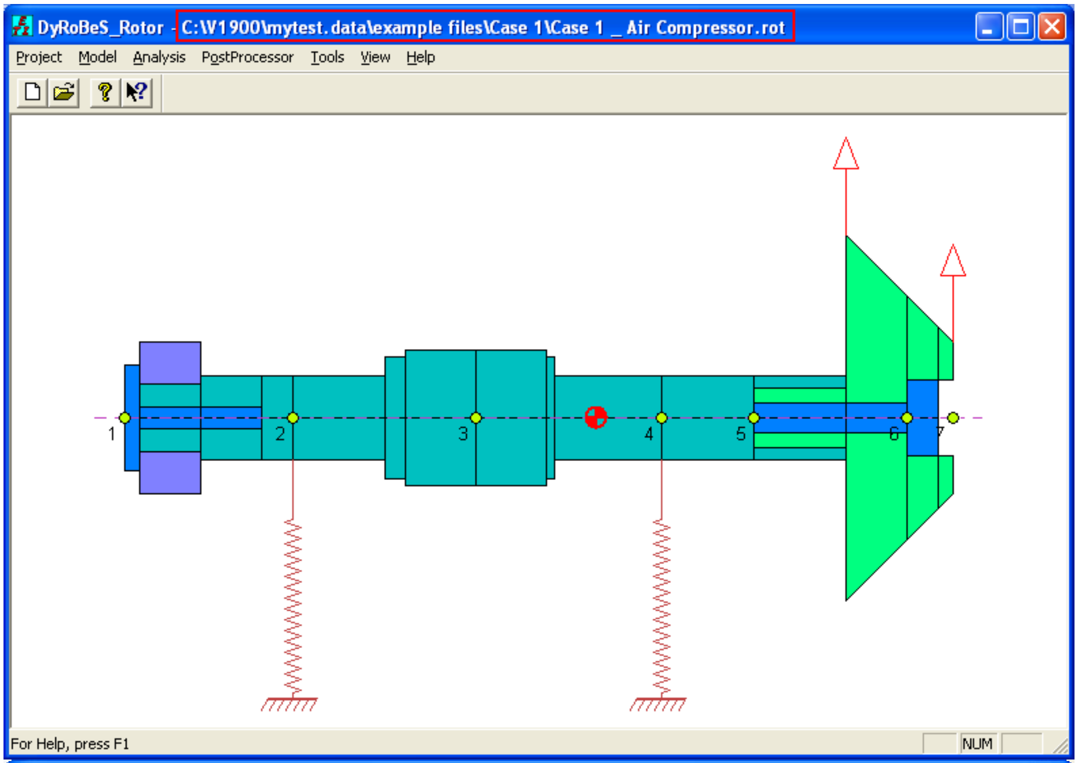
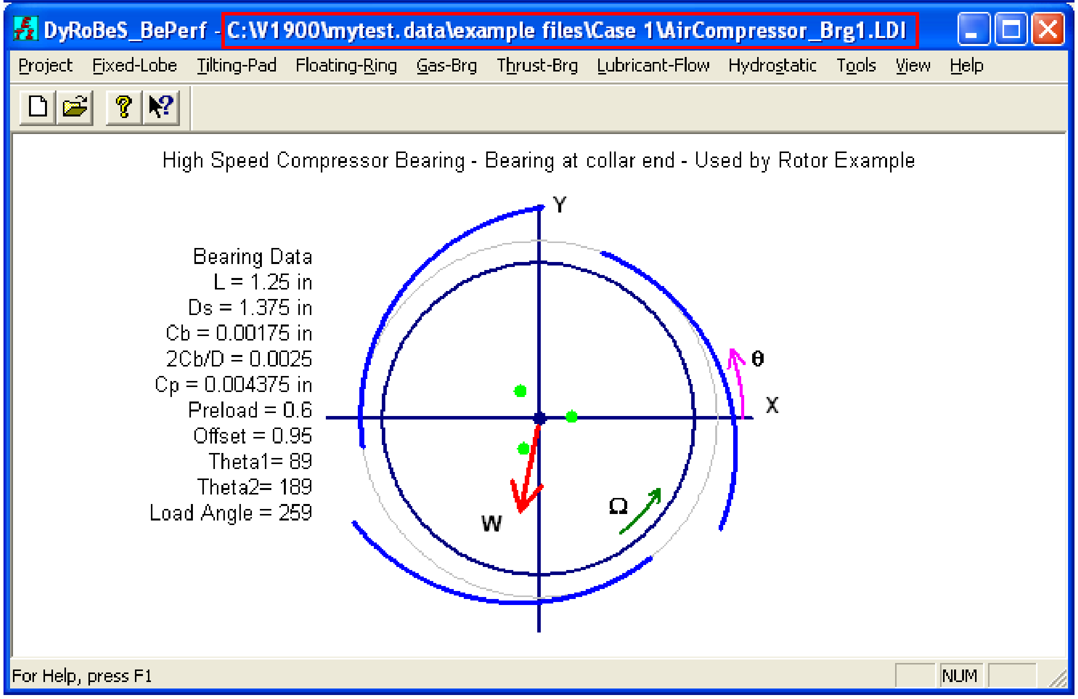
Examples for Ver 19.00

Three examples are used to demonstrate the new features implemented in Ver19.00 and some other commonly used features while performing the rotordynamics analysis.

Case 1 – Air Compressor

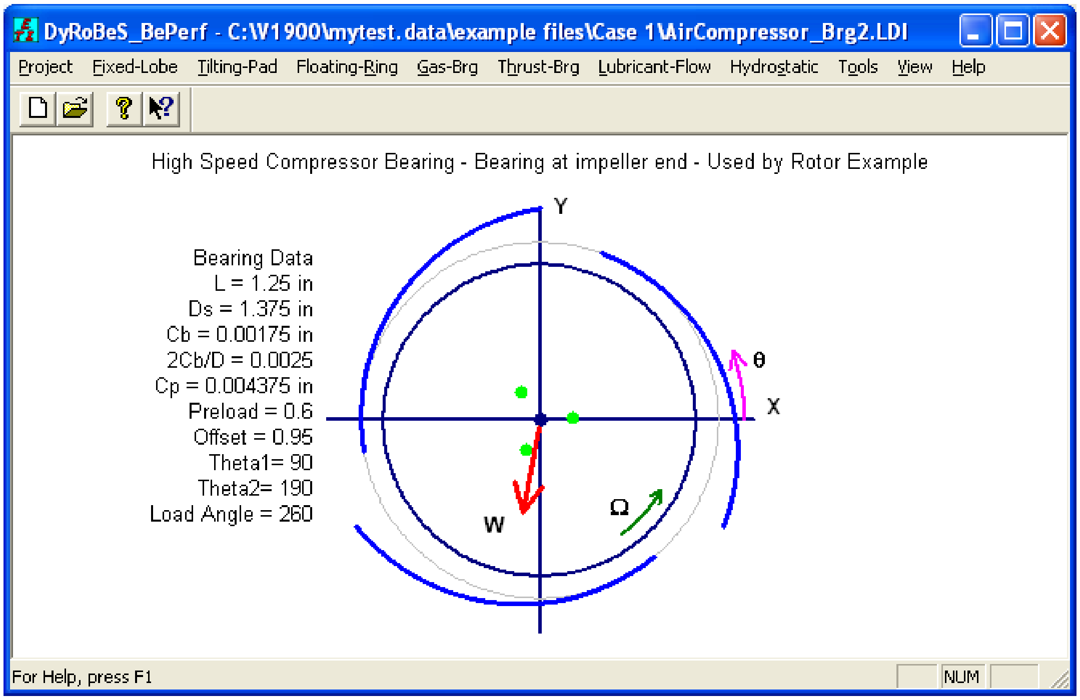
The rotor and bearing used in this example are shown below.





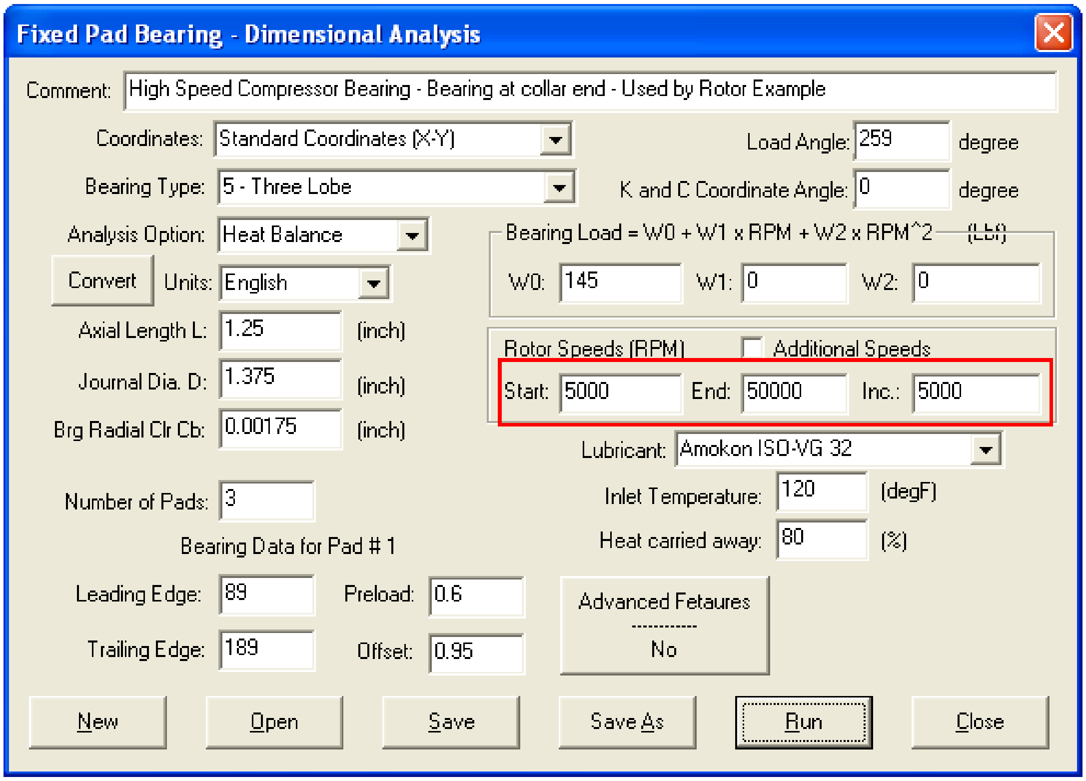
High Speed Compressor Bearing - Bearing at collar end - Used by Rotor Example

Bearing Data
L = 1.25 in
Ds = 1.375 in
Cb = 0.00175 in
2Cb/D = 0.0025
Cp = 0.004375 in
Preload = 0.6
Offset = 0.95
Theta1= 89
Theta2= 189
Load Angle = 259



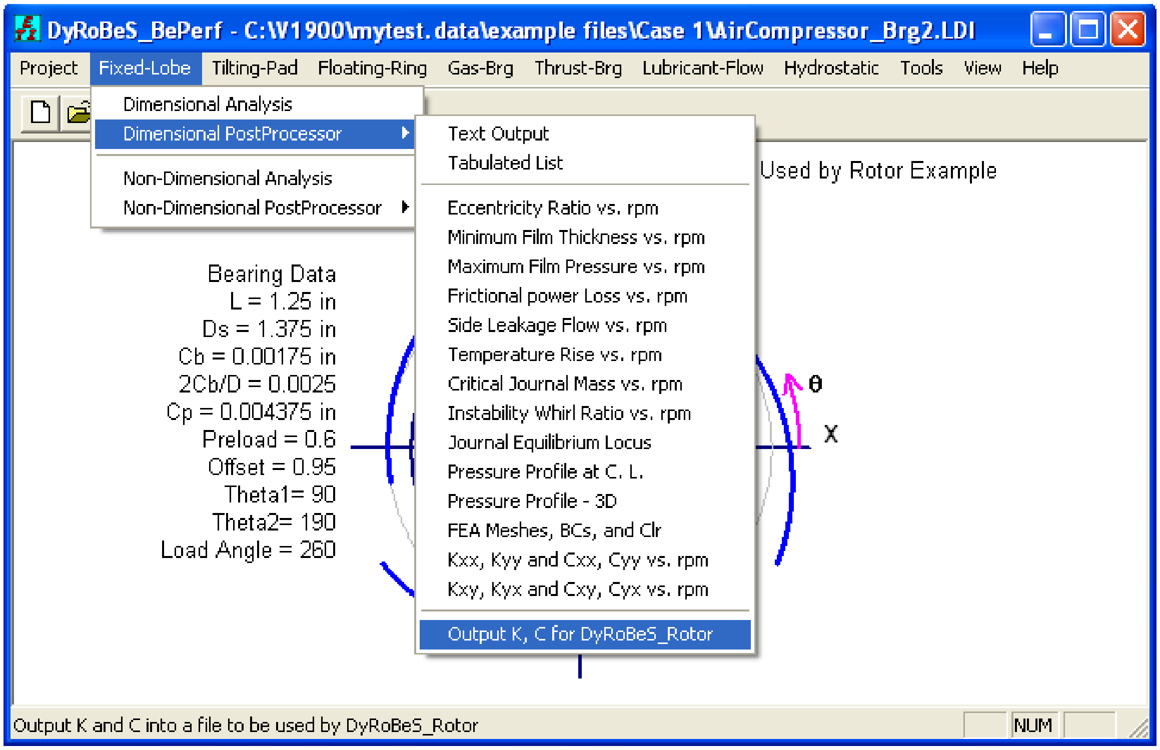
High Speed Compressor Bearing - Bearing at impeller end - Used by Rotor Example

Bearing Data
L = 1.25 in
Ds = 1.375 in
Cb = 0.00175 in
2Cb/D = 0.0025
Cp = 0.004375 in
Preload = 0.6
Offset = 0.95
Theta1= 90
Theta2= 190
Load Angle = 260



Comment: High Speed Compressor Bearing - Bearing at collar end - Used by Rotor Example
Coordinates: Standard Coordinates (X-Y)
Load Angle: 259 degree
Bearing Type: 5 - Three Lobe
K and C Coordinate Angle: 0 degree
Analysis Option: Heat Balance
Bearing Load = W0 + W1 x RPM + W2 x RPM^2 (Lbf)
W0: 145 W1: 0 W2: 0
Units: English
Axial Length L: 1.25 (inch)
Rotor Speeds (RPM) ☐ Additional Speeds
Start: 5000 End: 50000 Inc.: 5000
Journal Dia. D: 1.375 (inch)
Brg Radial Clr Cb: 0.00175 (inch)
Lubricant: Amokon ISO-VG 32
Number of Pads: 3
Inlet Temperature: 120 (degF)
Heat carried away: 80 (%)
Bearing Data for Pad # 1
Leading Edge: 89 Preload: 0.6
Trailing Edge: 189 Offset: 0.95

Note that the special characters, such as dot "." and white space " ", are allowed in the file and path name. The bearing coefficients are calculated using BePerf from 5,000 to 50,000 rpm with an increment of 5,000 rpm. After the bearing run, the bearing coefficients can be outputted and then imported into the Rotor program.

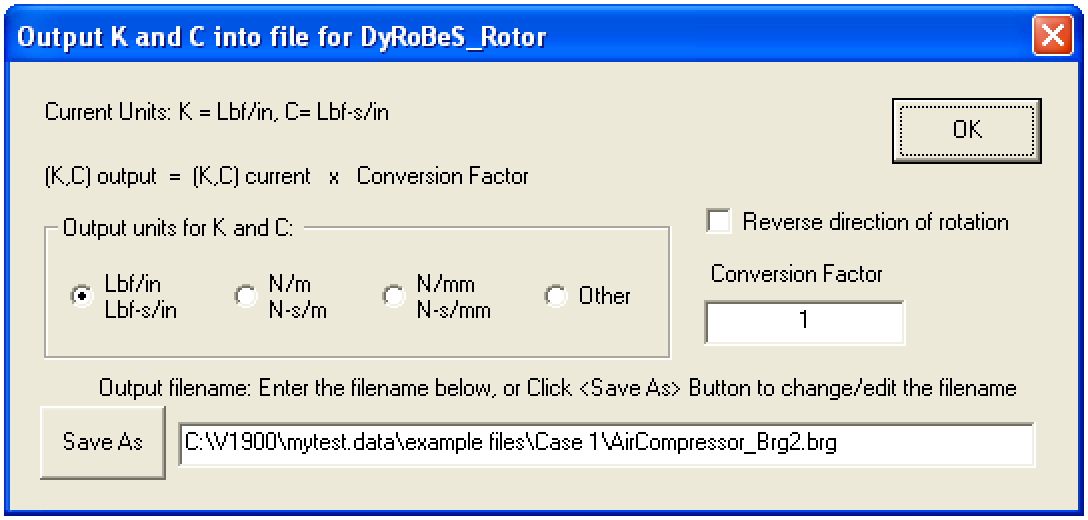


DyRoBeS_BePerf - C:\V1900\mytest.data\example files\Case 1\AirCompressor_Brg2.LDI

Used by Rotor Example

Bearing Data
L = 1.25 in
Ds = 1.375 in
Cb = 0.00175 in
2Cb/D = 0.0025
Cp = 0.004375 in
Preload = 0.6
Offset = 0.95
Theta1= 90
Theta2= 190
Load Angle = 260

Output K and C into a file to be used by DyRoBeS_Rotor



Output K and C into file for DyRoBeS_Rotor

Current Units: K = Lbf/in, C= Lbf-s/in

[K,C] output = [K,C] current x Conversion Factor

Output units for K and C:

● Lbf/in Lbf-s/in ○ N/m N-s/m ○ N/mm N-s/mm ○ Other

☐ Reverse direction of rotation

Conversion Factor: 1

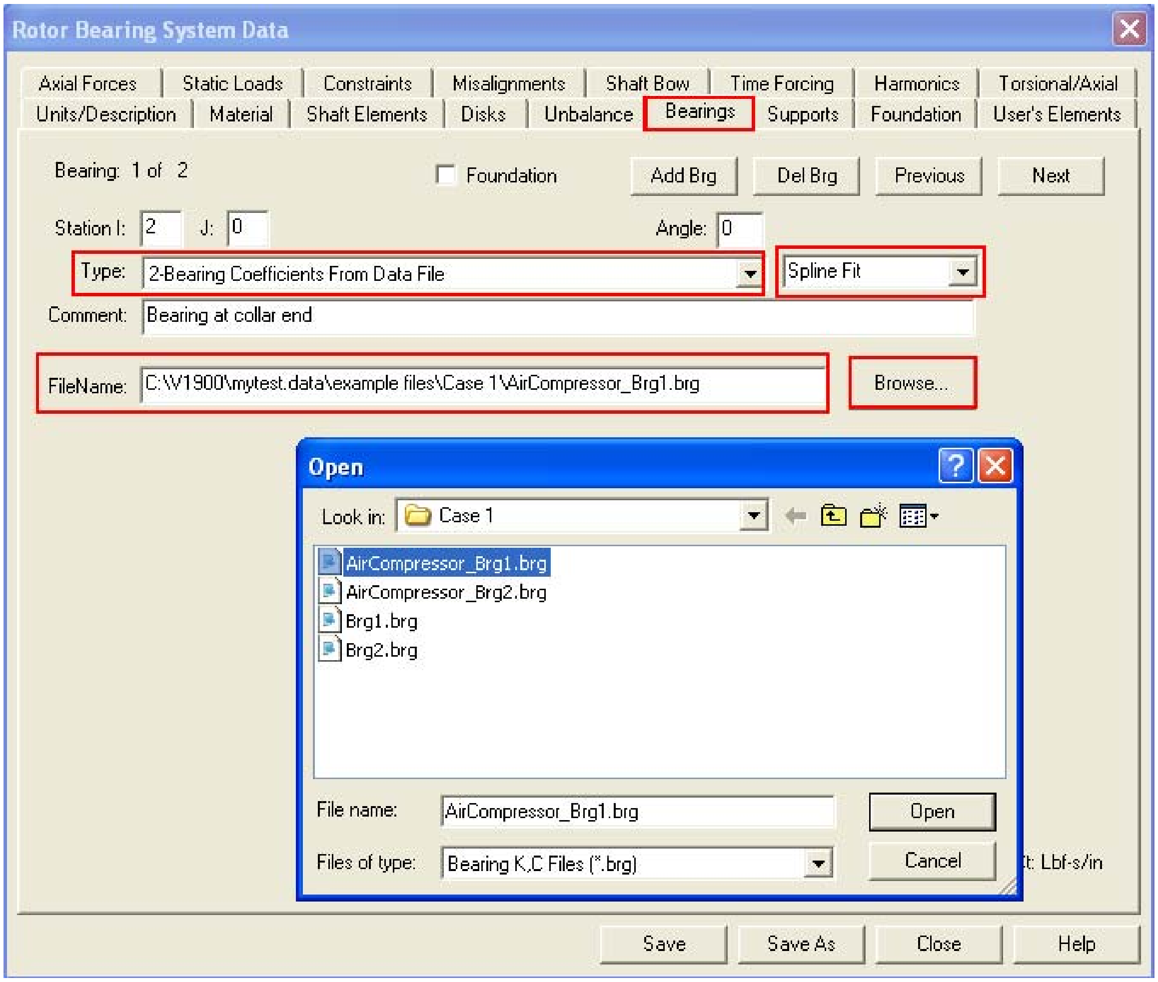
Output filename: Enter the filename below, or Click <Save As> Button to change/edit the filename

C:\V1900\mytest.data\example files\Case 1\AirCompressor_Brg2.brg

There is a Check Box named "Reverse direction of rotation" when outputting (saving) the bearing coefficients. Do **NOT** check this box unless you are performing a coupled Lateral-Torsional vibration analysis on a geared system and this particular shaft is rotating clockwise. Referring the previous bearing figure, all the bearing coefficients are calculated based on the shaft counter-clockwise rotation. For a single rotor system, this is always the case. For more details on the coupled lateral and torsional analysis, see book "Practical Rotordynamics and Fluid Film Bearing Design", Chapter 8.

The bearing coefficients can be imported into the Rotor program using the Bearing Type 2 – Bearing Coefficients From Data File (Rotor – Model – Data Editor – Bearings –

Select Type 2 – then Browse the bearing file outputted from BePerf). In Ver 19.00, the interpolation method for the speed dependent bearing coefficients can be either spline function or linear interpolation. Spline function was used before Ver 19.00.



Bearing: 1 of 2

Station I: 2 J: 0

Angle: 0

Type: 2-Bearing Coefficients From Data File

Spline Fit

Comment: Bearing at collar end

FileName: C:\V1900\mytest.data\example files\Case 1\AirCompressor_Brg1.brg

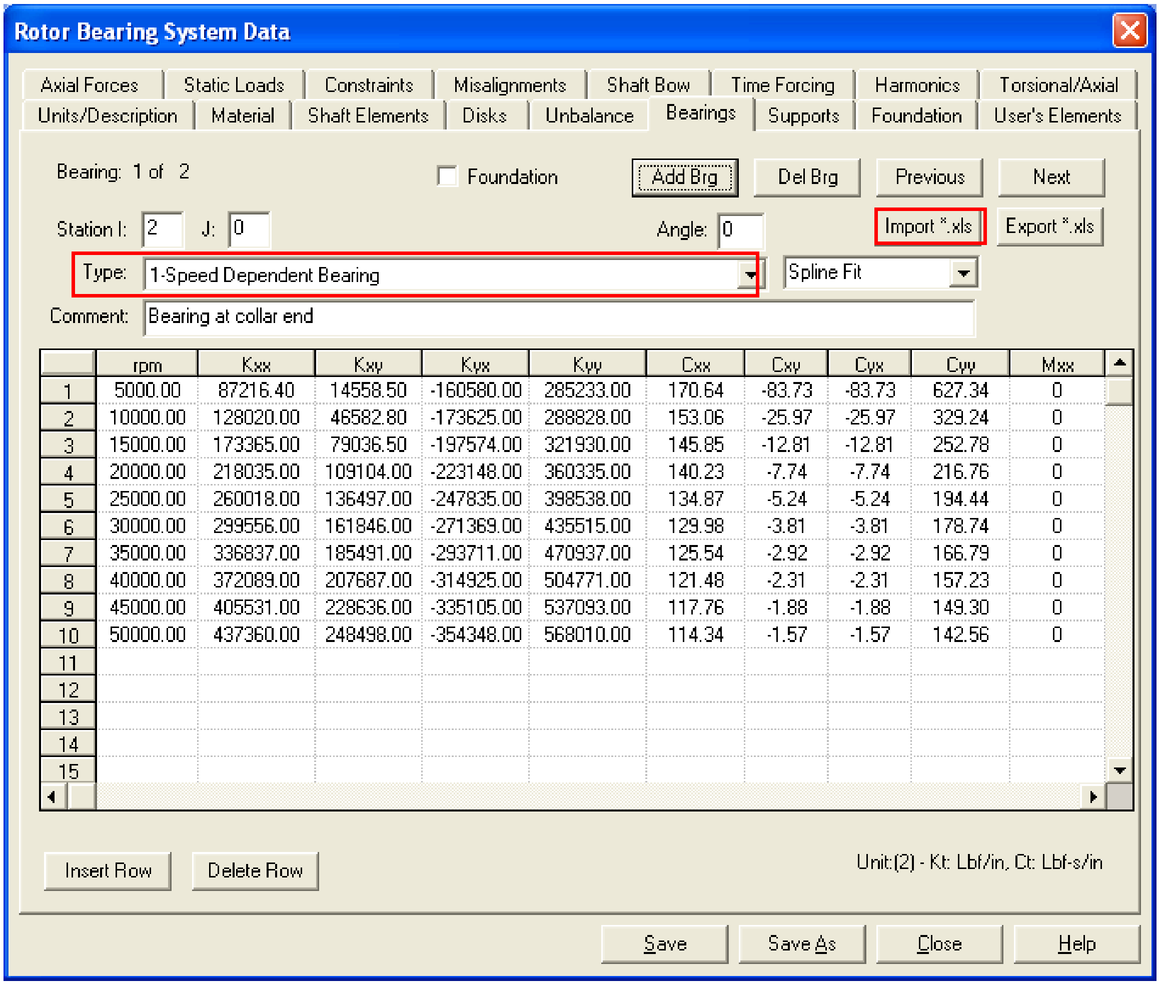
Look in: Case 1

AirCompressor_Brg1.brg
AirCompressor_Brg2.brg
Brg1.brg
Brg2.brg

File name: AirCompressor_Brg1.brg

Files of type: Bearing K,C Files (*.brg)

To keep the file simple and portable, we use Bearing Type 1- Speed Dependent Bearing and import the bearing coefficients from the BePerf output. If you have the bearing output file from BePerf program, this can be easily done by open the *.brg (output file from BePerf) using MS Excel, delete the first header line, save the file into xls format, then use the Import *.xls button in Rotor Bearing Tab to import the bearing coefficients. Note that this option is not commonly selected since you have all the necessary rotor and bearing data files and Bearing Type 2 is more suitable for this purpose. In some cases, if you obtain the bearing coefficients from other sources or if you need to share your rotor file but not the bearing data, then you can enter the bearing coefficients as the speed dependent bearing (Type 1).



Bearing: 1 of 2

Station I: 2 J: 0

Angle: 0

Type: 1-Speed Dependent Bearing

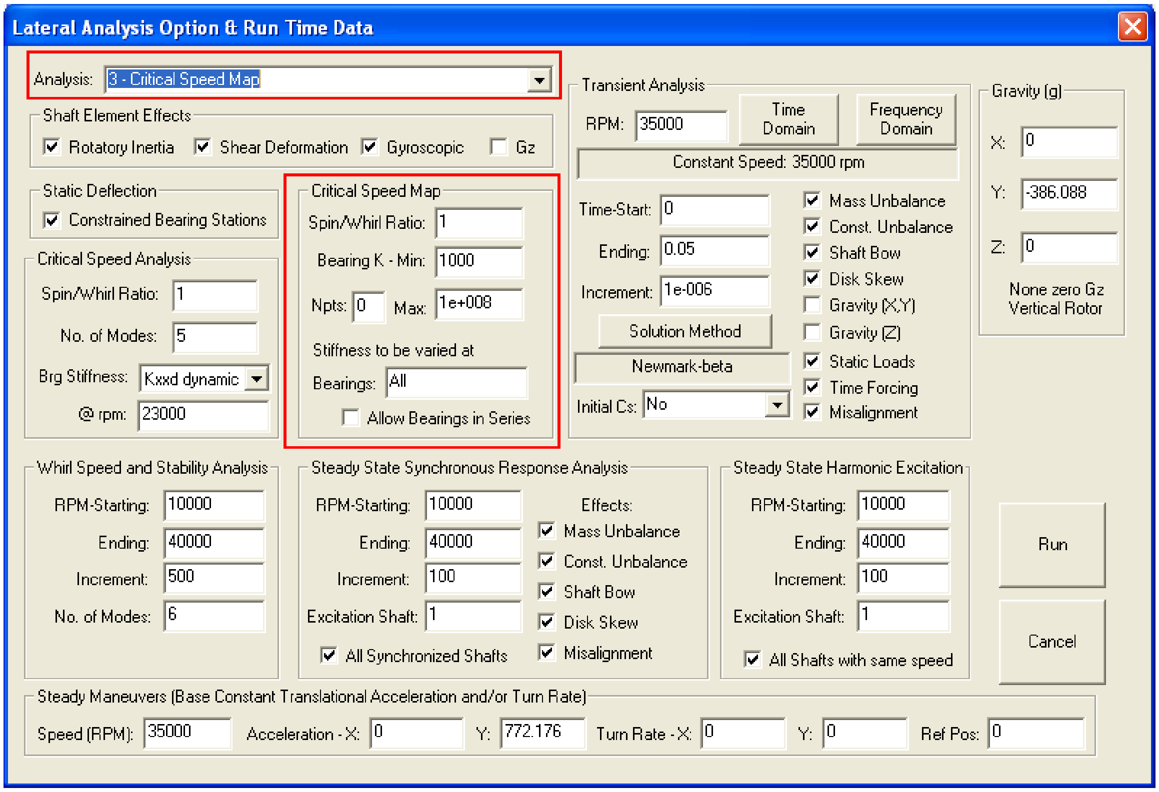
Spline Fit

Comment: Bearing at collar end

	rpm	Kxx	Kxy	Kyx	Kyy	Cxx	Cxy	Cyx	Cyy	Mxx
1	5000.00	87216.40	14558.50	-160580.00	285233.00	170.64	-83.73	-83.73	627.34	0
2	10000.00	128020.00	46582.80	-173625.00	288828.00	153.06	-25.97	-25.97	329.24	0
3	15000.00	173365.00	79036.50	-197574.00	321930.00	145.85	-12.81	-12.81	252.78	0
4	20000.00	218035.00	109104.00	-223148.00	360335.00	140.23	-7.74	-7.74	216.76	0
5	25000.00	260018.00	136497.00	-247835.00	398538.00	134.87	-5.24	-5.24	194.44	0
6	30000.00	299556.00	161846.00	-271369.00	435515.00	129.98	-3.81	-3.81	178.74	0
7	35000.00	336837.00	185491.00	-293711.00	470937.00	125.54	-2.92	-2.92	166.79	0
8	40000.00	372089.00	207687.00	-314925.00	504771.00	121.48	-2.31	-2.31	157.23	0
9	45000.00	405531.00	228636.00	-335105.00	537093.00	117.76	-1.88	-1.88	149.30	0
10	50000.00	437360.00	248498.00	-354348.00	568010.00	114.34	-1.57	-1.57	142.56	0
11										
12										
13										
14										
15										

Unit:(2) - Kt: Lbf/in, Ct: Lbf-s/in

The first analysis illustrated here is the Critical Speed Map, which is required by API. Note that the “spin/whirl ratio = 1” in the analysis input indicates the calculated critical speeds are the Synchronous Forward Critical Speeds commonly excited by the mass unbalance. The result can be viewed using the PostProcessor. The operating speed line and the bearing dynamic stiffness in the critical speed map can be plotted using the menu – Options – Settings. The bearing dynamic stiffness including damping effect is recommended in this map and required by the API. There are two intersection points (critical speeds) according to this map; one is around 23,000 rpm caused by K_{dx} and the other is around 26,000 rpm caused by K_{dy}. Due to significant damping in this case and the bearings are non-isotropic, there will only one critical speed around 26,000 rpm be observed in the unbalance response curve and machine test. In general, the higher one with more shaft flexibility will be observed.



Lateral Analysis Option & Run Time Data

Analysis: 3 - Critical Speed Map

Shaft Element Effects
☑ Rotatory Inertia ☑ Shear Deformation ☑ Gyroscopic ☐ Gz

Static Deflection
☑ Constrained Bearing Stations

Critical Speed Analysis
Spin/Whirl Ratio: 1
No. of Modes: 5
Brg Stiffness: Kxxd dynamic
@ rpm: 23000

Critical Speed Map
Spin/Whirl Ratio: 1
Bearing K - Min: 1000
Npts: 0 Max: 1e+008
Stiffness to be varied at
Bearings: All
☐ Allow Bearings in Series

Transient Analysis
RPM: 35000
Constant Speed: 35000 rpm
Time-Start: 0
Ending: 0.05
Increment: 1e-006
Newmark-beta
Initial Cs: No
☑ Mass Unbalance
☑ Const. Unbalance
☑ Shaft Bow
☑ Disk Skew
☐ Gravity (X,Y)
☐ Gravity (Z)
☑ Static Loads
☑ Time Forcing
☑ Misalignment

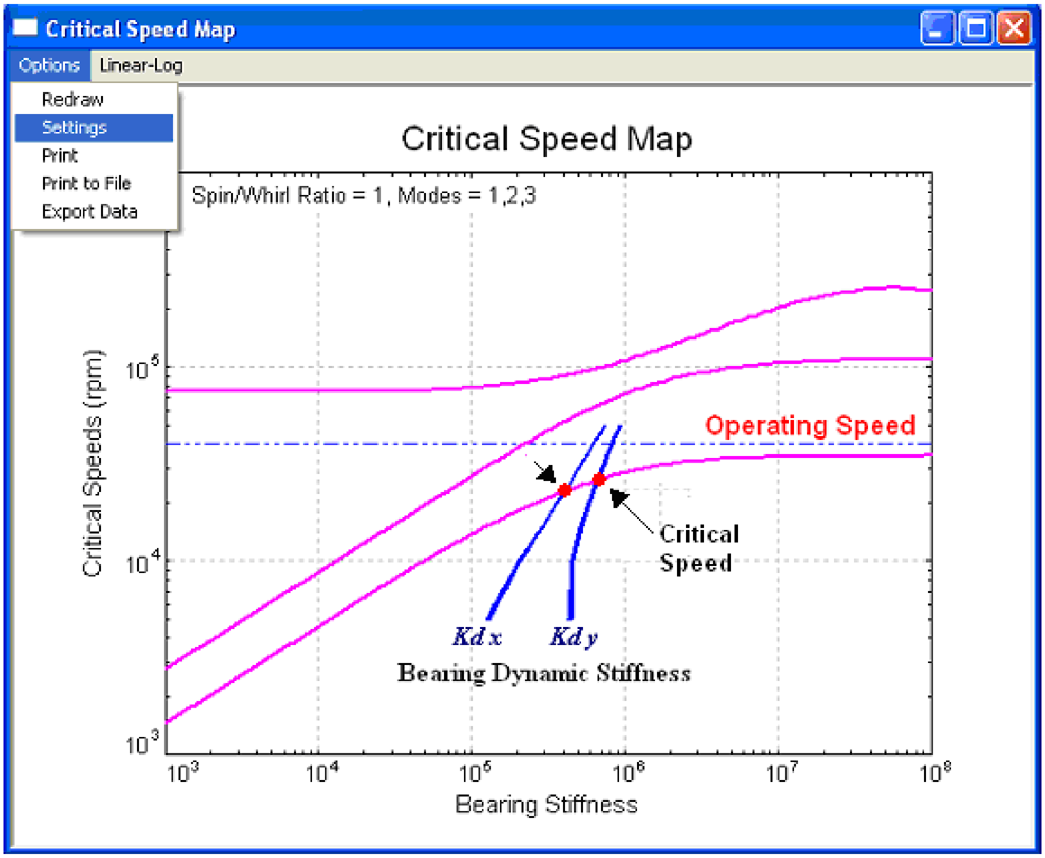
Gravity (g)
X: 0
Y: -386.088
Z: 0
None zero Gz Vertical Rotor

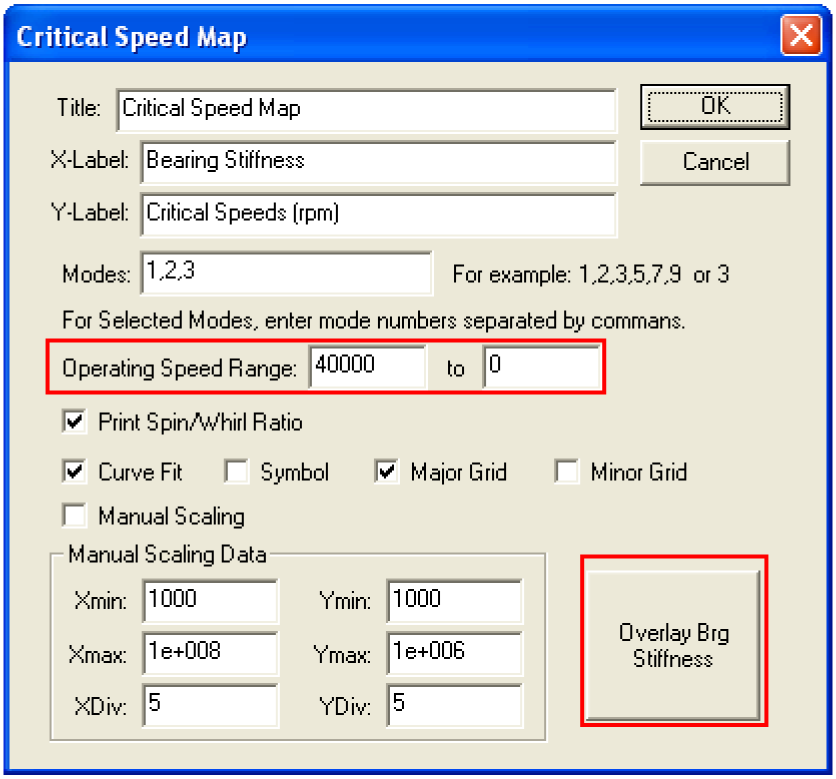
Whirl Speed and Stability Analysis
RPM-Starting: 10000
Ending: 40000
Increment: 500
No. of Modes: 6

Steady State Synchronous Response Analysis
RPM-Starting: 10000
Ending: 40000
Increment: 100
Excitation Shaft: 1
☑ All Synchronized Shafts
Effects:
☑ Mass Unbalance
☑ Const. Unbalance
☑ Shaft Bow
☑ Disk Skew
☑ Misalignment

Steady State Harmonic Excitation
RPM-Starting: 10000
Ending: 40000
Increment: 100
Excitation Shaft: 1
☑ All Shafts with same speed

Steady Maneuvers (Base Constant Translational Acceleration and/or Turn Rate)
Speed (RPM): 35000 Acceleration - X: 0 Y: 772.176 Turn Rate - X: 0 Y: 0 Ref Pos: 0





Title: Critical Speed Map

X-Label: Bearing Stiffness

Y-Label: Critical Speeds (rpm)

Modes: 1,2,3 For example: 1,2,3,5,7,9 or 3

For Selected Modes, enter mode numbers separated by commans.

Operating Speed Range: 40000 to 0

☑ Print Spin/Whirl Ratio

☑ Curve Fit ☐ Symbol ☑ Major Grid ☐ Minor Grid

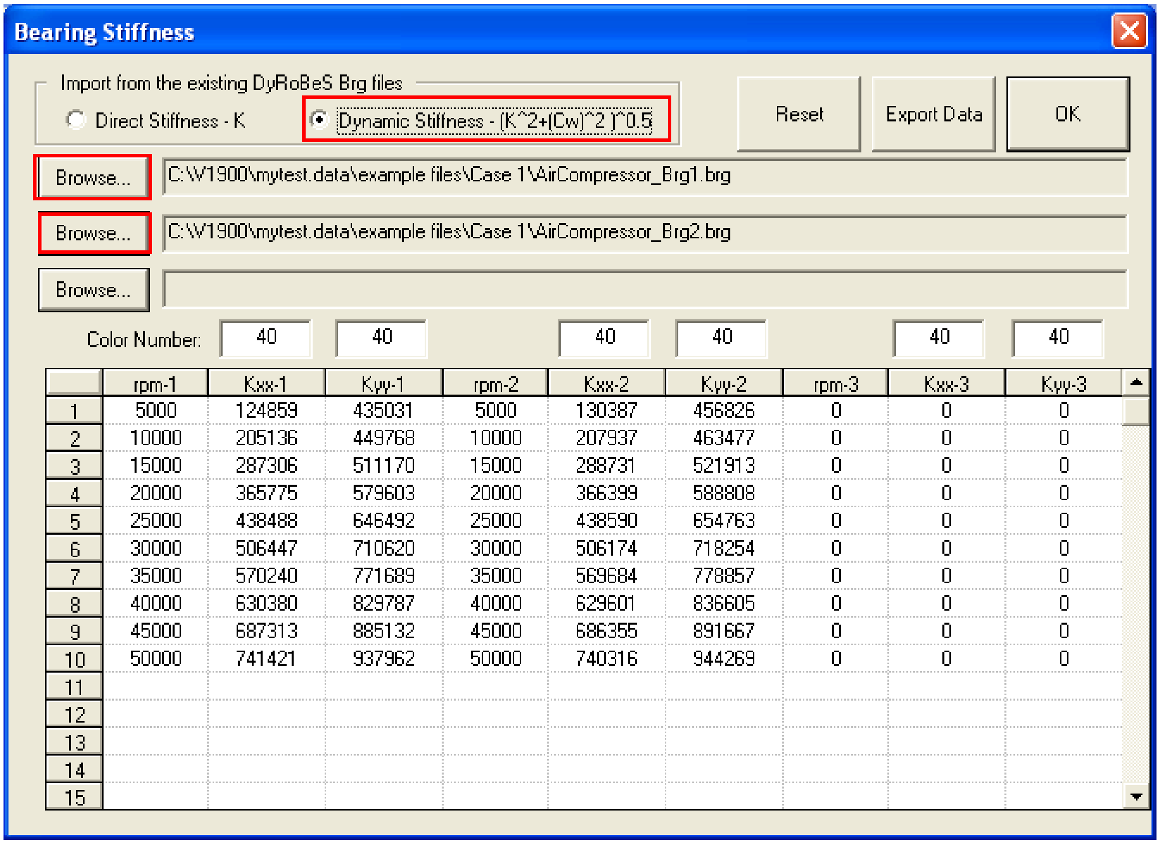
☐ Manual Scaling

Manual Scaling Data

Xmin: 1000 Ymin: 1000

Xmax: 1e+008 Ymax: 1e+006

XDiv: 5 YDiv: 5



Import from the existing DyRoBeS Brg files

○ Direct Stiffness - K ● Dynamic Stiffness - (K^2+(Cw)^2)^0.5

C:\V1900\mytest.data\example files\Case 1\AirCompressor_Brg1.brg

C:\V1900\mytest.data\example files\Case 1\AirCompressor_Brg2.brg

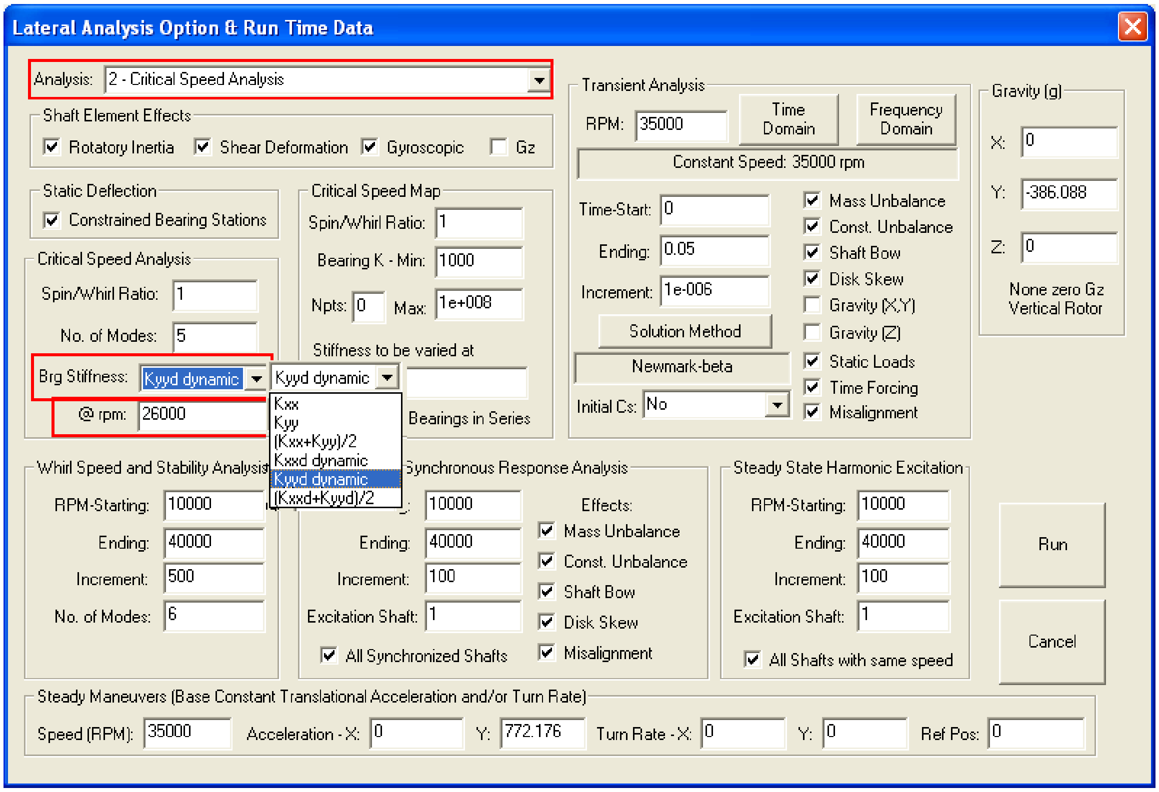
Color Number: 40 40 40 40 40 40

	rpm-1	Kxx-1	Kyy-1	rpm-2	Kxx-2	Kyy-2	rpm-3	Kxx-3	Kyy-3
1	5000	124859	435031	5000	130387	456826	0	0	0
2	10000	205136	449768	10000	207937	463477	0	0	0
3	15000	287306	511170	15000	288731	521913	0	0	0
4	20000	365775	579603	20000	366399	588808	0	0	0
5	25000	438488	646492	25000	438590	654763	0	0	0
6	30000	506447	710620	30000	506174	718254	0	0	0
7	35000	570240	771689	35000	569684	778857	0	0	0
8	40000	630380	829787	40000	629601	836605	0	0	0
9	45000	687313	885132	45000	686355	891667	0	0	0
10	50000	741421	937962	50000	740316	944269	0	0	0
11									
12									
13									
14									
15									

To examine the critical speed mode shapes, the critical speed analysis is performed. First, let us examine the critical speed around 26,000 rpm estimated from the Critical Speed Map. In Ver 19.00, the **dynamic** stiffness option is added and the speed can be specified. Before Ver 19, only the **direct** stiffness and the bearing coefficients from the Last speed point (for the speed dependent coefficients) were used. For compatible with the old versions, the speed ZERO can be entered to indicate the last speed point will be used. From the energy distribution, the bearing at impeller end has much more potential energy than that of the collar end (33.7% vs. 5.2%). Therefore, this bearing is more critical in the design. For the critical speed around 23,000 rpm (in the x-direction), enter 23.000 rpm and select *Kxx*dynamic in the stiffness option. Most of the potential energy in this case is in the bearings and the shaft only has 36% potential energy. This mode is more close to the rigid bode mode compared with the mode at the 26,000 rpm, therefore, this mode is not observed in the unbalance response curve, which will be shown later.

In Ver 19, the bearing coefficients after interpolation and used in the analysis are also printed in the text output for reference. A warning message will appear if the analysis speed is outside the speed range of the bearing coefficients. Again, in the Critical Speed Analysis, the ZERO speed indicates the last speed point will be used as before ver 19.

```
*******************************************************************************
 Brg Coefficients after Interpolation
  No. rpm      Kxx       Kxy       Kyx       Kyy      Cxx      Cxy      Cyx     Cyy
  1  26000.   268110.   141715.   -252637.   406053.  133.853  -4.91026 -4.91026 190.982
  2  26000.   269498.   137247.   -259252.   410936.  133.480  -6.44488 -6.44488 193.375
 =============================================================================
 ********************** Critical Speed Analysis *****************************

               *** Y-Direction Properties are specified ***
               Dynamic Stiffness = sqrt(Kyy^2+(omegaCyy)^2)

               Bearing Coefficients Used @ Speed =  26000.00 RPM

      Bearing No:  1    Stiffness Kt =  659747.46       Kr =  0.0000000
      Bearing No:  2    Stiffness Kt =  667890.00       Kr =  0.0000000

            *******   Spin(1)/Whirl Ratio =  1.000    *******

               no     rpm           R/S          Hz

                1    26408.9      2765.53      440.148
                2    63294.6      6628.20      1054.91
                3    98313.0      10295.3      1638.55
                4    302000.      31625.3      5033.33
                5    590132.      61798.5      9835.53
                6   0.101755E+07  106558.      16959.2
                7   0.176134E+07  184447.      29355.7
                8   0.342898E+07  359082.      57149.7
                9   0.463345E+07  485214.      77224.2

      ******************************************************************
```



Lateral Analysis Option & Run Time Data

Analysis: 2 - Critical Speed Analysis

Shaft Element Effects

☑ Rotatory Inertia ☑ Shear Deformation ☑ Gyroscopic ☐ Gz

Static Deflection

☑ Constrained Bearing Stations

Critical Speed Analysis

Spin/Whirl Ratio: 1

No. of Modes: 5

Brg Stiffness: Kyyd dynamic

@ rpm: 26000

Critical Speed Map

Spin/Whirl Ratio: 1

Bearing K - Min: 1000

Npts: 0 Max: 1e+008

Stiffness to be varied at

Kyyd dynamic

- Kxx
- Kyy
- (Kxx+Kyy)/2
- Kxxd dynamic
- Kyyd dynamic
- (Kxxd+Kyyd)/2

Bearings in Series

Transient Analysis

RPM: 35000

Constant Speed: 35000 rpm

Time-Start: 0

Ending: 0.05

Increment: 1e-006

Newmark-beta

Initial Cs: No

☑ Mass Unbalance

☑ Const. Unbalance

☑ Shaft Bow

☑ Disk Skew

☐ Gravity (X,Y)

☐ Gravity (Z)

☑ Static Loads

☑ Time Forcing

☑ Misalignment

Gravity (g)

X: 0

Y: -386.088

Z: 0

None zero Gz Vertical Rotor

Whirl Speed and Stability Analysis

RPM-Starting: 10000

Ending: 40000

Increment: 500

No. of Modes: 6

Synchronous Response Analysis

10000

Ending: 40000

Increment: 100

Excitation Shaft: 1

☑ All Synchronized Shafts

Effects:

☑ Mass Unbalance

☑ Const. Unbalance

☑ Shaft Bow

☑ Disk Skew

☑ Misalignment

Steady State Harmonic Excitation

RPM-Starting: 10000

Ending: 40000

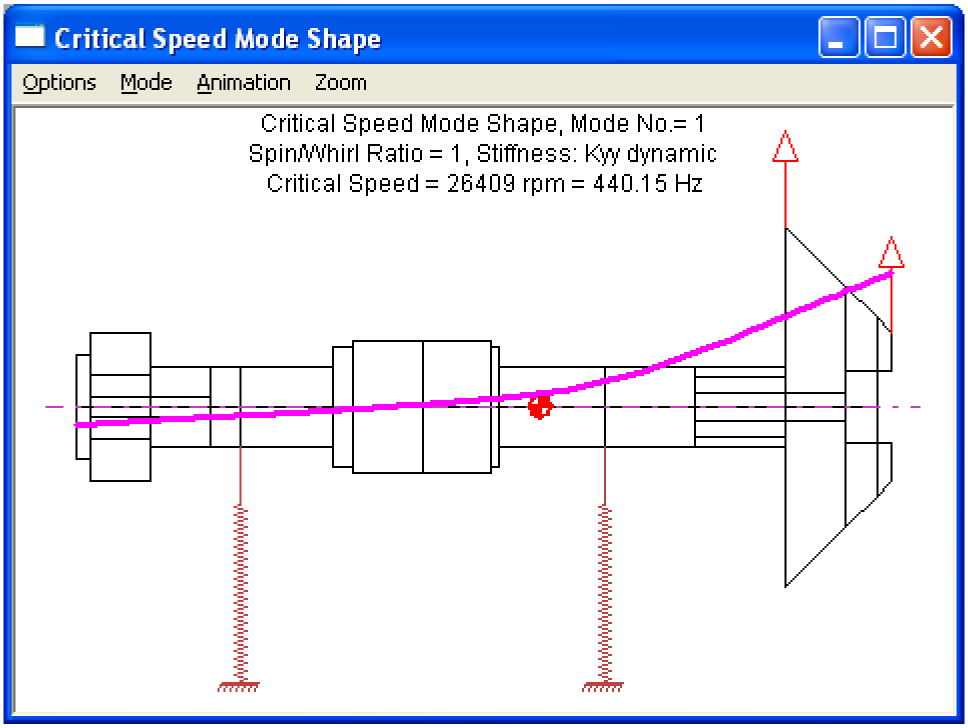
Increment: 100

Excitation Shaft: 1

☑ All Shafts with same speed

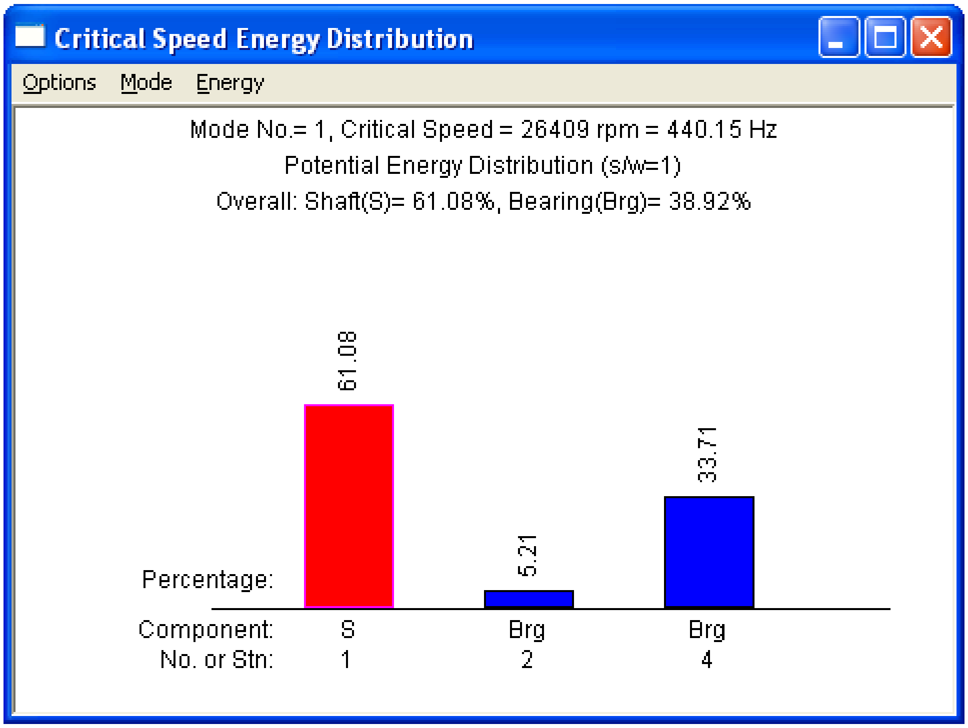
Steady Maneuvers (Base Constant Translational Acceleration and/or Turn Rate)

Speed (RPM): 35000 Acceleration - X: 0 Y: 772.176 Turn Rate - X: 0 Y: 0 Ref Pos: 0

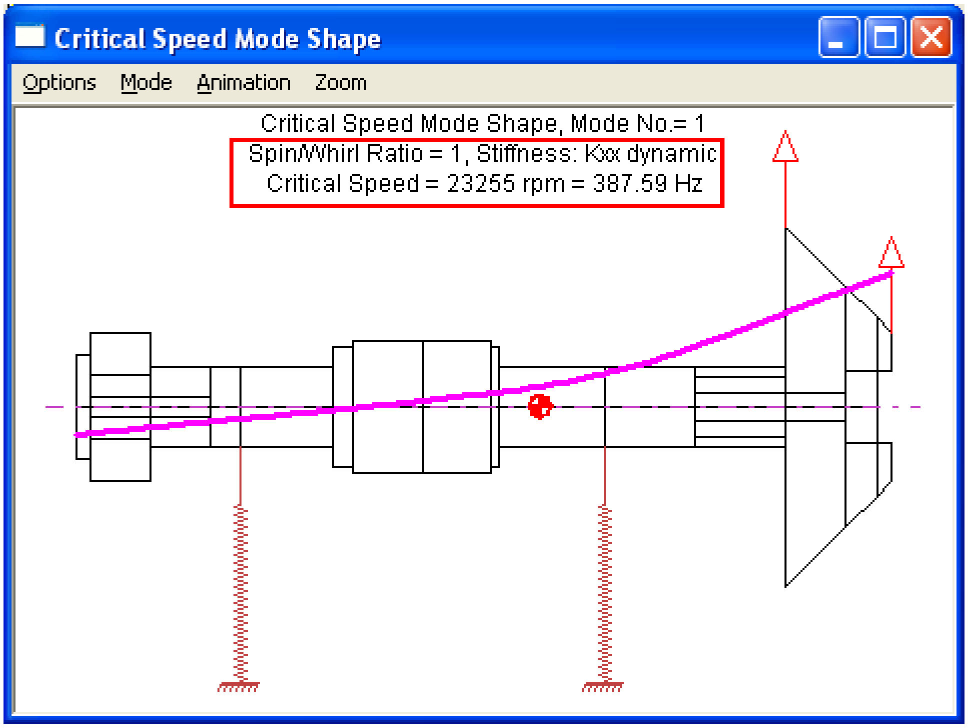


Critical Speed Mode Shape

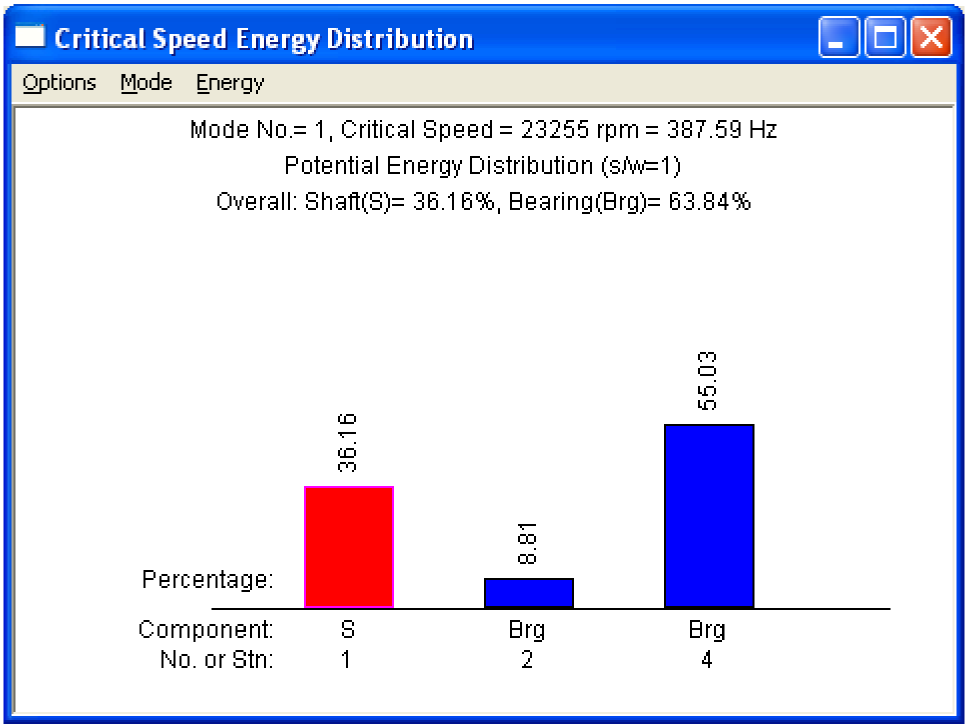
Critical Speed Mode Shape, Mode No.= 1
Spin/Whirl Ratio = 1, Stiffness: Kyy dynamic
Critical Speed = 26409 rpm = 440.15 Hz



Mode No.= 1, Critical Speed = 26409 rpm = 440.15 Hz
Potential Energy Distribution (s/w=1)
Overall: Shaft(S)= 61.08%, Bearing(Brg)= 38.92%

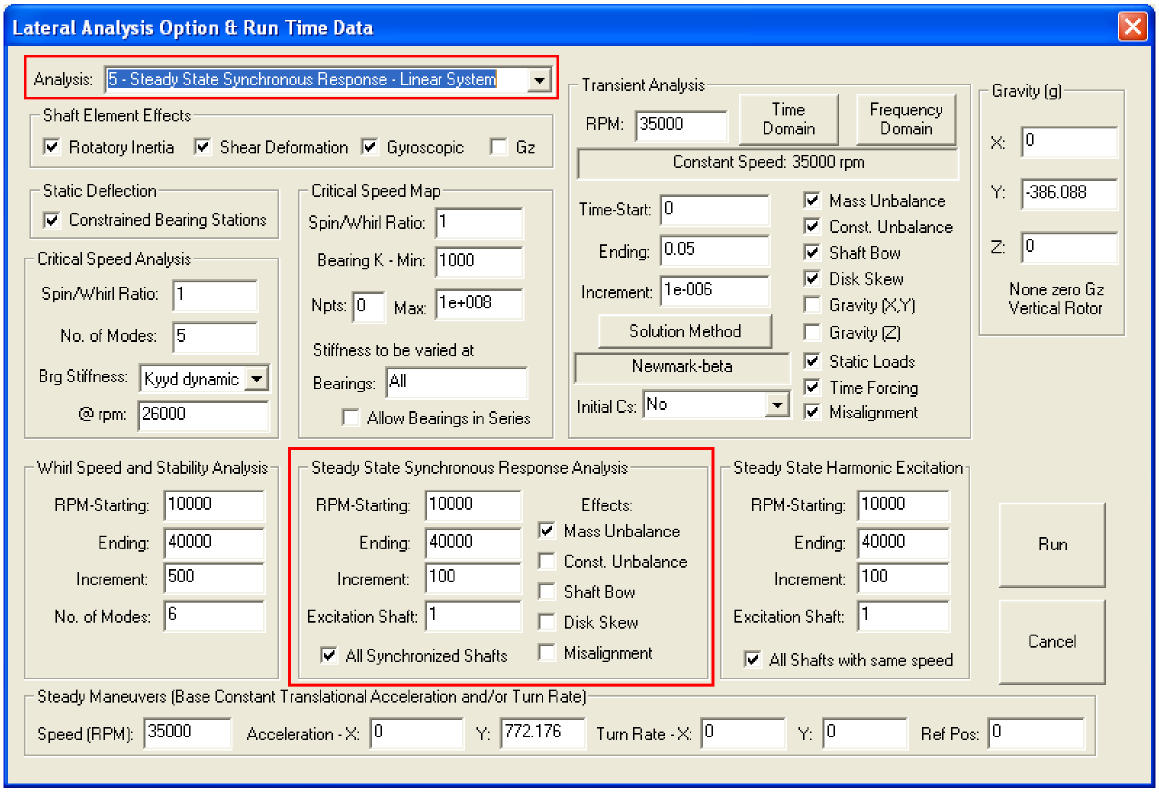


Critical Speed Mode Shape, Mode No.= 1
Spin/Whirl Ratio = 1, Stiffness: Kxx dynamic
Critical Speed = 23255 rpm = 387.59 Hz



Mode No.= 1, Critical Speed = 23255 rpm = 387.59 Hz
Potential Energy Distribution (s/w=1)
Overall: Shaft(S)= 36.16%, Bearing(Brg)= 63.84%

The next analysis is the unbalance response analysis. The analysis speed starts from 10,000 rpm to 40,000 rpm with an increment of 100 rpm. Since this speed increment (100 rpm) is smaller than the speed increment (5,000 rpm) in the bearing coefficients, interpolation will be implemented in the program. The interpolation method (spline or linear) is specified in the Bearing input tab. The vibration at the probe station (station 5) is shown in the Bode plot (PostProcessor – Steady Synchronous Response – Bode Plot). Some graphic settings can be adjusted under Options – Settings. In this example, English units are used. The response displacement is in inches. But, it is common to use mils in US to describe the vibration amplitude. Therefore, we entered 1000 in the Amplitude Scale to convert the inches to mils. The Text Color box is checked to show the corresponding color in the text printout in the plot. The curve color can also be changed in the Preference Settings – Post-Processor Graph Colors. Also, the amplitude printout is formatted with floating point with 2 decimal points. Some of the graphic settings can be pre-defined and saved in the Preference Settings File (Project – Preference Settings – Post-Processor Graph Settings and Post-Processor Graph Colors). These graphic features are implemented in all the post-processor plots when applicable. Again, use Options – Settings to make necessary adjustments to meet your needs.



Analysis: 5 - Steady State Synchronous Response - Linear System

Shaft Element Effects
☑ Rotatory Inertia ☑ Shear Deformation ☑ Gyroscopic ☐ Gz

Static Deflection
☑ Constrained Bearing Stations

Critical Speed Analysis
Spin/Whirl Ratio: 1
No. of Modes: 5
Brg Stiffness: Kyyd dynamic
@ rpm: 26000

Critical Speed Map
Spin/Whirl Ratio: 1
Bearing K - Min: 1000
Npts: 0 Max: 1e+008
Stiffness to be varied at
Bearings: All
☐ Allow Bearings in Series

Transient Analysis
RPM: 35000
Constant Speed: 35000 rpm
Time-Start: 0
Ending: 0.05
Increment: 1e-006
Newmark-beta
Initial Cs: No
☑ Mass Unbalance
☑ Const. Unbalance
☑ Shaft Bow
☑ Disk Skew
☐ Gravity (X,Y)
☐ Gravity (Z)
☑ Static Loads
☑ Time Forcing
☑ Misalignment

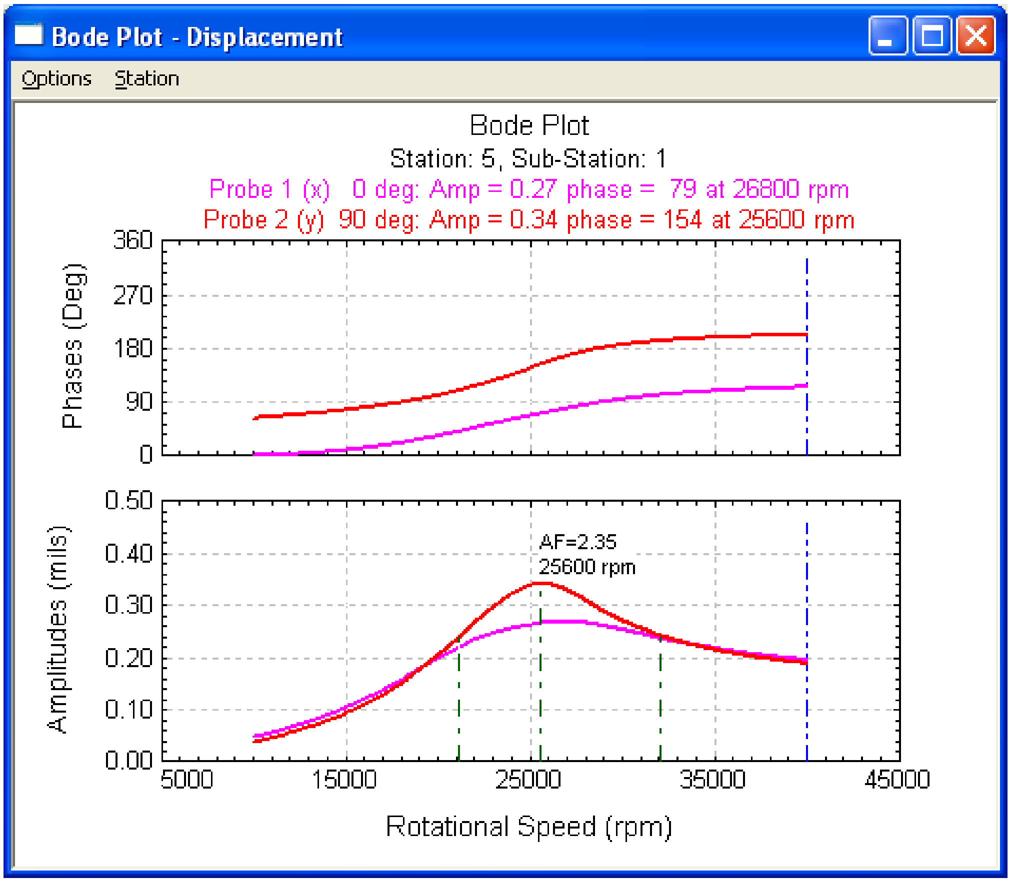
Gravity (g)
X: 0
Y: -386.088
Z: 0
None zero Gz Vertical Rotor

Whirl Speed and Stability Analysis
RPM-Starting: 10000
Ending: 40000
Increment: 500
No. of Modes: 6

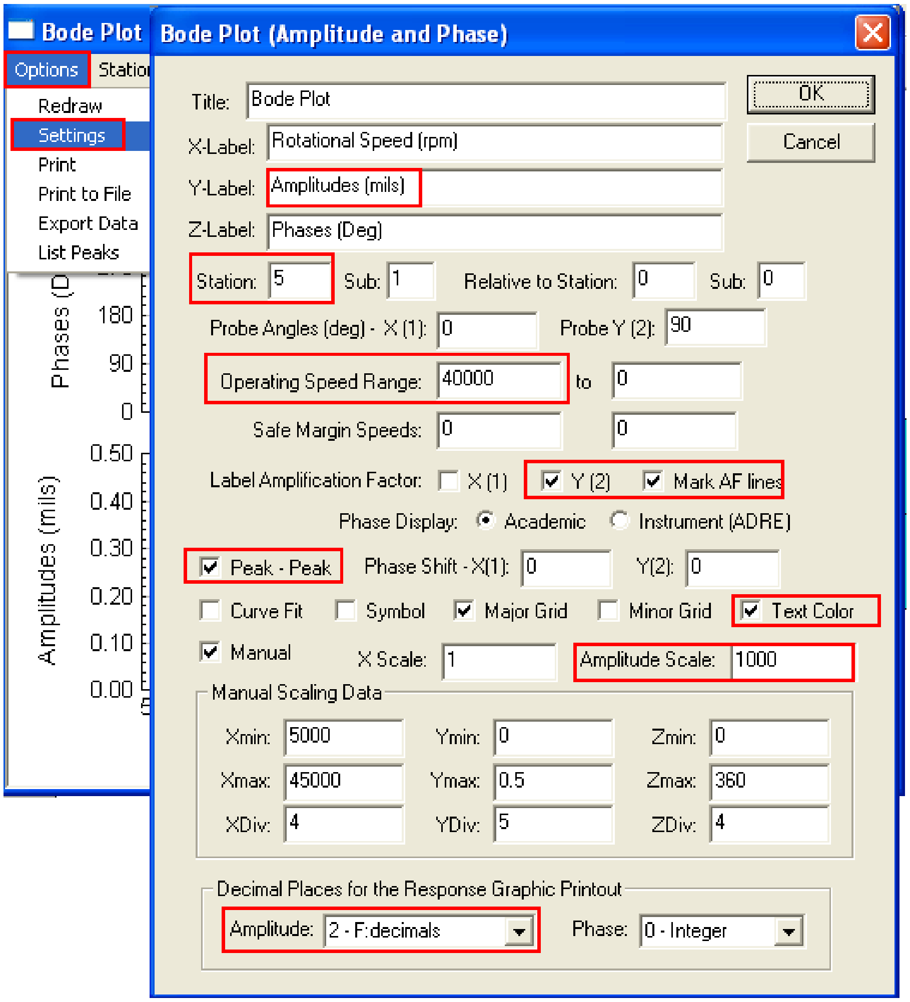
Steady State Synchronous Response Analysis
RPM-Starting: 10000
Ending: 40000
Increment: 100
Excitation Shaft: 1
☑ All Synchronized Shafts
Effects:
☑ Mass Unbalance
☐ Const. Unbalance
☐ Shaft Bow
☐ Disk Skew
☐ Misalignment

Steady State Harmonic Excitation
RPM-Starting: 10000
Ending: 40000
Increment: 100
Excitation Shaft: 1
☑ All Shafts with same speed

Steady Maneuvers (Base Constant Translational Acceleration and/or Turn Rate)
Speed (RPM): 35000 Acceleration - X: 0 Y: 772.176 Turn Rate - X: 0 Y: 0 Ref Pos: 0



Station: 5, Sub-Station: 1
Probe 1 (x) 0 deg: Amp = 0.27 phase = 79 at 26800 rpm
Probe 2 (y) 90 deg: Amp = 0.34 phase = 154 at 25600 rpm



Title: Bode Plot

X-Label: Rotational Speed (rpm)

Y-Label: Amplitudes (mils)

Z-Label: Phases (Deg)

Station: 5 Sub: 1 Relative to Station: 0 Sub: 0

Probe Angles (deg) - X (1): 0 Probe Y (2): 90

Operating Speed Range: 40000 to 0

Safe Margin Speeds: 0 0

Label Amplification Factor: ☐ X (1) ☑ Y (2) ☑ Mark AF lines

Phase Display: ● Academic ○ Instrument (ADRE)

☑ Peak - Peak Phase Shift - X(1): 0 Y(2): 0

☐ Curve Fit ☐ Symbol ☑ Major Grid ☐ Minor Grid ☑ Text Color

☑ Manual X Scale: 1 Amplitude Scale: 1000

Manual Scaling Data

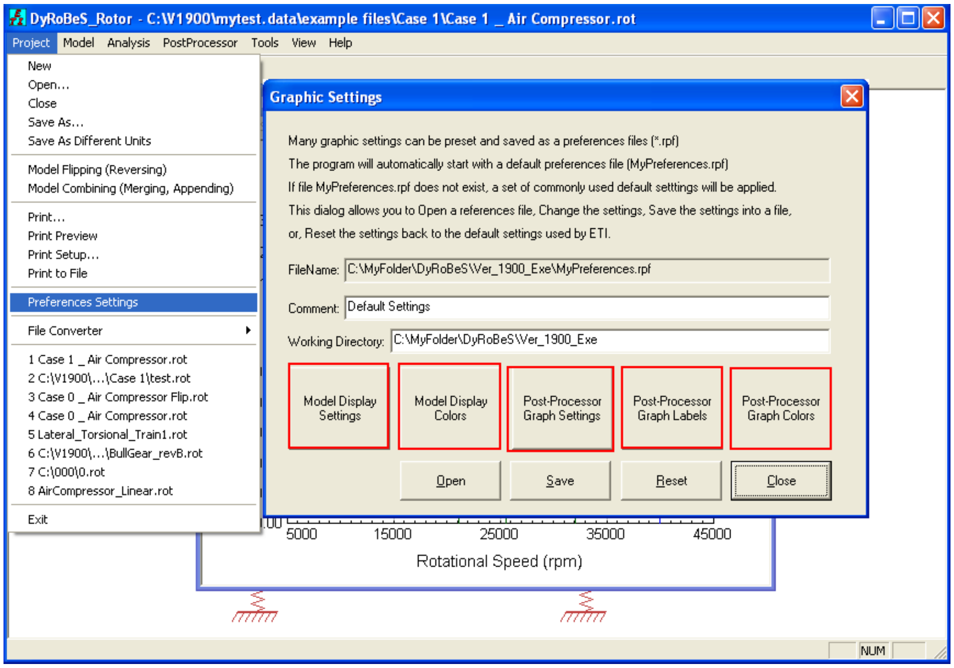
Xmin: 5000 Ymin: 0 Zmin: 0

Xmax: 45000 Ymax: 0.5 Zmax: 360

XDiv: 4 YDiv: 5 ZDiv: 4

Decimal Places for the Response Graphic Printout

Amplitude: 2 - F:decimals Phase: 0 - Integer

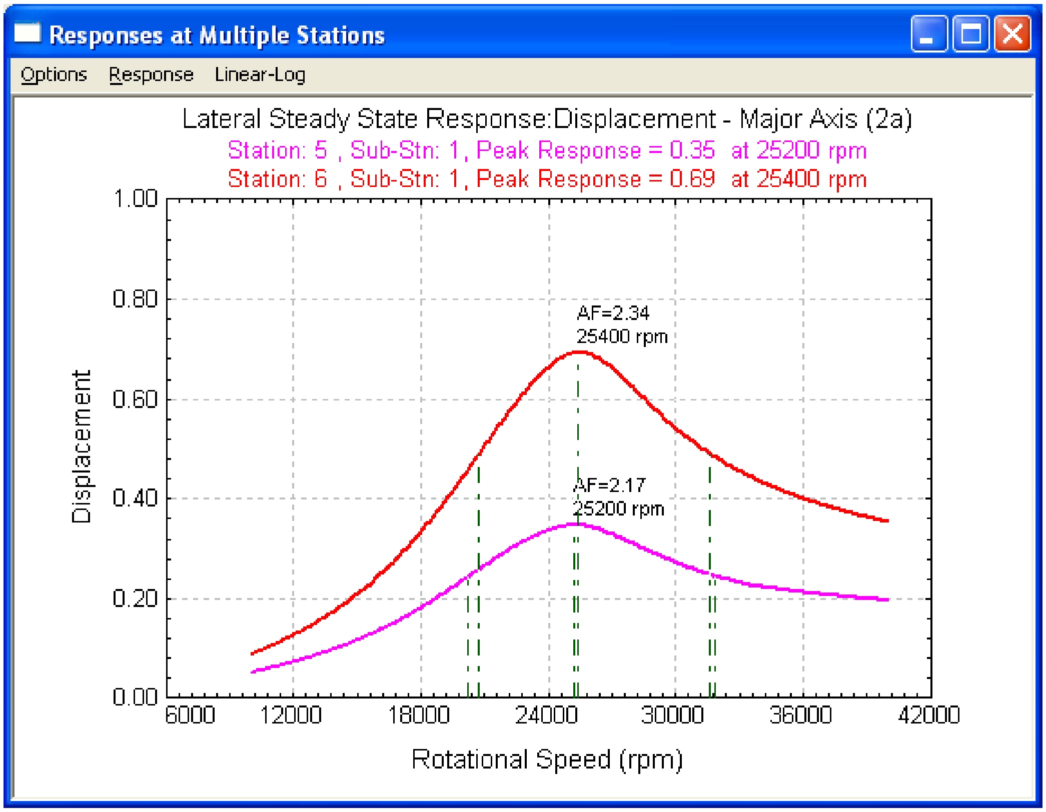


Many graphic settings can be preset and saved as a preferences files (*.rpf)
The program will automatically start with a default preferences file (MyPreferences.rpf)
If file MyPreferences.rpf does not exist, a set of commonly used default setttings will be applied.
This dialog allows you to Open a references file, Change the settings, Save the settings into a file,
or, Reset the settings back to the default settings used by ETI.

FileName: C:\MyFolder\DyRoBeS\Ver_1900_Exe\MyPreferences.rpf

Comment: Default Settings

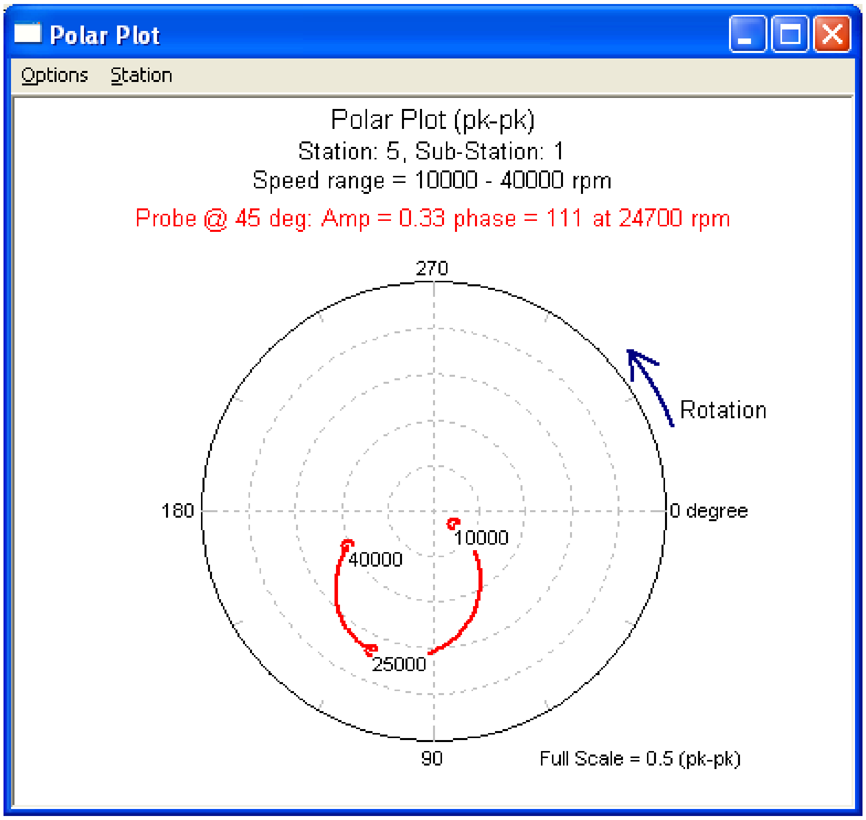
Working Directory: C:\MyFolder\DyRoBeS\Ver_1900_Exe



Lateral Steady State Response:Displacement - Major Axis (2a)

Station: 5 , Sub-Stn: 1, Peak Response = 0.35 at 25200 rpm

Station: 6 , Sub-Stn: 1, Peak Response = 0.69 at 25400 rpm



Polar Plot (pk-pk)

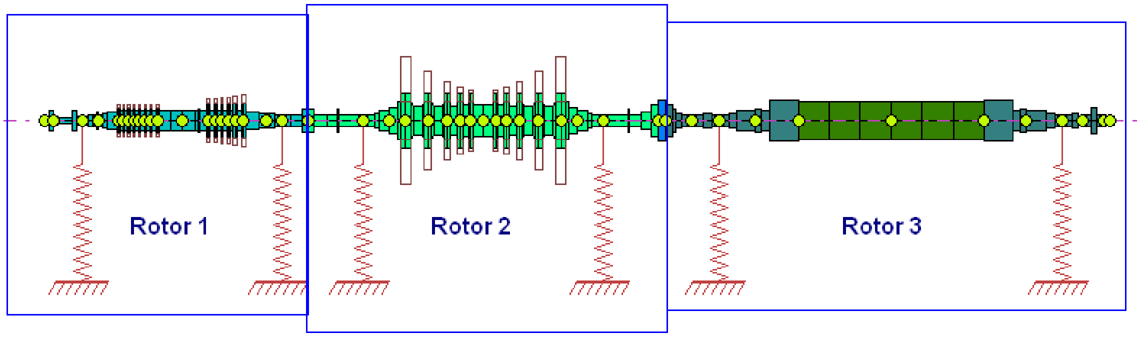
Station: 5, Sub-Station: 1

Speed range = 10000 - 40000 rpm

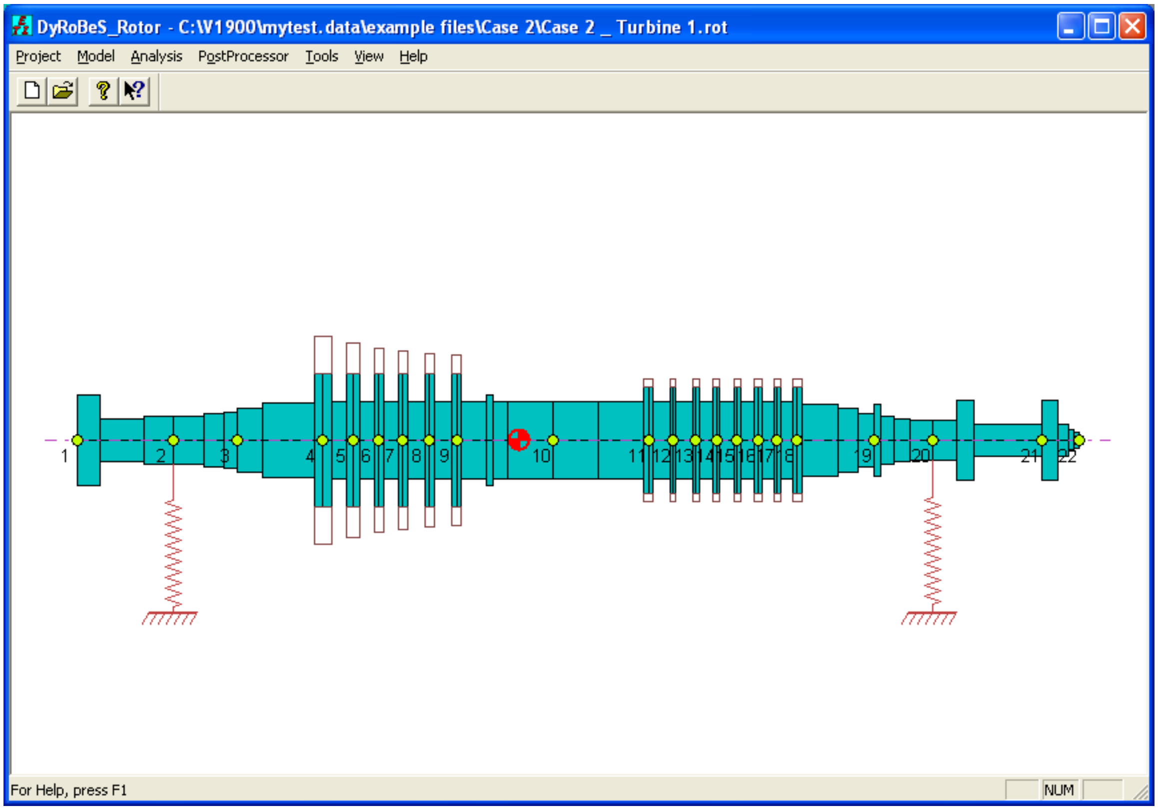
Probe @ 45 deg: Amp = 0.33 phase = 111 at 24700 rpm

Case 2 – Turbine – Generator Set

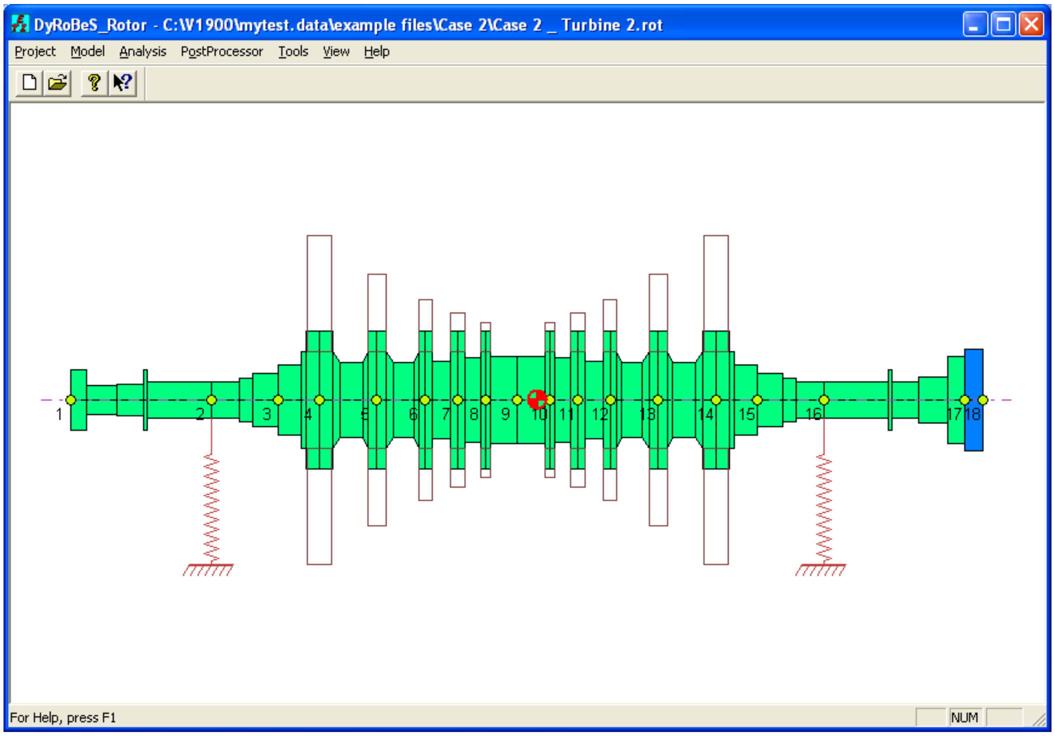
This example is a turbine-generator set. The model was built in three separate rotors (files) as shown below. It is noticed that the individual Rotor 1 was modeled in the reversed direction (right to left) compared to the entire train. This can occur frequently since all the drawings (data or model) were provided from different suppliers, or modeled by different engineers. In this example, the Model Flipping and Model Combining features will be demonstrated.



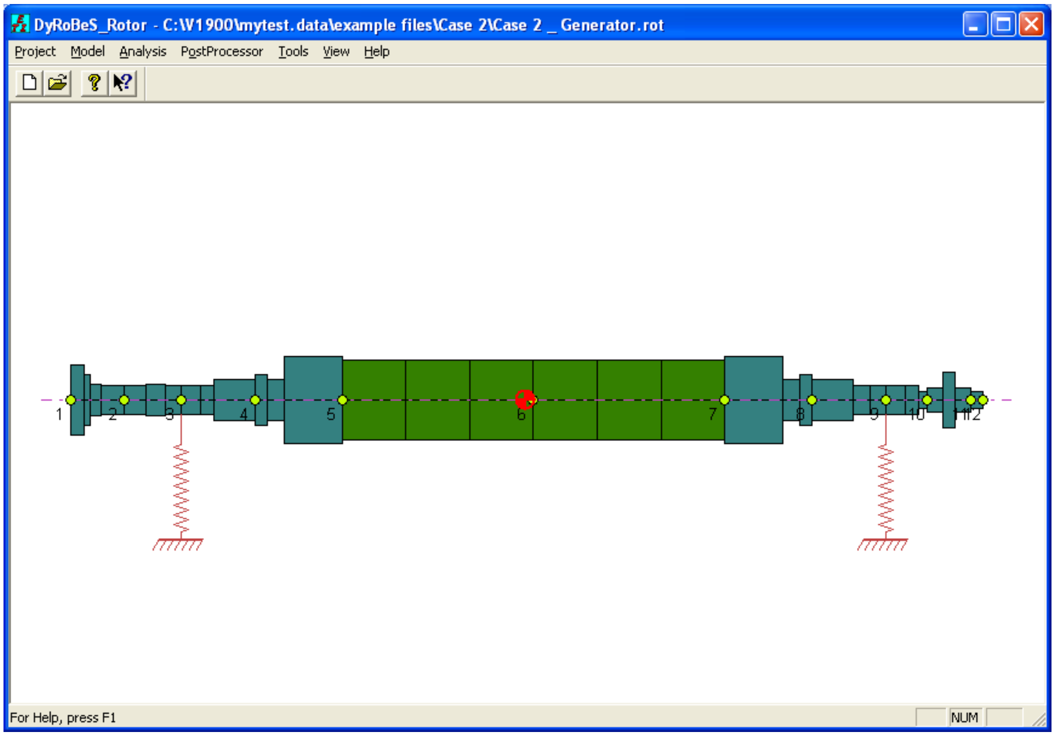
Rotor 1



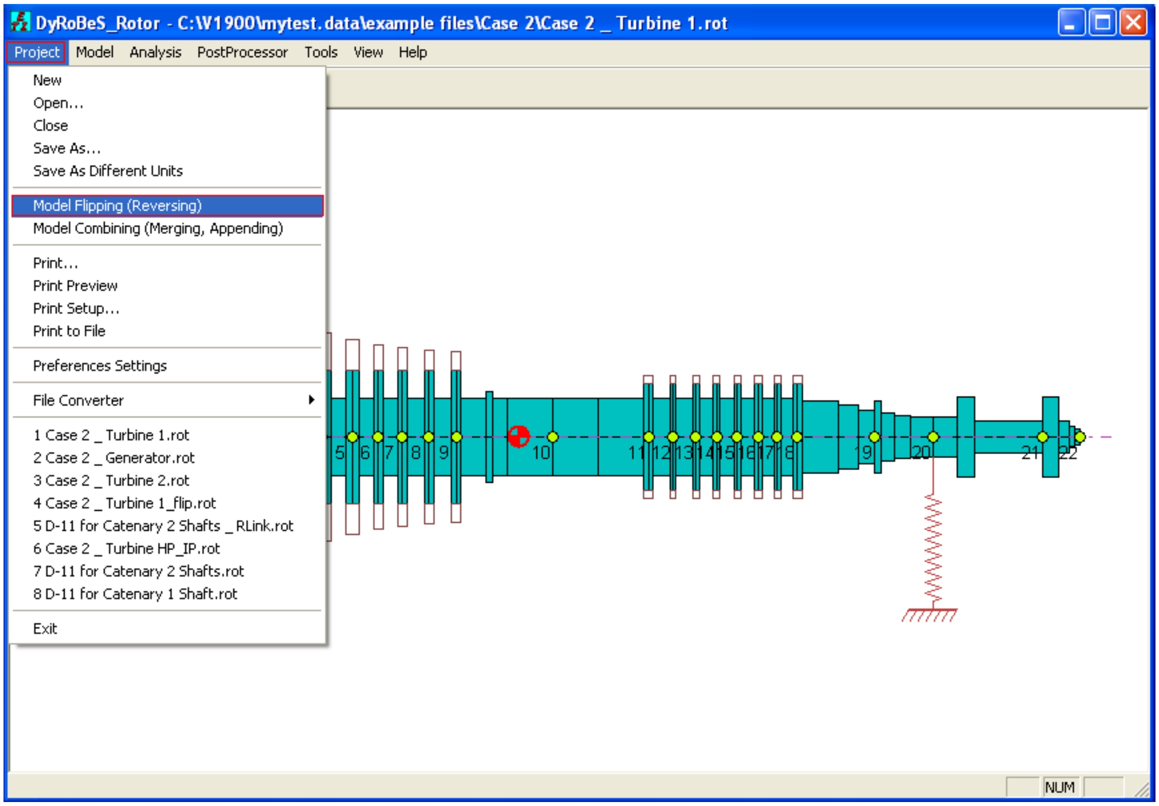
Rotor 2

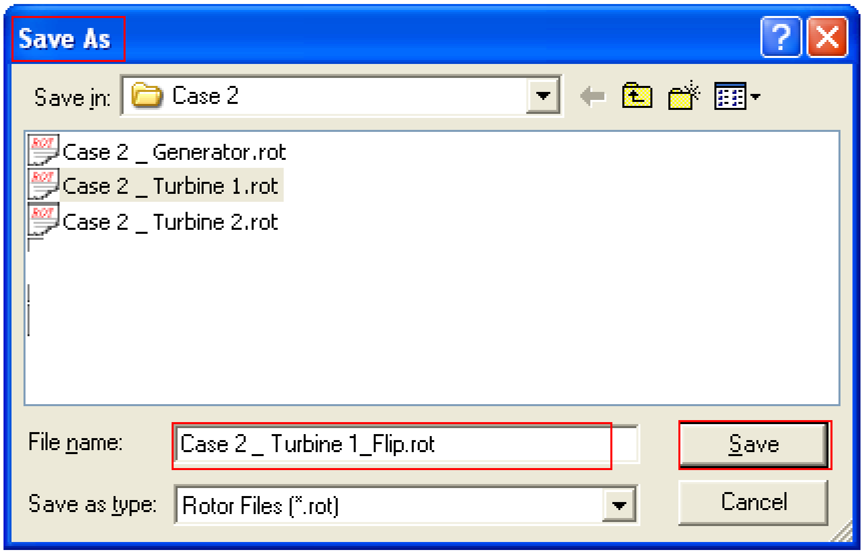


Rotor 3



<u>Step 1</u> is to flip the rotor 1 model before combining with others: Open the original rotor 1 file, Select Model Flipping under Project menu, then Save the flipped model in a different file name (in case, the original file is needed for other purposes). After this is done, the main window will be updated with this new file name and new model.

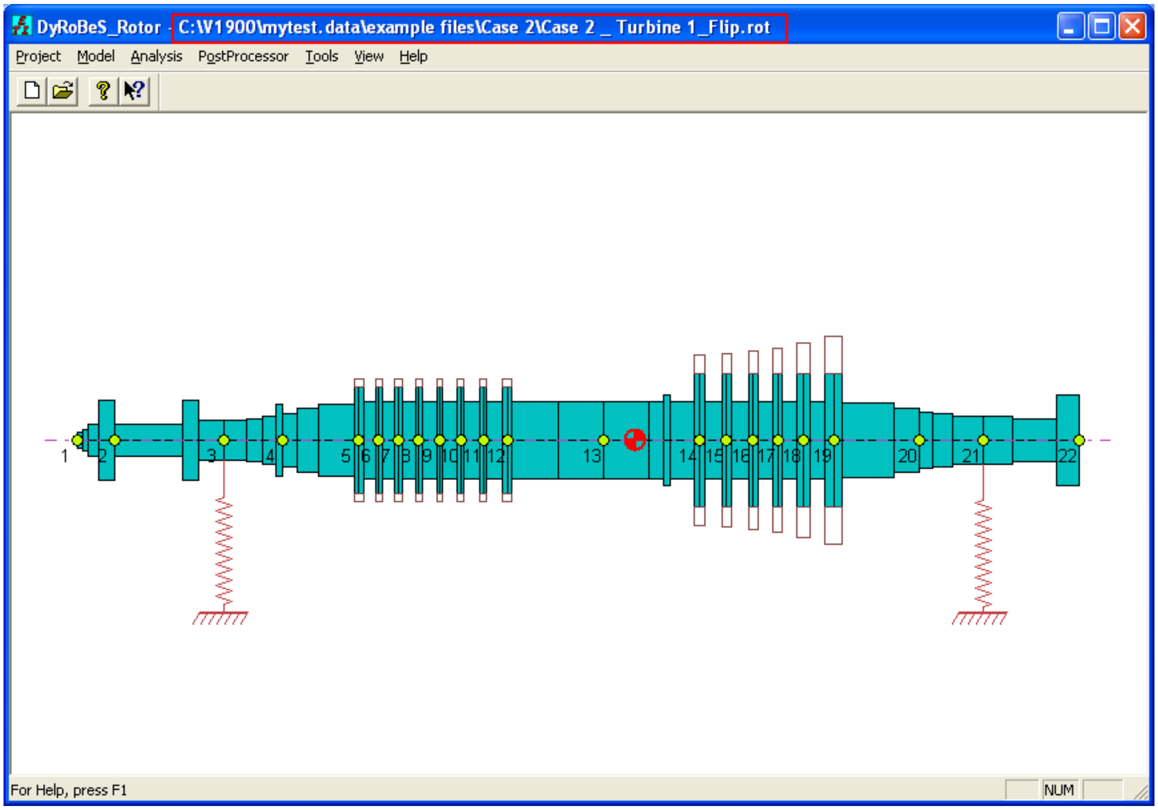




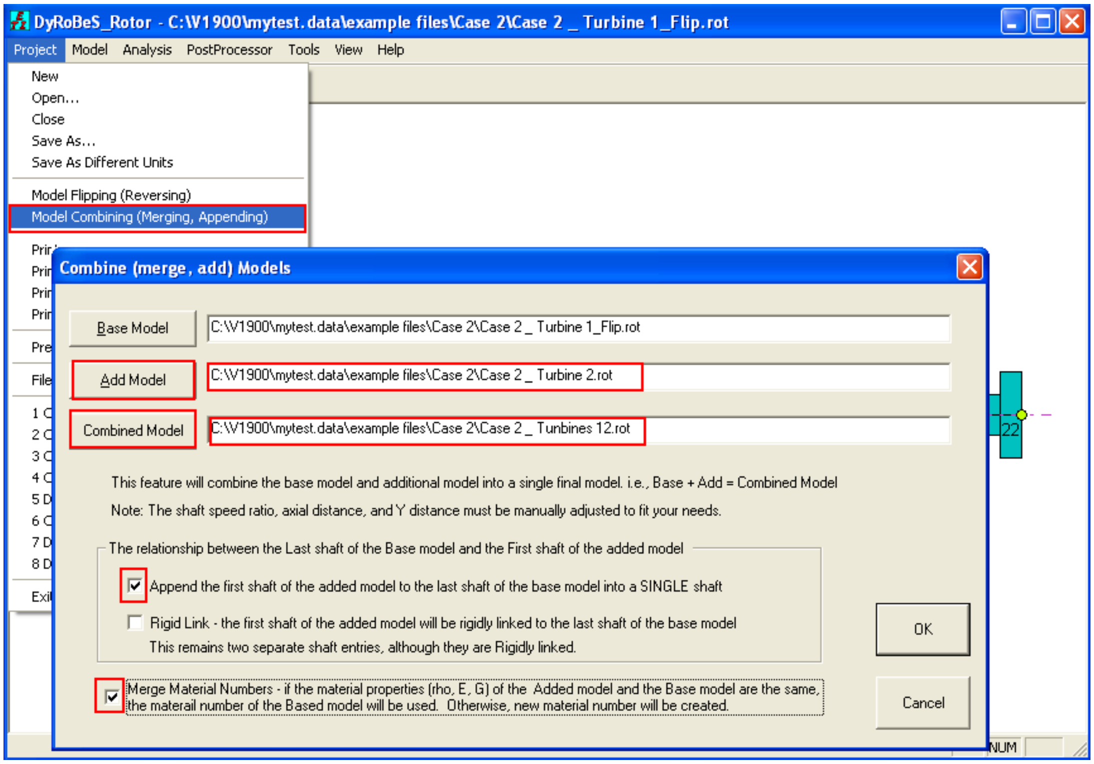
Save in: Case 2

File name: Case 2 _ Turbine 1_Flip.rot

Save as type: Rotor Files (*.rot)



<u>Step 2</u> to combine (merge, append) the Rotor 2 file into this rotor 1: Select Model Combining under Project menu while the Rotor 1 is still an active project in the screen. A dialog box will appear once the Model Combining is selected. Since the rotor 1 is still active and is used as the base model. Click Add Model to add the second rotor and also click Combined Model to save the combined model into a file. Since all three rotors are in-line in this case, we can simply append the rotor 2 into the rotor 1 in a single shaft without generating a second shaft in the model. We can also use Rigid Link option to keep the rotor 2 in a second shaft and rigidly link to Rotor 1. Both will yield the same analysis results. The Merge Material Number box is checked, that is, if the material properties (Rho, E, G, and description) in rotor 2 can be found in the Rotor 1 material library, then the existing material number in Rotor 1 will be used for Rotor 2, and it will not duplicate the same material in another material number. If the Merge Material box is not checked, the material number in rotor 2 will append to the material numbers in Rotor 1 as a new material. After this step, the main window will be updated with this new combined model.



DyRoBeS_Rotor - C:\V1900\mytest.data\example files\Case 2\Case 2 _ Turbine 1_Flip.rot

Combine (merge, add) Models

Base Model: C:\V1900\mytest.data\example files\Case 2\Case 2 _ Turbine 1_Flip.rot

Add Model: C:\V1900\mytest.data\example files\Case 2\Case 2 _ Turbine 2.rot

Combined Model: C:\V1900\mytest.data\example files\Case 2\Case 2 _ Tunbines 12.rot

This feature will combine the base model and additional model into a single final model. i.e., Base + Add = Combined Model

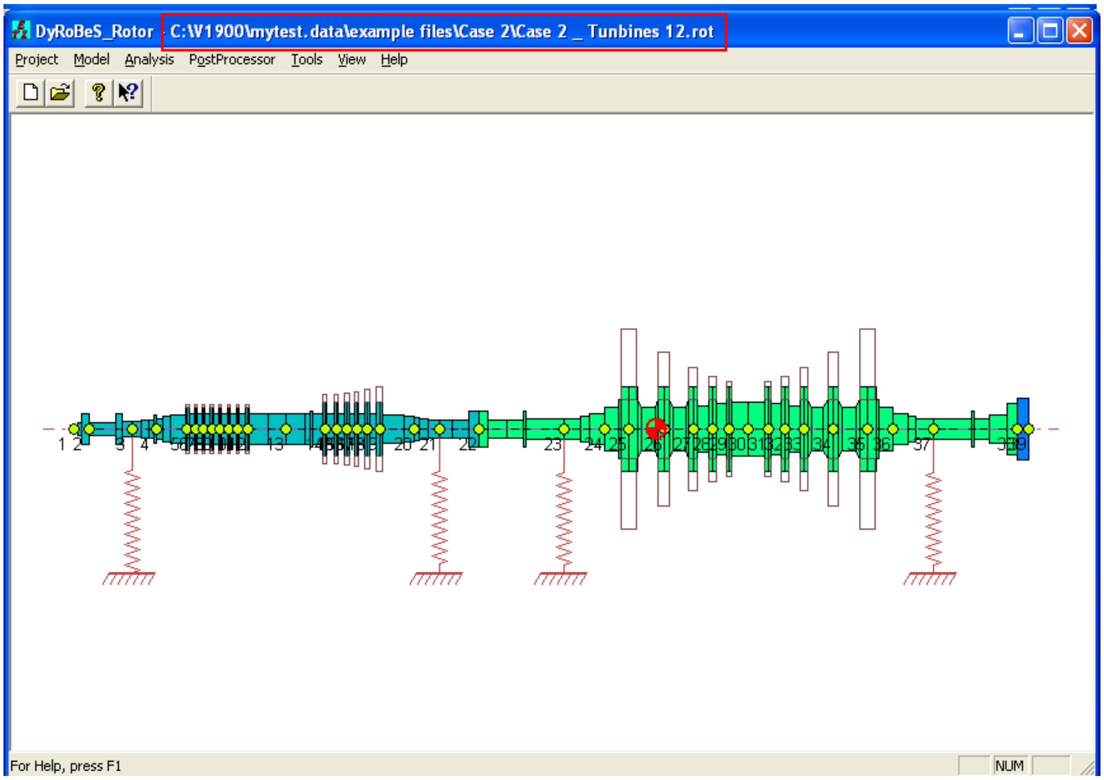
Note: The shaft speed ratio, axial distance, and Y distance must be manually adjusted to fit your needs.

The relationship between the Last shaft of the Base model and the First shaft of the added model

☑ Append the first shaft of the added model to the last shaft of the base model into a SINGLE shaft

☐ Rigid Link - the first shaft of the added model will be rigidly linked to the last shaft of the base model
This remains two separate shaft entries, although they are Rigidly linked.

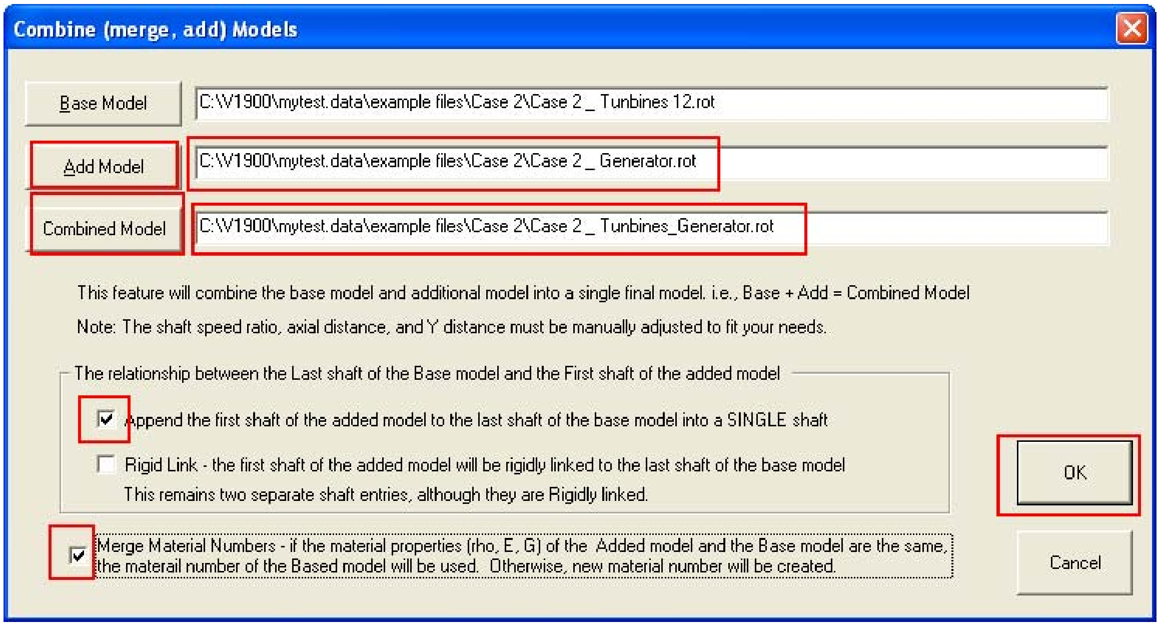
☑ Merge Material Numbers - if the material properties (rho, E, G) of the Added model and the Base model are the same, the materail number of the Based model will be used. Otherwise, new material number will be created.



DyRoBeS_Rotor - C:\V1900\mytest.data\example files\Case 2\Case 2 _ Tunbines 12.rot

For Help, press F1

Step 3 is to combine the generator (rotor 3). Again, Select Model Combining under Project menu and enter the necessary information as shown below to add the generator into the system. After these two steps, the separate three rotors are combined into a single model.


Combine (merge, add) Models

Base Model: C:\V1900\mytest.data\example files\Case 2\Case 2 _ Tunbines 12.rot

Add Model: C:\V1900\mytest.data\example files\Case 2\Case 2 _ Generator.rot

Combined Model: C:\V1900\mytest.data\example files\Case 2\Case 2 _ Tunbines_Generator.rot

This feature will combine the base model and additional model into a single final model. i.e., Base + Add = Combined Model

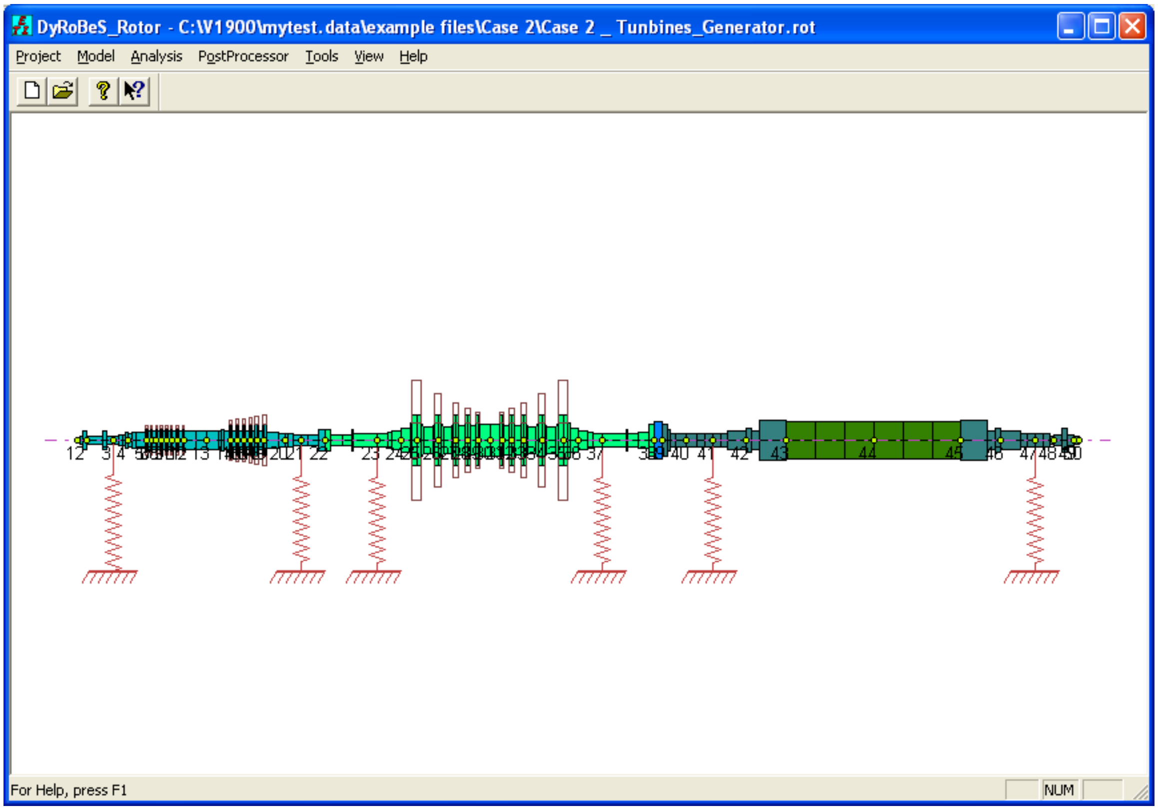
Note: The shaft speed ratio, axial distance, and Y distance must be manually adjusted to fit your needs.

The relationship between the Last shaft of the Base model and the First shaft of the added model

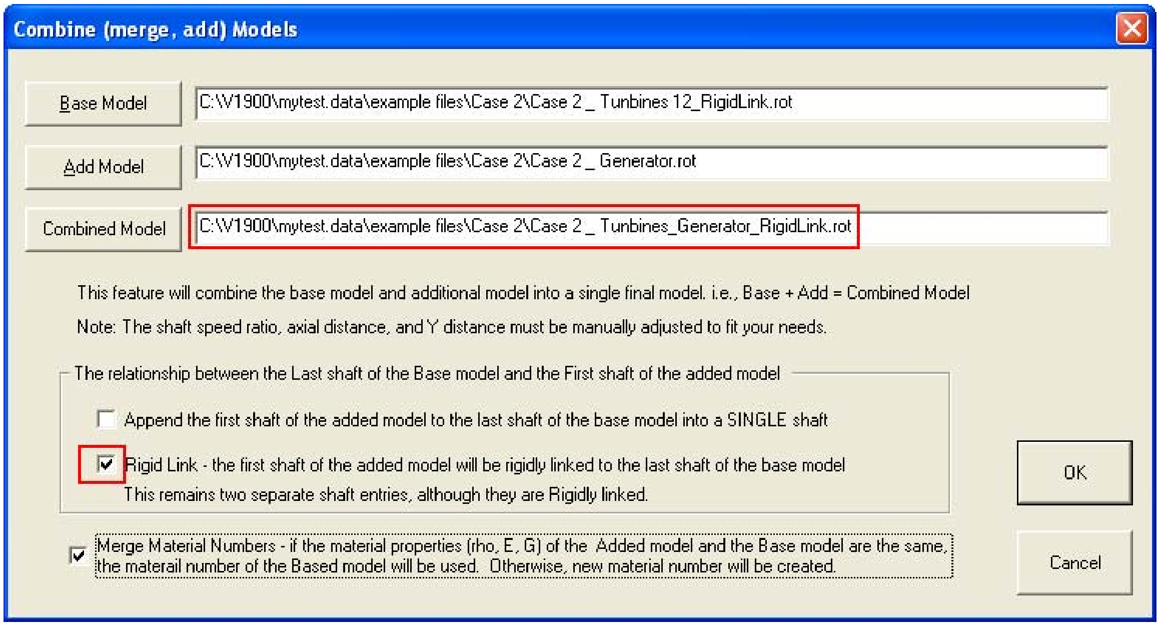
☑ Append the first shaft of the added model to the last shaft of the base model into a SINGLE shaft

☐ Rigid Link - the first shaft of the added model will be rigidly linked to the last shaft of the base model
This remains two separate shaft entries, although they are Rigidly linked.

☑ Merge Material Numbers - if the material properties (rho, E, G) of the Added model and the Base model are the same, the materail number of the Based model will be used. Otherwise, new material number will be created.



If you prefer to keep these three rotors in separate shafts in the system, then you may use the Rigid Link option instead of the Append in the check box as shown below. Both methods yield the same analysis results.



Base Model: C:\V1900\mytest.data\example files\Case 2\Case 2 _ Tunbines 12_RigidLink.rot

Add Model: C:\V1900\mytest.data\example files\Case 2\Case 2 _ Generator.rot

Combined Model: C:\V1900\mytest.data\example files\Case 2\Case 2 _ Tunbines_Generator_RigidLink.rot

This feature will combine the base model and additional model into a single final model. i.e., Base + Add = Combined Model

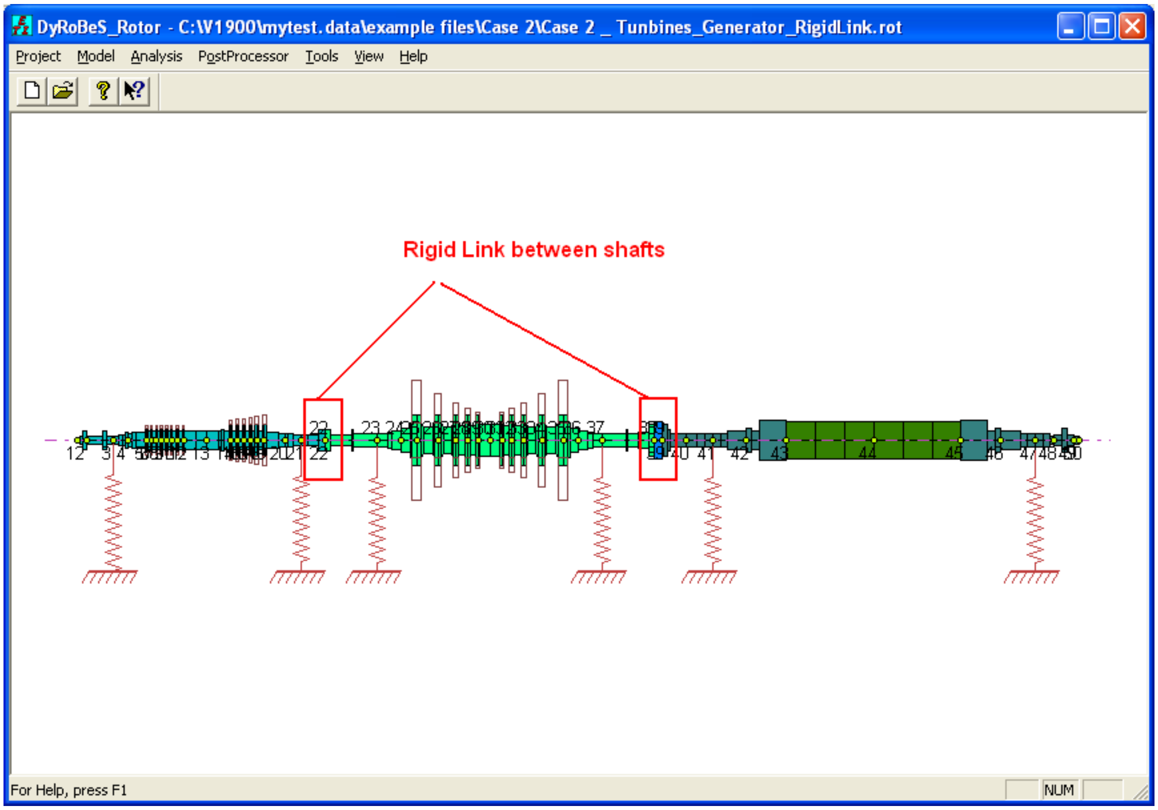
Note: The shaft speed ratio, axial distance, and Y distance must be manually adjusted to fit your needs.

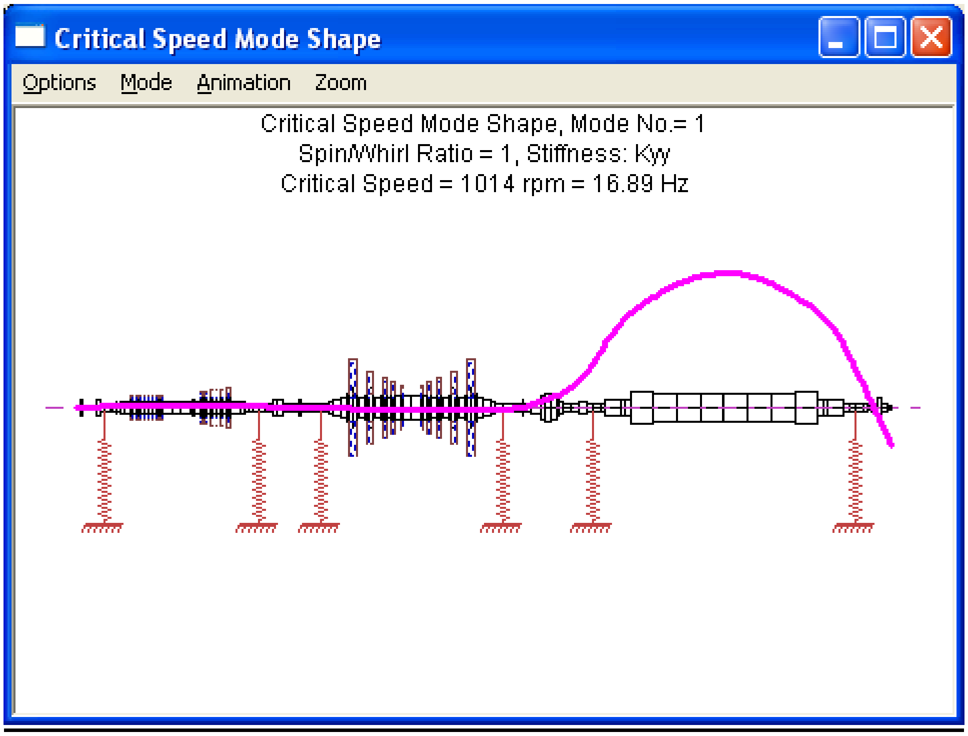
The relationship between the Last shaft of the Base model and the First shaft of the added model

☐ Append the first shaft of the added model to the last shaft of the base model into a SINGLE shaft

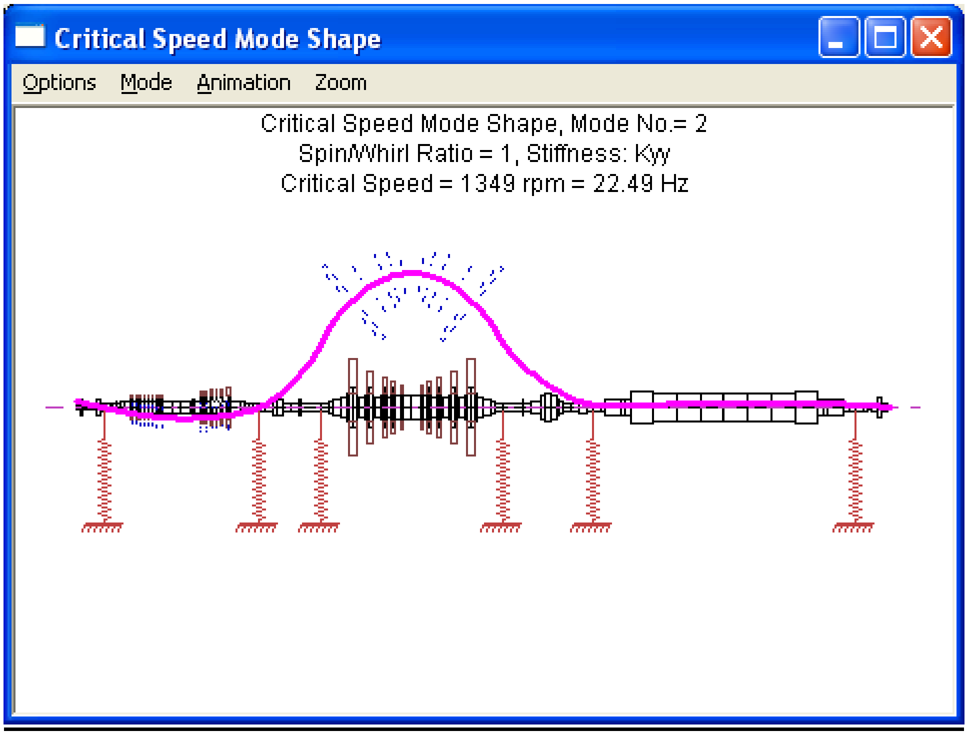
☑ Rigid Link - the first shaft of the added model will be rigidly linked to the last shaft of the base model
This remains two separate shaft entries, although they are Rigidly linked.

☑ Merge Material Numbers - if the material properties (rho, E, G) of the Added model and the Base model are the same, the materail number of the Based model will be used. Otherwise, new material number will be created.

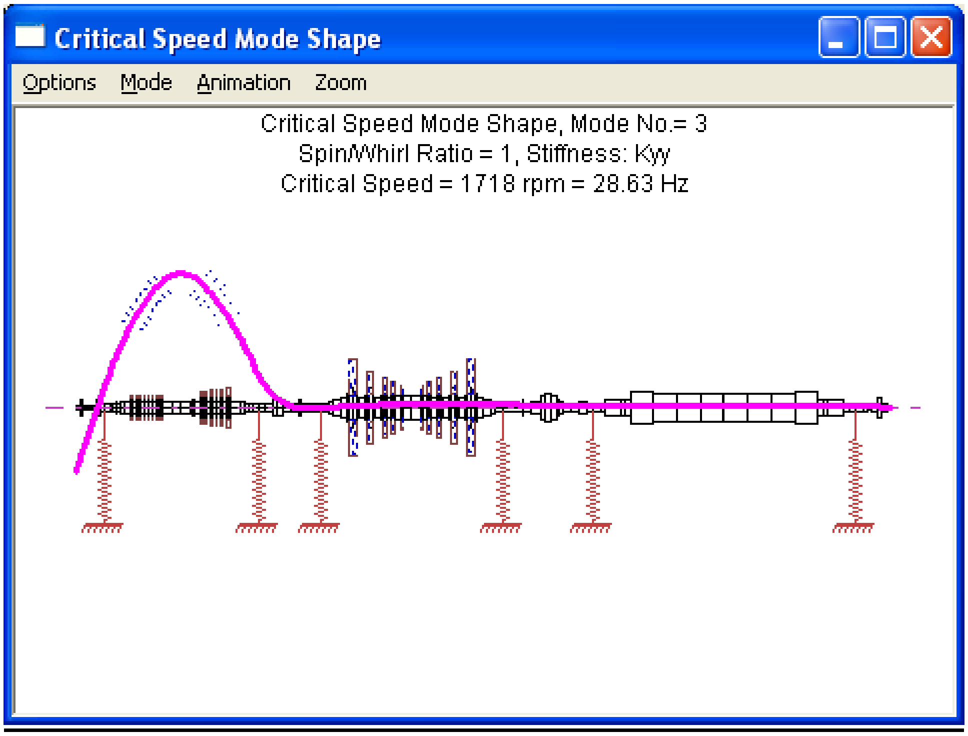




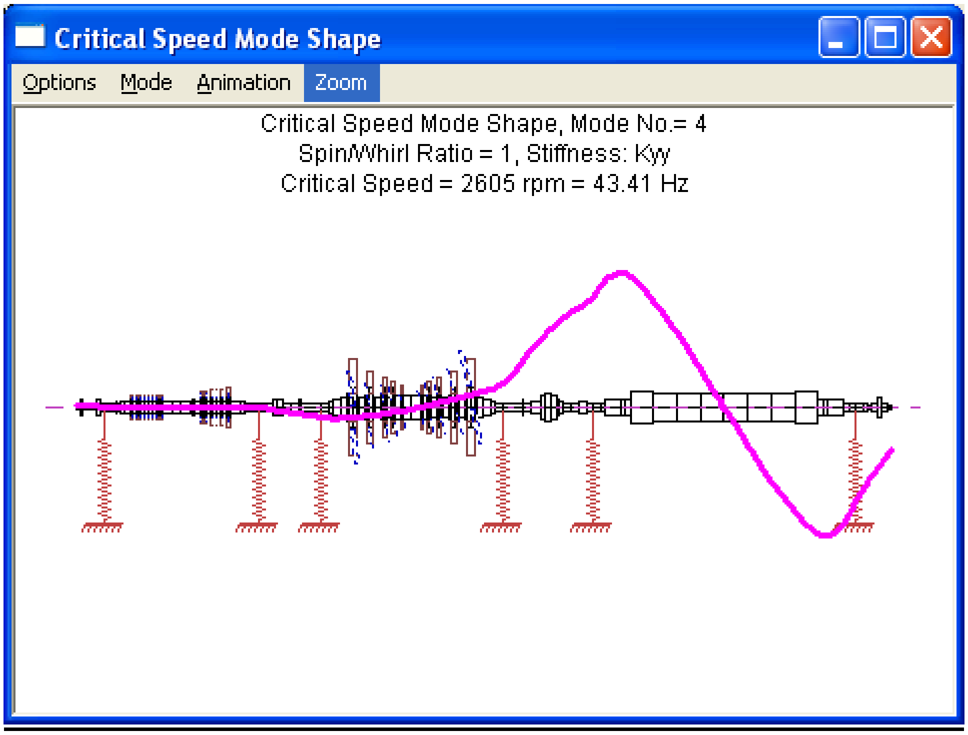
Critical Speed Mode Shape, Mode No.= 1
Spin/Whirl Ratio = 1, Stiffness: Kyy
Critical Speed = 1014 rpm = 16.89 Hz



Critical Speed Mode Shape, Mode No.= 2
Spin/Whirl Ratio = 1, Stiffness: Kyy
Critical Speed = 1349 rpm = 22.49 Hz



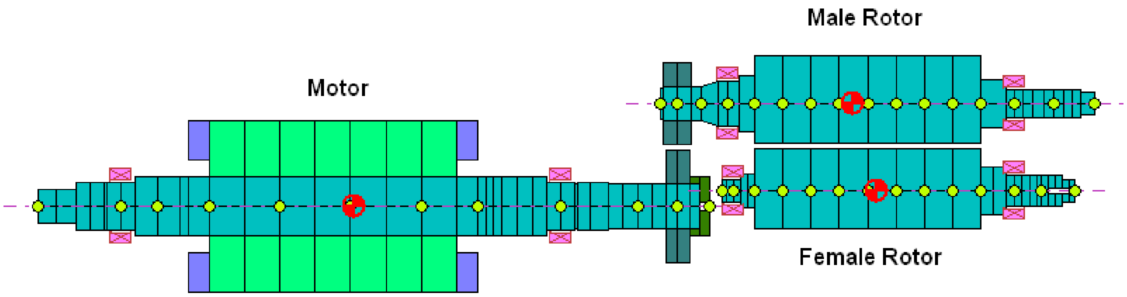
Critical Speed Mode Shape, Mode No.= 3
Spin/Whirl Ratio = 1, Stiffness: Kyy
Critical Speed = 1718 rpm = 28.63 Hz



Critical Speed Mode Shape, Mode No.= 4
Spin/Whirl Ratio = 1, Stiffness: Kyy
Critical Speed = 2605 rpm = 43.41 Hz

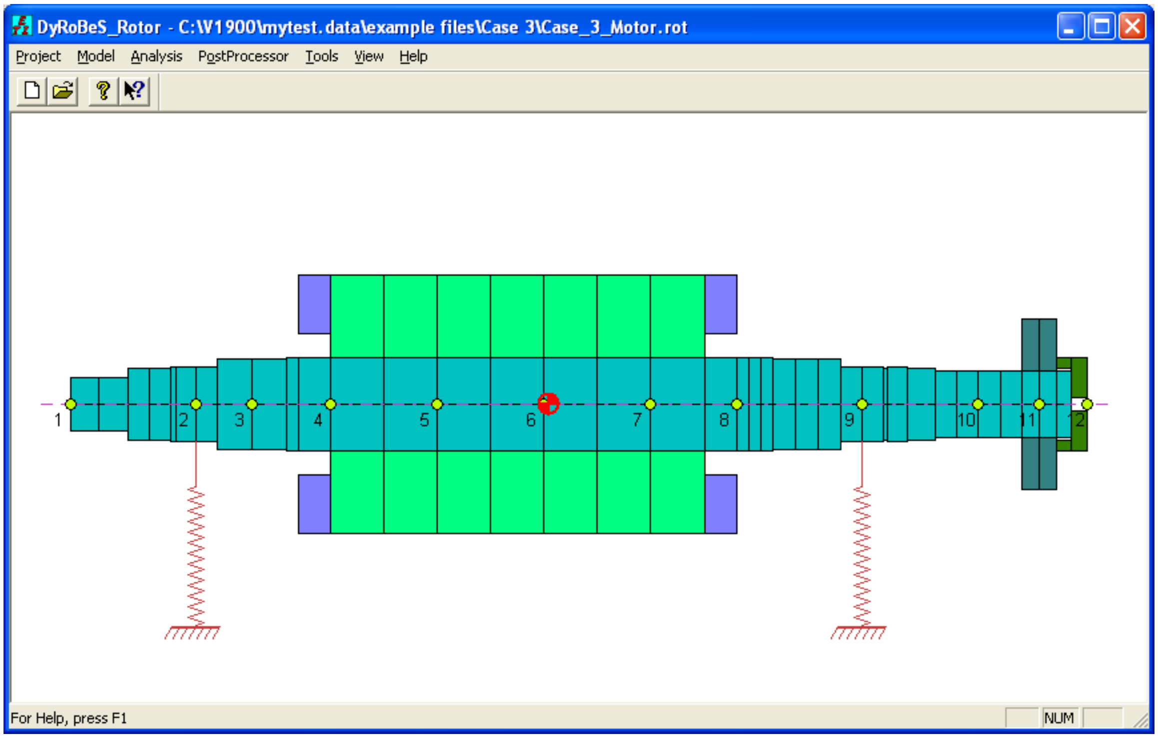
Case 3 – Rotary Compressor Train

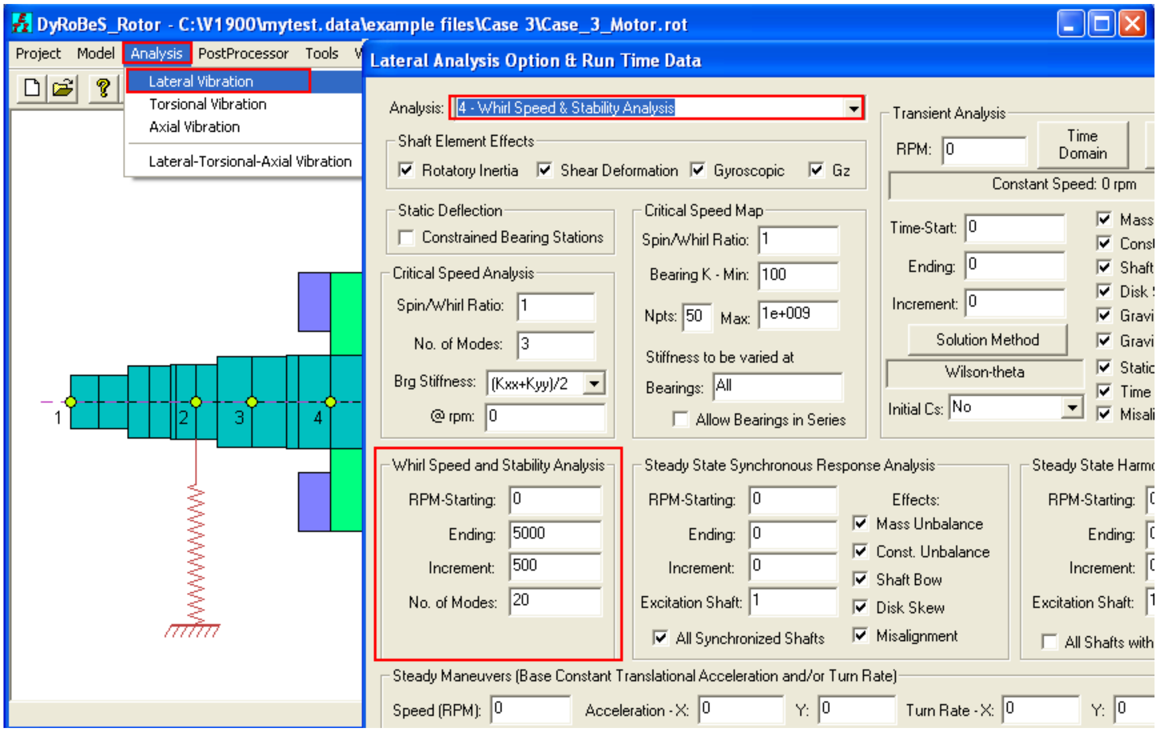
In this example, we will demonstrate the coupled lateral and torsional analysis and the effect of the gear mesh coupling on the system natural frequencies. This system is a motor, which drives a rotatory compressor with a male rotor and a female rotor.



Again, the rotors are modeled separately as shown below. Each rotor is analyzed first before assembly into a complete system. For each individual rotor, the **lateral** whirl speed analysis is performed to examine the system natural frequencies. They show that all the natural frequencies are far above the rotor operating speed and all potential excitation frequencies. Also, the gyroscopic effect is insignificant in this example. The natural frequencies do not vary much with the rotor speed for all three rotors. However, the coupled lateral and torsional natural frequencies of the entire system (3 rotors together) decreased significantly in this example show below.

Motor





Analysis: 4 - Whirl Speed & Stability Analysis

Shaft Element Effects
☑ Rotatory Inertia ☑ Shear Deformation ☑ Gyroscopic ☑ Gz

Static Deflection
☐ Constrained Bearing Stations

Critical Speed Analysis
Spin/Whirl Ratio: 1
No. of Modes: 3
Brg Stiffness: (Kxx+Kyy)/2
@ rpm: 0

Critical Speed Map
Spin/Whirl Ratio: 1
Bearing K - Min: 100
Npts: 50 Max: 1e+009
Stiffness to be varied at
Bearings: All
☐ Allow Bearings in Series

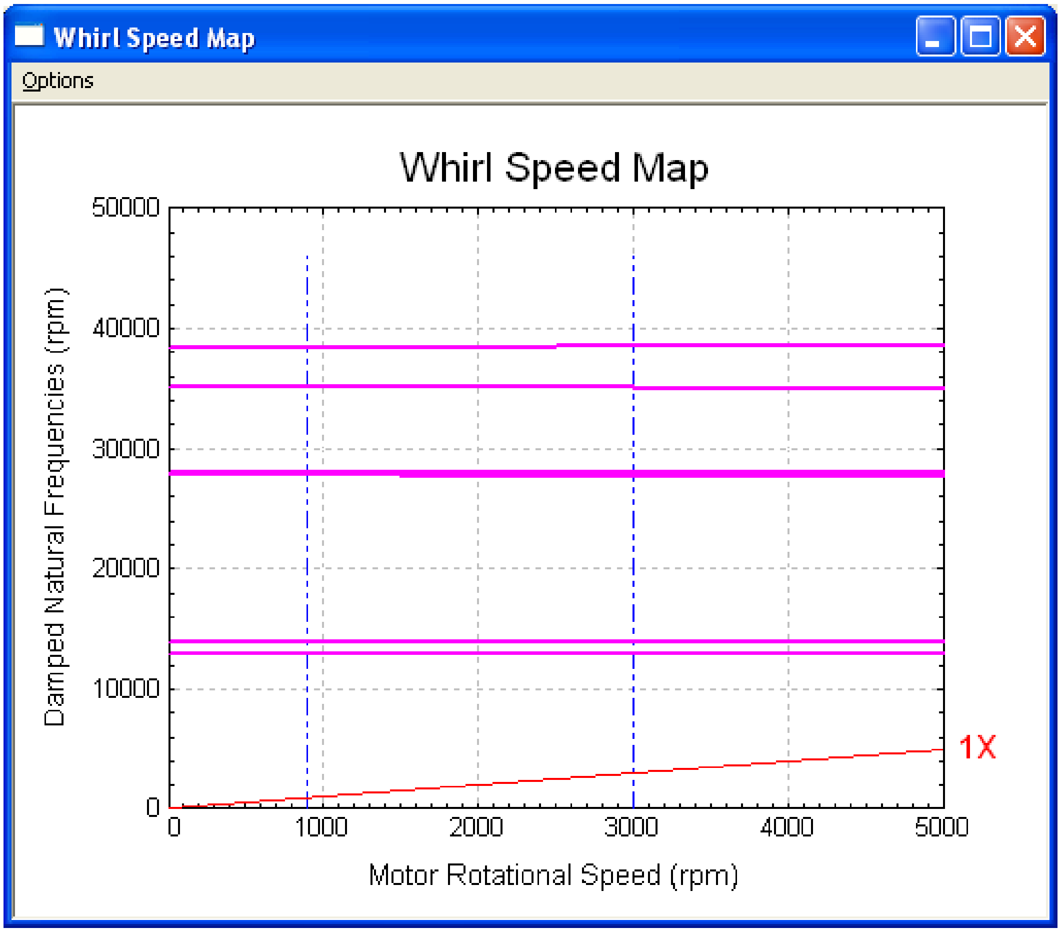
Transient Analysis
RPM: 0 Time Domain
Constant Speed: 0 rpm
Time-Start: 0
Ending: 0
Increment: 0
Solution Method
Wilson-theta
Initial Cs: No
☑ Mass
☑ Const
☑ Shaft
☑ Disk
☑ Gravi
☑ Gravi
☑ Static
☑ Time
☑ Misali

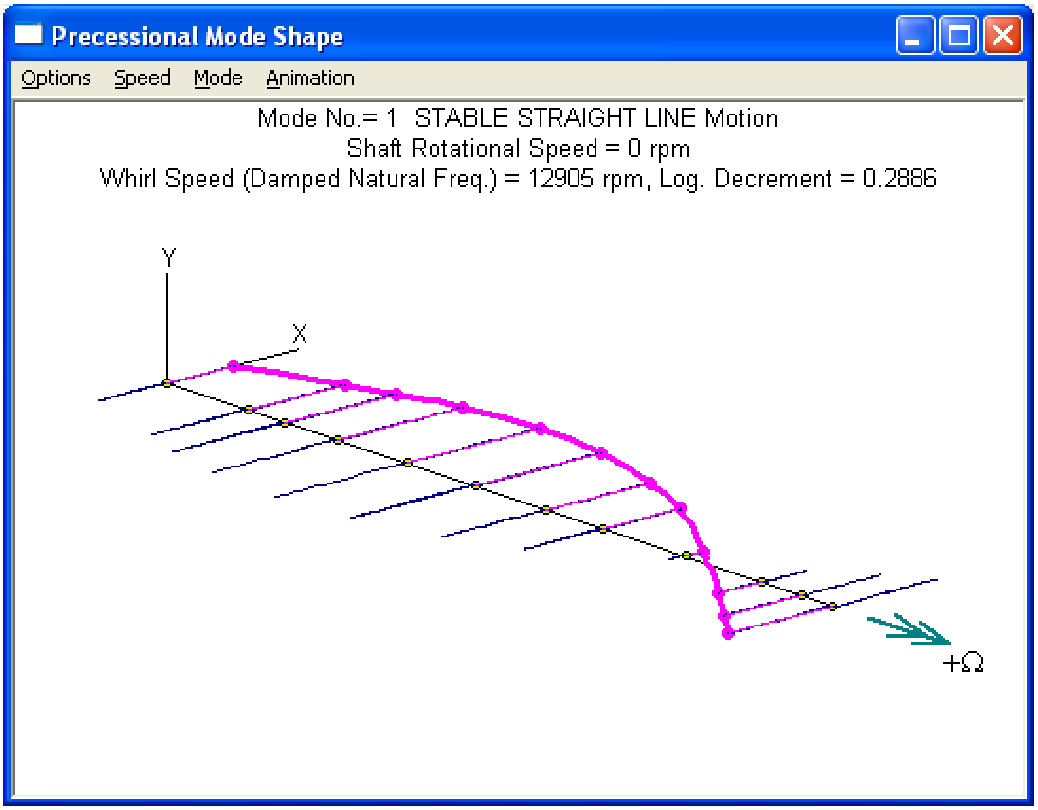
Whirl Speed and Stability Analysis
RPM-Starting: 0
Ending: 5000
Increment: 500
No. of Modes: 20

Steady State Synchronous Response Analysis
RPM-Starting: 0
Ending: 0
Increment: 0
Excitation Shaft: 1
☑ All Synchronized Shafts
Effects:
☑ Mass Unbalance
☑ Const. Unbalance
☑ Shaft Bow
☑ Disk Skew
☑ Misalignment

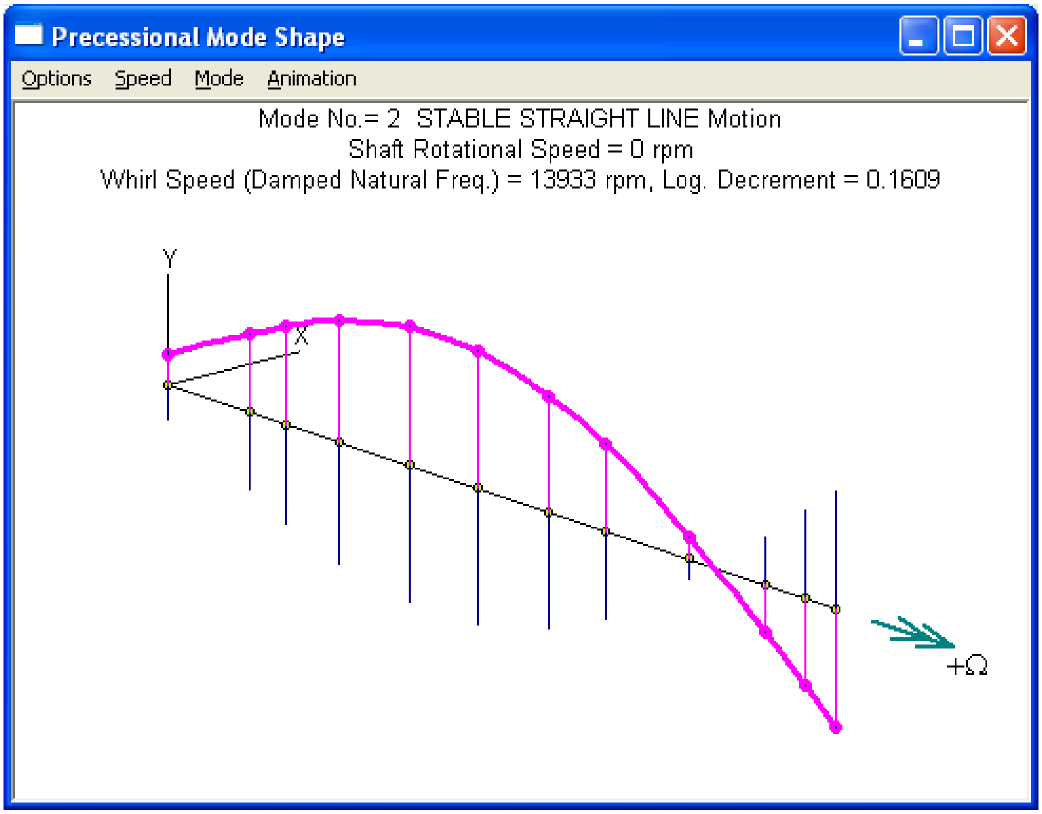
Steady State Harmo
RPM-Starting:
Ending:
Increment:
Excitation Shaft:
☐ All Shafts with

Steady Maneuvers (Base Constant Translational Acceleration and/or Turn Rate)
Speed (RPM): 0 Acceleration - X: 0 Y: 0 Turn Rate - X: 0 Y: 0



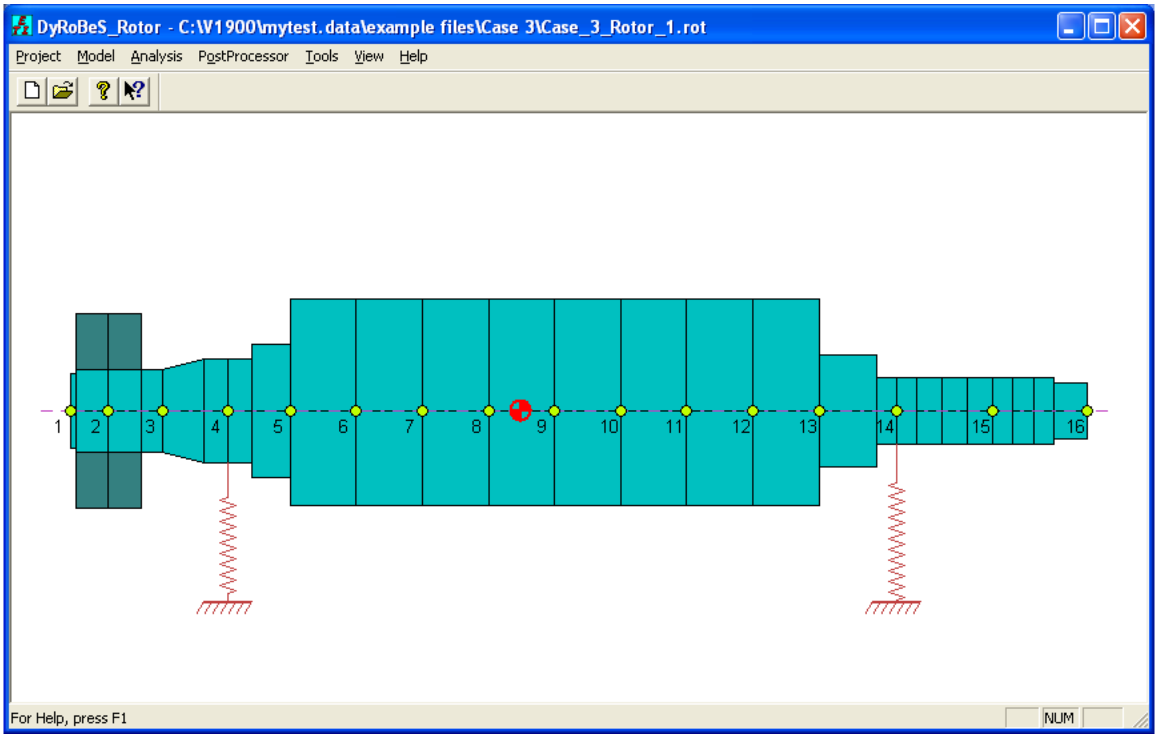


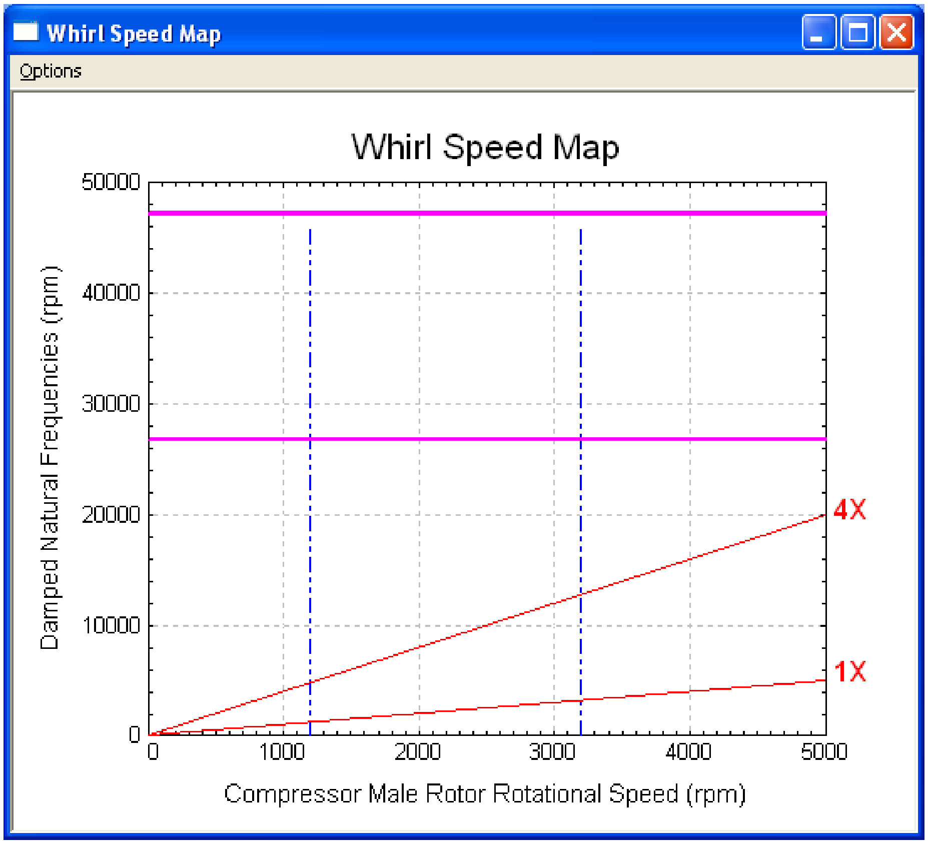
Mode No.= 1 STABLE STRAIGHT LINE Motion
Shaft Rotational Speed = 0 rpm
Whirl Speed (Damped Natural Freq.) = 12905 rpm, Log. Decrement = 0.2886

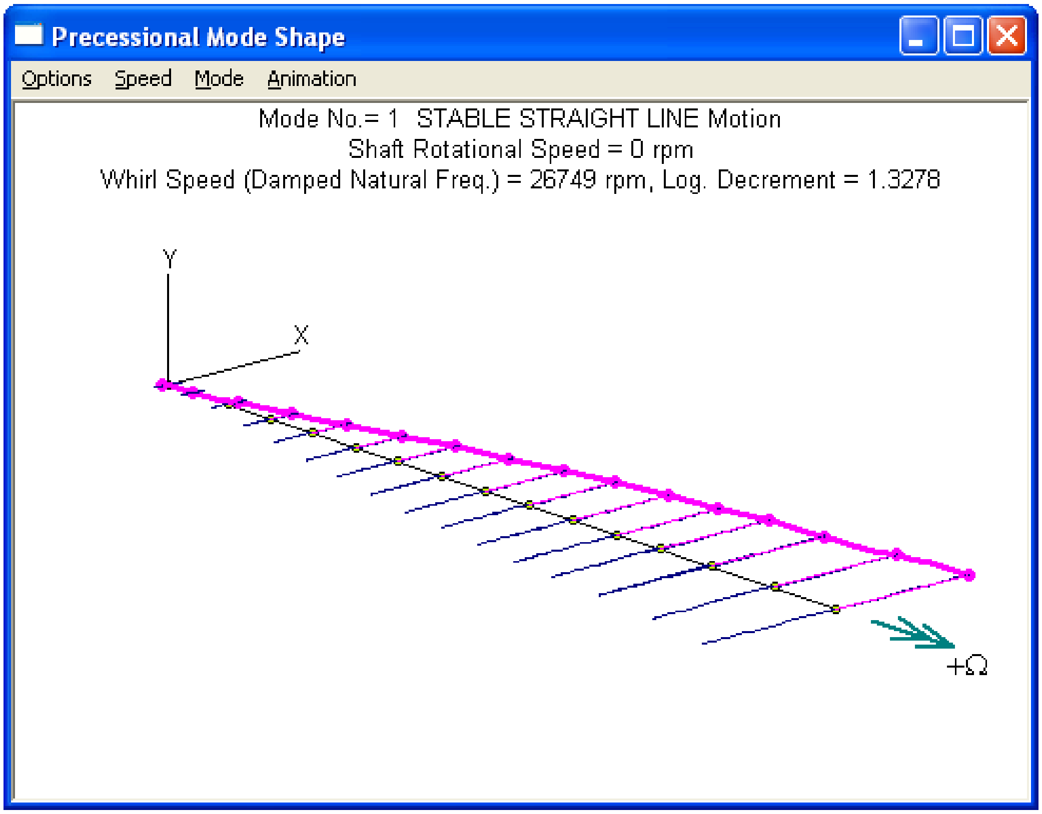


Mode No.= 2 STABLE STRAIGHT LINE Motion
Shaft Rotational Speed = 0 rpm
Whirl Speed (Damped Natural Freq.) = 13933 rpm, Log. Decrement = 0.1609

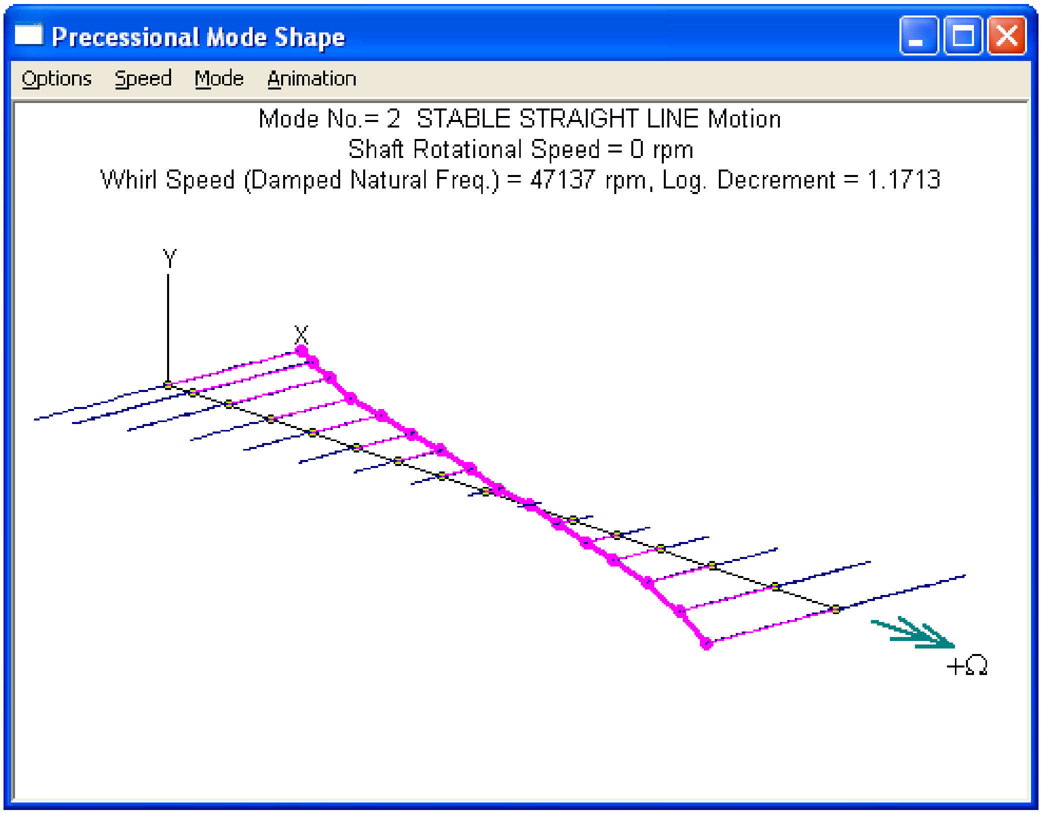
Compressor – Male Motor





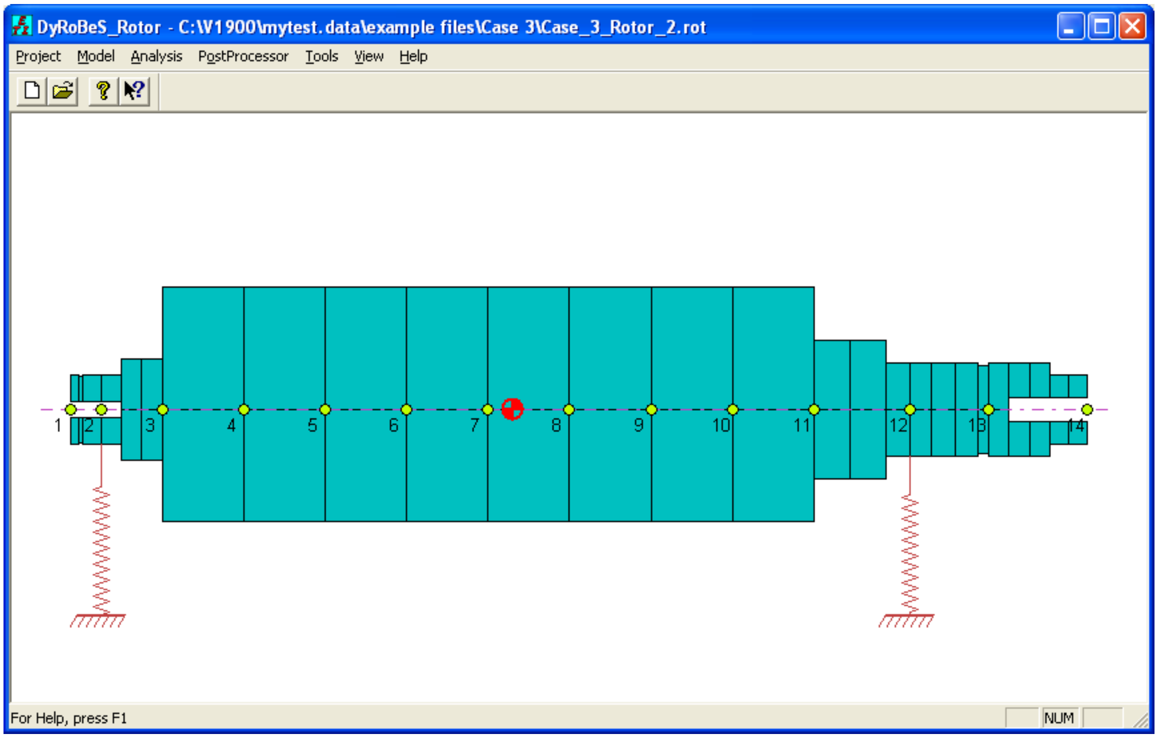


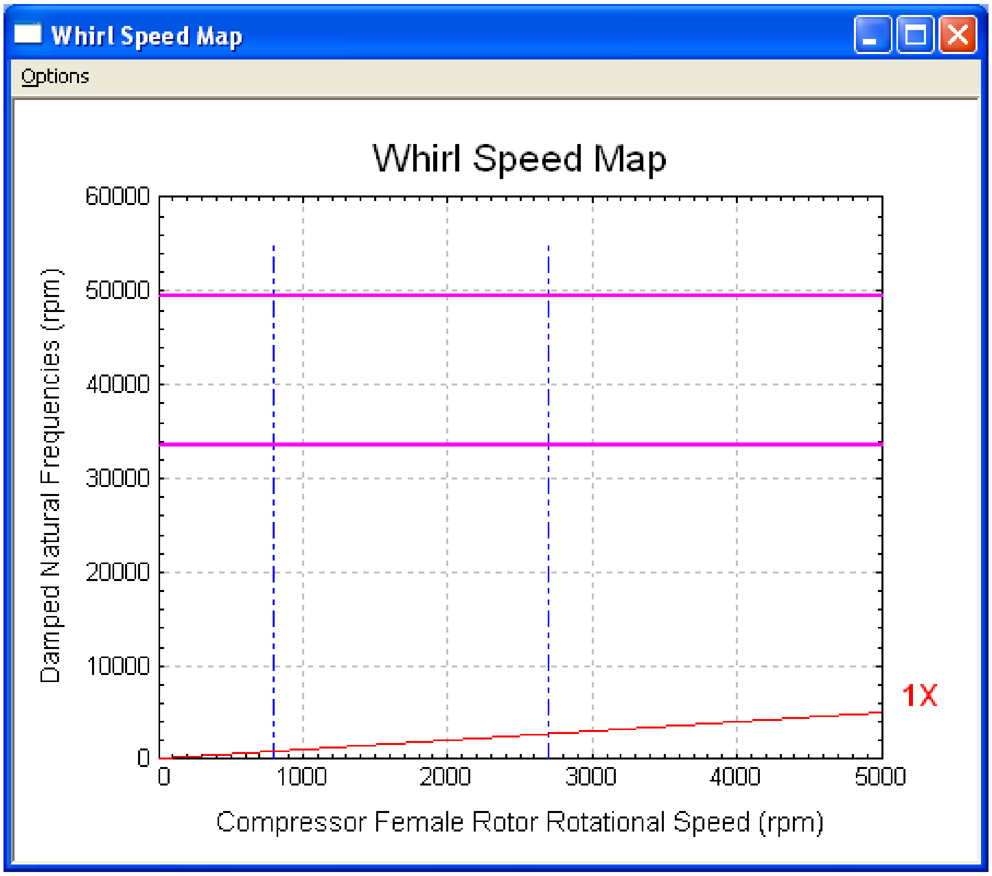
Mode No.= 1 STABLE STRAIGHT LINE Motion
Shaft Rotational Speed = 0 rpm
Whirl Speed (Damped Natural Freq.) = 26749 rpm, Log. Decrement = 1.3278

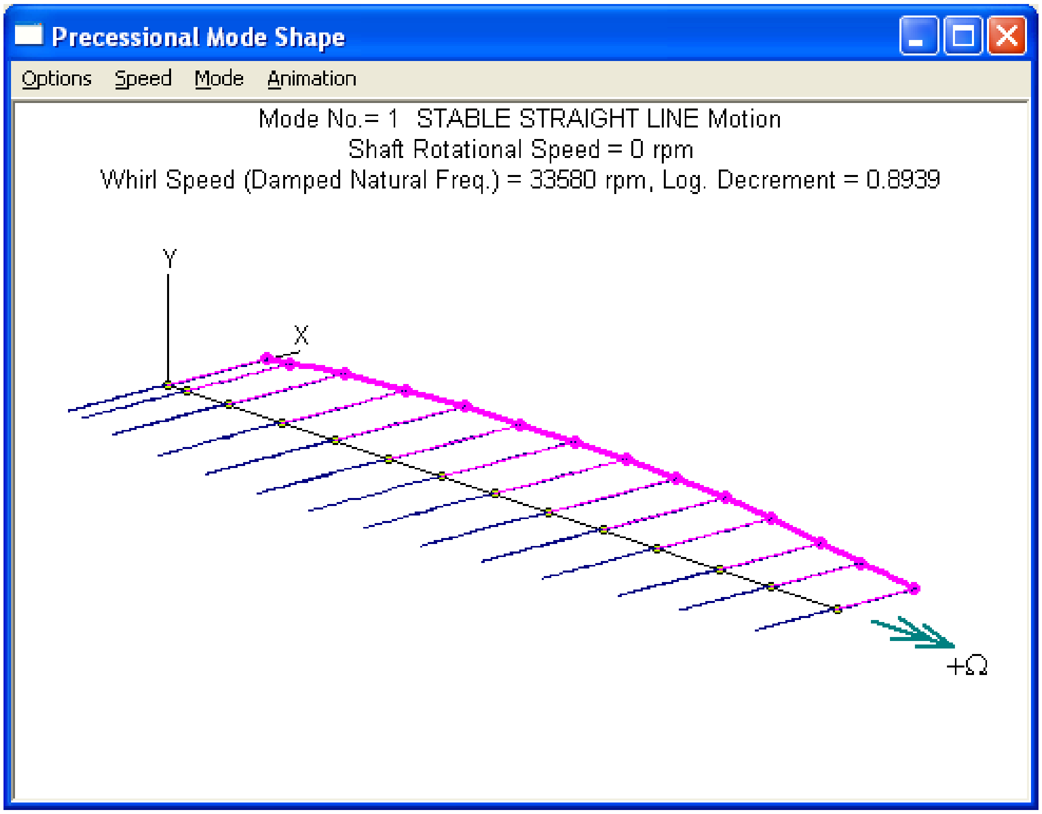


Mode No.= 2 STABLE STRAIGHT LINE Motion
Shaft Rotational Speed = 0 rpm
Whirl Speed (Damped Natural Freq.) = 47137 rpm, Log. Decrement = 1.1713

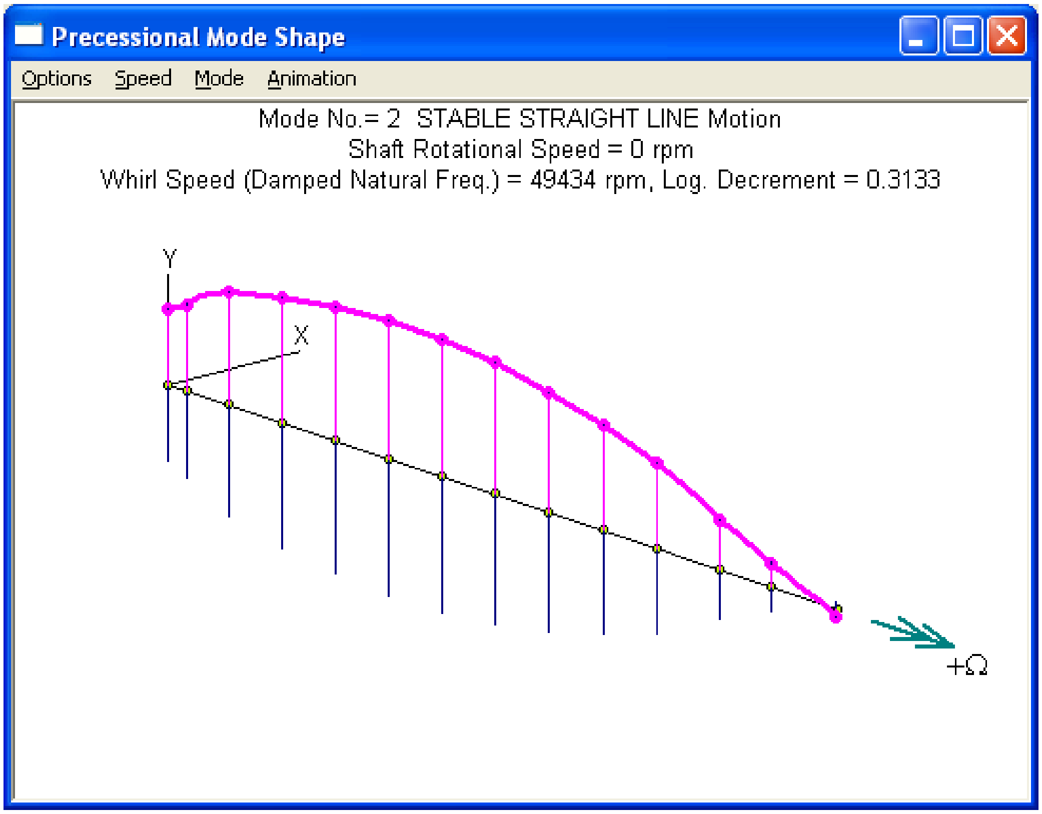
Compressor – Female Rotor







Mode No.= 1 STABLE STRAIGHT LINE Motion
Shaft Rotational Speed = 0 rpm
Whirl Speed (Damped Natural Freq.) = 33580 rpm, Log. Decrement = 0.8939

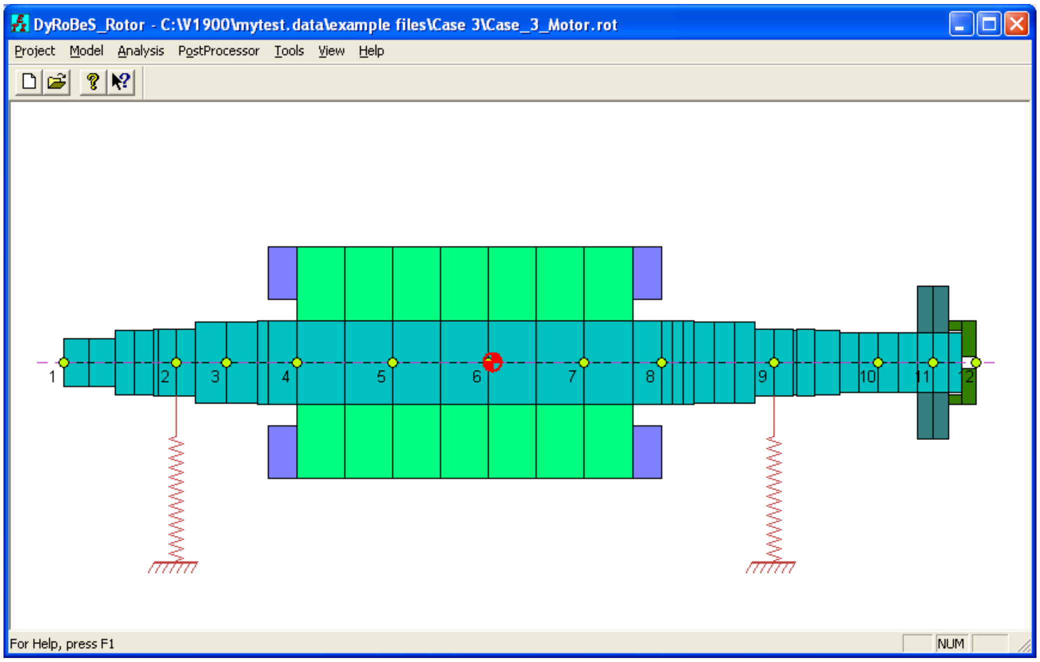


Mode No.= 2 STABLE STRAIGHT LINE Motion
Shaft Rotational Speed = 0 rpm
Whirl Speed (Damped Natural Freq.) = 49434 rpm, Log. Decrement = 0.3133

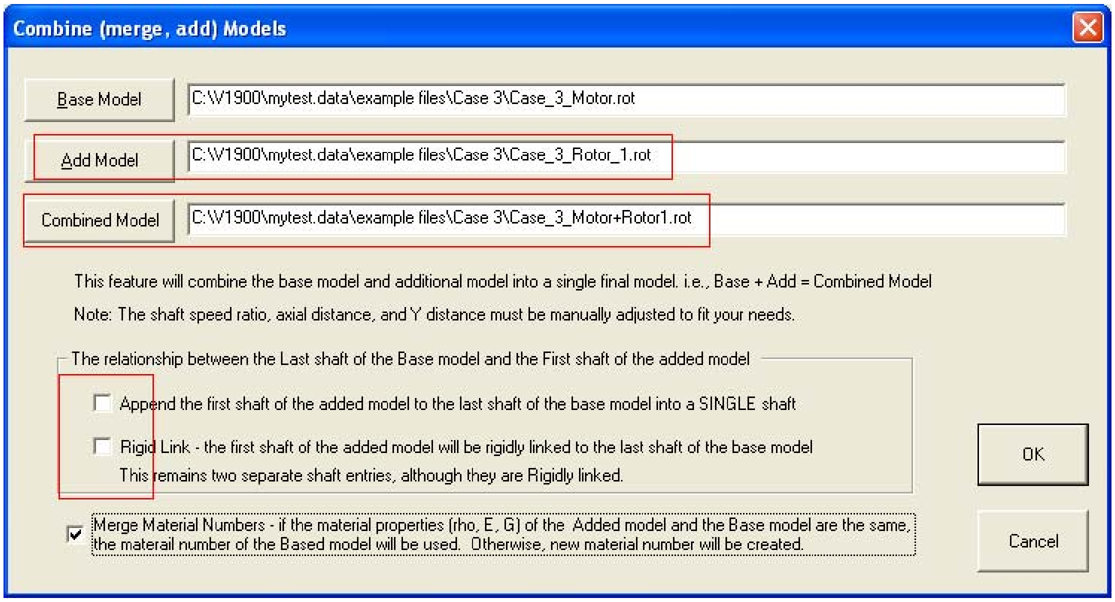
Combined Gear Train

Now, let us combine three rotors together. The steps are described below:

1. Open the Motor Model as a base model



2. Select Model Combining under Project menu and enter the data blow. In this example, three rotors are coupled by the gear meshes. Therefore, do **NOT** check the Append and Rigid Link boxes. After this is done, the combined model will be shown in the main window. Since the Append and Rigid Link boxes are not checked, the second rotor will be shown in the right hand side of the first rotor with a small gap in between.



Base Model: C:\V1900\mytest.data\example files\Case 3\Case_3_Motor.rot

Add Model: C:\V1900\mytest.data\example files\Case 3\Case_3_Rotor_1.rot

Combined Model: C:\V1900\mytest.data\example files\Case 3\Case_3_Motor+Rotor1.rot

This feature will combine the base model and additional model into a single final model. i.e., Base + Add = Combined Model

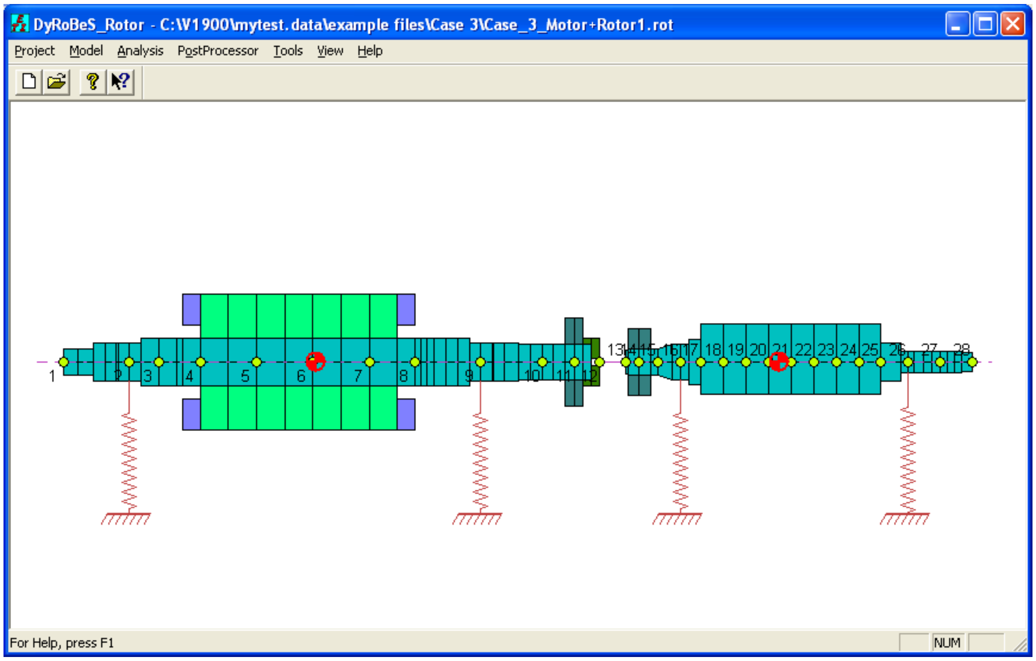
Note: The shaft speed ratio, axial distance, and Y distance must be manually adjusted to fit your needs.

The relationship between the Last shaft of the Base model and the First shaft of the added model

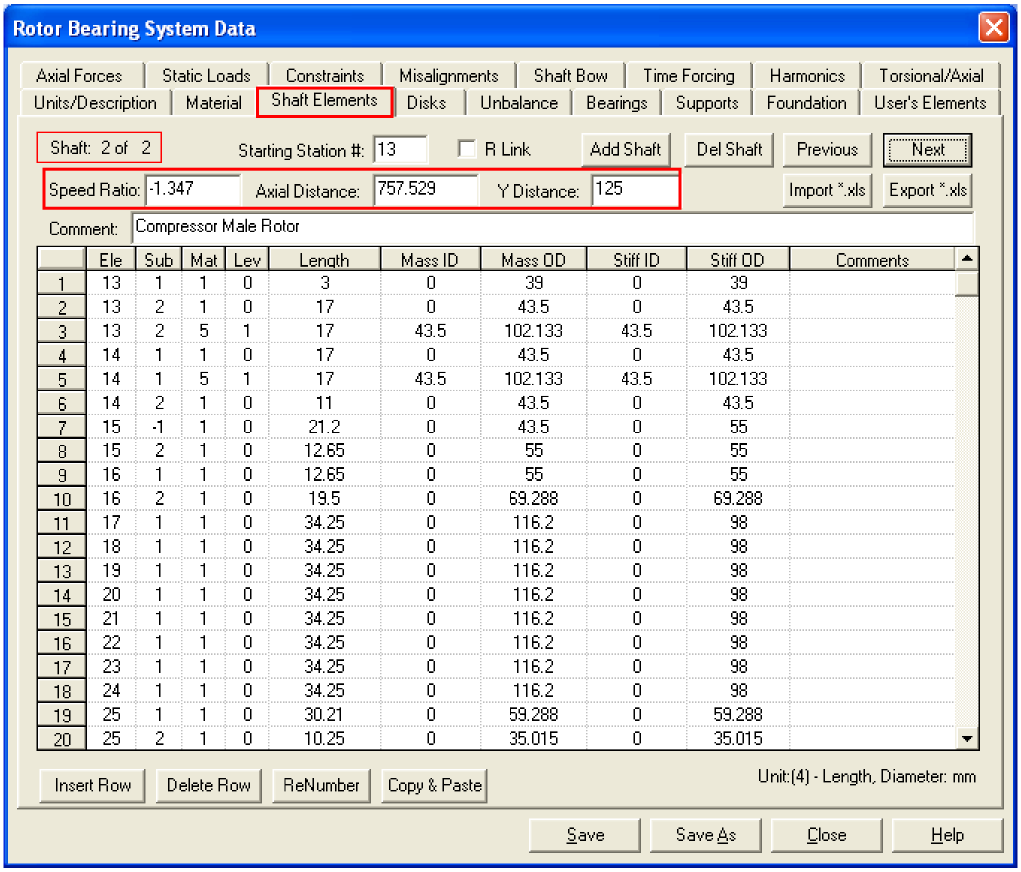
☐ Append the first shaft of the added model to the last shaft of the base model into a SINGLE shaft

☐ Rigid Link - the first shaft of the added model will be rigidly linked to the last shaft of the base model
This remains two separate shaft entries, although they are Rigidly linked.

☑ Merge Material Numbers - if the material properties (rho, E, G) of the Added model and the Base model are the same, the materail number of the Based model will be used. Otherwise, new material number will be created.



3. Since this is a geared system, we need to enter the speed ratio and also adjust the rotor position for proper display. Model – Data Editor – Shaft Elements – Second Shaft. Enter speed ratio, Axial and Y distances.



Shaft: 2 of 2

Starting Station #: 13

☐ R Link

Speed Ratio: -1.347

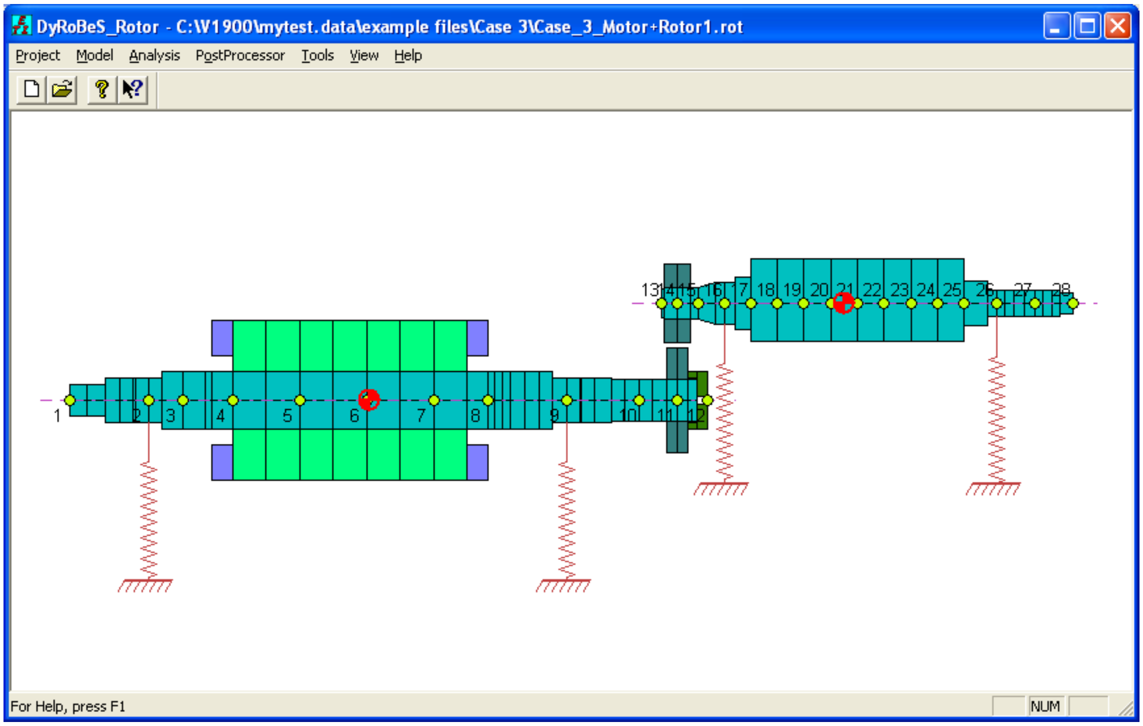
Axial Distance: 757.529

Y Distance: 125

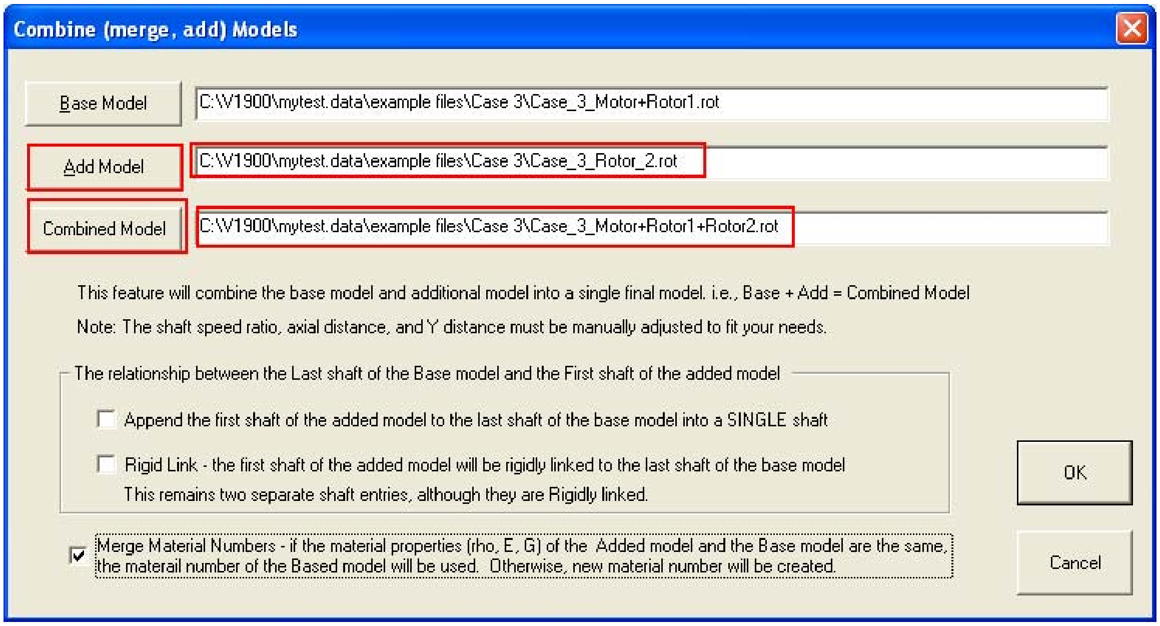
Comment: Compressor Male Rotor

	Ele	Sub	Mat	Lev	Length	Mass ID	Mass OD	Stiff ID	Stiff OD	Comments
1	13	1	1	0	3	0	39	0	39	
2	13	2	1	0	17	0	43.5	0	43.5	
3	13	2	5	1	17	43.5	102.133	43.5	102.133	
4	14	1	1	0	17	0	43.5	0	43.5	
5	14	1	5	1	17	43.5	102.133	43.5	102.133	
6	14	2	1	0	11	0	43.5	0	43.5	
7	15	-1	1	0	21.2	0	43.5	0	55	
8	15	2	1	0	12.65	0	55	0	55	
9	16	1	1	0	12.65	0	55	0	55	
10	16	2	1	0	19.5	0	69.288	0	69.288	
11	17	1	1	0	34.25	0	116.2	0	98	
12	18	1	1	0	34.25	0	116.2	0	98	
13	19	1	1	0	34.25	0	116.2	0	98	
14	20	1	1	0	34.25	0	116.2	0	98	
15	21	1	1	0	34.25	0	116.2	0	98	
16	22	1	1	0	34.25	0	116.2	0	98	
17	23	1	1	0	34.25	0	116.2	0	98	
18	24	1	1	0	34.25	0	116.2	0	98	
19	25	1	1	0	30.21	0	59.288	0	59.288	
20	25	2	1	0	10.25	0	35.015	0	35.015	

Unit:(4) - Length, Diameter: mm



4. Combine the last rotor into the system. Again, we need to enter the speed ratio and the axial and Y distances in the Shaft Elements tab. We also need to enter the gear mesh data to couple these three rotors.



Base Model: C:\V1900\mytest.data\example files\Case 3\Case_3_Motor+Rotor1.rot

Add Model: C:\V1900\mytest.data\example files\Case 3\Case_3_Rotor_2.rot

Combined Model: C:\V1900\mytest.data\example files\Case 3\Case_3_Motor+Rotor1+Rotor2.rot

This feature will combine the base model and additional model into a single final model. i.e., Base + Add = Combined Model

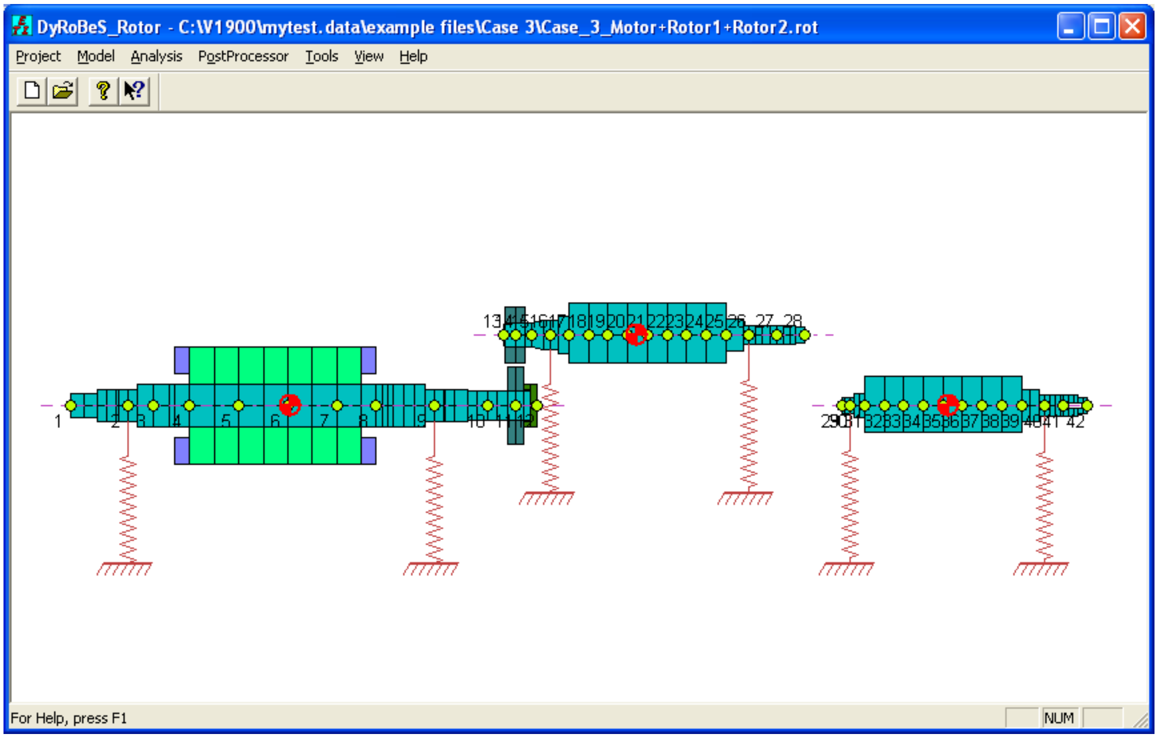
Note: The shaft speed ratio, axial distance, and Y distance must be manually adjusted to fit your needs.

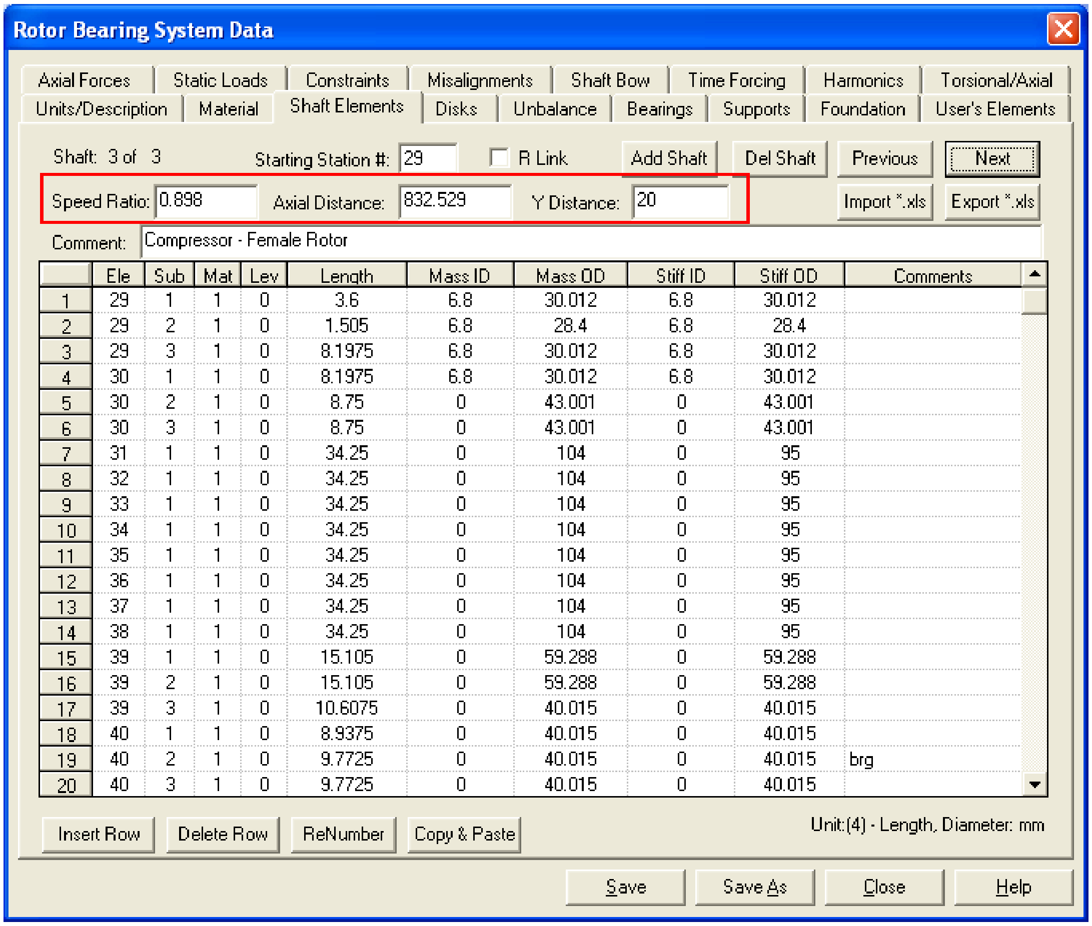
The relationship between the Last shaft of the Base model and the First shaft of the added model

☐ Append the first shaft of the added model to the last shaft of the base model into a SINGLE shaft

☐ Rigid Link - the first shaft of the added model will be rigidly linked to the last shaft of the base model
This remains two separate shaft entries, although they are Rigidly linked.

☑ Merge Material Numbers - if the material properties (rho, E, G) of the Added model and the Base model are the same, the materail number of the Based model will be used. Otherwise, new material number will be created.





Shaft: 3 of 3

Starting Station #: 29

☐ R Link

Speed Ratio: 0.898

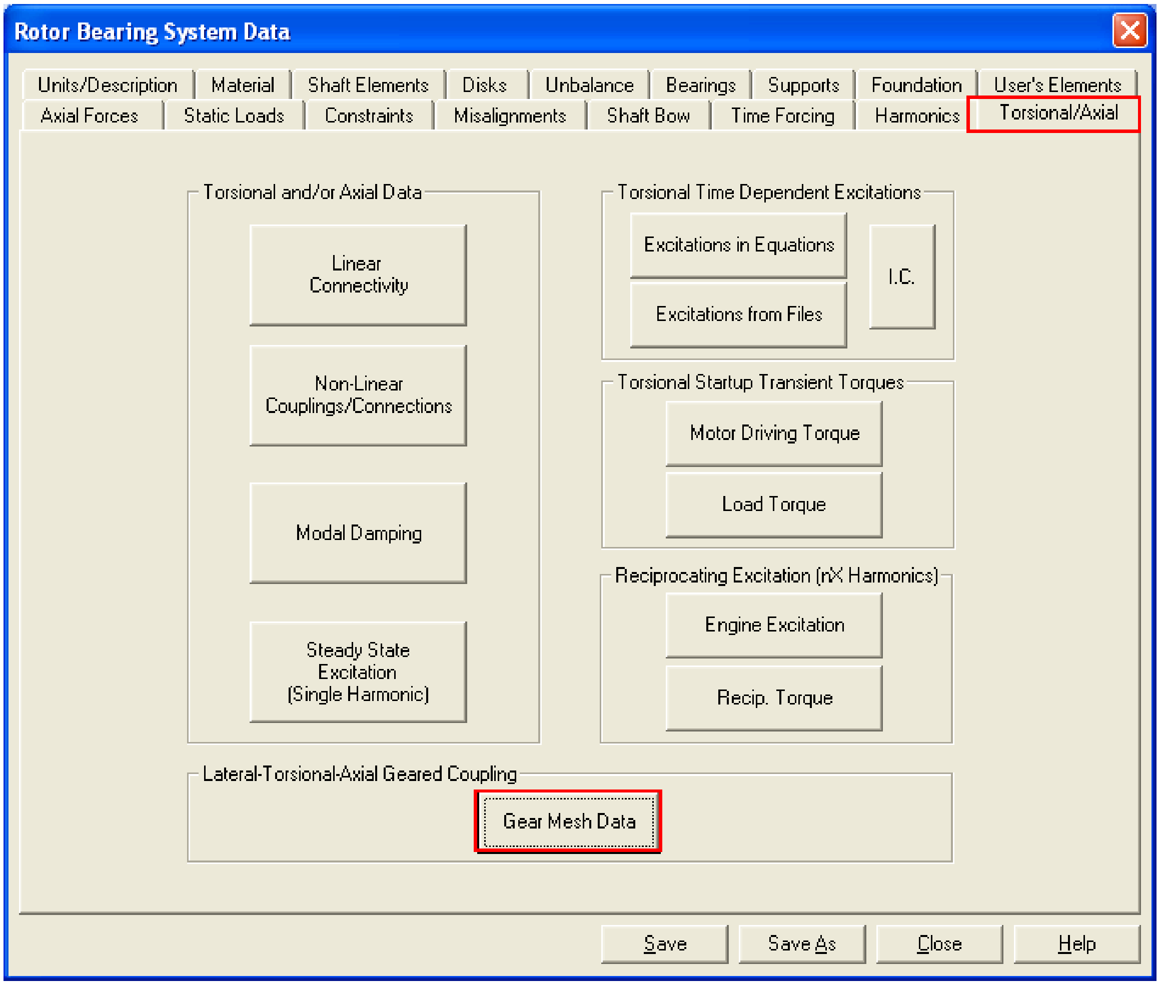
Axial Distance: 832.529

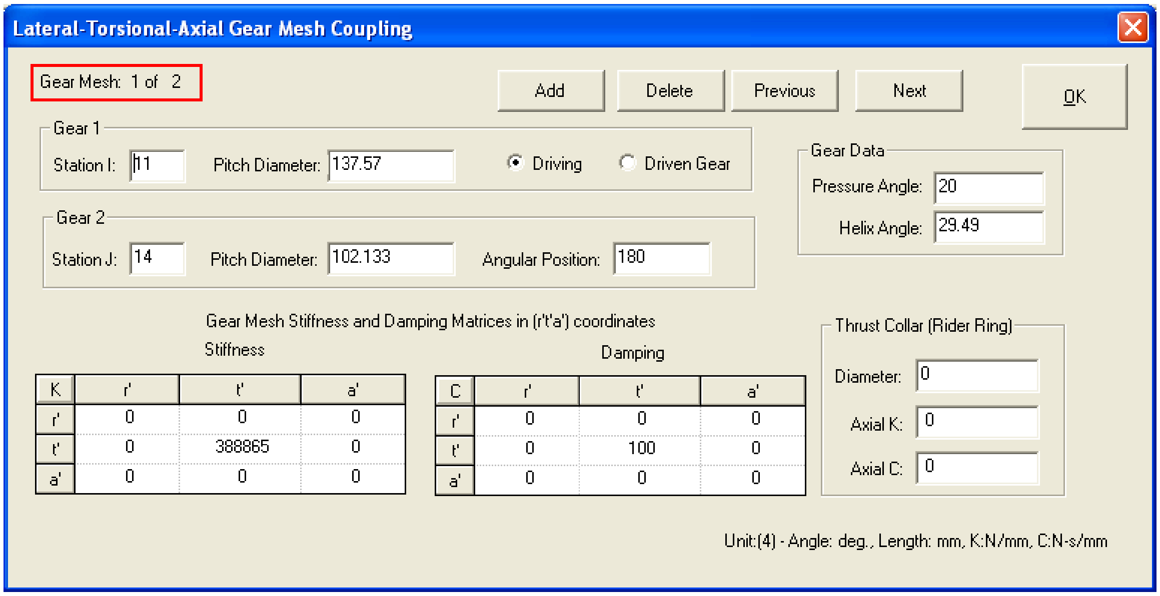
Y Distance: 20

Comment: Compressor - Female Rotor

	Ele	Sub	Mat	Lev	Length	Mass ID	Mass OD	Stiff ID	Stiff OD	Comments
1	29	1	1	0	3.6	6.8	30.012	6.8	30.012	
2	29	2	1	0	1.505	6.8	28.4	6.8	28.4	
3	29	3	1	0	8.1975	6.8	30.012	6.8	30.012	
4	30	1	1	0	8.1975	6.8	30.012	6.8	30.012	
5	30	2	1	0	8.75	0	43.001	0	43.001	
6	30	3	1	0	8.75	0	43.001	0	43.001	
7	31	1	1	0	34.25	0	104	0	95	
8	32	1	1	0	34.25	0	104	0	95	
9	33	1	1	0	34.25	0	104	0	95	
10	34	1	1	0	34.25	0	104	0	95	
11	35	1	1	0	34.25	0	104	0	95	
12	36	1	1	0	34.25	0	104	0	95	
13	37	1	1	0	34.25	0	104	0	95	
14	38	1	1	0	34.25	0	104	0	95	
15	39	1	1	0	15.105	0	59.288	0	59.288	
16	39	2	1	0	15.105	0	59.288	0	59.288	
17	39	3	1	0	10.6075	0	40.015	0	40.015	
18	40	1	1	0	8.9375	0	40.015	0	40.015	
19	40	2	1	0	9.7725	0	40.015	0	40.015	brg
20	40	3	1	0	9.7725	0	40.015	0	40.015	

Unit:(4) - Length, Diameter: mm





Gear Mesh: 1 of 2

Gear 1

Station I: 11 Pitch Diameter: 137.57 ● Driving ○ Driven Gear

Gear 2

Station J: 14 Pitch Diameter: 102.133 Angular Position: 180

Gear Data

Pressure Angle: 20

Helix Angle: 29.49

Gear Mesh Stiffness and Damping Matrices in (r't'a') coordinates

Stiffness

K	r'	t'	a'
r'	0	0	0
t'	0	388865	0
a'	0	0	0

Damping

C	r'	t'	a'
r'	0	0	0
t'	0	100	0
a'	0	0	0

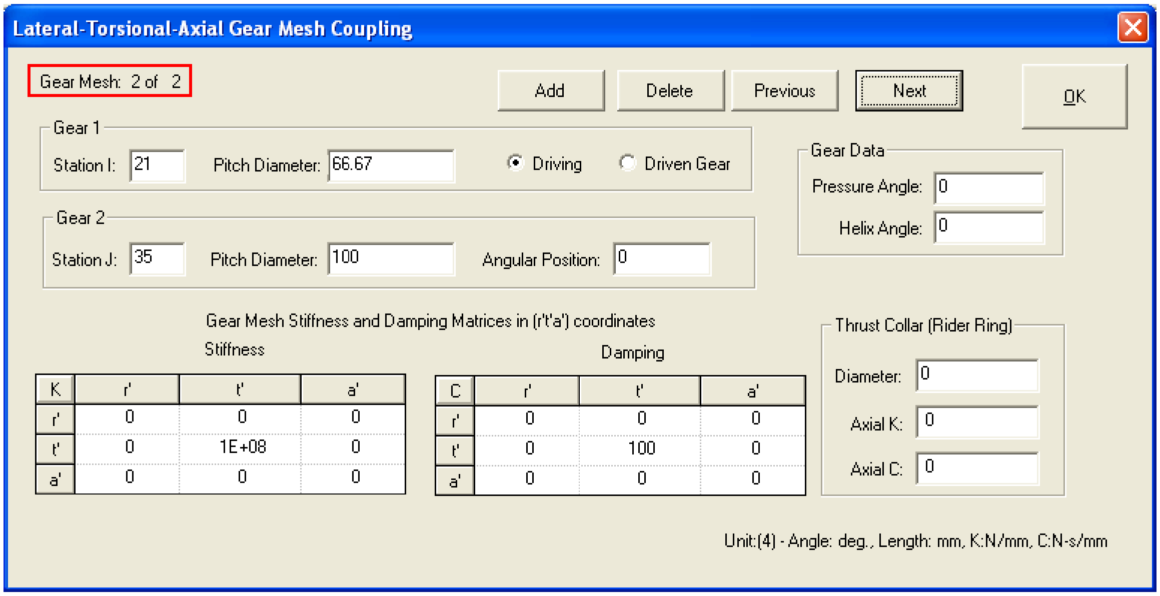
Thrust Collar (Rider Ring)

Diameter: 0

Axial K: 0

Axial C: 0

Unit:(4) - Angle: deg., Length: mm, K:N/mm, C:N-s/mm



Lateral-Torsional-Axial Gear Mesh Coupling

Gear Mesh: 2 of 2

Gear 1

Station I: 21

Pitch Diameter: 66.67

● Driving ○ Driven Gear

Gear 2

Station J: 35

Pitch Diameter: 100

Angular Position: 0

Gear Data

Pressure Angle: 0

Helix Angle: 0

Gear Mesh Stiffness and Damping Matrices in (r't'a') coordinates

Stiffness

K	r'	t'	a'
r'	0	0	0
t'	0	1E+08	0
a'	0	0	0

Damping

C	r'	t'	a'
r'	0	0	0
t'	0	100	0
a'	0	0	0

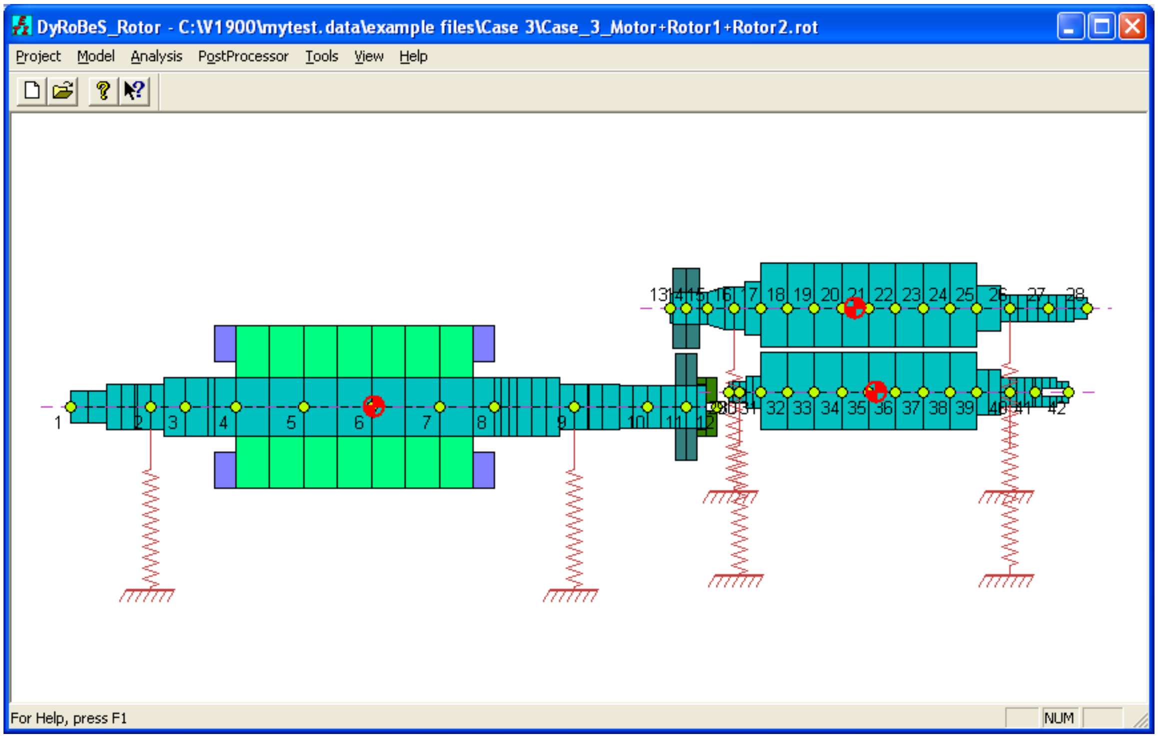
Thrust Collar (Rider Ring)

Diameter: 0

Axial K: 0

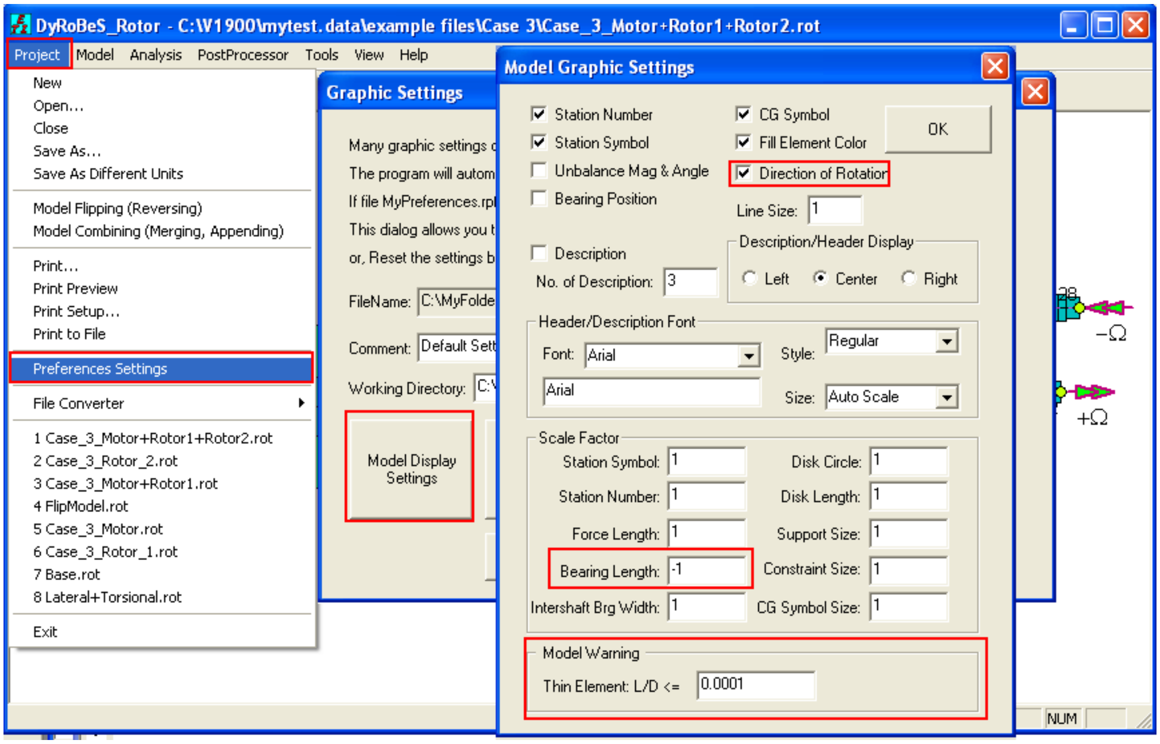
Axial C: 0

Unit:(4) - Angle: deg., Length: mm, K:N/mm, C:N-s/mm



For Help, press F1

5. The regular bearing with a spring display can complicate the plot. We can display the bearing with a representing small box by changing the bearing length parameter under Project – Preference Settings – Model Display Settings – Bearing Length – make it a NEGATIVE value. Also, noted that one parameter is added in Ver 19 is the L/D ratio. If the element L/D ratio is less than this pre-defined value, a warning message will be prompted.



Many graphic settings c
The program will autom
If file MyPreferences.rp
This dialog allows you t
or, Reset the settings b

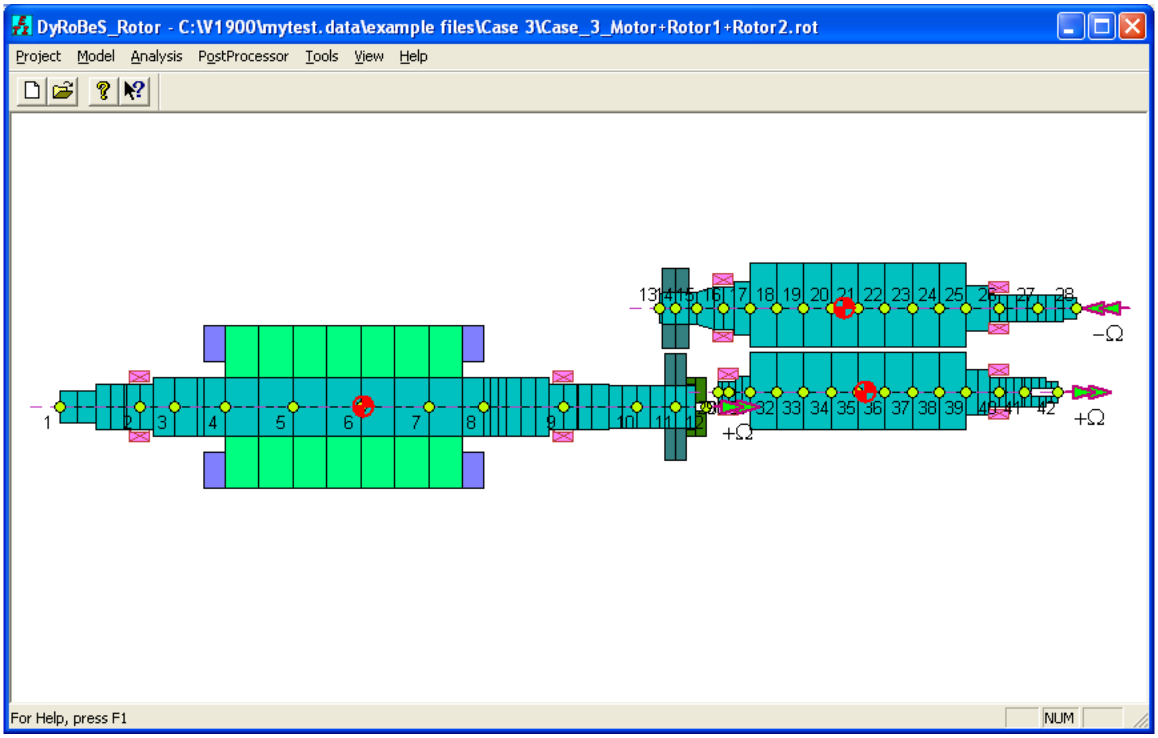
FileName: C:\MyFolde
Comment: Default Sett
Working Directory: C:\

☑ Station Number
☑ Station Symbol
☐ Unbalance Mag & Angle
☐ Bearing Position
☑ CG Symbol
☑ Fill Element Color
☑ Direction of Rotatior
Line Size: 1
☐ Description
No. of Description: 3
Description/Header Display: ○ Left ● Center ○ Right

Header/Description Font
Font: Arial
Style: Regular
Arial
Size: Auto Scale

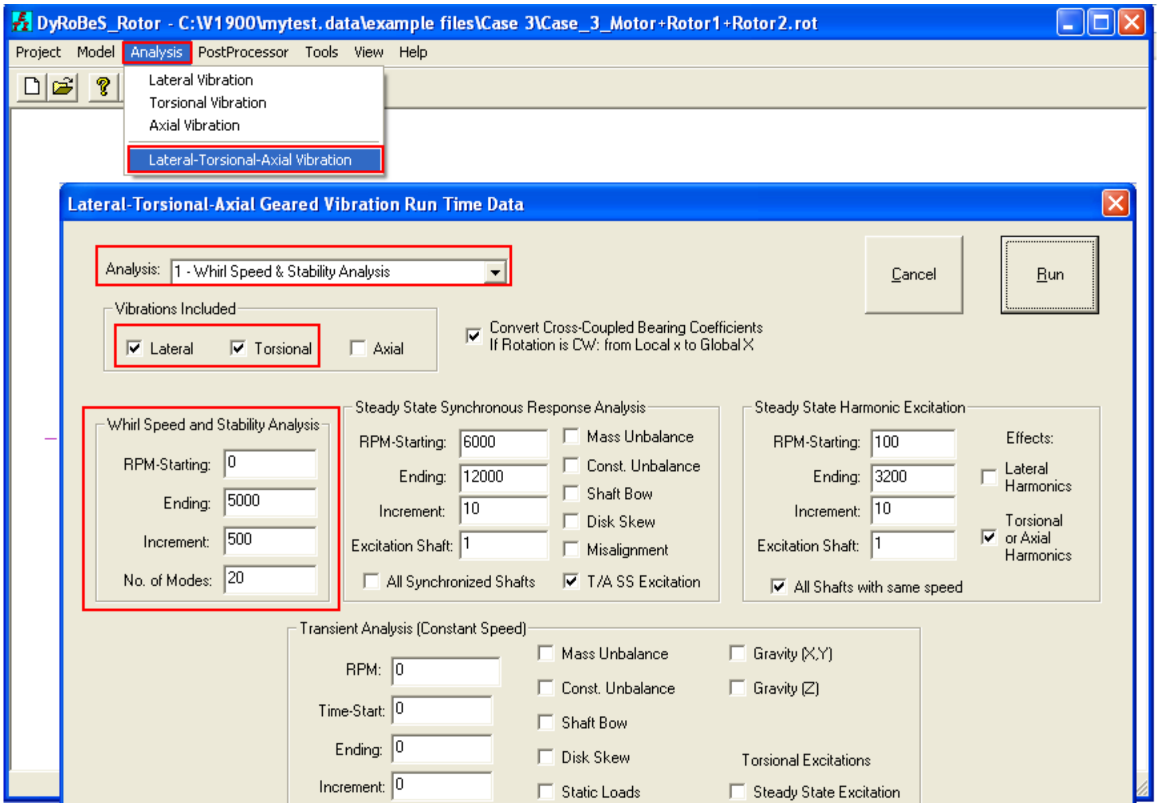
Scale Factor
Station Symbol: 1
Disk Circle: 1
Station Number: 1
Disk Length: 1
Force Length: 1
Support Size: 1
Bearing Length: -1
Constraint Size: 1
Intershaft Brg Width: 1
CG Symbol Size: 1

Model Warning
Thin Element: L/D <= 0.0001



To perform the coupled lateral and torsional analysis, Select Lateral-Torsional-Axial Vibration under the Analysis menu. A dialog box shows up for the analysis inputs. Select Whirl Speed & Stability Analysis. In the Vibration Included group box, check the Lateral and Torsional boxes to include the lateral and torsional vibrations. That is, coupled lateral and torsional vibration through the gear meshes. Check the Convert

Cross-Coupled Bearing Coefficients box. This indicates that if the shaft rotates clockwise, then the bearing coefficients for this shaft will be converted to comply with this direction of rotation. For more details on this conversion, see book “Practical Rotordynamics and Fluid Film Bearing Design”, Chapter 8. For a multiple rotor system, the speed input in the analysis dialog is the first shaft speed. The first shaft in DyRoBeS is always the reference shaft. In this example, it is the motor speed. The compressor male rotor is designed with the speed range of 1200-2900 rpm. Therefore, the motor speed range is 891-2153 rpm. The excitations considered are 1X Motor, 1X Compressor (1.347X Motor), and 4X Compressor (5.388X Motor). In this example, there is one interference point at 9660 cpm present within the operating speed range. The X-Axis (speed axis) in the whirl speed map can be converted into the compressor male rotor speed by multiplying the X-Axis by the speed ratio of 1.347 in the Options-Settings. Once the X-axis is converted into the compressor male rotor speed, the 1X Motor excitation is 0.7424 X Compressor excitation. To avoid confusion, a small label “LTA” is shown in the right bottom of the plot to indicate this plot is from the coupled vibration option. The mode shape for this interference point at 9660 cpm frequency is also shown. For the coupled vibration, since the displacements are normalized with different units, different scale may be required. In this example, the torsional displacement is enlarged fifty times. Again, go to Options – Settings to make necessary adjustments.



Analysis: 1 - Whirl Speed & Stability Analysis

Vibrations Included

☑ Lateral ☑ Torsional ☐ Axial

☑ Convert Cross-Coupled Bearing Coefficients If Rotation is CW: from Local x to Global X

Whirl Speed and Stability Analysis

RPM-Starting: 0

Ending: 5000

Increment: 500

No. of Modes: 20

Steady State Synchronous Response Analysis

RPM-Starting: 6000

Ending: 12000

Increment: 10

Excitation Shaft: 1

☐ Mass Unbalance

☐ Const. Unbalance

☐ Shaft Bow

☐ Disk Skew

☐ Misalignment

☐ All Synchronized Shafts

☑ T/A SS Excitation

Steady State Harmonic Excitation

RPM-Starting: 100

Ending: 3200

Increment: 10

Excitation Shaft: 1

Effects:

☐ Lateral Harmonics

☑ Torsional or Axial Harmonics

☑ All Shafts with same speed

Transient Analysis (Constant Speed)

RPM: 0

Time-Start: 0

Ending: 0

Increment: 0

☐ Mass Unbalance

☐ Const. Unbalance

☐ Shaft Bow

☐ Disk Skew

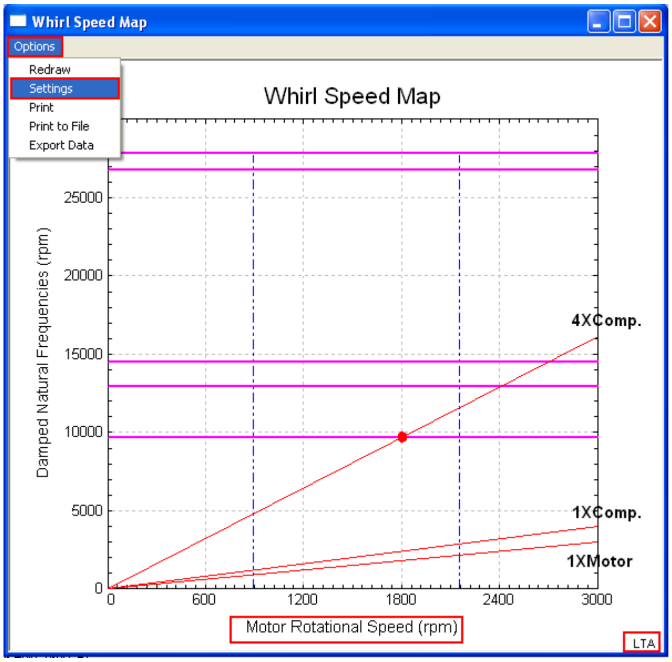
☐ Static Loads

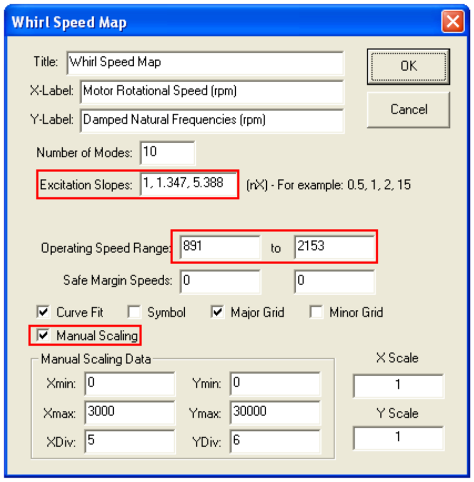
☐ Gravity (X,Y)

☐ Gravity (Z)

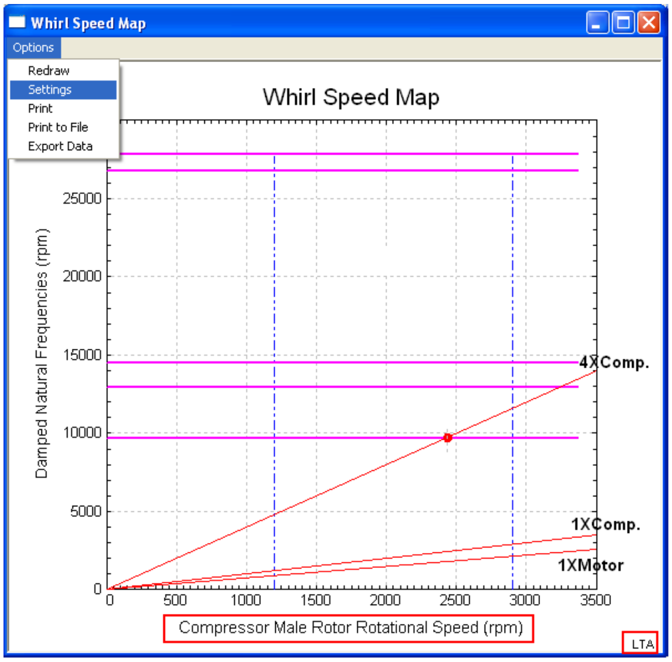
Torsional Excitations

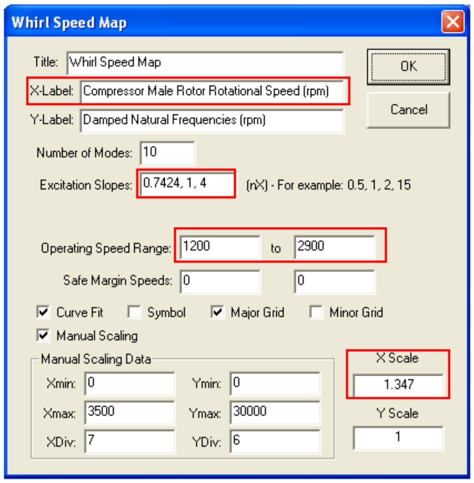
☐ Steady State Excitation



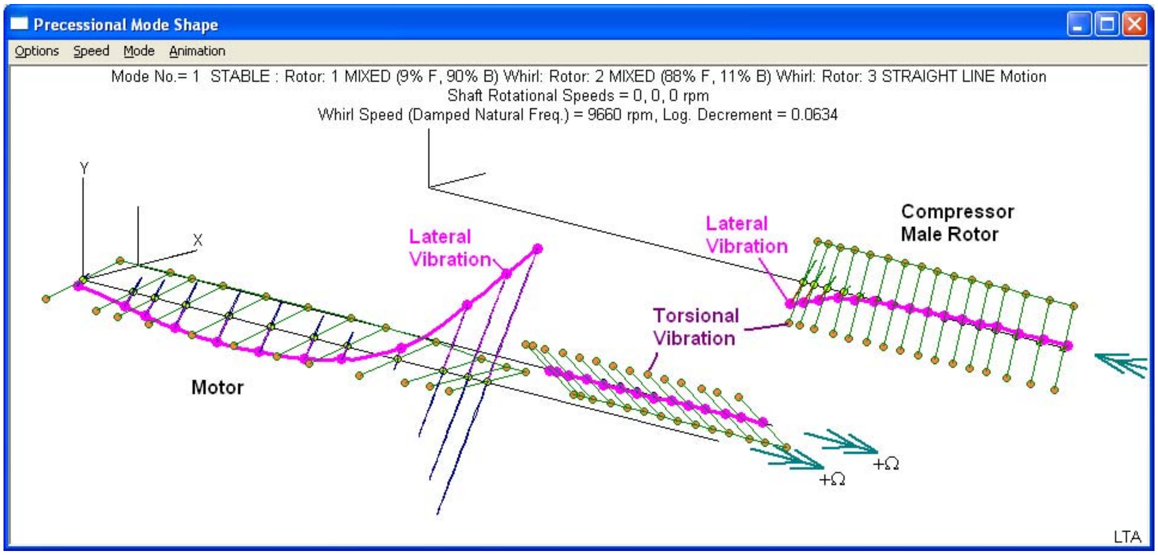


Title: Whirl Speed Map
X-Label: Motor Rotational Speed (rpm)
Y-Label: Damped Natural Frequencies (rpm)
Number of Modes: 10
Excitation Slopes: 1, 1.347, 5.388 (nX) - For example: 0.5, 1, 2, 15
Operating Speed Range: 891 to 2153
Safe Margin Speeds: 0 0
☑ Curve Fit ☐ Symbol ☑ Major Grid ☐ Minor Grid
☑ Manual Scaling
Manual Scaling Data
Xmin: 0 Ymin: 0
Xmax: 3000 Ymax: 30000
XDiv: 5 YDiv: 6
X Scale: 1
Y Scale: 1





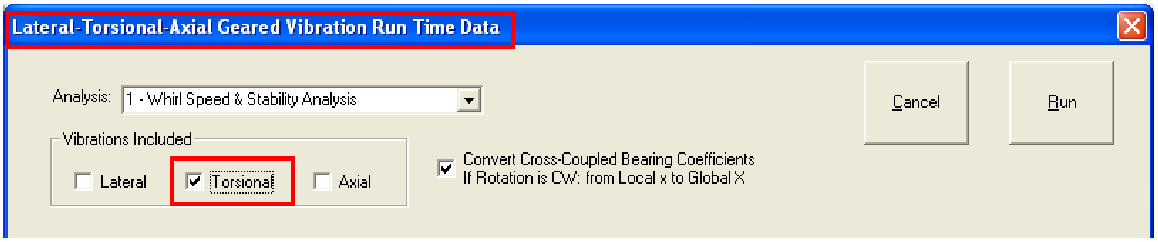
Title: Whirl Speed Map
X-Label: Compressor Male Rotor Rotational Speed (rpm)
Y-Label: Damped Natural Frequencies (rpm)
Number of Modes: 10
Excitation Slopes: 0.7424, 1, 4 (nX) - For example: 0.5, 1, 2, 15
Operating Speed Range: 1200 to 2900
Safe Margin Speeds: 0 0
☑ Curve Fit ☐ Symbol ☑ Major Grid ☐ Minor Grid
☑ Manual Scaling
Manual Scaling Data
Xmin: 0 Ymin: 0
Xmax: 3500 Ymax: 30000
XDiv: 7 YDiv: 6
X Scale: 1.347
Y Scale: 1



Mode No.= 1 STABLE : Rotor: 1 MIXED (9% F, 90% B) Whirl: Rotor: 2 MIXED (88% F, 11% B) Whirl: Rotor: 3 STRAIGHT LINE Motion
Shaft Rotational Speeds = 0, 0, 0 rpm
Whirl Speed (Damped Natural Freq.) = 9660 rpm, Log. Decrement = 0.0634

From the mode shape shown above, it indicates that this mode is a coupled lateral and torsional mode with very large torsional motion at the compressor and significant lateral motion at the motor driver end. Consequently, torsional excitation from the compressor rotor can cause high lateral vibration in the motor gear end, mainly in the Y direction (line of action) and small vibration in the X direction. With the natural frequency of 9660 cpm, the strong 4X response occurs at the compressor rotor speed of 9660/4=2,415 rpm and motor speed of 9660/5.388=1793 rpm.

To further study this system, in the Lateral-Torsional-Axial vibration run time input, we can check the Torsional vibration only. This will only analyze the torsional vibration with the flexibility in the gear meshes.

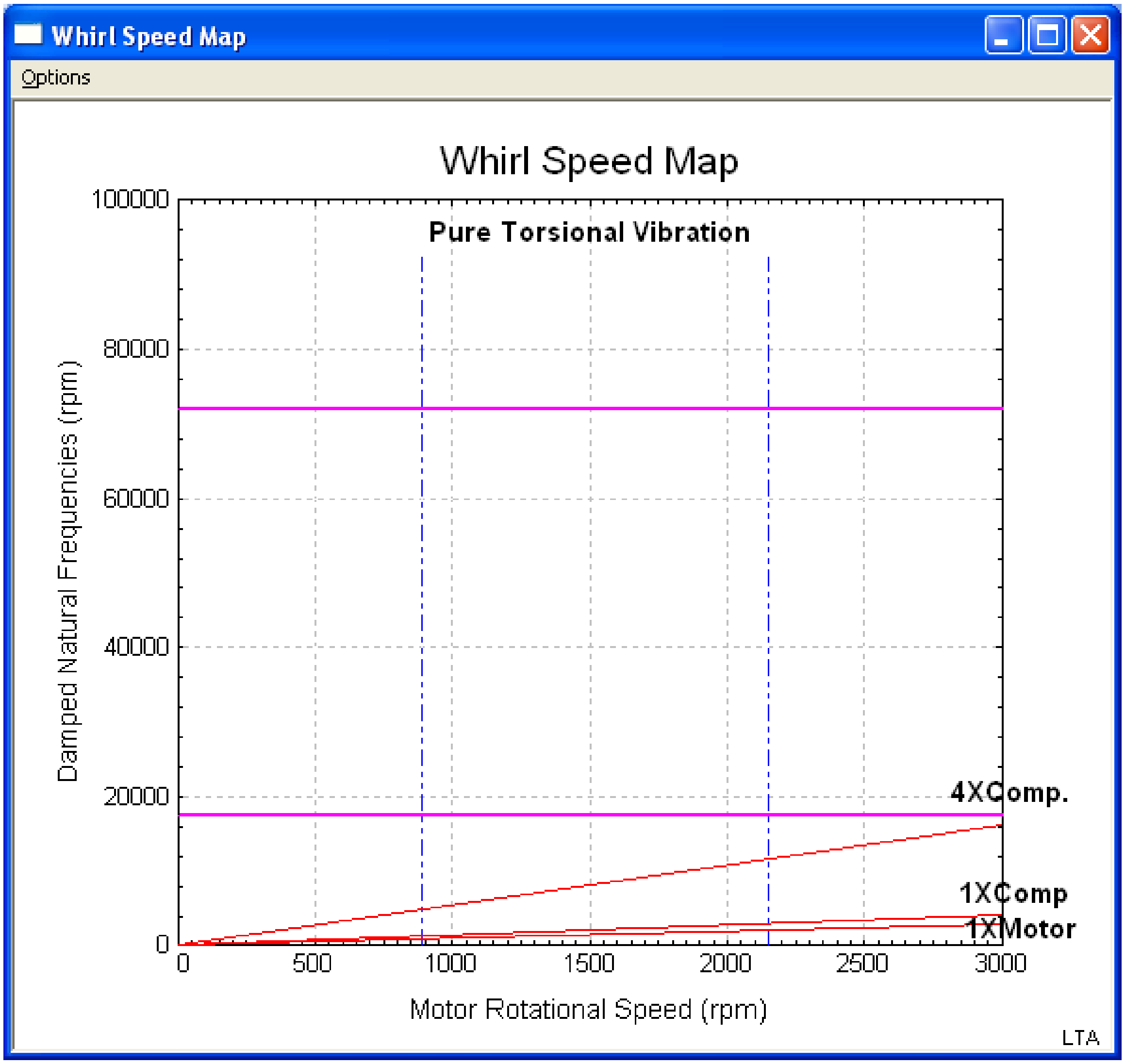


Analysis: 1 - Whirl Speed & Stability Analysis

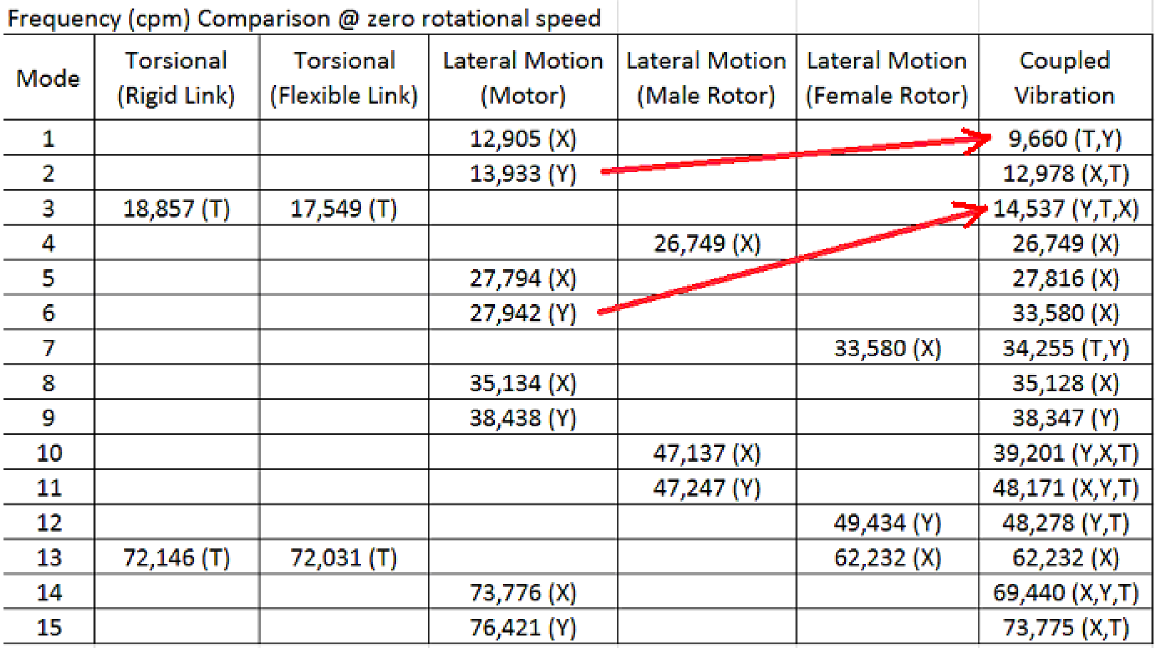
Vibrations Included

☐ Lateral ☑ Torsional ☐ Axial

☑ Convert Cross-Coupled Bearing Coefficients
If Rotation is CW: from Local x to Global X



In summary, only the coupled lateral-torsional vibration analysis produces the interference point (potential resonance point) in the whirl speed map (Campbell Diagram). All the individual analysis on the lateral vibration and purely torsional analysis do not have interference point. Since the gyroscopic effect is very small and the frequencies stay almost the same as the speed increases, the following table summarizes the first several frequencies at zero rotor speed for various analyses:



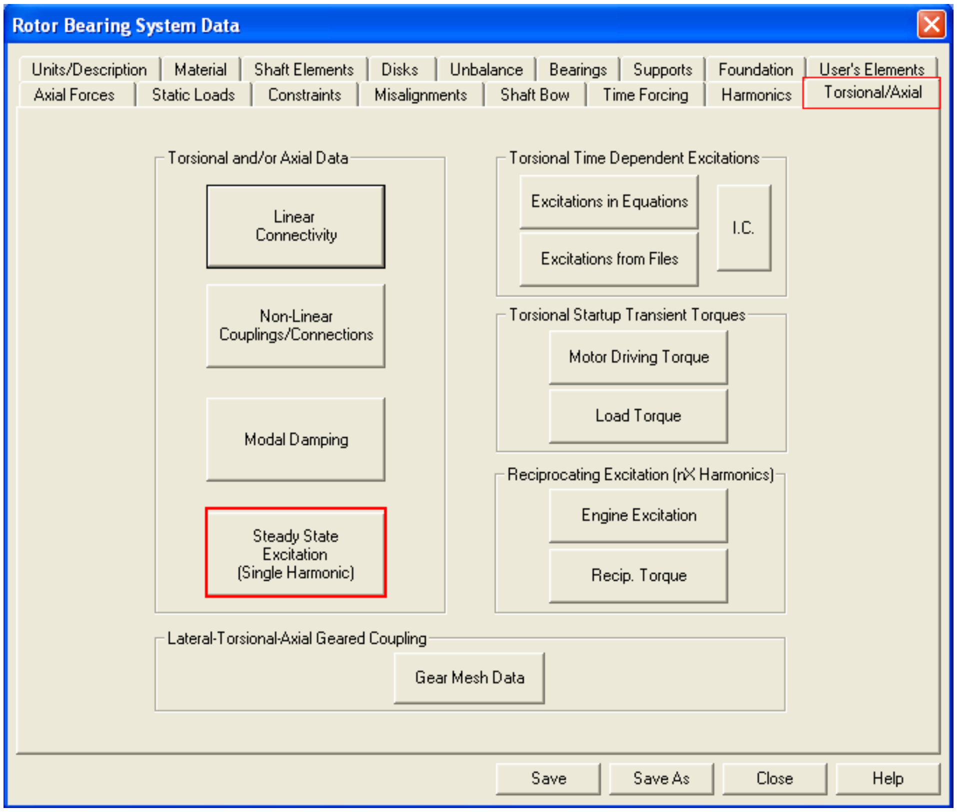
Frequency (cpm) Comparison @ zero rotational speed

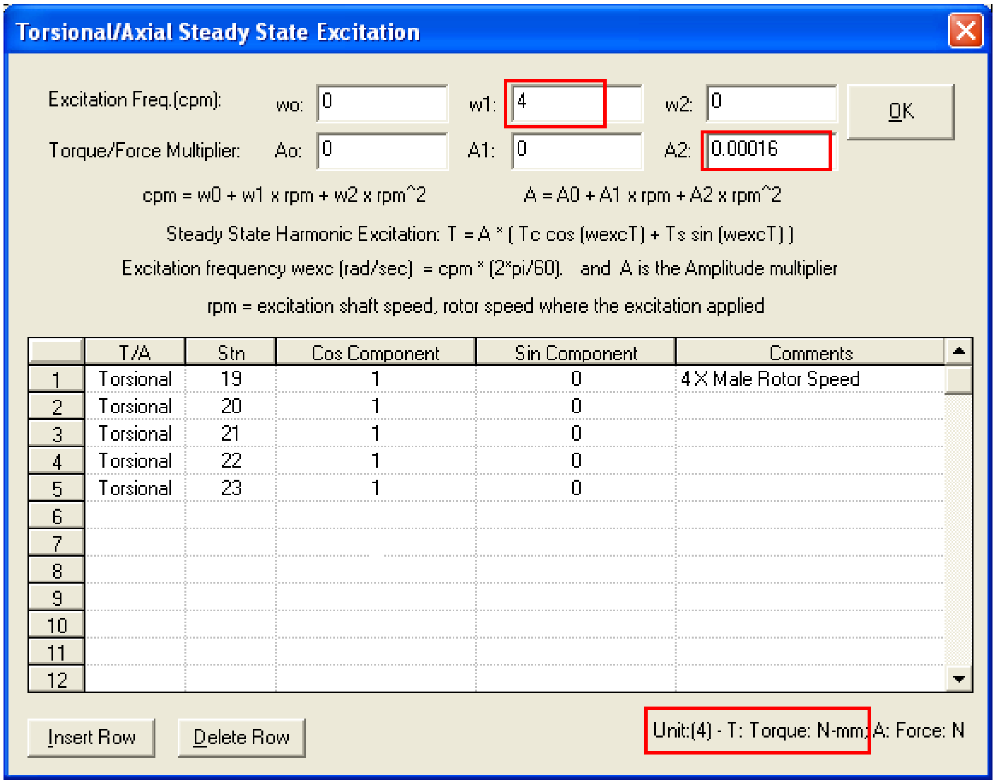
Mode	Torsional (Rigid Link)	Torsional (Flexible Link)	Lateral Motion (Motor)	Lateral Motion (Male Rotor)	Lateral Motion (Female Rotor)	Coupled Vibration
1			12,905 (X)			9,660 (T,Y)
2			13,933 (Y)			12,978 (X,T)
3	18,857 (T)	17,549 (T)				14,537 (Y,T,X)
4				26,749 (X)		26,749 (X)
5			27,794 (X)			27,816 (X)
6			27,942 (Y)			33,580 (X)
7					33,580 (X)	34,255 (T,Y)
8			35,134 (X)			35,128 (X)
9			38,438 (Y)			38,347 (Y)
10				47,137 (X)		39,201 (Y,X,T)
11				47,247 (Y)		48,171 (X,Y,T)
12					49,434 (Y)	48,278 (Y,T)
13	72,146 (T)	72,031 (T)			62,232 (X)	62,232 (X)
14			73,776 (X)			69,440 (X,Y,T)
15			76,421 (Y)			73,775 (X,T)

Note: T indicates Torsional motion, X lateral motion mainly in X direction, Y lateral motion mainly in Y direction.

In view of the above table and the corresponding mode shapes, the frequency of the motor lateral motion mode (13,933 cpm) in the Y direction (line of action) decreases significantly due to the flexibility introduced by the gear mesh to become the lowest natural frequency (9,660 cpm) of the complete gear train. The frequency in the X direction (12,905 cpm) of the motor lateral motion is nearly unaffected by this torsional coupling effect and becomes 12,978 cpm in the coupled system.

To further study the torsional excitation effect on the rotor lateral vibration, the torsional excitation caused by the compressor is added into the model. The compressor has a 4/6 lobes design for the male and female rotors. It is known that it produces a strong 4X (male rotor speed) port passing torsional excitation from the compressor. This excitation is entered from Model – Data Editor – Torsional/Axial – Steady State Excitation as shown below. Note that the excitations are applied at shaft 2 (compressor male rotor), the excitation frequency is 4X of the compressor male rotor speed, not the motor speed. Also, the exciting torque increases with the square of the compressor speed.





Excitation Freq.(cpm): wo: 0 w1: 4 w2: 0

Torque/Force Multiplier: Ao: 0 A1: 0 A2: 0.00016

cpm = w0 + w1 x rpm + w2 x rpm^2 A = A0 + A1 x rpm + A2 x rpm^2

Steady State Harmonic Excitation: T = A * (Tc cos (wexcT) + Ts sin (wexcT))

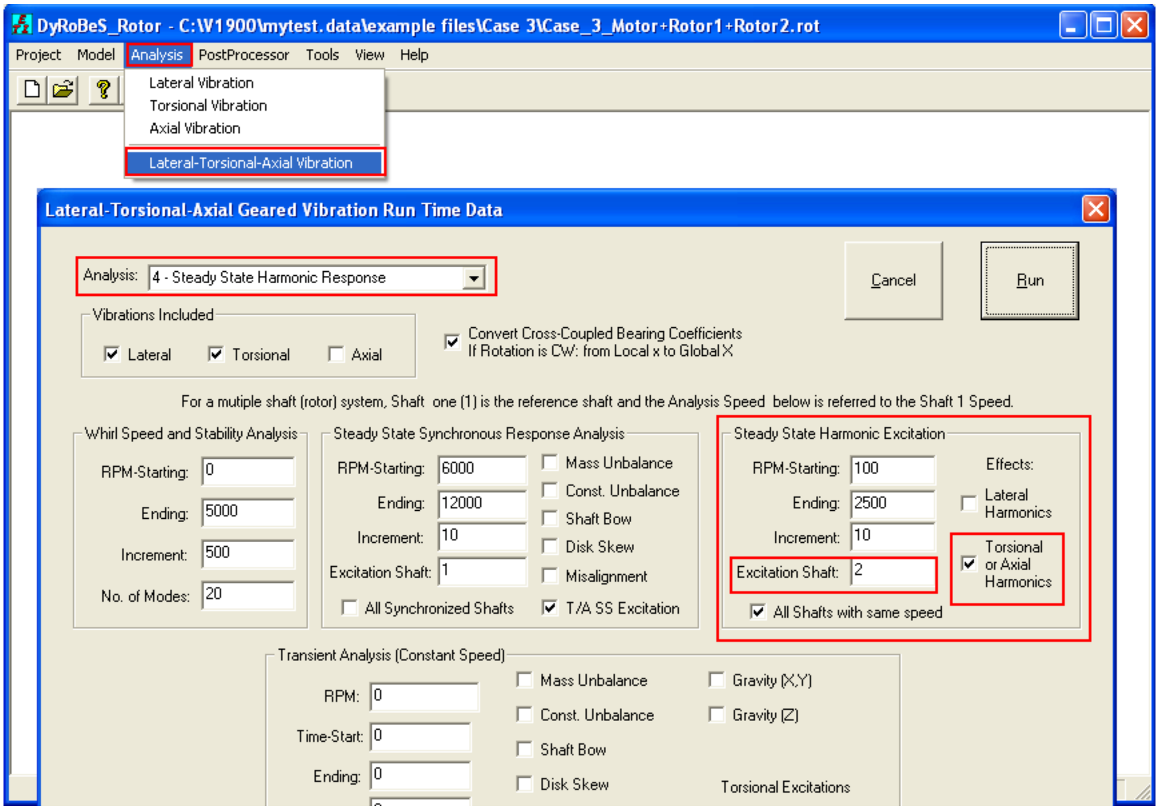
Excitation frequency wexc (rad/sec) = cpm * (2*pi/60), and A is the Amplitude multiplier

rpm = excitation shaft speed, rotor speed where the excitation applied

	T/A	Stn	Cos Component	Sin Component	Comments
1	Torsional	19	1	0	4 X Male Rotor Speed
2	Torsional	20	1	0	
3	Torsional	21	1	0	
4	Torsional	22	1	0	
5	Torsional	23	1	0	
6					
7					
8					
9					
10					
11					
12					

Unit:(4) - T: Torque: N-mm; A: Force: N

When performing the coupled lateral-torsional analysis, select Lateral-Torsional-Axial Vibration from the Analysis menu and enter the data below. Note that the analysis rotor speed is always referred to the shaft 1 rotor speed. Since the excitation is on shaft 2 (compressor male rotor), enter 2 in the excitation shaft field. Check the Torsional Harmonics to include the torsional harmonic excitation in the analysis. Several postprocessor plots are shown below. Although the excitation is due to torsional torque, the lateral vibration can be significant in this coupled gear system.



Lateral-Torsional-Axial Geared Vibration Run Time Data

Analysis: 4 - Steady State Harmonic Response

Vibrations Included: ☑ Lateral ☑ Torsional ☐ Axial

☑ Convert Cross-Coupled Bearing Coefficients If Rotation is CW: from Local x to Global X

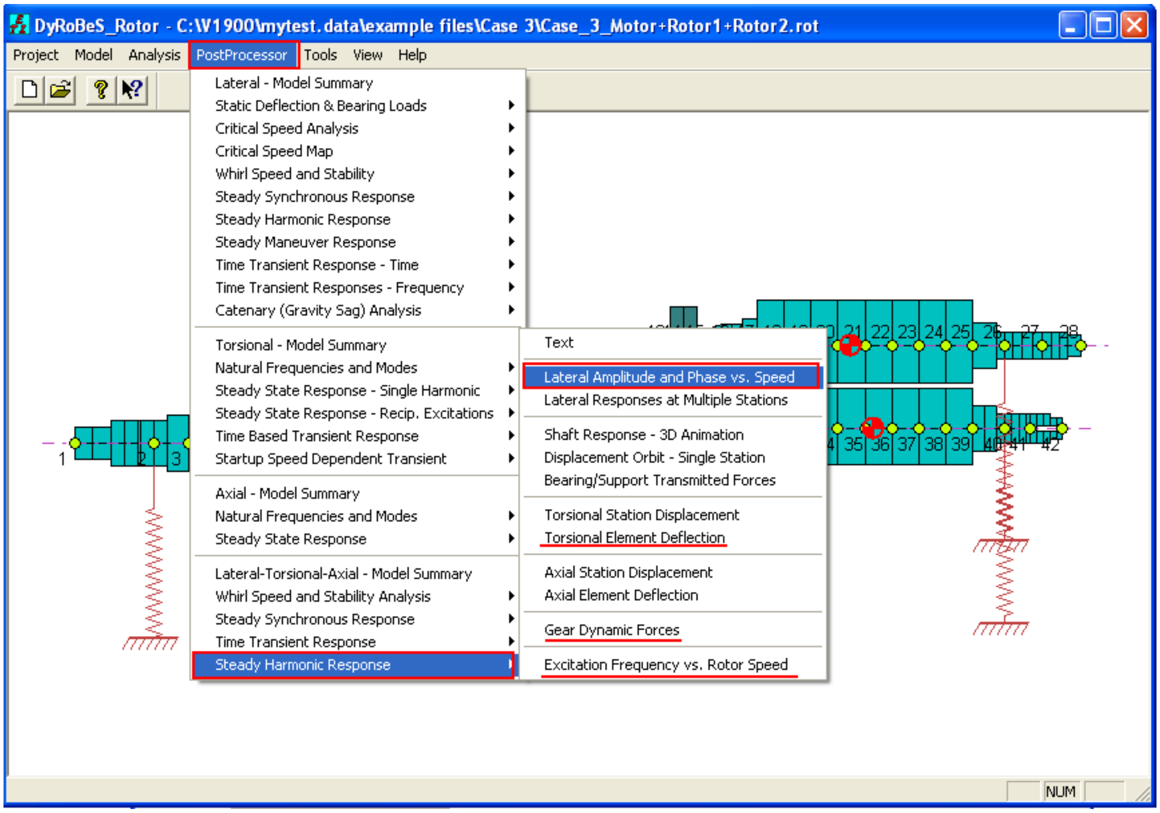
For a mutiple shaft (rotor) system, Shaft one (1) is the reference shaft and the Analysis Speed below is referred to the Shaft 1 Speed.

Whirl Speed and Stability Analysis
RPM-Starting: 0
Ending: 5000
Increment: 500
No. of Modes: 20

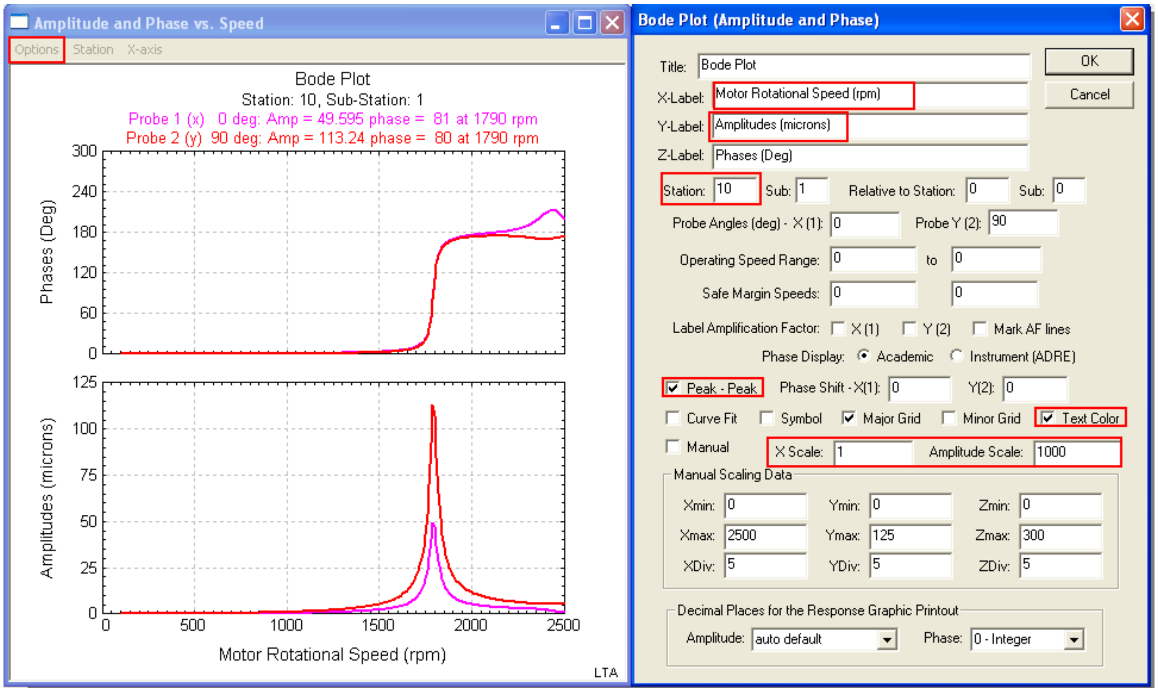
Steady State Synchronous Response Analysis
RPM-Starting: 6000
Ending: 12000
Increment: 10
Excitation Shaft: 1
☐ All Synchronized Shafts
☐ Mass Unbalance
☐ Const. Unbalance
☐ Shaft Bow
☐ Disk Skew
☐ Misalignment
☑ T/A SS Excitation

Steady State Harmonic Excitation
RPM-Starting: 100
Ending: 2500
Increment: 10
Excitation Shaft: 2
☑ All Shafts with same speed
Effects:
☐ Lateral Harmonics
☑ Torsional or Axial Harmonics

Transient Analysis (Constant Speed)
RPM: 0
Time-Start: 0
Ending: 0
☐ Mass Unbalance
☐ Const. Unbalance
☐ Shaft Bow
☐ Disk Skew
☐ Gravity (X,Y)
☐ Gravity (Z)
Torsional Excitations



Again, by default, the rotor speed shown in the plot is the analysis speed (shaft 1 speed). To plot the vibration vs. the compressor male rotor speed, we can multiply the X-axis by 1.347.

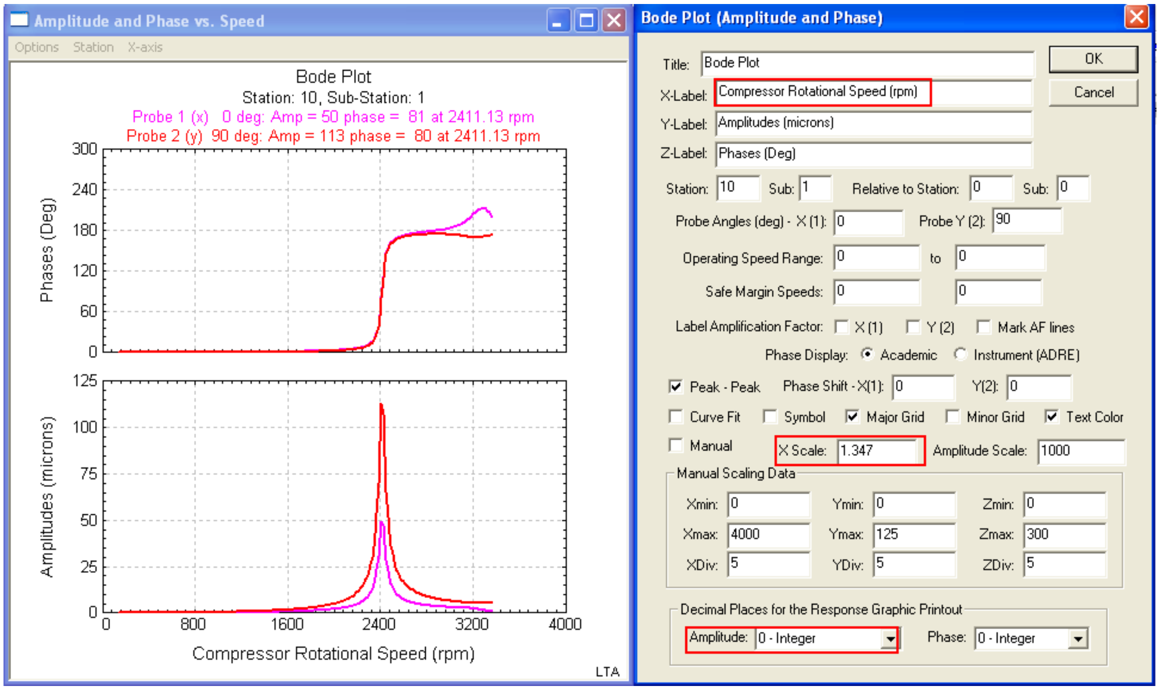


Probe 1 (x) 0 deg: Amp = 49.595 phase = 81 at 1790 rpm
Probe 2 (y) 90 deg: Amp = 113.24 phase = 80 at 1790 rpm

Title: Bode Plot
X-Label: Motor Rotational Speed (rpm)
Y-Label: Amplitudes (microns)
Z-Label: Phases (Deg)
Station: 10 Sub: 1 Relative to Station: 0 Sub: 0
Probe Angles (deg) - X (1): 0 Probe Y (2): 90
Operating Speed Range: 0 to 0
Safe Margin Speeds: 0 0
Label Amplification Factor: ☐ X (1) ☐ Y (2) ☐ Mark AF lines
Phase Display: ● Academic ○ Instrument (ADRE)
☑ Peak - Peak Phase Shift - X(1): 0 Y(2): 0
☐ Curve Fit ☐ Symbol ☑ Major Grid ☐ Minor Grid ☑ Text Color
☐ Manual X Scale: 1 Amplitude Scale: 1000

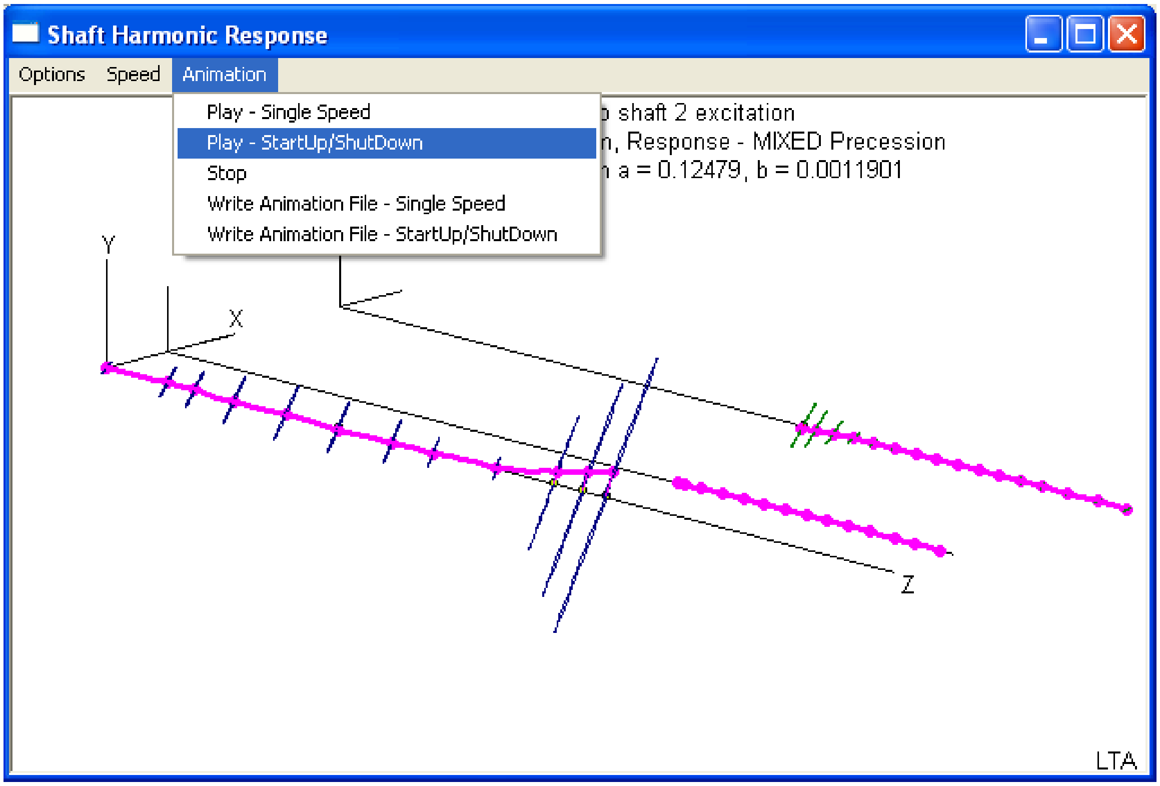
Manual Scaling Data
Xmin: 0 Ymin: 0 Zmin: 0
Xmax: 2500 Ymax: 125 Zmax: 300
XDiv: 5 YDiv: 5 ZDiv: 5

Decimal Places for the Response Graphic Printout
Amplitude: auto default Phase: 0 - Integer

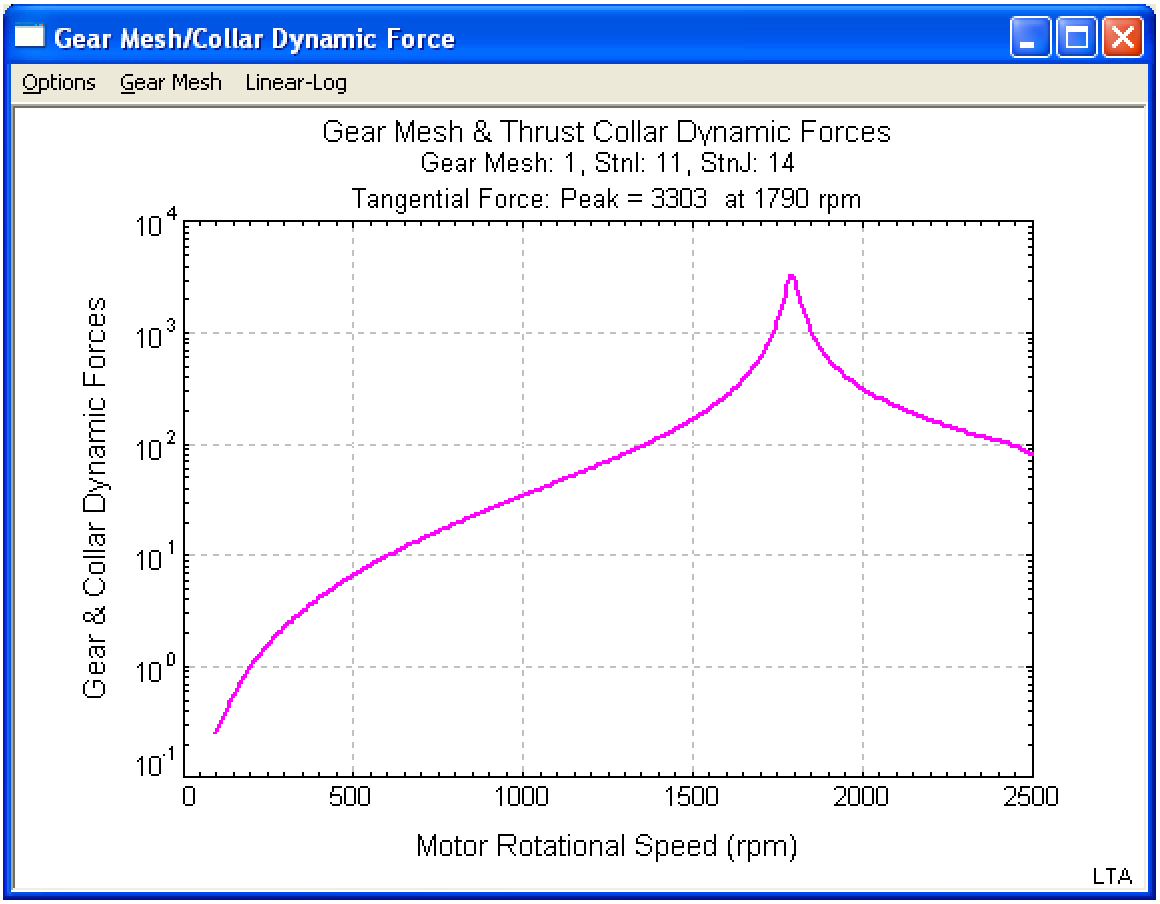


Bode Plot
Station: 10, Sub-Station: 1
Probe 1 (x) 0 deg: Amp = 50 phase = 81 at 2411.13 rpm
Probe 2 (y) 90 deg: Amp = 113 phase = 80 at 2411.13 rpm

Title: Bode Plot
X-Label: Compressor Rotational Speed (rpm)
Y-Label: Amplitudes (microns)
Z-Label: Phases (Deg)
Station: 10 Sub: 1 Relative to Station: 0 Sub: 0
Probe Angles (deg) - X (1): 0 Probe Y (2): 90
Operating Speed Range: 0 to 0
Safe Margin Speeds: 0 0
Label Amplification Factor: ☐ X (1) ☐ Y (2) ☐ Mark AF lines
Phase Display: ● Academic ○ Instrument (ADRE)
☑ Peak - Peak Phase Shift - X(1): 0 Y(2): 0
☐ Curve Fit ☐ Symbol ☑ Major Grid ☐ Minor Grid ☑ Text Color
☐ Manual X Scale: 1.347 Amplitude Scale: 1000
Manual Scaling Data
Xmin: 0 Ymin: 0 Zmin: 0
Xmax: 4000 Ymax: 125 Zmax: 300
XDiv: 5 YDiv: 5 ZDiv: 5
Decimal Places for the Response Graphic Printout
Amplitude: 0 - Integer Phase: 0 - Integer



shaft 2 excitation
n, Response - MIXED Precession
n a = 0.12479, b = 0.0011901

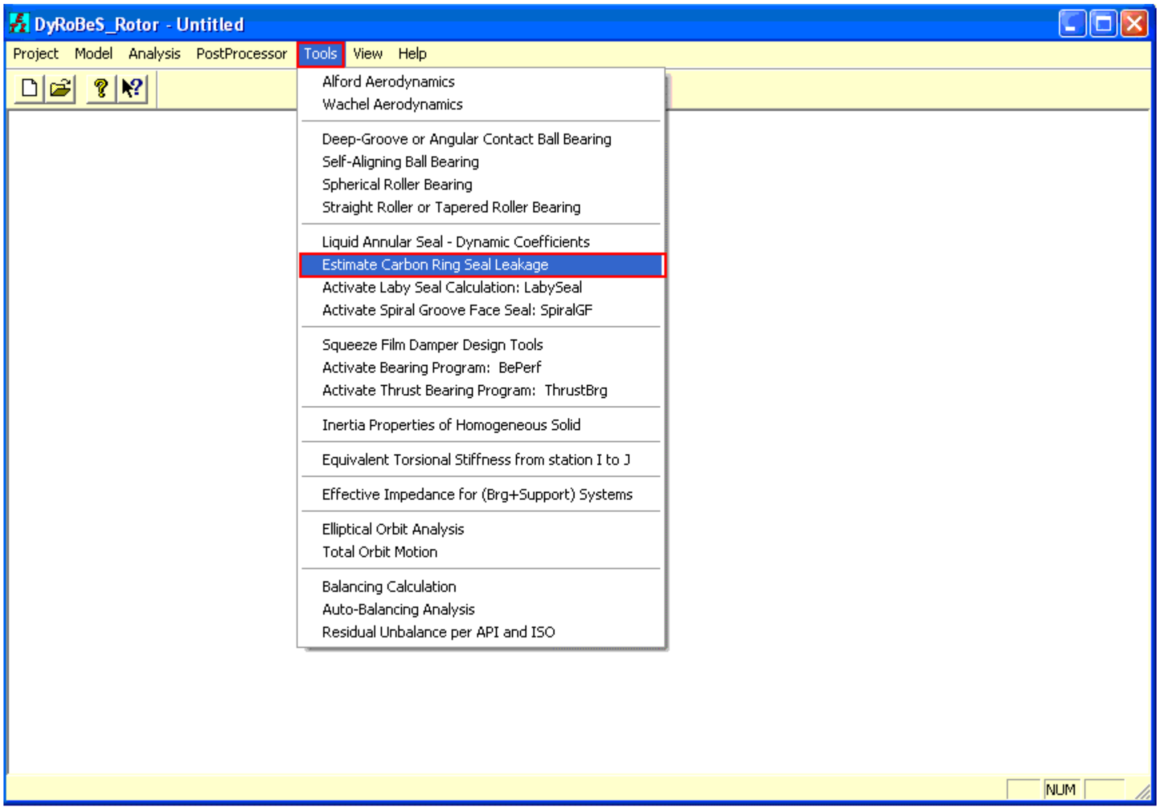

Gear Mesh/Collar Dynamic Force
Options
Gear Mesh
Linear-Log
Gear Mesh & Thrust Collar Dynamic Forces
Gear Mesh: 1, StnI: 11, StnJ: 14
Tangential Force: Peak = 3303 at 1790 rpm
Gear & Collar Dynamic Forces
10^{4}
10^{3}
10^{2}
10^{1}
10^{0}
10^{-1}
0
500
1000
1500
2000
2500
Motor Rotational Speed (rpm)
LTA

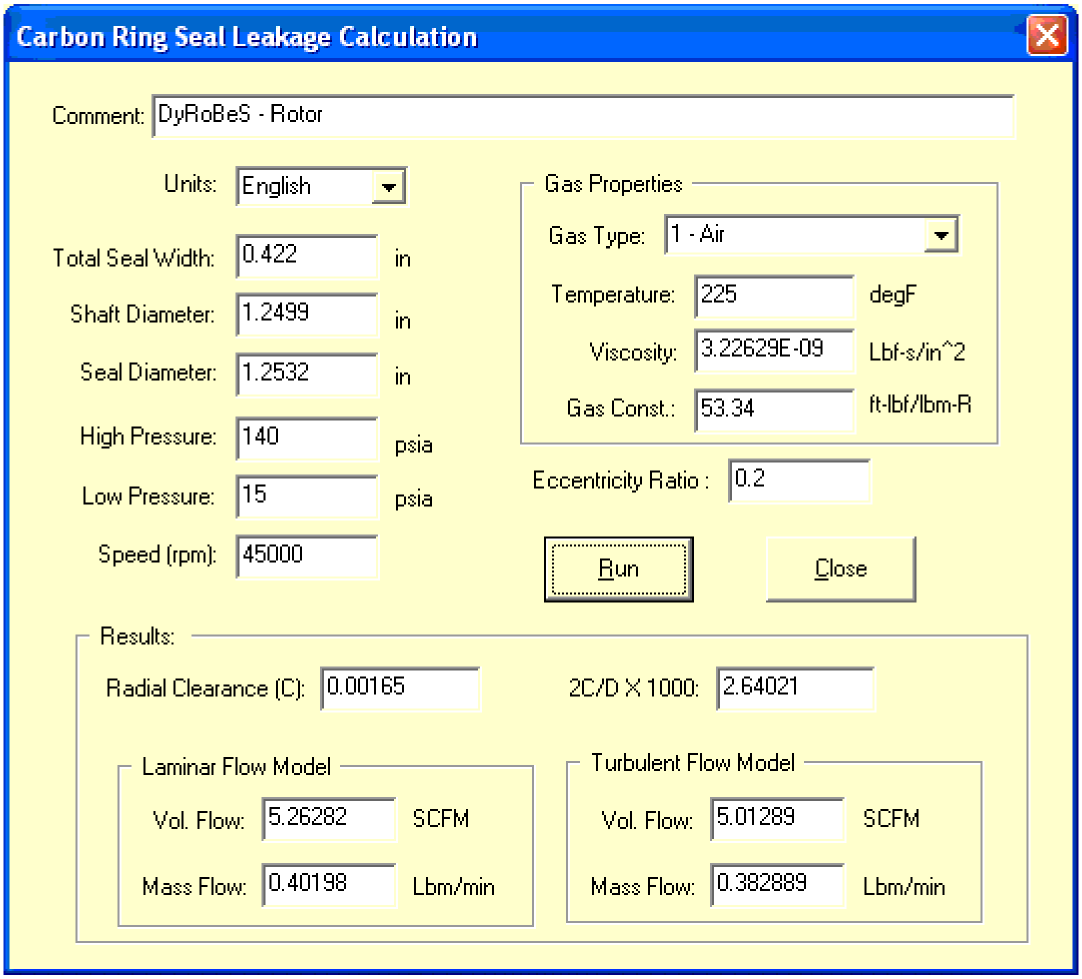
Carbon Ring Seal Calculation

The feature calculate the leakage for a carbon ring seal commonly used in the compressors and blowers. The calculation method is based on the air force report by Bauer et al. (1965). The original equations were adjusted with some correction factors to fit the experimental data tested by AMS Seals Inc.

> Bauer, P., Glickman, M., and Iwatsuki, F., May 1965, "Analytical techniques for the Design of Seals for Use in Rocket Propulsion Systems, Volume II Dynamic Seals," Technical Report AFRPL-TR-65-61, Air Force Rocket Propulsion Laboratory, Research and Technology Division.

To activate this feature, Rotor – Tools – Estimate the Carbon Ring Seal Leakage.





Comment: DyRoBeS - Rotor

Units: English

Total Seal Width: 0.422 in

Shaft Diameter: 1.2499 in

Seal Diameter: 1.2532 in

High Pressure: 140 psia

Low Pressure: 15 psia

Speed (rpm): 45000

Gas Properties

Gas Type: 1 - Air

Temperature: 225 degF

Viscosity: 3.22629E-09 Lbf-s/in^2

Gas Const.: 53.34 ft-lbf/lbm-R

Eccentricity Ratio : 0.2

Results:

Radial Clearance (C): 0.00165

2C/D X 1000: 2.64021

Laminar Flow Model

Vol. Flow: 5.26282 SCFM

Mass Flow: 0.40198 Lbm/min

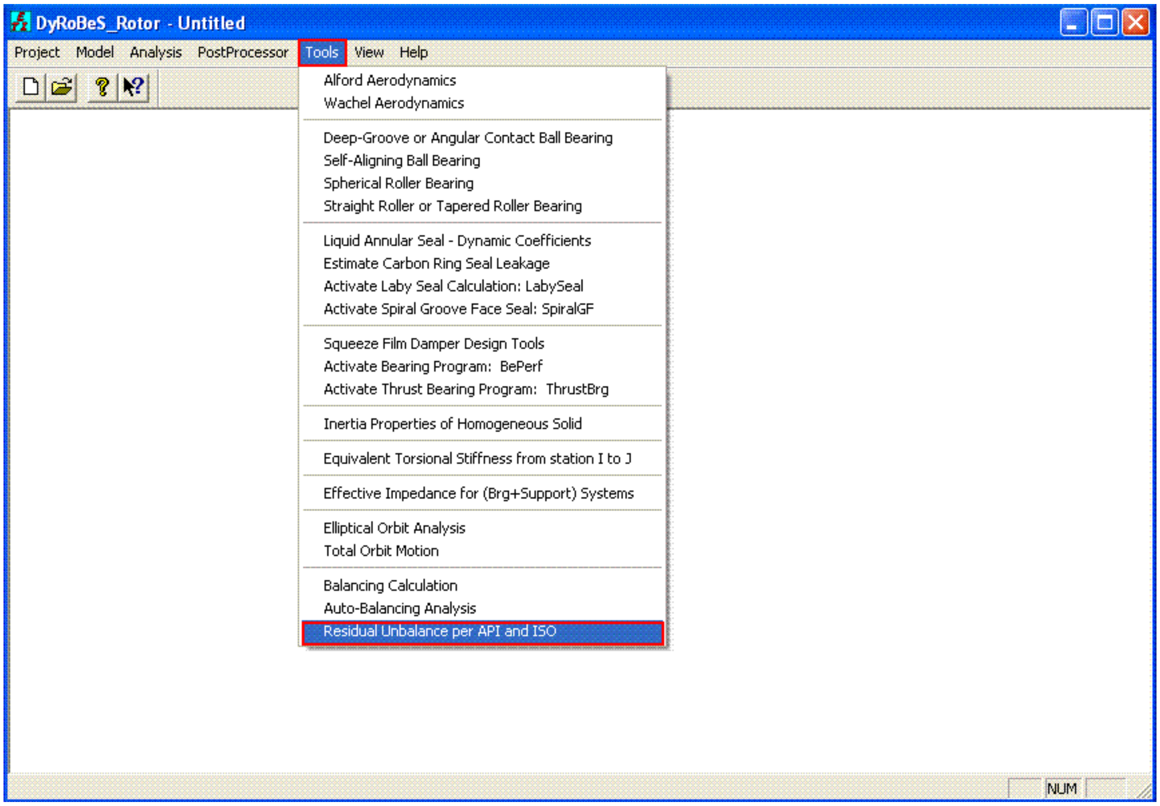
Turbulent Flow Model

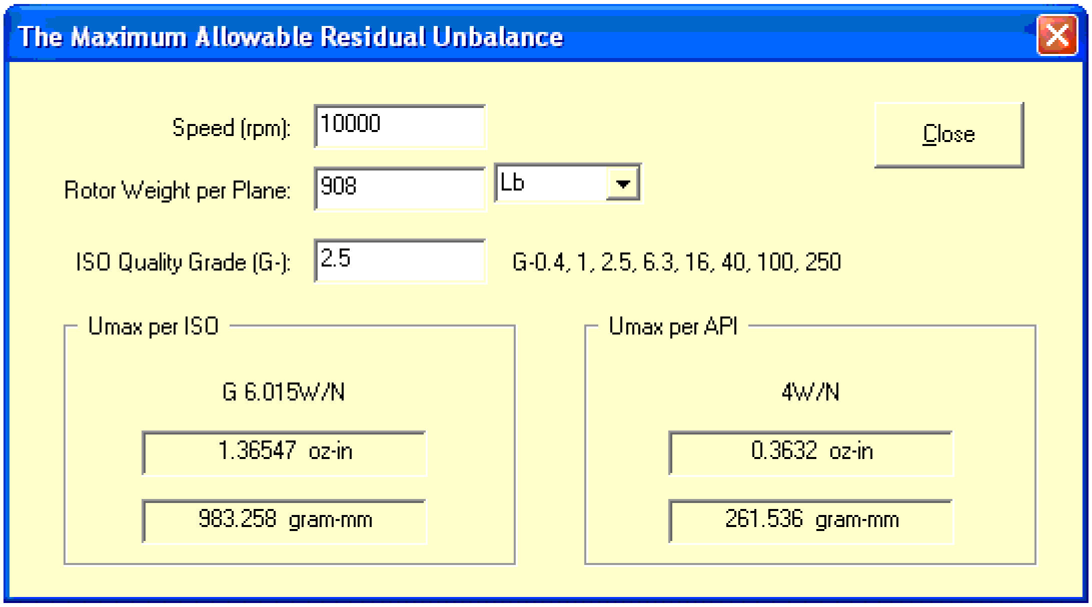
Vol. Flow: 5.01289 SCFM

Mass Flow: 0.382889 Lbm/min

The Maximum Allowable Residual Unbalance per API and ISO Specifications

The feature calculates the amount of maximum allowable residual unbalance in the rotor per API and ISO specifications. For more details, see book “Practical Rotordynamics and Fluid Film Bearing Design”, page 400-401.
To activate the function, Rotor –Tools – Residual Unbalance per API and ISO.




The Maximum Allowable Residual Unbalance

Speed (rpm): 10000

Rotor Weight per Plane: 908 Lb

ISO Quality Grade (G-): 2.5 G-0.4, 1, 2.5, 6.3, 16, 40, 100, 250

Umax per ISO

G 6.015W/N

1.36547 oz-in

983.258 gram-mm

Umax per API

4W/N

0.3632 oz-in

261.536 gram-mm