Ver 20 – Design Comparison and New Feature Notes

Part I – Rotor

New features and many improvements have been added in Rotor in Ver 20. Some of the new features are demonstrated in the following examples. Two main new features are:

- Add Bearing Type 15 in Rotor. This option allows the Rotor and BePerf be fully integrated.
- Add Design Comparison to compare different designs.
  1. Compare different (.rot) files
  2. Same rot file, but different bearing files
  3. Same rot and bearing files, but different bearing variables

0) Example

1st File: V20_Example_Compressor_33.rot
Rotor supported by two 3-Lobe bearings
Brg1: V20_Example_Compressor_Brg1.LDI
Brg2: V20_Example_Compressor_Brg2.LDI

2nd File: V20_Example_Compressor_3T.rot
Rotor supported by a 3-Lobe bearing and a Tilting pad bearing
Brg1: V20_Example_Compressor_Brg1.LDI
Brg2: V20_Example_Compressor_Brg2TPJ.TDI (Tilting Pad Bearing)

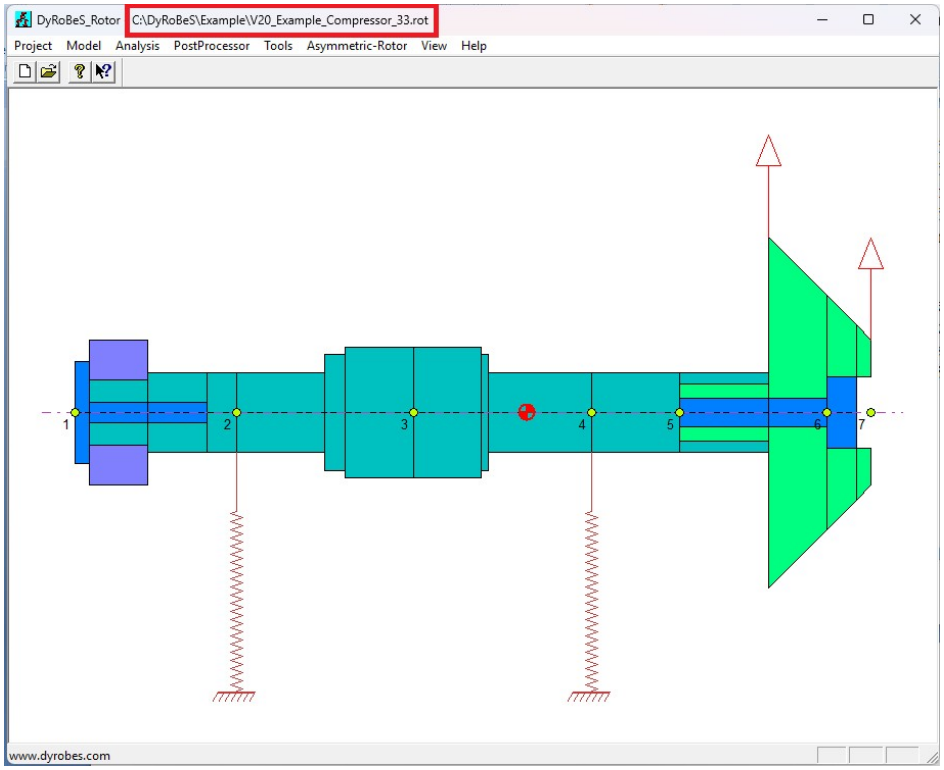
The only difference in these two files is the bearing at rotor station 4. The first file has two 3-lobe bearings at both stations 2 and 4. The second file has a 3-lobe bearing at station 2 and a tilting pad bearing at station 4.

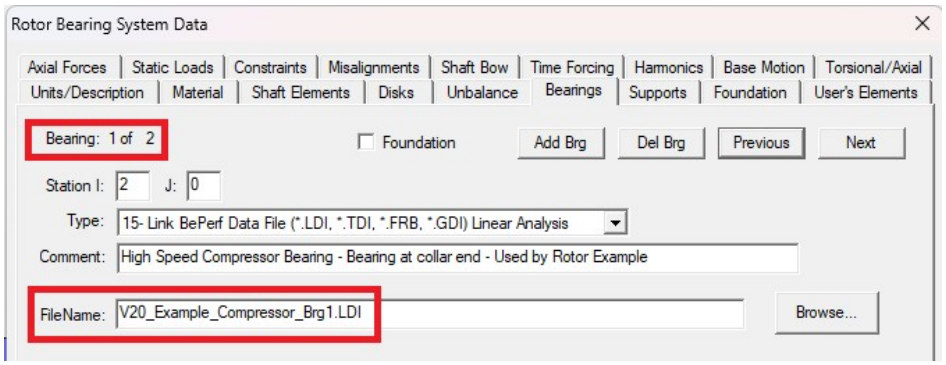
Note that these three bearing files *.LDI (fixed-lobe bearings) and *.TDI (tilting pad bearing) were created using BePerf. It is assumed that the bearing file has been analyzed using BePerf and the bearing performance, such as film thickness, has met the design requirement. When performing the rotor dynamic analysis, the bearings are first analyzed by BePerf internally and the associated *.brg files are created to be used by Rotor program.

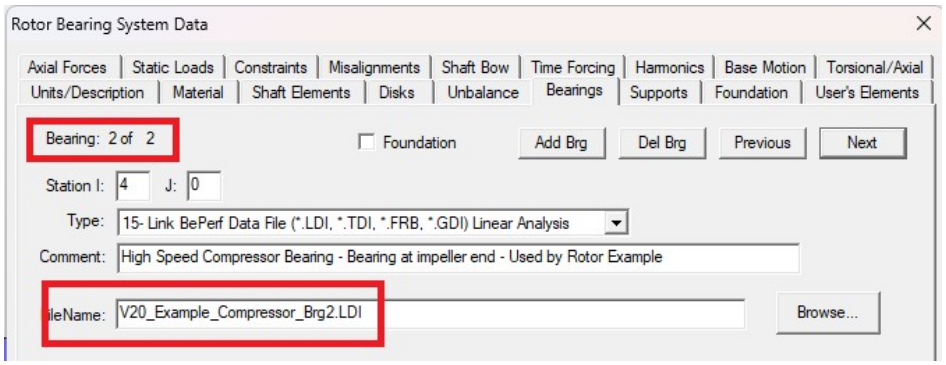
In this example, the Steady State Synchronous Response and Whirl Speed/Stability with Aerodynamic Cross-Coupling will be used in the Design Comparison. Before we do the design comparison, please run the Analysis Type 5 (Steady State Synchronous Response) and 12 (Whirl Speed and Stability Analysis with Aerodynamic Cross-Coupling) for each rotor file, respectively. There results can be used to verify the results from using the Design Comparison option. As said that two analyses (Analysis Type 15 and 18) are used to illustrate the Design Comparison feature in this example.

Option 1 – Compare different (.rot) files

Open the first file V20_Example_Compressor_33.rot using Rotor Program.

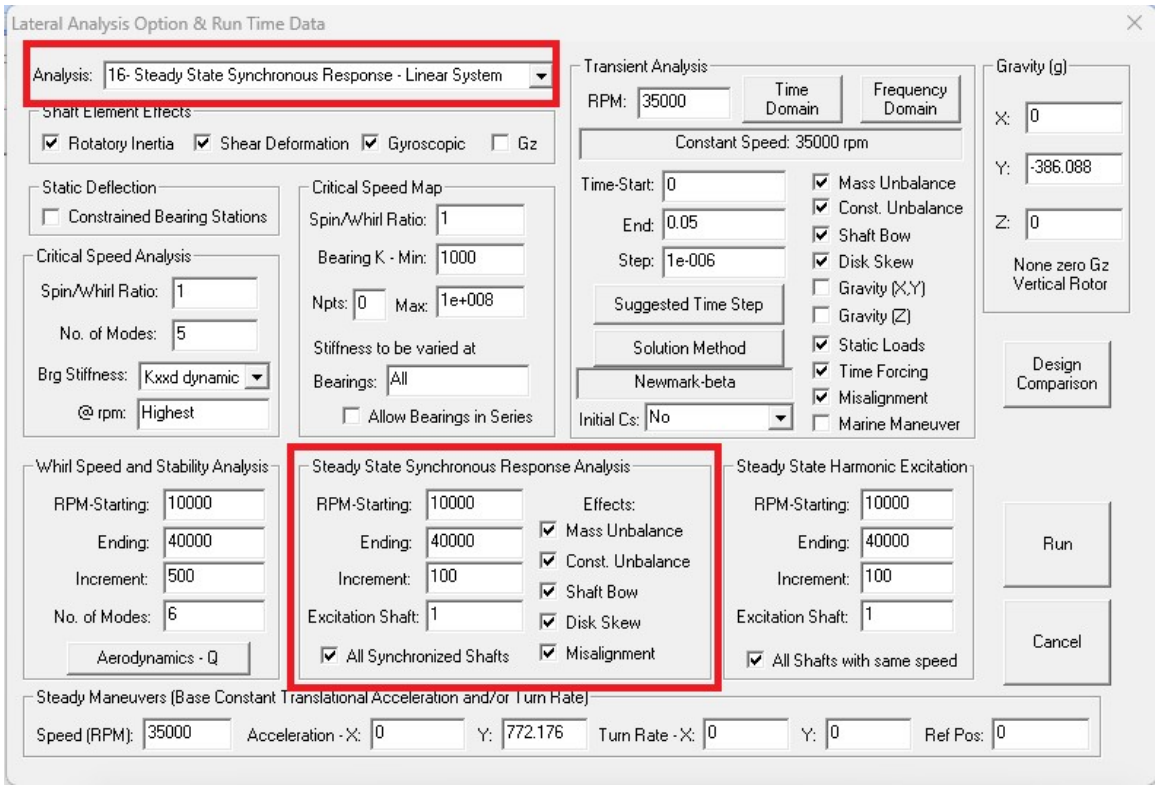




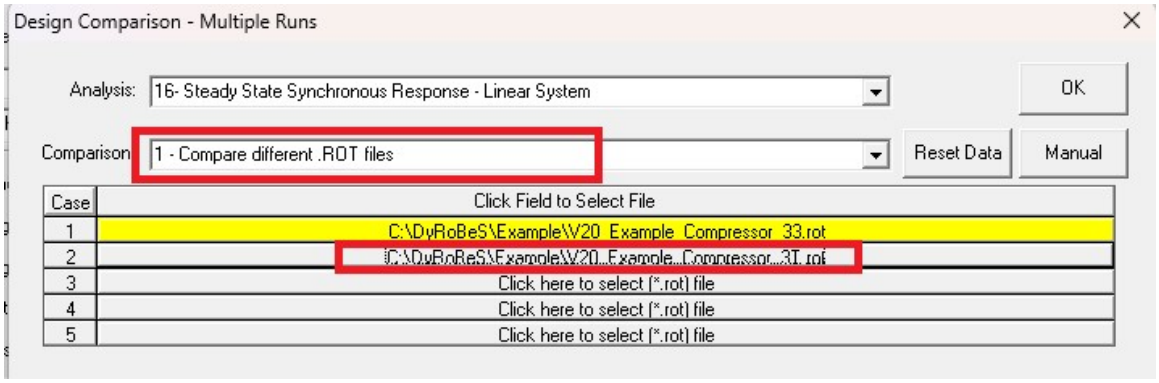


For file V20_Example_Compressor_33.rot, the second bearing at station 4 is: V20_Example_Compressor_Brg2TPJ.TDI.

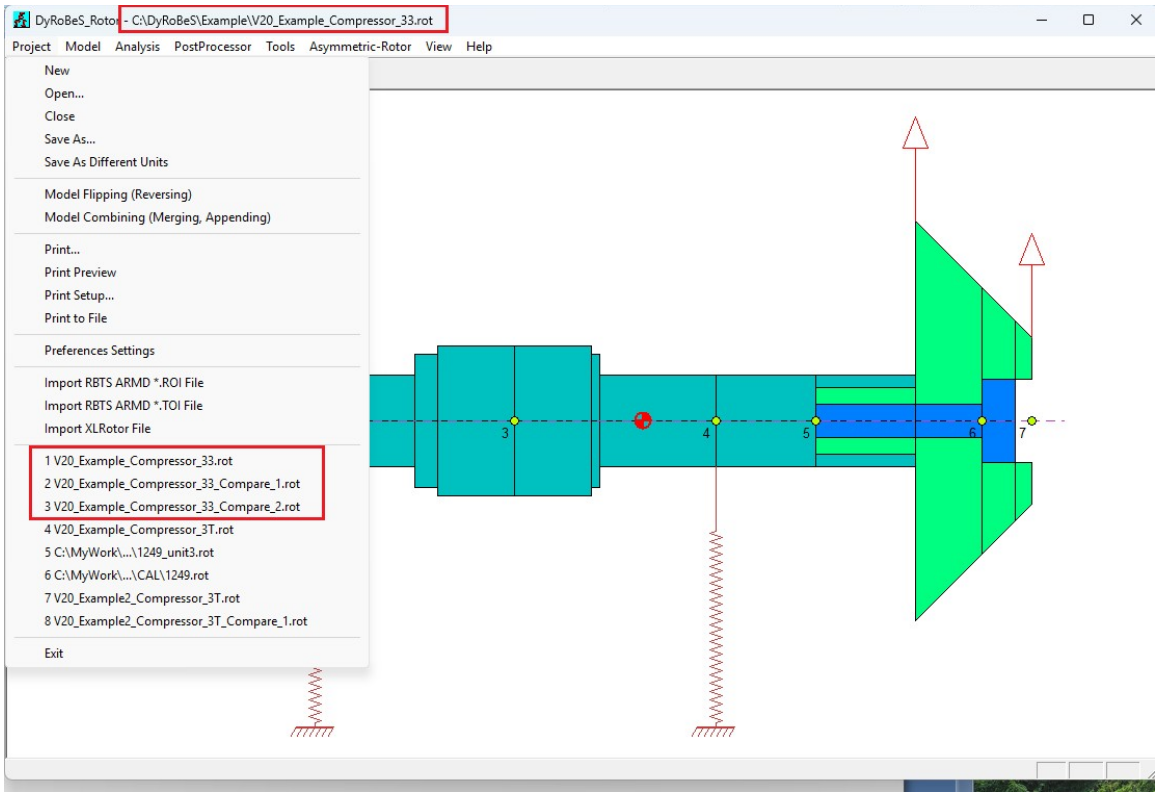
Let us compare the Steady State Synchronous Response first, Select Analysis Type 16 and enter the corresponding speeds, as shown below:



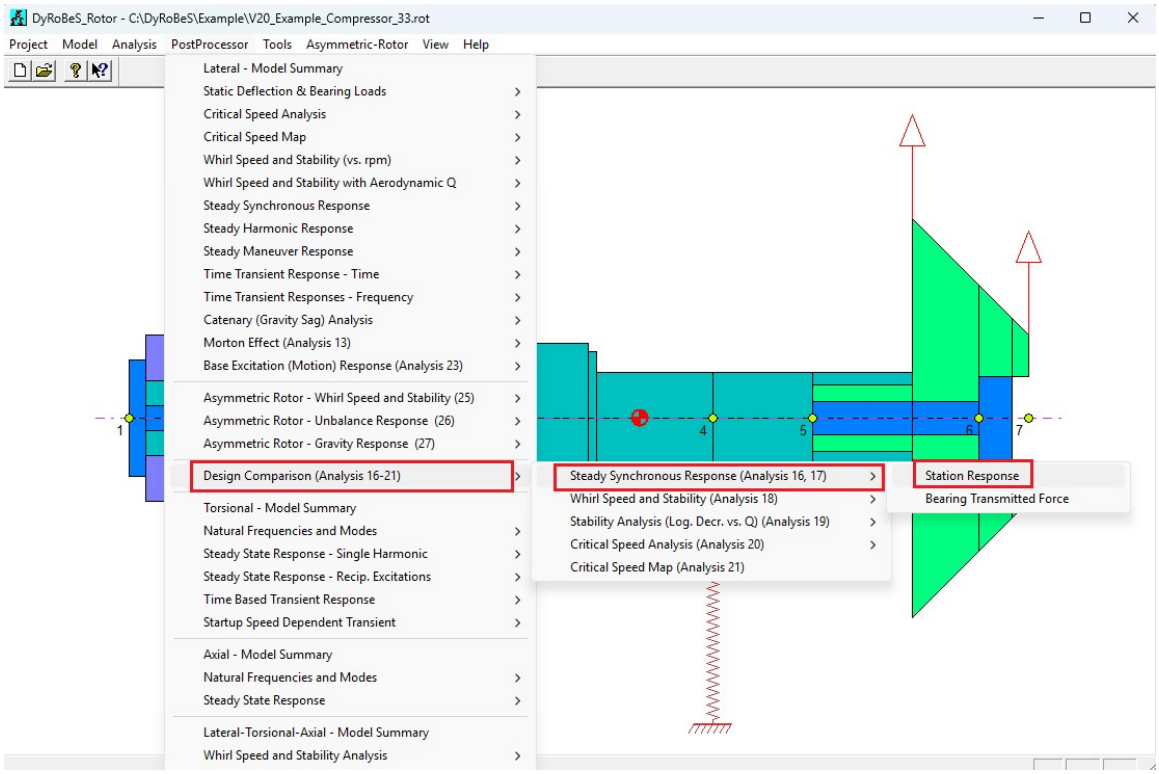
In the Design Comparison Input Page, Select Compare different .Rot files and click the second filename field, browse and select the file (V20_Example_Compressor_3T.rot). In general Case 1 is the current active file. Up to 5 files can be selected and compared in this option, as shown below.

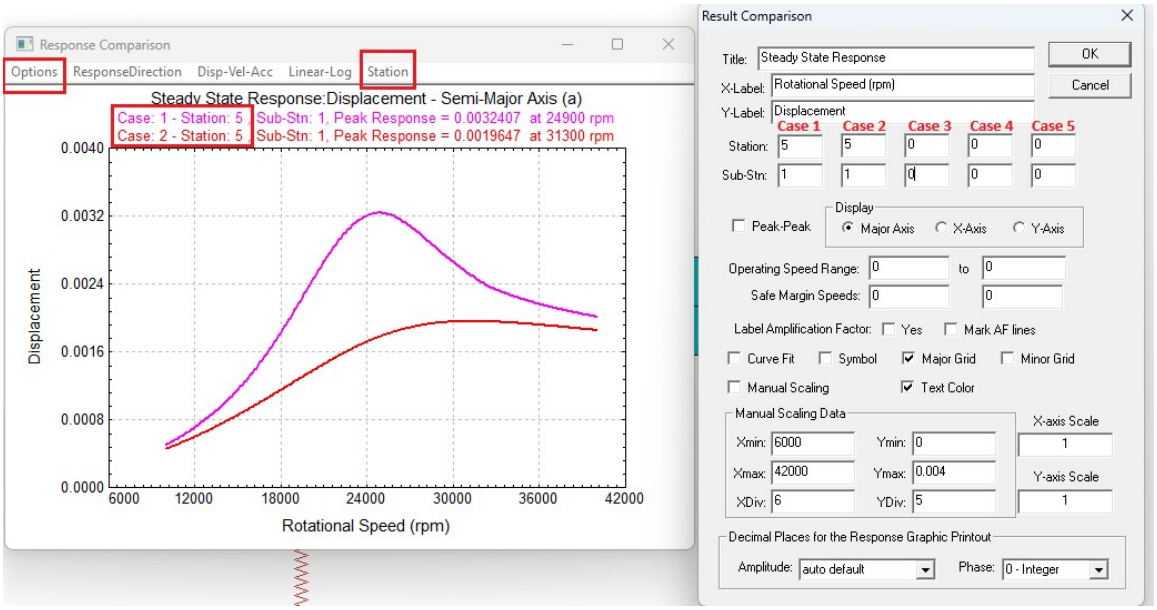


After the analysis is performed, several **temporary** files with _Compare_***x***.rot extension have been created. These files store the analysis results for postprocessor. The number of files created depends on the number of cases compared. ***x*** is the case number.



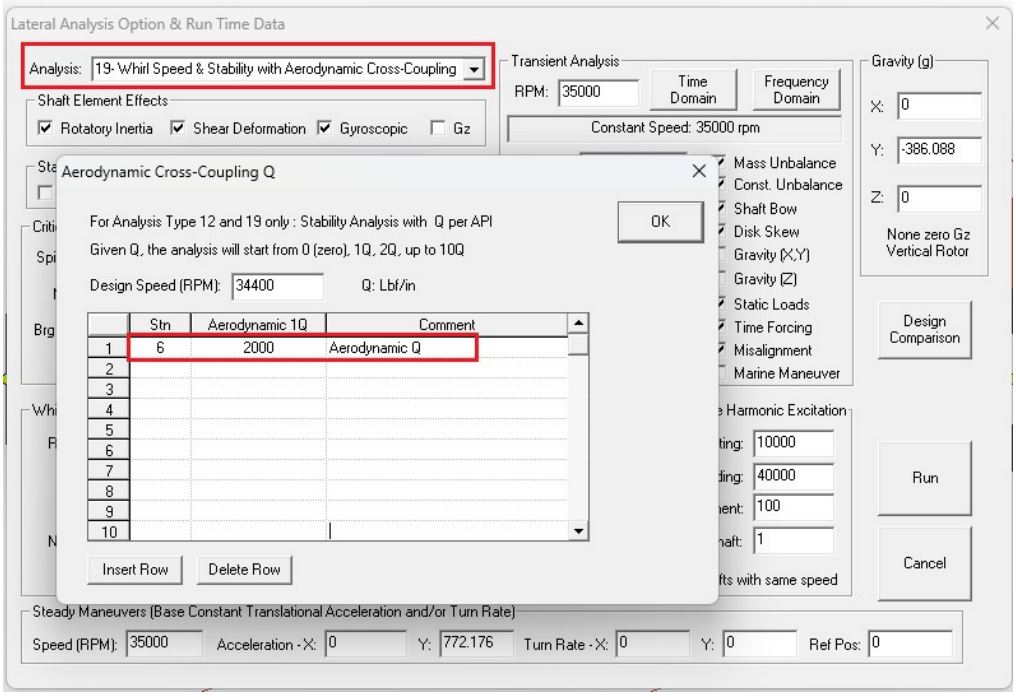
The compared and combined results can be viewed from the postprocessor as shown below:



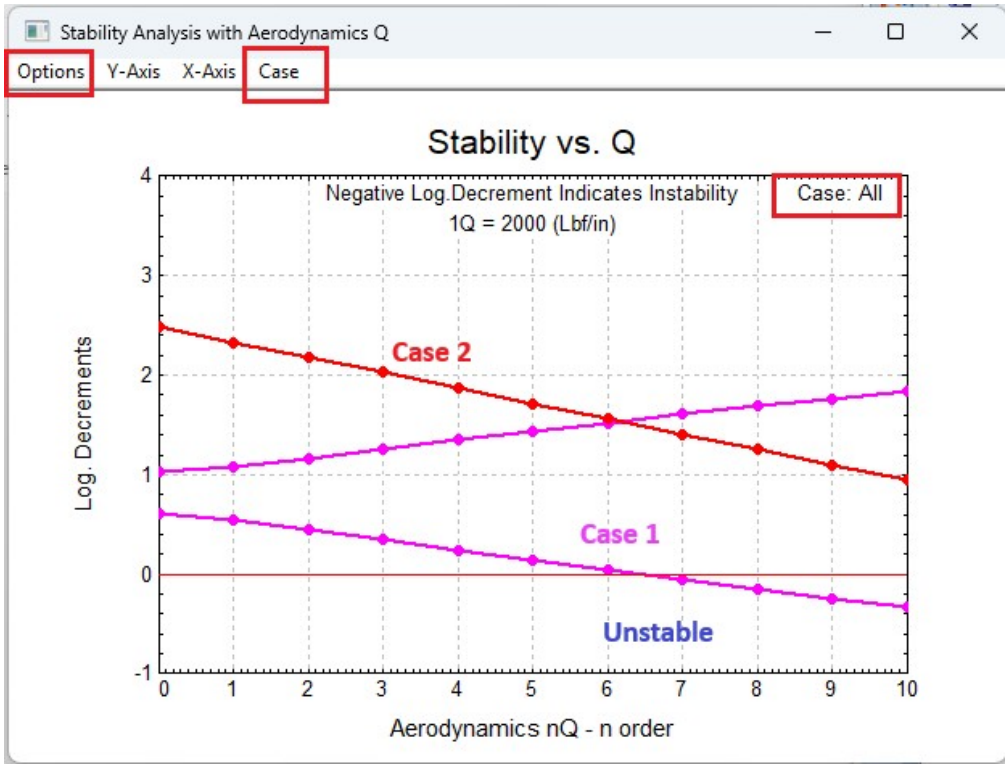


Since the two rotor systems under comparison are identical, except the bearing at stain 4. We can simply click the "Station" from the main menu to view the desired station response comparison. Or go to Options – Settings to change the required display. You can compare the results at the same station for all the cases, or different stations for different cases. The outputs can be the response (displacement, velocity, or acceleration) for the semi-major axis, X axis, or Y-axis.

The figure below shows the design comparison for the stability with aerodynamic cross-coupling term per API requirement (Analysis Type 19).

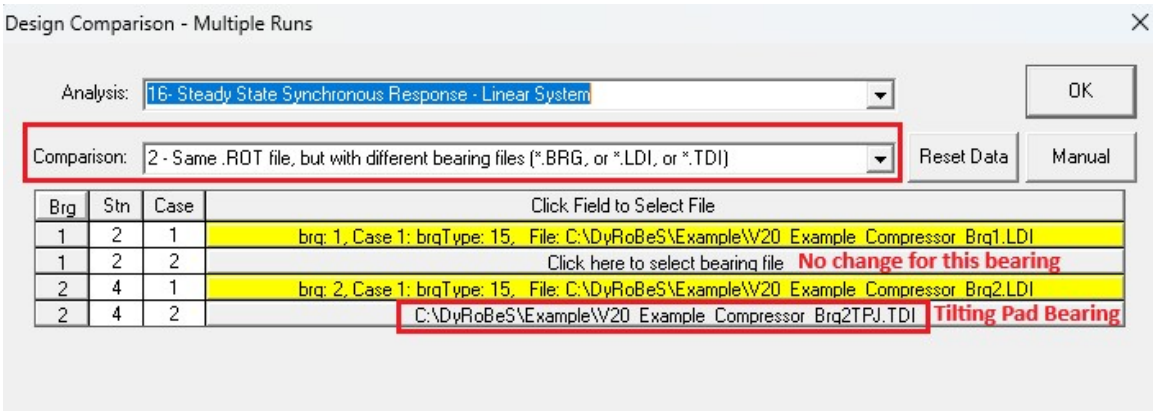


The results are shown below. Note that the results can be displayed case by case, or displayed all the cases. Below is the plot that shows all the cases. It shows the rotor system with 3-lobe bearing becomes unstable when Q is greater than 6.5. The rotor system with a tilting pad bearing is stable even at 10 Q.



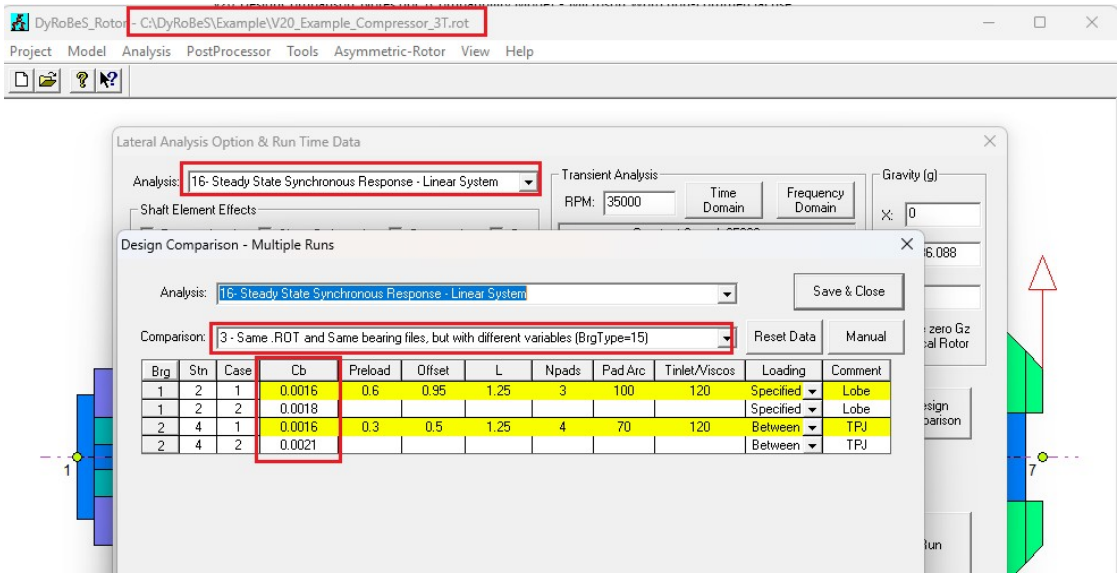
Option 2 – Same Rot file, but with different bearing files

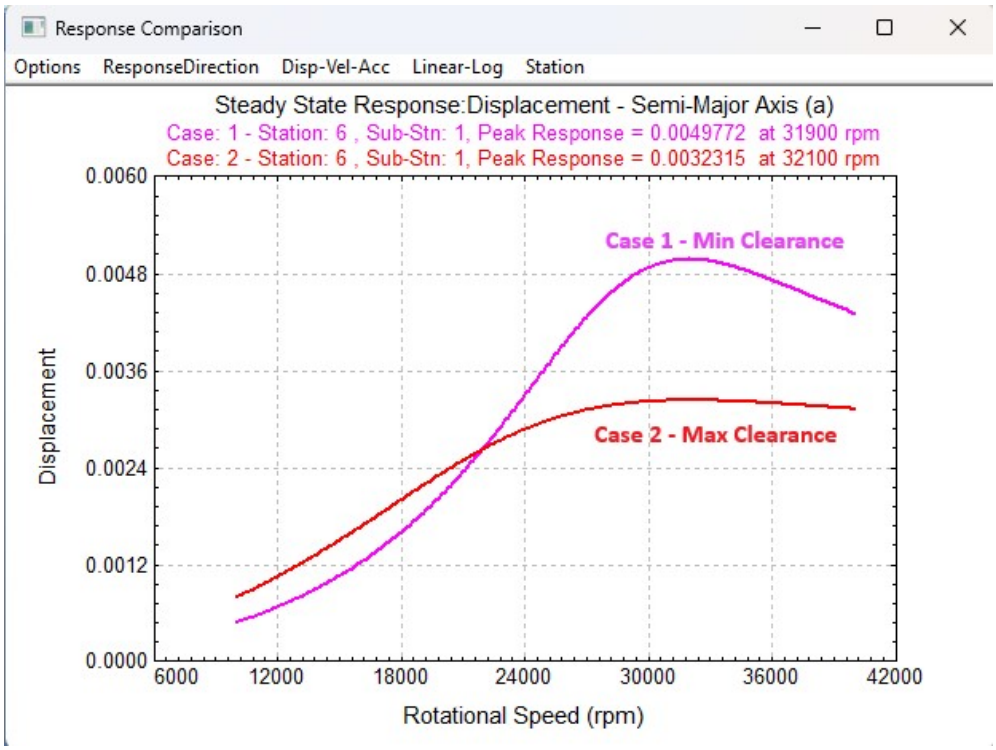
In this option, only TWO (2) cases can be compared. The rotor file is the same, the only parameters can be changed are bearings. If no bearing file is selected for Case 2, then the file from Case 1 will be used in Case 2. Below shows that the first bearing at station 2 is not changed for case 2, but the second bearing in case 1 is a fixed lobe bearing and case 2 is a tilting pad bearing. The results for these two cases are the same as comparing two files as described before. Results are not repeated here.



Option 3 – Same Rot file and same bearing files, but with different bearing parameters. This option is valid only for Bearing Type 15.

The options provide quick comparison for different bearing parameters, such as bearing clearance, preload, offset, length, etc. But the bearing type is the same. This time let us open the rotor file: **V20_Example_Compressor_3T.rot** and compare the rotor Steady State Synchronous Response with the minimum (Case 1) and maximum (Case 2) bearing clearances. The inputs and results are shown below:



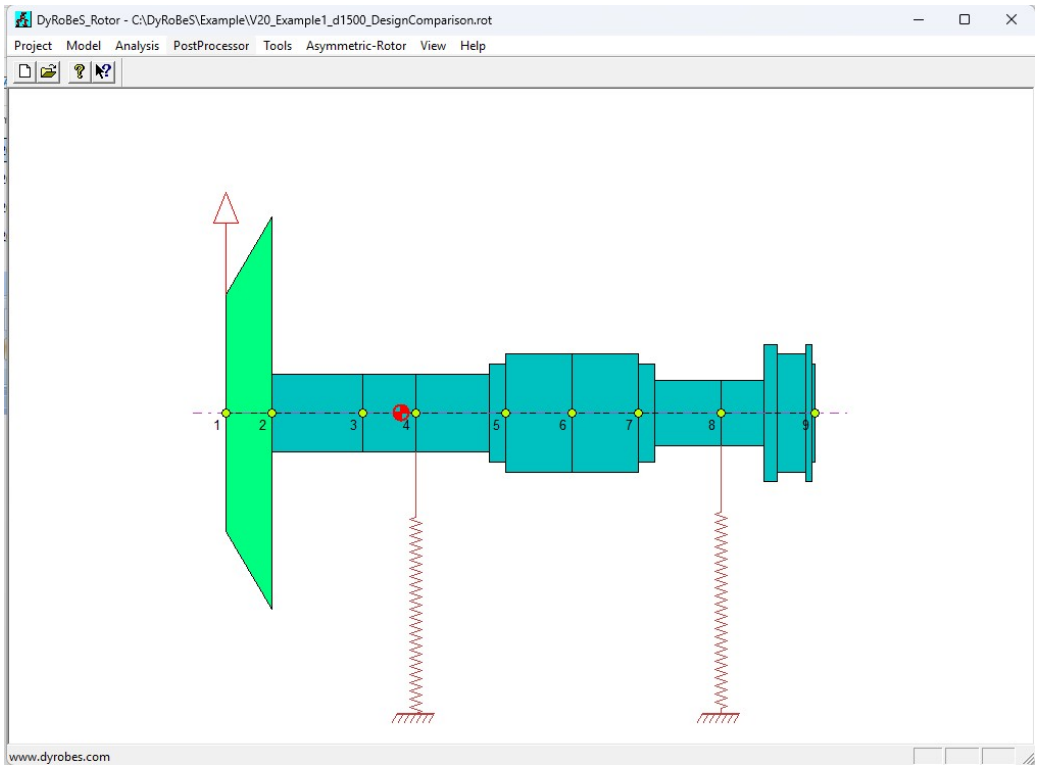


1) Example 1

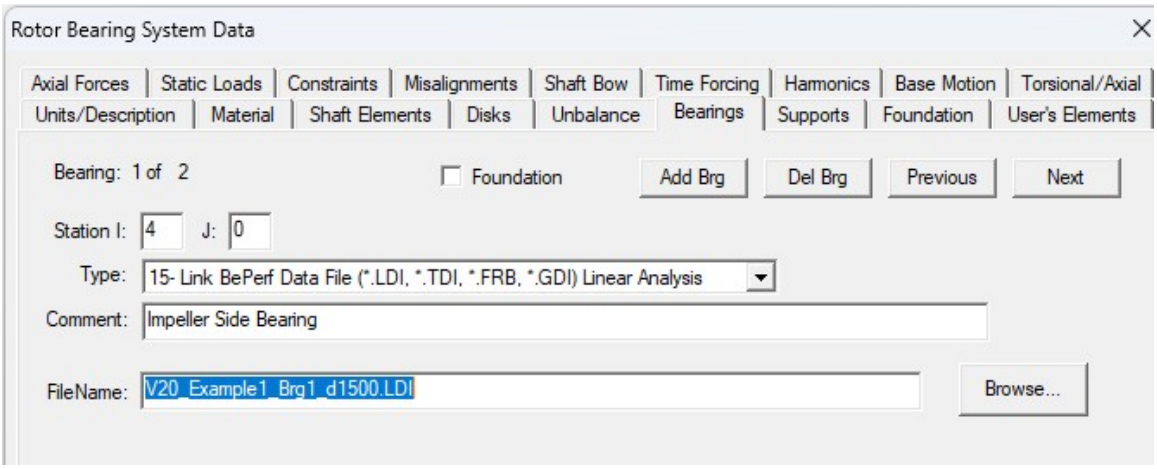
1st File: V20_Example1_d1500_DesignComparison.rot (Shaft Dia. 1.5 in)
Brg1: V20_Example1_Brg1_d1500.LDI (3 Lobe Design)
V20_Example_Brg1_d1500_TPJ.TDI (Tilting Pad Design)
Brg2: V20_Example1_Brg2.LDI

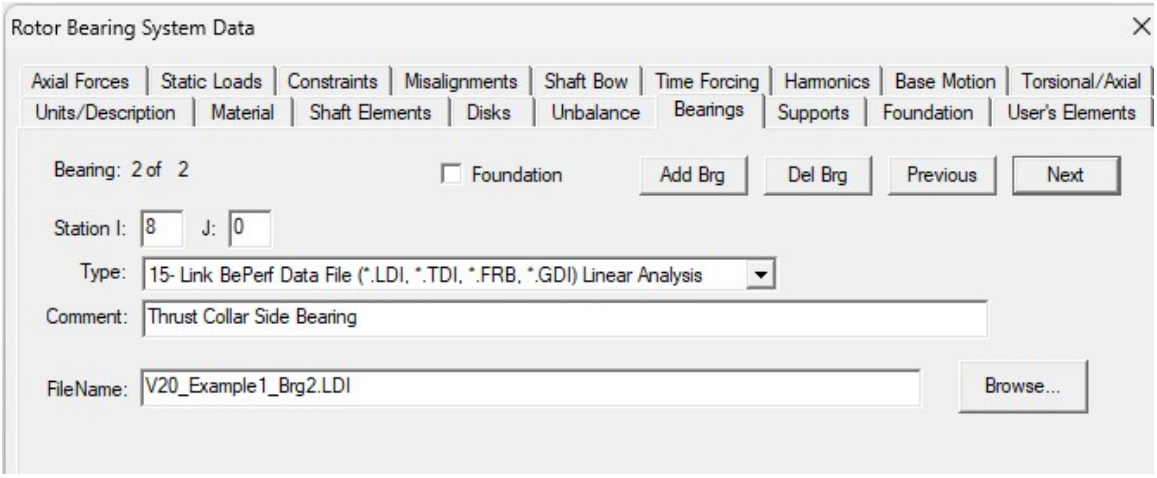
2nd File: V20_Example1_d1375_DesignComparison.rot – Shaft Dia. 1.375 in
Brg1: V20_Example1_Brg1_d1375.LDI (impeller end)
Brg2: V20_Example1_Brg2.LDI

Open the first file: **V20_Example1_d1500_DesignComparison.rot**



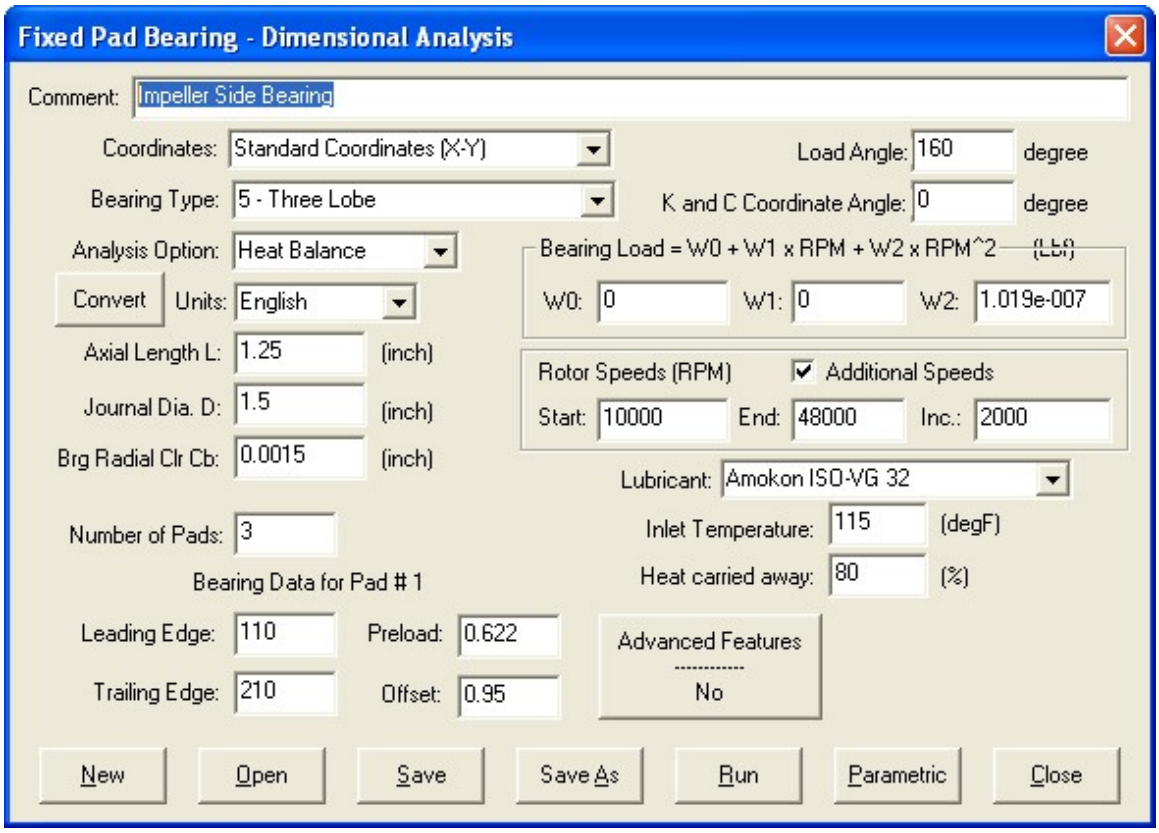
Note that in this example, the two bearings are entered as Bearing Type 15 as shown below. In Ver 20, for simplicity and file portability, if the bearing file is in the same folder as the rotor file, the pathname of the bearing file will not be shown in the filename filed, as illustrated in the following figures.

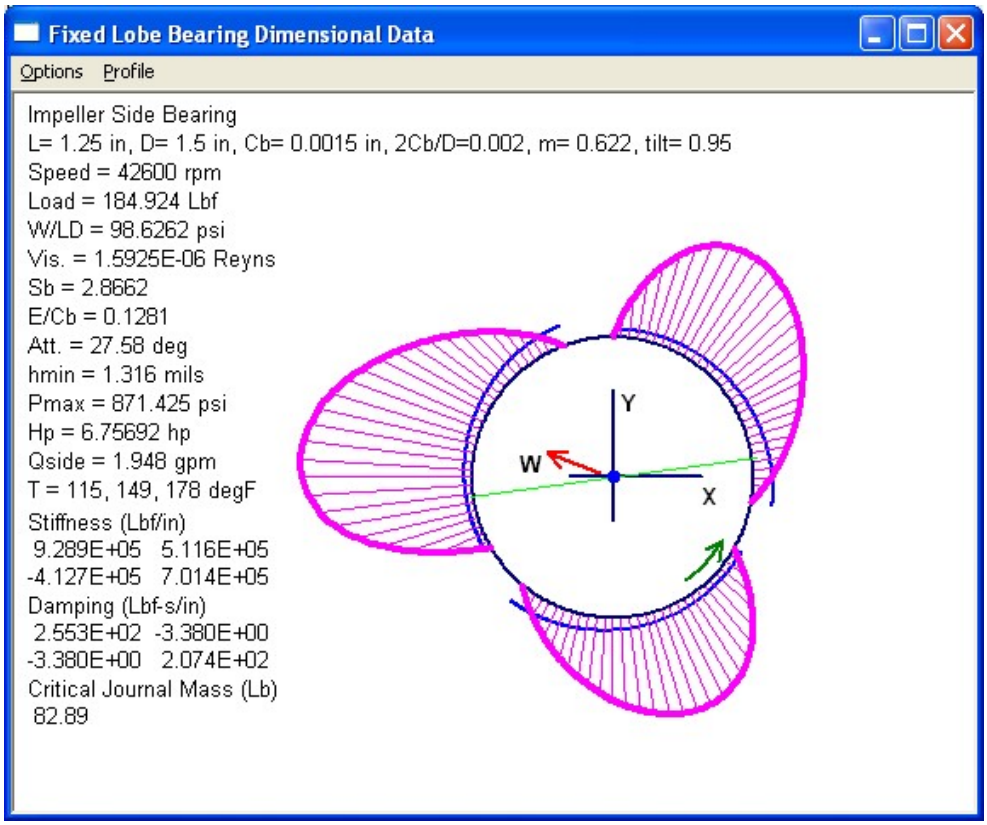


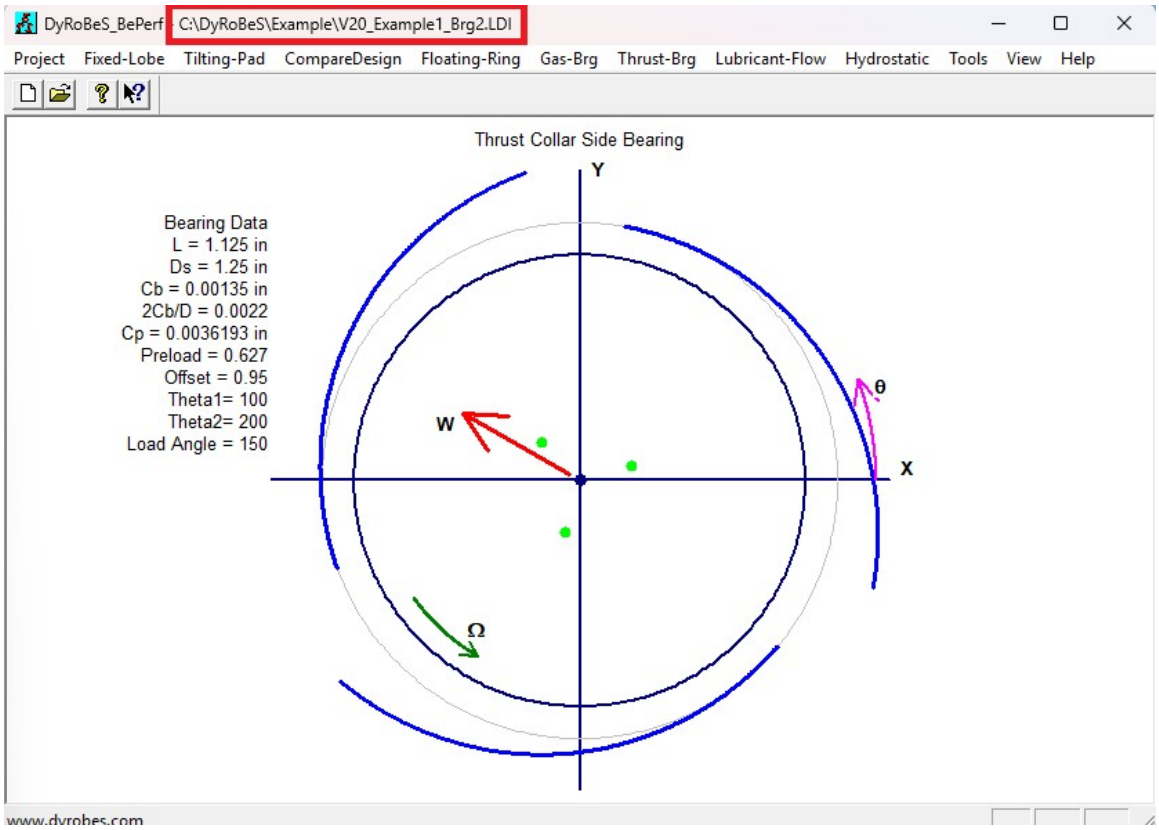


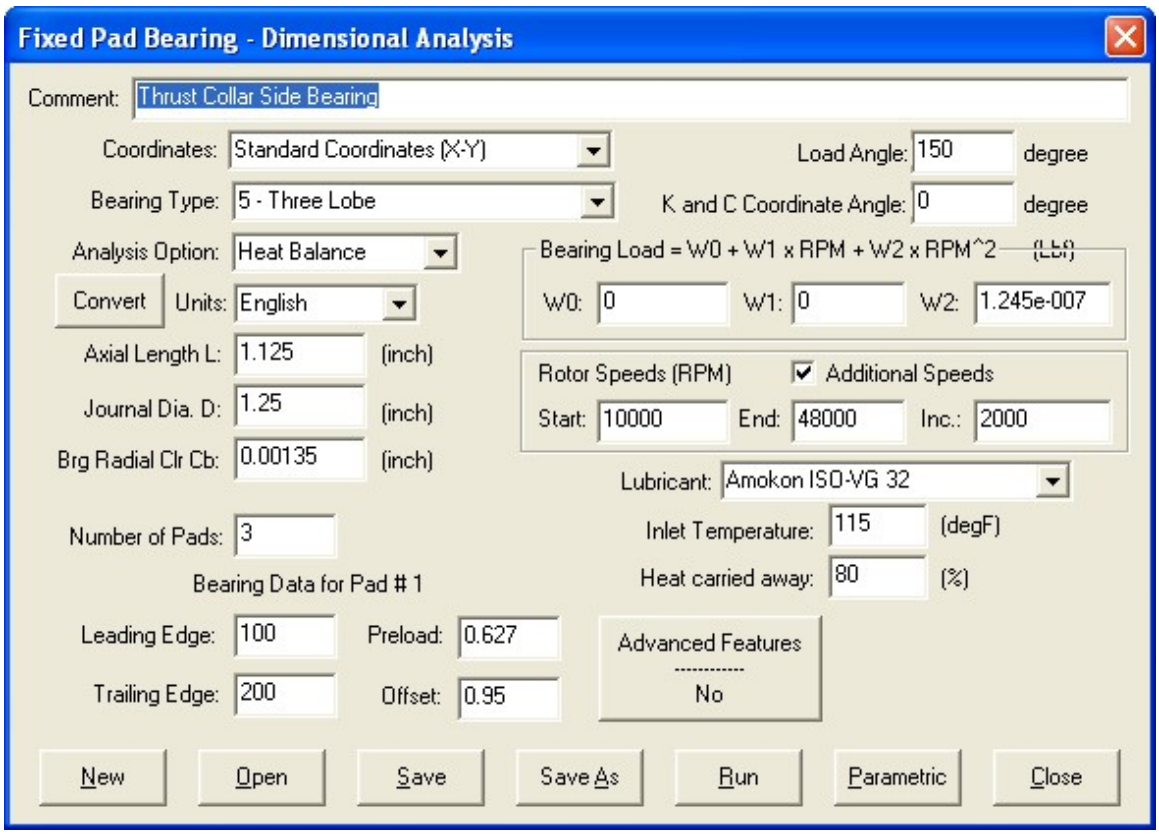
The bearing files, V20_Example1_Brg1_d1500.LDI and V20_Example1_Brg2.LDI, were created using BePerf. The bearing design involves film thickness, temperature rise, maximum film pressure, etc, not just bearing stiffness and damping for rotordynamics. The bearing performance should meet the bearing design criteria before analyzing the rotordynamics. The bearing parameters and performance at design speed from BePerf are shown below for reference:

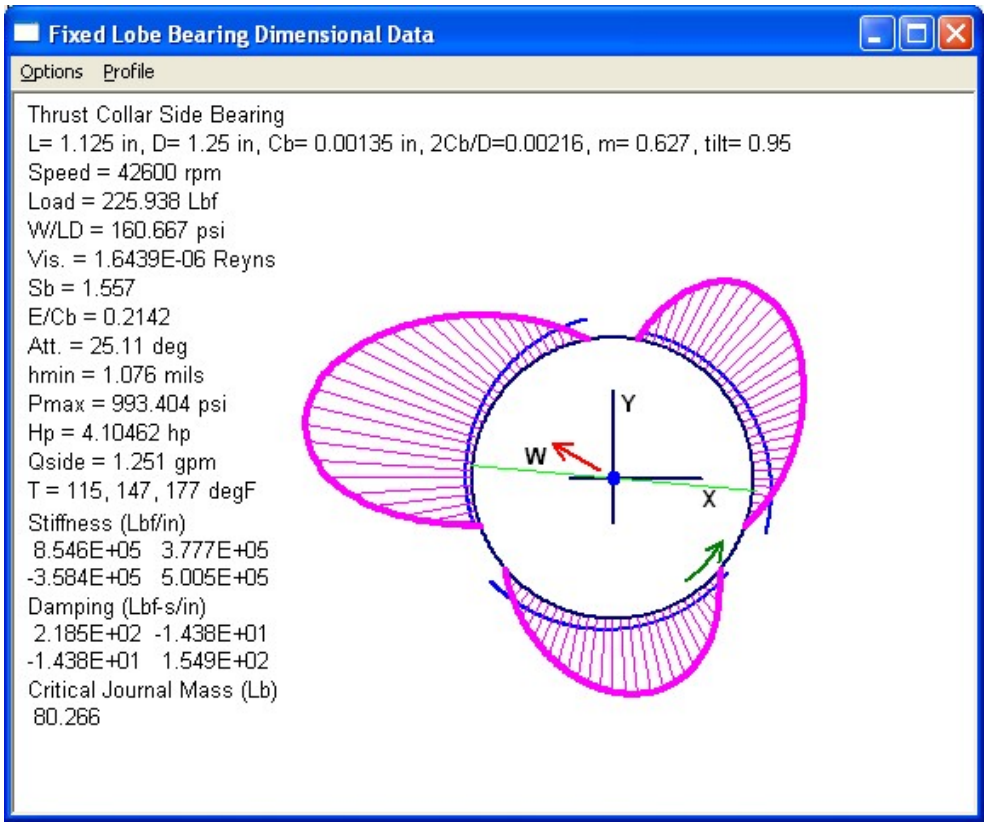
DyRoBeS_BePerf
C:\DyRoBeS\Example\V20_Example1_Brg1_d1500.LDI
Project
Fixed-Lobe
Tilting-Pad
CompareDesign
Floating-Ring
Gas-Brg
Thrust-Brg
Lubricant-Flow
Hydrostatic
Tools
View
Help
Impeller Side Bearing
Bearing Data
L = 1.25 in
Ds = 1.5 in
Cb = 0.0015 in
2Cb/D = 0.0020
Cp = 0.00396825 in
Preload = 0.622
Offset = 0.95
Theta1= 110
Theta2= 210
Load Angle = 160
Y
X
W
θ
Ω
www.dyrobes.com


Fixed Pad Bearing - Dimensional Analysis
Comment: Impeller Side Bearing
Coordinates: Standard Coordinates (X-Y)
Load Angle: 160 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)
Convert
Units: English
W0: 0
W1: 0
W2: 1.019e-007
Axial Length L: 1.25 (inch)
Journal Dia. D: 1.5 (inch)
Brg Radial Clr Cb: 0.0015 (inch)
Rotor Speeds (RPM)
Additional Speeds
Start: 10000
End: 48000
Inc.: 2000
Lubricant: Amokon ISO-VG 32
Number of Pads: 3
Inlet Temperature: 115 (degF)
Heat carried away: 80 (%)
Bearing Data for Pad # 1
Leading Edge: 110
Preload: 0.622
Trailing Edge: 210
Offset: 0.95
Advanced Features
No
New
Open
Save
Save As
Run
Parametric
Close

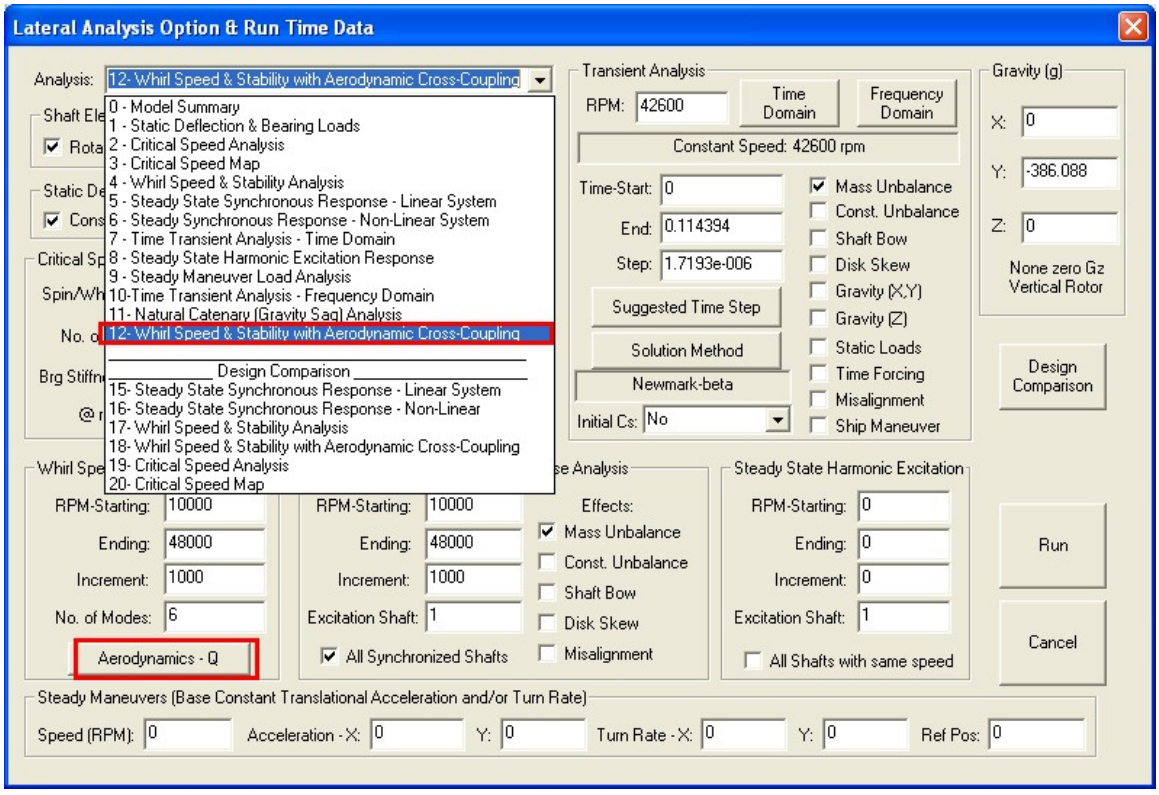

Fixed Lobe Bearing Dimensional Data
Options Profile
Impeller Side Bearing
L= 1.25 in, D= 1.5 in, Cb= 0.0015 in, 2Cb/D=0.002, m= 0.622, tilt= 0.95
Speed = 42600 rpm
Load = 184.924 Lbf
W/LD = 98.6262 psi
Vis. = 1.5925E-06 Reyns
Sb = 2.8662
E/Cb = 0.1281
Att. = 27.58 deg
hmin = 1.316 mils
Pmax = 871.425 psi
Hp = 6.75692 hp
Qside = 1.948 gpm
T = 115, 149, 178 degF
Stiffness (Lbf/in)
9.289E+05 5.116E+05
-4.127E+05 7.014E+05
Damping (Lbf-s/in)
2.553E+02 -3.380E+00
-3.380E+00 2.074E+02
Critical Journal Mass (Lb)
82.89
Y
W
X

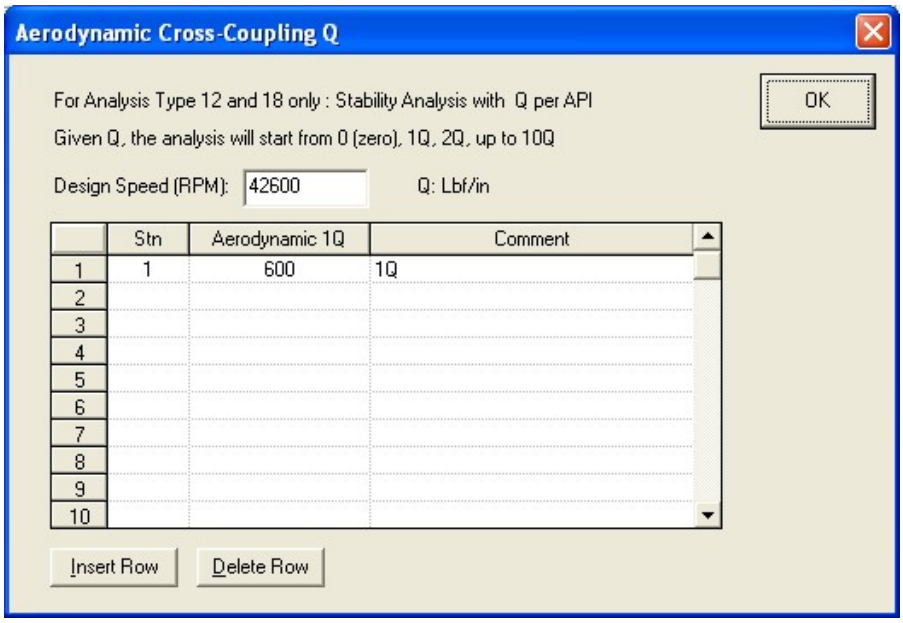

DyRoBeS_BePerf
C:\DyRoBeS\Example\V20_Example1_Brg2.LDI
Project Fixed-Lobe Tilting-Pad CompareDesign Floating-Ring Gas-Brg Thrust-Brg Lubricant-Flow Hydrostatic Tools View Help
Thrust Collar Side Bearing
Bearing Data
L = 1.125 in
Ds = 1.25 in
Cb = 0.00135 in
2Cb/D = 0.0022
Cp = 0.0036193 in
Preload = 0.627
Offset = 0.95
Theta1= 100
Theta2= 200
Load Angle = 150
Y
W
θ
X
Ω
www.dyrobes.com

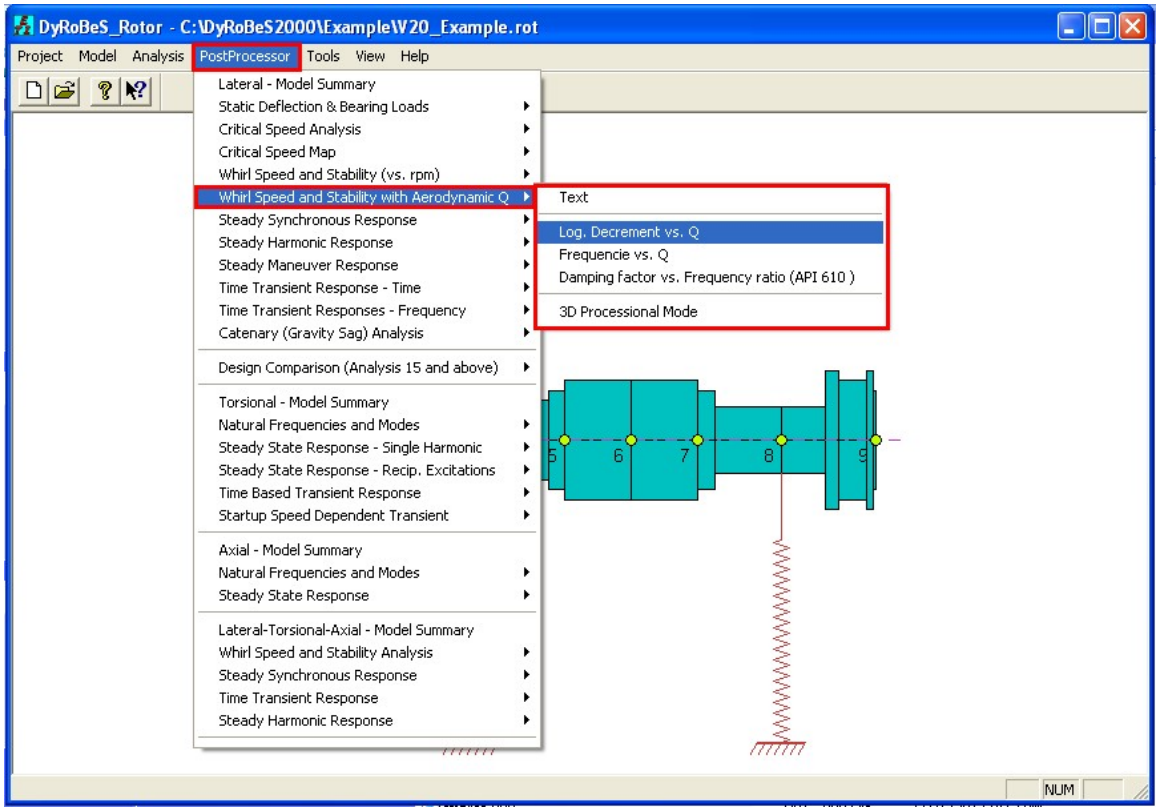

Fixed Pad Bearing - Dimensional Analysis
Comment: Thrust Collar Side Bearing
Coordinates: Standard Coordinates (X-Y)
Load Angle: 150 degree
Bearing Type: 5 - Three Lobe
K and C Coordinate Angle: 0 degree
Analysis Option: Heat Balance
Bearing Load = W0 + W1 x RPM + W2 x RPM^2 (LBf)
Convert
Units: English
W0: 0
W1: 0
W2: 1.245e-007
Axial Length L: 1.125 (inch)
Rotor Speeds (RPM)
Additional Speeds
Journal Dia. D: 1.25 (inch)
Start: 10000
End: 48000
Inc.: 2000
Brg Radial Clr Cb: 0.00135 (inch)
Lubricant: Amokon ISO-VG 32
Number of Pads: 3
Inlet Temperature: 115 (degF)
Heat carried away: 80 (%)
Bearing Data for Pad # 1
Leading Edge: 100
Preload: 0.627
Advanced Features
No
Trailing Edge: 200
Offset: 0.95
New
Open
Save
Save As
Run
Parametric
Close


Fixed Lobe Bearing Dimensional Data
Options Profile
Thrust Collar Side Bearing
L= 1.125 in, D= 1.25 in, Cb= 0.00135 in, 2Cb/D=0.00216, m= 0.627, tilt= 0.95
Speed = 42600 rpm
Load = 225.938 Lbf
W/LD = 160.667 psi
Vis. = 1.6439E-06 Reyns
Sb = 1.557
E/Cb = 0.2142
Att. = 25.11 deg
hmin = 1.076 mils
Pmax = 993.404 psi
Hp = 4.10462 hp
Qside = 1.251 gpm
T = 115, 147, 177 degF
Stiffness (Lbf/in)
8.546E+05 3.777E+05
-3.584E+05 5.005E+05
Damping (Lbf-s/in)
2.185E+02 -1.438E+01
-1.438E+01 1.549E+02
Critical Journal Mass (Lb)
80.266
Y
W
X

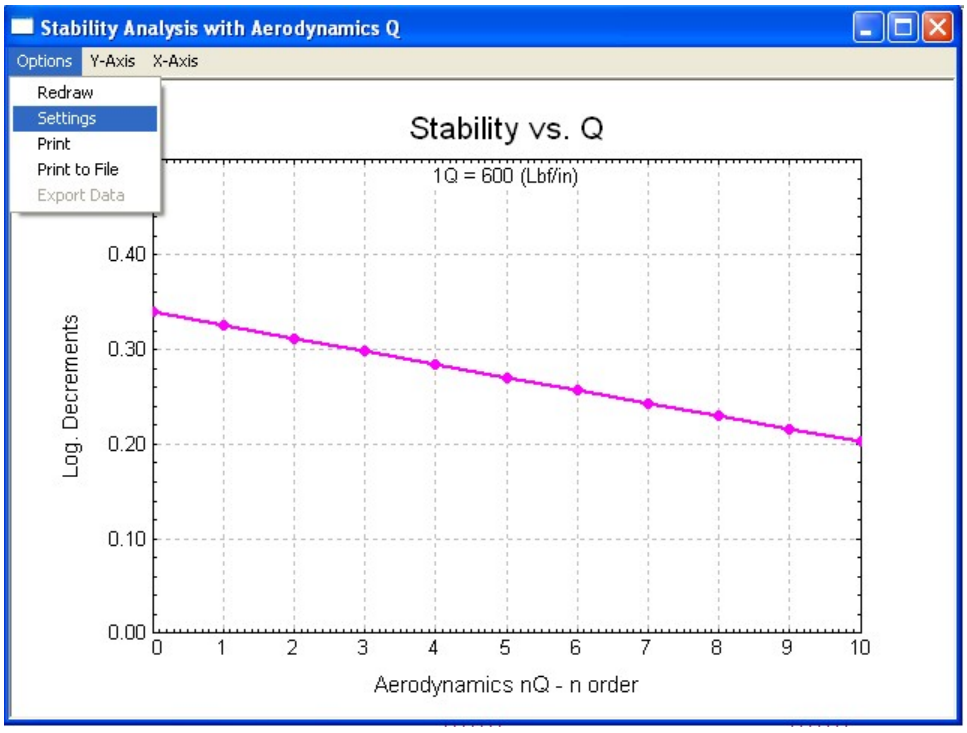
The first analysis before performing the design comparison is the Analysis 12 – Whirl Speed and Stability Analysis with Aerodynamics Cross-Coupling. This is a new feature added in Ver 20. It performs the Whirl Speed and Stability Analysis, just like Analysis 4, at a specified design speed with additional aerodynamic cross-coupling. In this example, at the design speed, the compressor impeller has a cross-coupling of 600 Lbf/in (1Q). The analysis will start from zero Q, 1Q, up to 10 Q, as required by API.



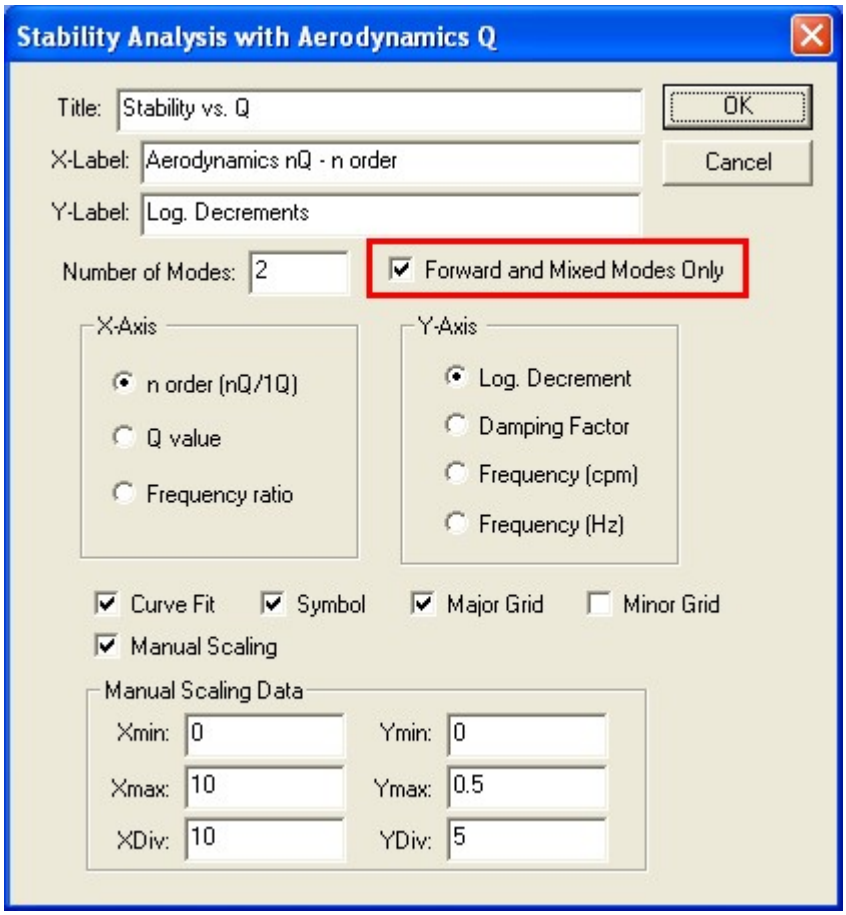




In this Analysis 12, the results (Eigenvalues) are plotted vs. Q (aerodynamics cross-coupling). If there are several stations with Q, then the results are plotted vs. total Q (summation of all the Qs from all the stations). For example:



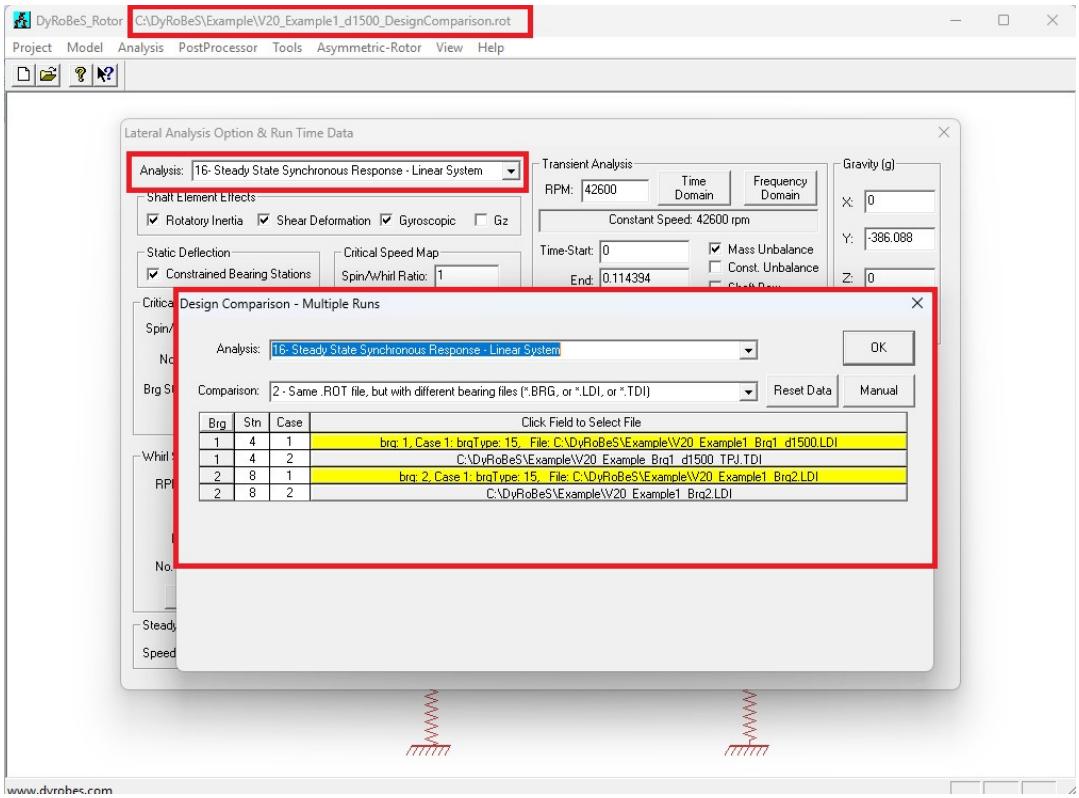
The above result shows that the stability decreases as the *Q* increases. Since the stability concerns are all in the Forward modes, in the Options-Settings, one can check the Forward and Mixed Modes only box to exclude the backward modes.



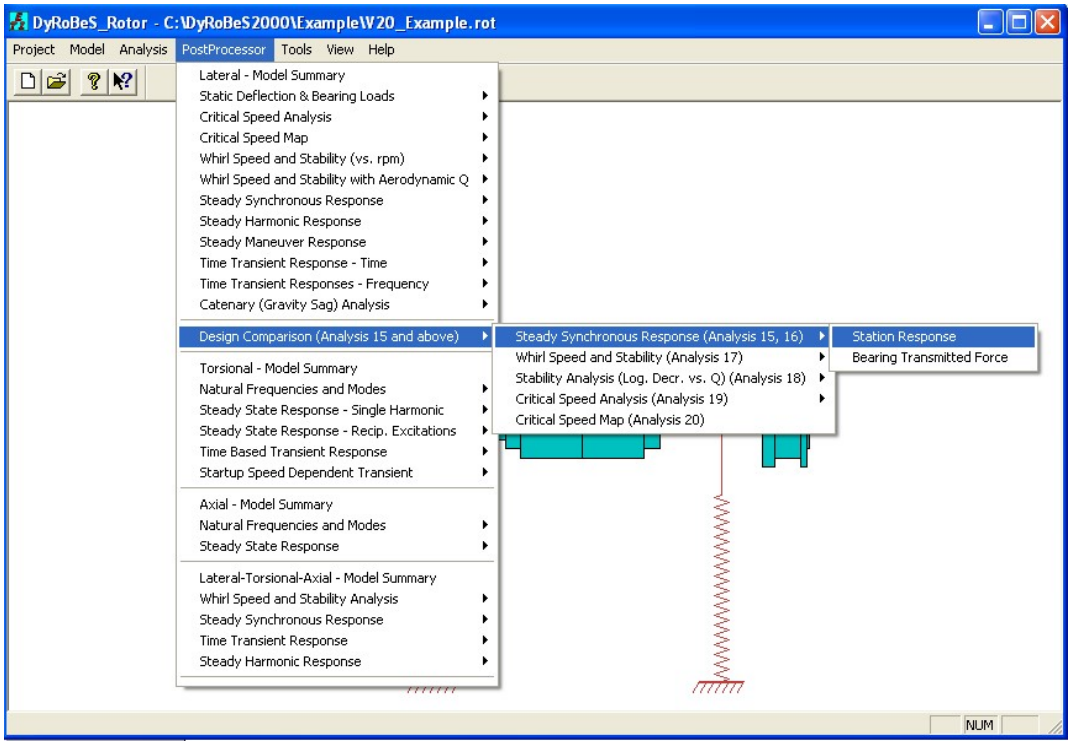
One design comparison analysis is Analysis 15 – Steady State Synchronous Response. There are three ways to compare different design:

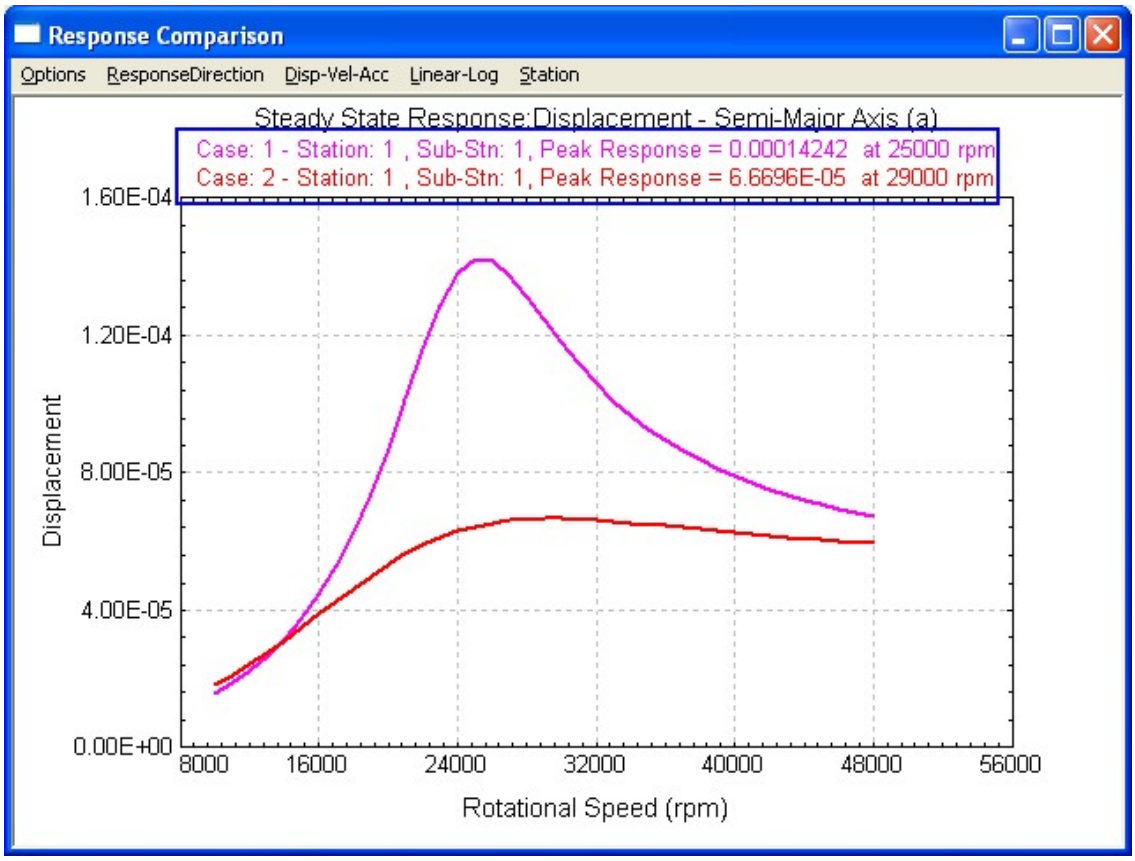
1. Compare two different (.rot) files
2. Same rot file, but different bearing files
3. Same rot and bearing files, but different bearing variables

The first option is typically used in the preliminary design to determine the shaft diameters and rotor geometry. The second option is used to determine the bearing types and different bearing designs. The third option is used to examine the bearing parameters due to manufacturing tolerance and design limits. The following input shows that the Case 1 is the original design with two 3-lobe bearings at both stations 4 and 8, however, in Case 2, the bearing #1 (3-lobe bearing) is replaced by a Tilting Pad Bearing (*.TDI). Again, this tilting pad bearing file was created using BePerf. The bearing #2 is unchanged.

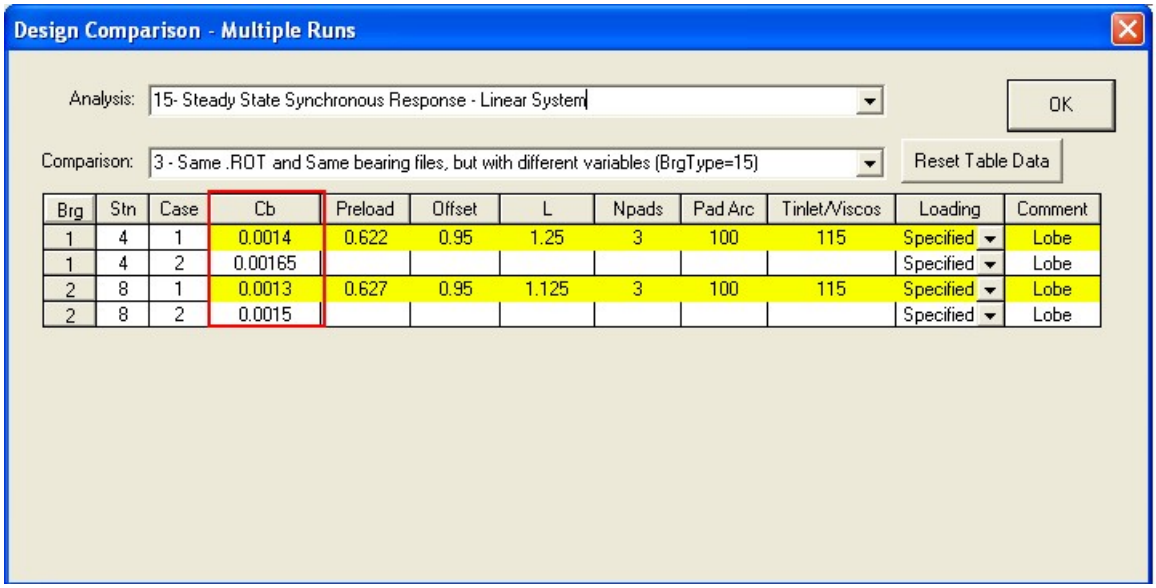


The results can be displayed as shown below. It shows that the response with tilting pad bearing (Case 2) is much smaller than the response with the 3-lobe bearing (Case 1).

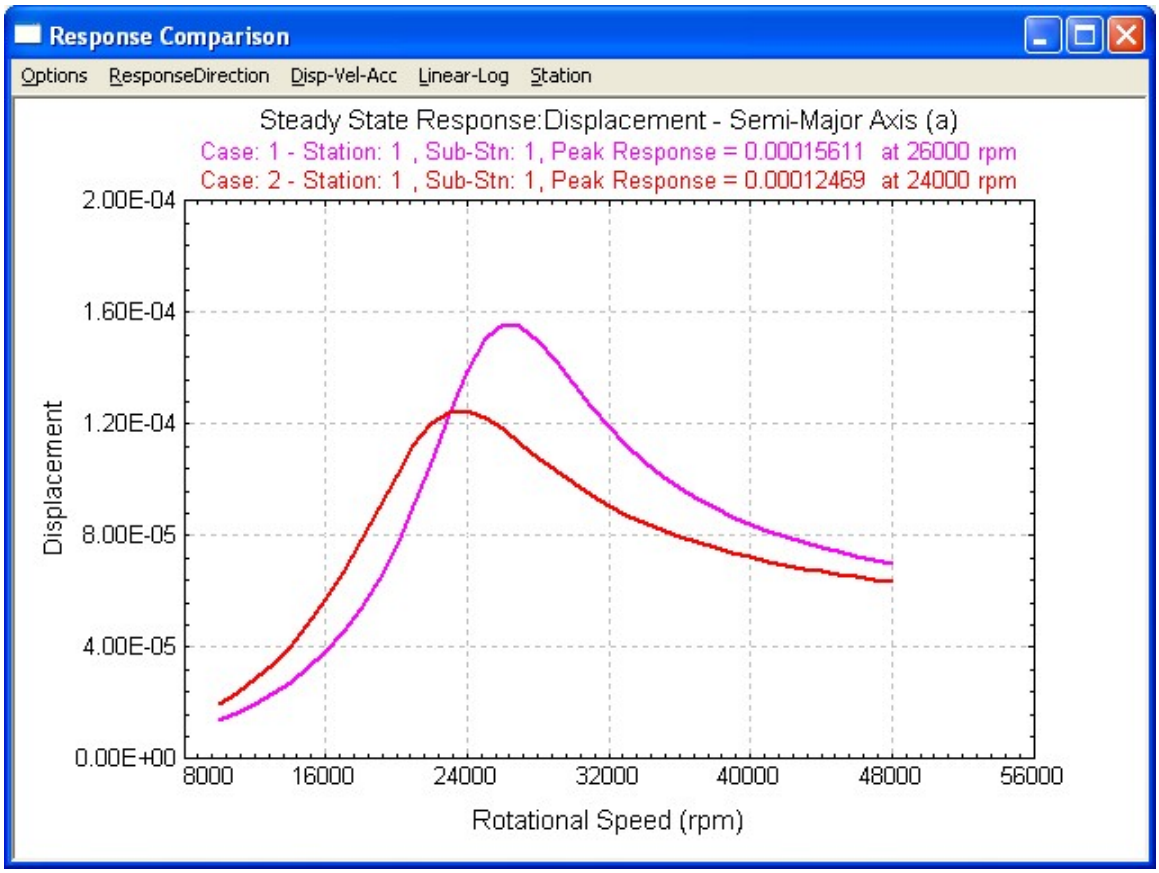




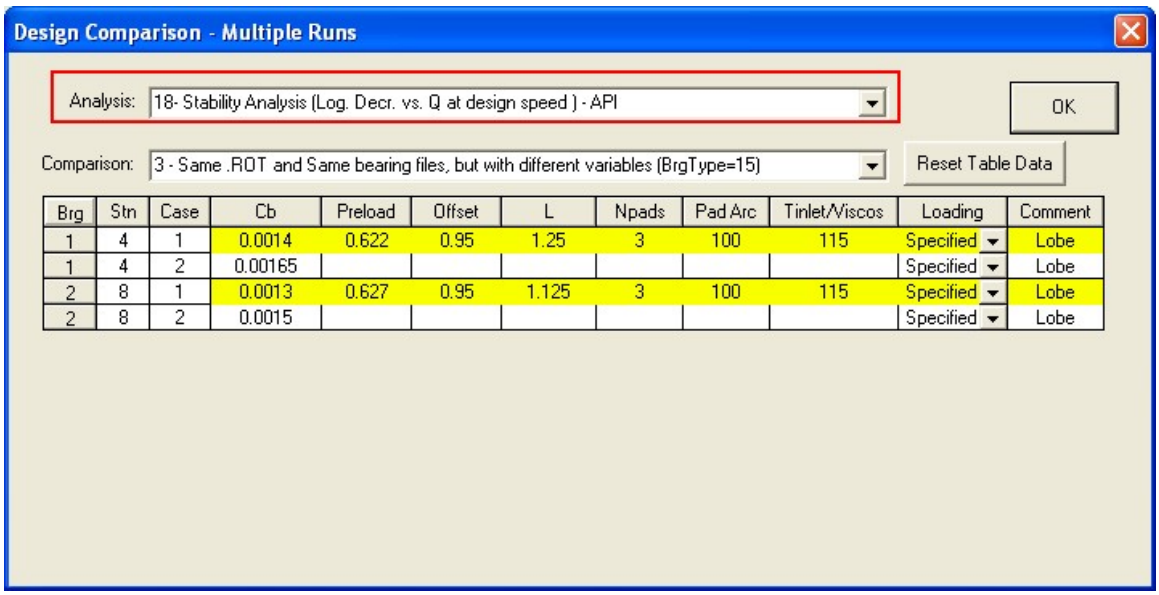
Sometimes, we would like to see the results with limits on the bearing parameters, such as min-max clearance, inlet temperature, etc. Then the option 3 is the choice, as shown below. In Case1, we use the minimum bearing clearance and Case 2 is the maximum bearing clearance. It shows the large clearance has smaller response.



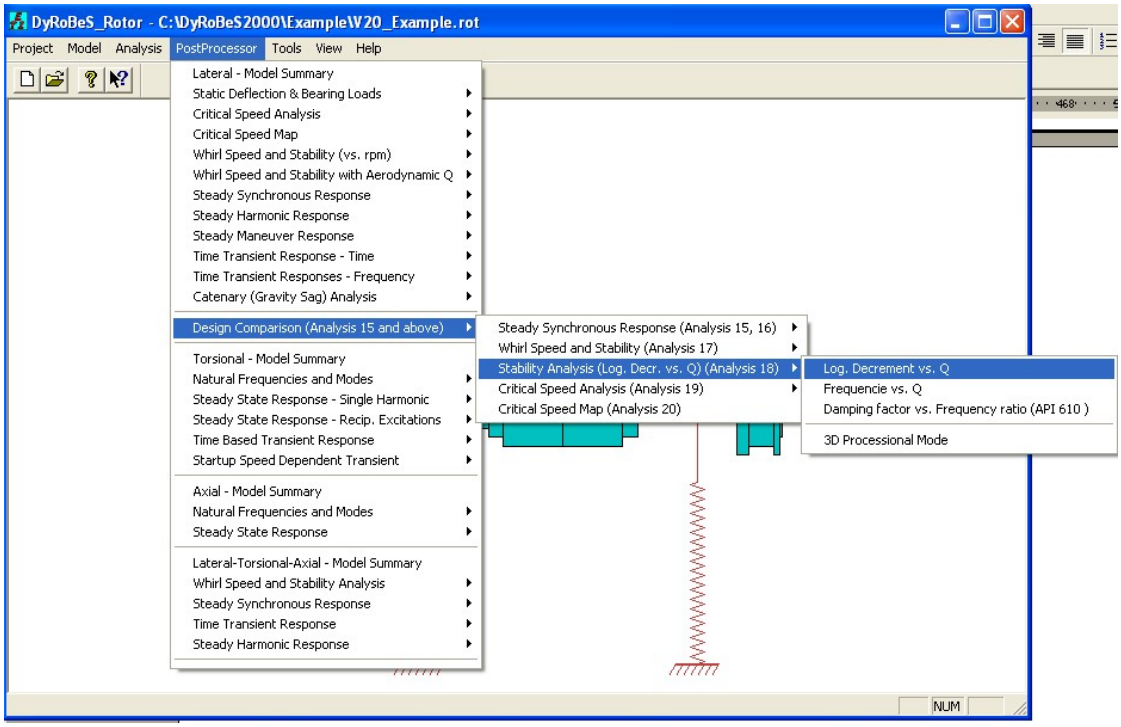
Brg	Stn	Case	Cb	Preload	Offset	L	Npads	Pad Arc	Tinlet/Viscos	Loading	Comment
1	4	1	0.0014	0.622	0.95	1.25	3	100	115	Specified	Lobe
1	4	2	0.00165							Specified	Lobe
2	8	1	0.0013	0.627	0.95	1.125	3	100	115	Specified	Lobe
2	8	2	0.0015							Specified	Lobe

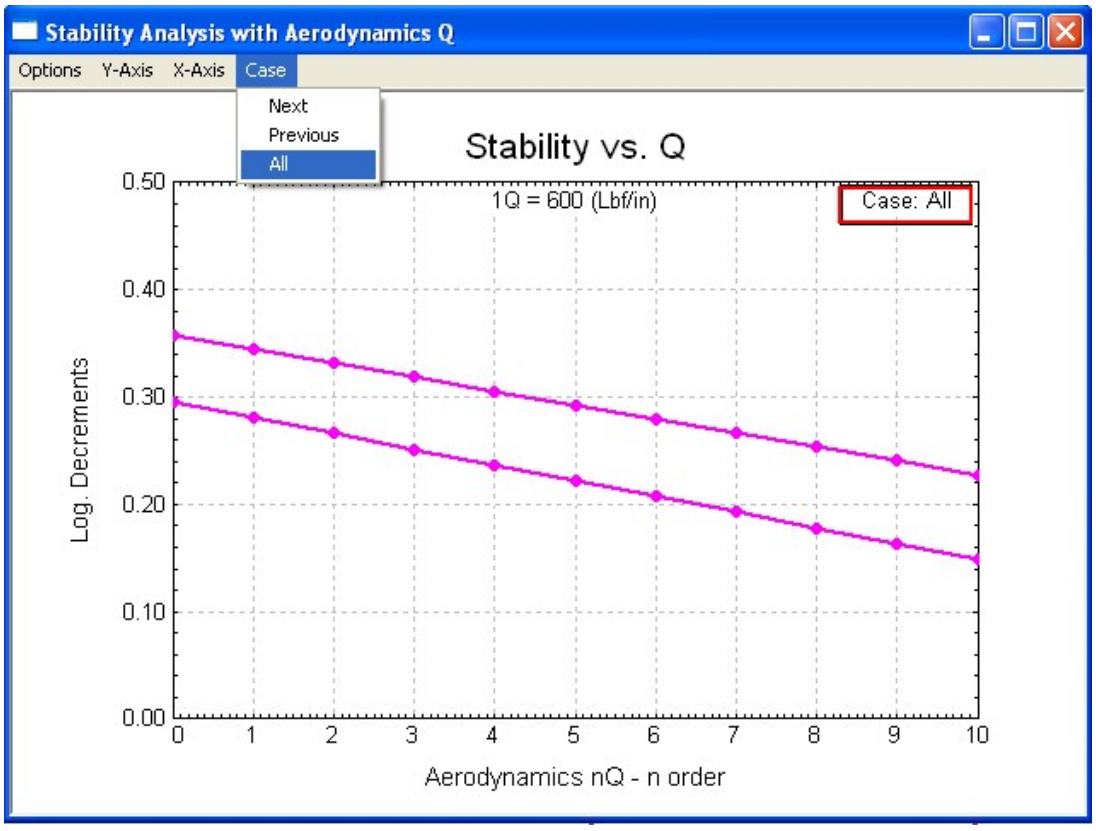


We can also compare the stability with various bearing parameters.



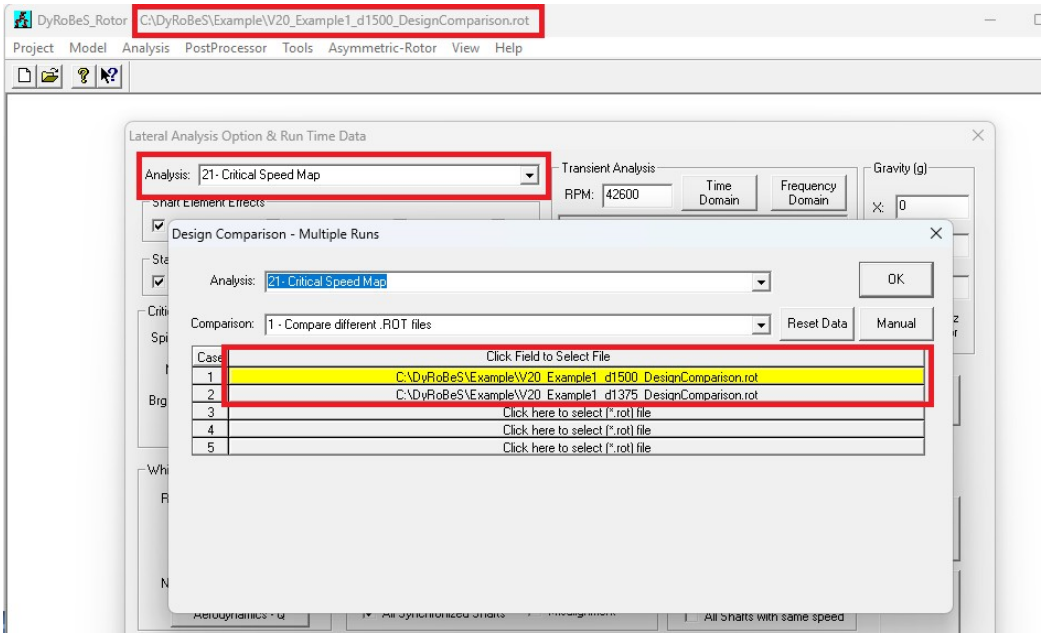
Brg	Stn	Case	Cb	Preload	Offset	L	Npads	Pad Arc	Tinlet/Viscos	Loading	Comment
1	4	1	0.0014	0.622	0.95	1.25	3	100	115	Specified	Lobe
1	4	2	0.00165							Specified	Lobe
2	8	1	0.0013	0.627	0.95	1.125	3	100	115	Specified	Lobe
2	8	2	0.0015							Specified	Lobe

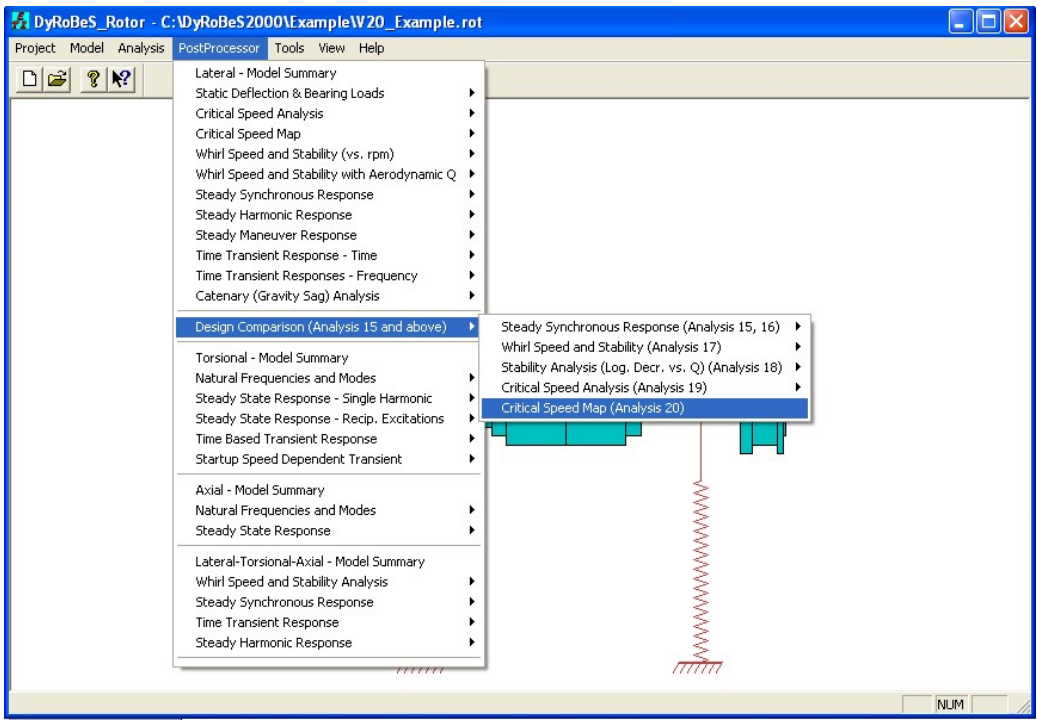


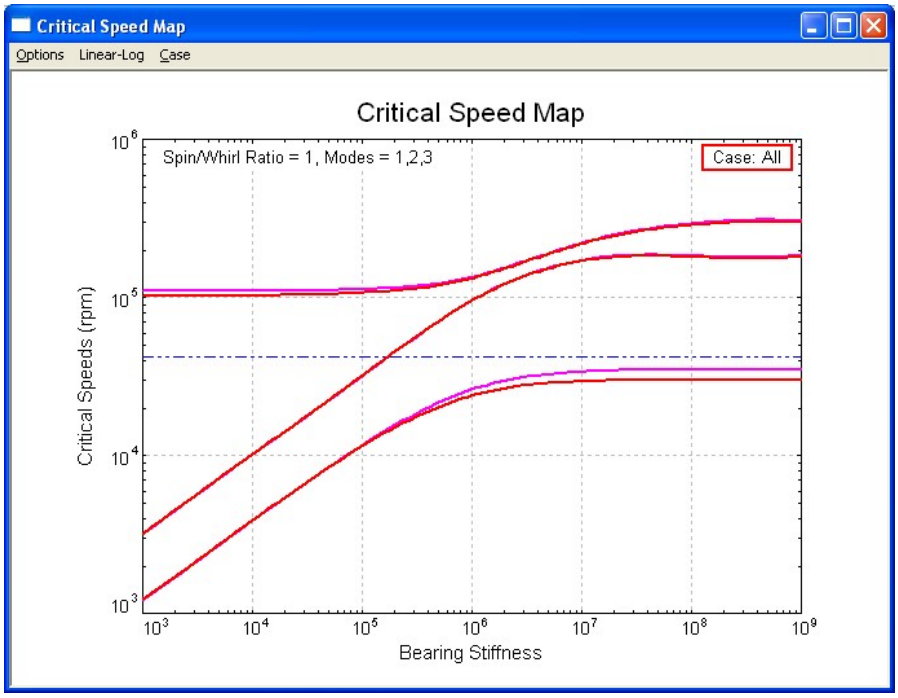


In some comparison charts, we can plot either Case by Case, or plot them in the same chart as shown above.

The comparison with different rotor files is typically used to determine the rotor configuration. For example, the following compares the two rotor files, the first one has a shaft diameter of 1.5 inches and the second one is 1.375 inches. As expected that the Case 2 with smaller shaft diameter has lower first critical speed.



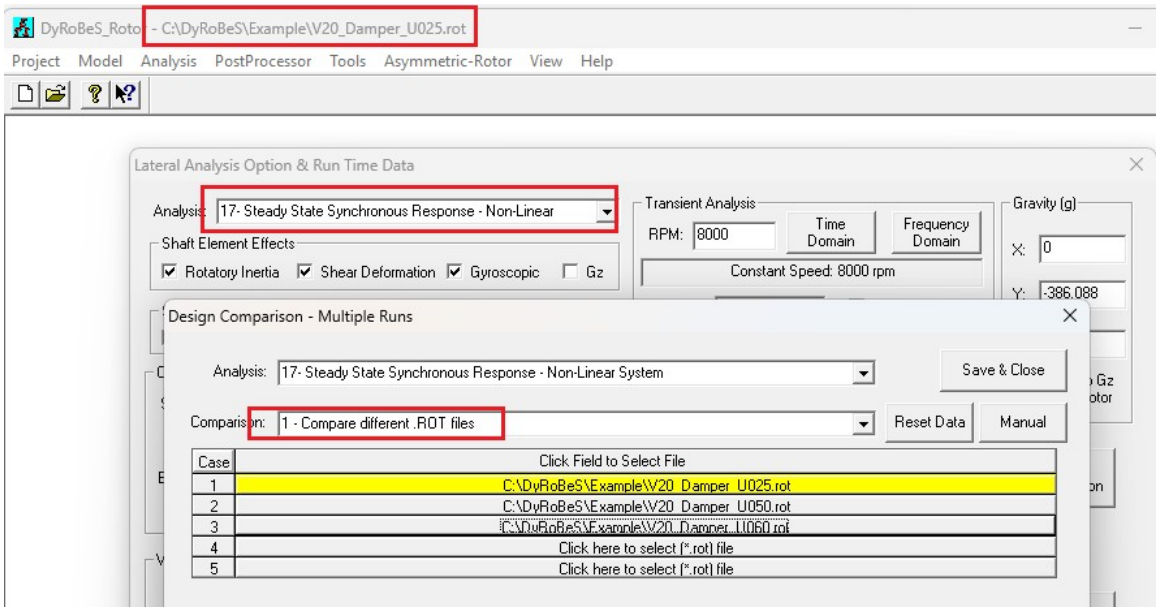


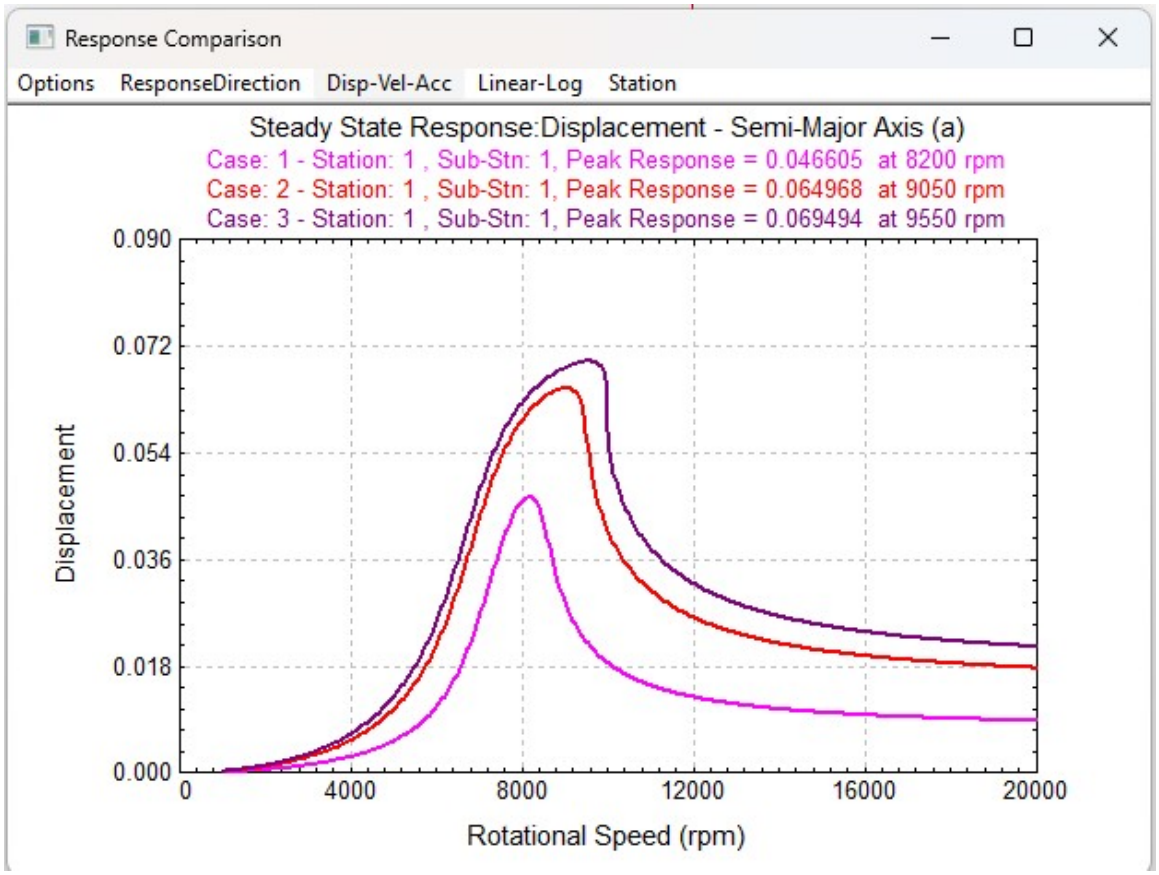


Again, there are so many new features that cannot be demonstrated in this limited write-up. Users can explore these new features easily.

2) Example 2 – Squeeze Film Damper (Nonlinear System)

This example compares three rotor files with different mass unbalance. Since the rotor file contains a nonlinear squeeze film damper, therefore only analysis type 17 can be analyzed for this example.




Response Comparison
Options
ResponseDirection
Disp-Vel-Acc
Linear-Log
Station
Steady State Response:Displacement - Semi-Major Axis (a)
Case: 1 - Station: 1 , Sub-Stn: 1, Peak Response = 0.046605 at 8200 rpm
Case: 2 - Station: 1 , Sub-Stn: 1, Peak Response = 0.064968 at 9050 rpm
Case: 3 - Station: 1 , Sub-Stn: 1, Peak Response = 0.069494 at 9550 rpm
Displacement
0.090
0.072
0.054
0.036
0.018
0.000
0
4000
8000
12000
16000
20000
Rotational Speed (rpm)