DyRoBeS©-Rotor

User's Manual

Table of Contents

Installation

DyRoBeS© runs on Windows 95, 98, 2000, XP and NT systems.

To install the program:

1. Insert CD into CD driver. The installation should start automatically. If not, run SETUP.EXE from CD, InstallShield will guide you through the installation process.

2. Plug the HASP key into your LPT1 or USB port.
   Run HDD32.EXE from DyRoBeS directory to install the device driver.
   For NT users, you need to have the administrative privilege to install the device driver. If you have problems, ask your IT department.

3. This following step is for Network users only.
   The HASP key must be on the network server or terminal with NT system.
   Run License Manager (nhsrvw32.exe) to facilitate communication between DyRoBeS program and security device.

If you have any questions regarding the installation of security device and license manager, feel free to contact Aladdin Knowledge Systems at (800) 223-4277 for technical support. You can also download the latest version of device driver HDD32.EXE from www.hasp.com.

A number of examples installed under **DyRoBeS\Example** directory are included in the software package to demonstrate the program's features and capabilities. Users are encouraged to go through the examples and verify the results.

The complete User's Manuals are stored in the Help Books, DyRoBeS Rotor Help and DyRoBeS BePerf Help. You can also press <F1> at any time while you are in the DyRoBeS program to get help.

Getting Started

DyRoBeS is a *Windows-Based* program. Its operation is entirely consistent with the industrial standard operation in the *Windows* environment. There are many ways to invoke a *Windows-Based* program. Four commonly used methods to start *DyRoBeS-Rotor* are described below:

1. Click *DyRoBeS-Rotor* from the Start Menu - Program - *DyRoBeS* folder, as shown in Figure 1.1.

2. Double click the *Rotor.exe* file from *Windows Explorer*, as shown in Figure 1.2.

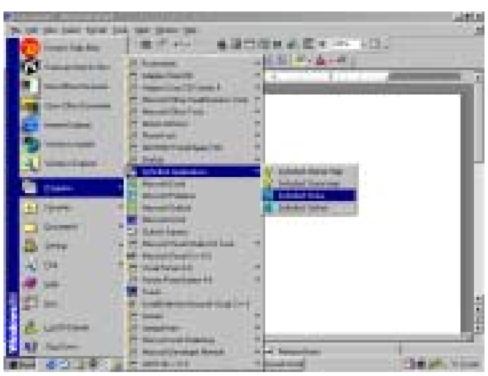
3. Double click the *DyRoBeS-Rotor* icon if you have created the short-cuts, as shown in Figure 1.3.

4. Double click the data file (*.ROT) created by *DyRoBeS-Rotor*. This will open the file with *DyRoBeS-Rotor*, as shown in Figure 1.4. This method is useful if you want to open an existing data file.

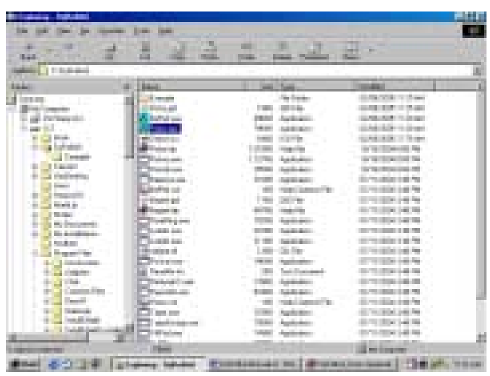
When you start *DyRoBeS-Rotor* by using methods 1, 2, and 3, the mainframe window, as shown in Figure 1.5, appears on the screen. The default file name “Untitled” is shown in the filename header and the document window is empty. Now, you are ready to open an existing file or create a new file.

When you start *DyRoBeS-Rotor* by double clicking the data file (method 4), the document window shows the rotor model and the filename is shown in the filename header, as shown in Figure 1.6. Now, you can make changes, perform analysis, or review the results.

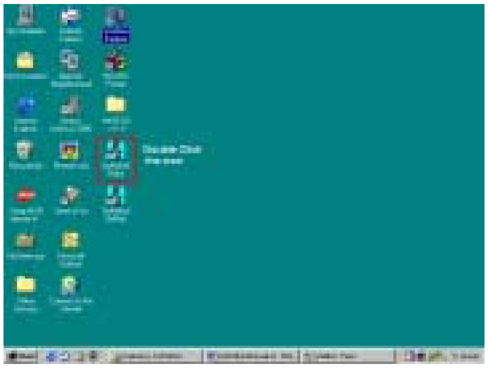
You can resize the mainframe window as you wish. To resize the window, simply drag the window boundaries or click on the resize button.

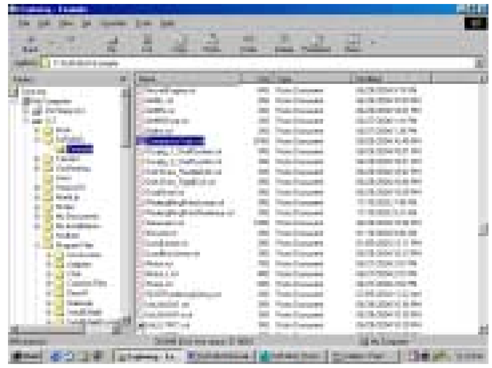


Start *DyRoBeS-Rotor* from Start Menu



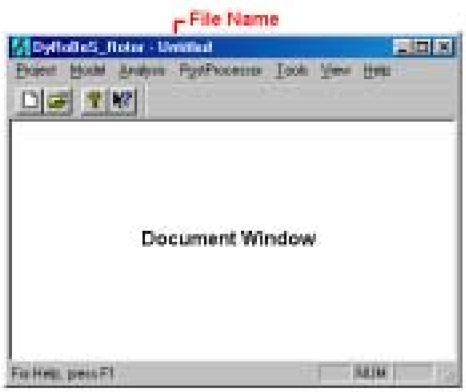
Start *DyRoBeS-Rotor* from *Explorer*

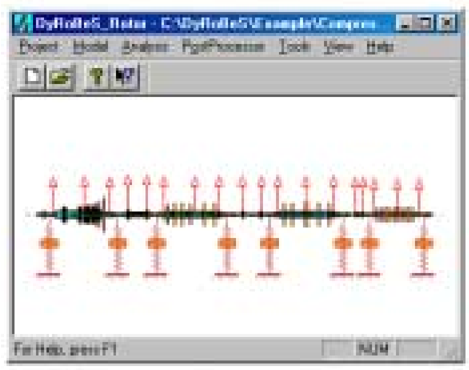




Start *DyRoBeS-Rotor* from Shortcut

Start *DyRoBeS-Rotor* from (*.rot) file





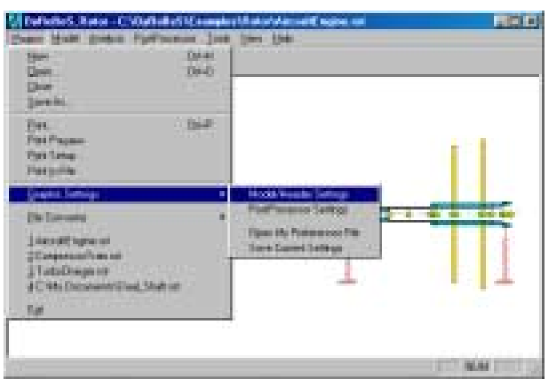
Project

A Project is also called a "File" or a "Document" which contains the rotor bearing system data and run time parameters. All the options under the Project, as shown in the following figure, are self-explanatory. You can start with a **New** file, **Open** an existing file, **Close** the current file, **Save** the file **As** a separate filename. Four most recently opened files are listed in the recent-file-list for quick selection. The filename and pathname follow the standard convention for the Windows environment (white space is allowed). The data file has the extension. ".rot".

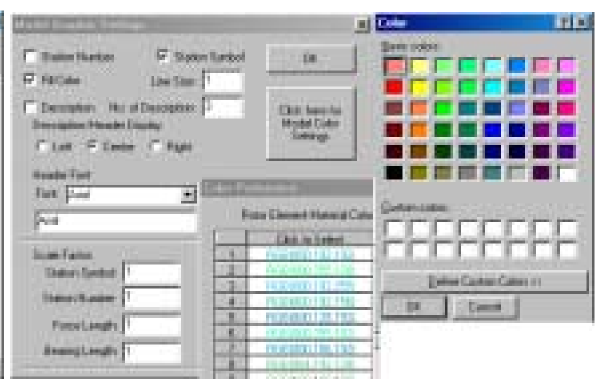
Once an existing file is opened/selected or a new file is created, the associated rotor bearing system model will be graphically displayed in the document window. You can **Print** the document window to the printer or to a bmp file.

Graphic Settings allows you to set the default settings for many graphic features. You can save these settings into a preference file, such as one for screen and one for printer. To change color for a specific setting, simply click the RGB color value to open the Color Dialog Box for selection, as illustrated in the following figure.

The **File Converter** option allows you to convert the old DOS *DyRoBeS* files into the new *Windows* version format. The data file for the DOS version does not have file extension, but the new *Windows* version data files have the file extension ".rot". This file extension will be added automatically for you. If you have other data format, contact DyRoBeS developer to add a converter for you.



Options under Project Menu



Graphic Settings

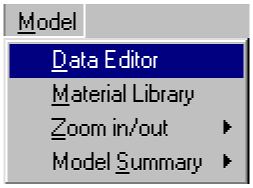
Description of File Name Extension

After the analysis is performed, additional files will be created for the post processing. The description of the file extension is listed below for reference.

Analysis Name	ASCII TEXT	Binary
Input File	ROT	
Lateral Analysis		
Model Summary	OU0	None
Static Deflection & Bearing Loads	OU1	ST
Critical Speed Analysis	OU2	CS, CSE
Critical Speed Map	OU3	CSM
Whirl Speed/Stability Analysis	OU4	WS, WSM
Steady Synchronous Response Linear Systems	OU5	UR, URF
Steady Synchronous Response Non-Linear Systems	OU6	UR, URF
Time Transient Analysis	OU7	TR, TRF
Torsional Analysis		
Model Summary	OT0	None
Natural Frequency Analysis	OT1	OTA
Steady Forced Response	OT2	OTB
Short Circuit Transient	OT3	OTC
Startup Transient	OT4	OTD
Axial Analysis		
Model Summary	OA0	
Natural Frequency Analysis	OA1	OAA
Steady Forced Response	OA2	OAB

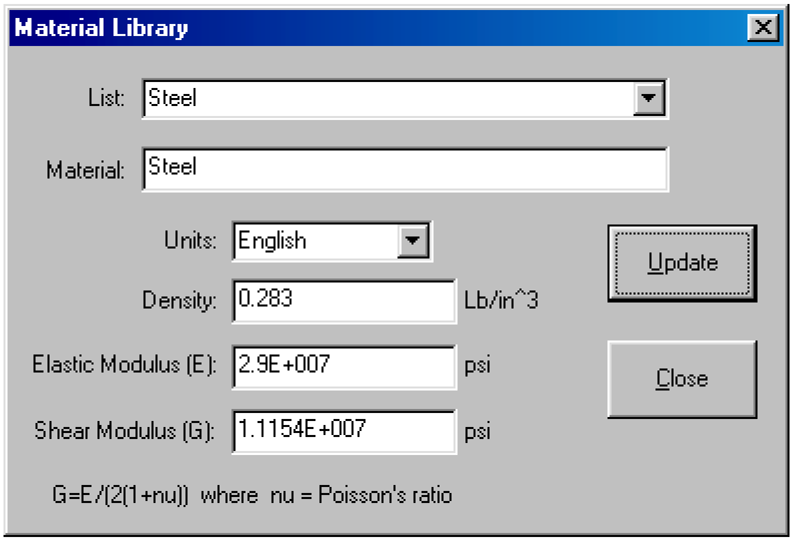
Model

Under the Model menu, you can build a new rotor bearing system model or modify/edit your existing model by clicking the **Data Editor**. The usage of the Data Editor will be explained in Modeling/Data Editor session. You can also create and modify your **Material Library**. **Zoom in/out** allows you to visualize the model in detail. The **Model Summary** summarizes the system parameters and tabulates the related input data in a very organized ASCII format (text) that allows you to verify your model.



Material Library

Use this option to add and modify your materials. Use the *List* to select a material, then enter the material data. Click *Update* to save the material data into the material library.

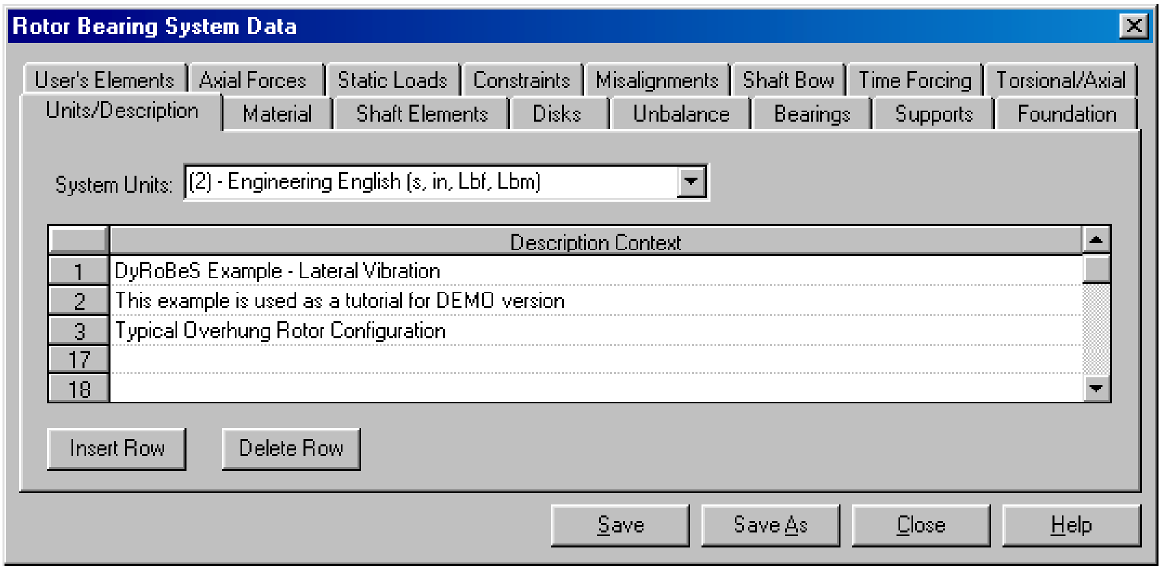


Model Summary

The Model Summary summarizes the system parameters and tabulates the related input data in a very organized ASCII format (text) that allows you to verify your model. This file may be used in a report and reformatted for formal reports. The model summary is useful for details of the rotor weight, inertia, length, and center of gravity location. It is also important to review if the analysis does not run correctly.

Modeling/Data Editor

A number of folders, as shown below, with different tabs are provided in the **Data Editor** and you can enter your data accordingly. The description for each folder will be explained in the following sessions.

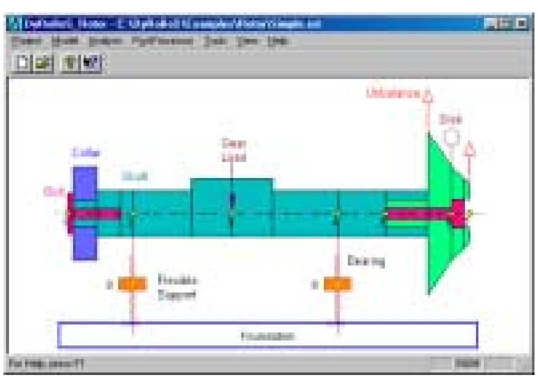


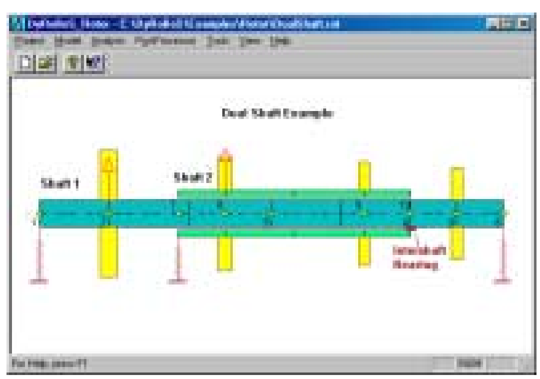
Since the same data file can be used in the lateral, torsional, and/or axial vibrations, data in the irrelevant folder will not be used in a particular analysis. The usage of the data folder is listed below for reference.

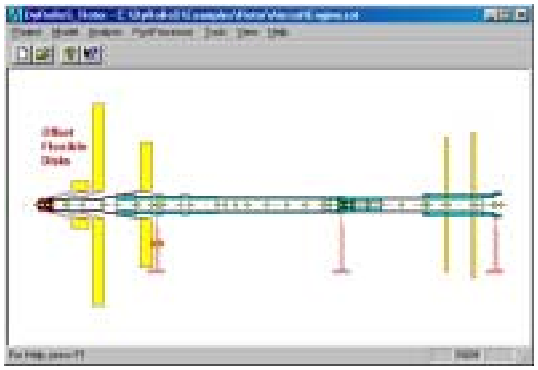
Since saving data is just a click on the **Save** or/and **Save As** buttons, it is a good practice to save your data from time to time to prevent any data loss.

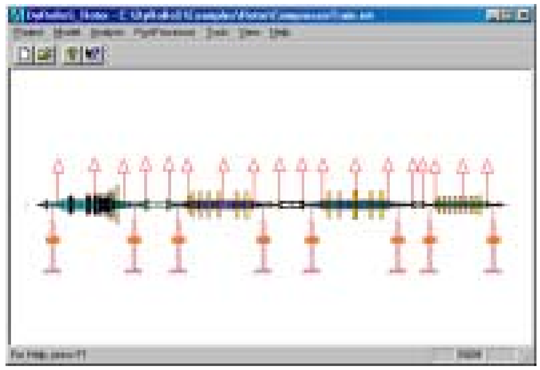
Typical Rotor Configurations

Followings are some typical rotor configurations:









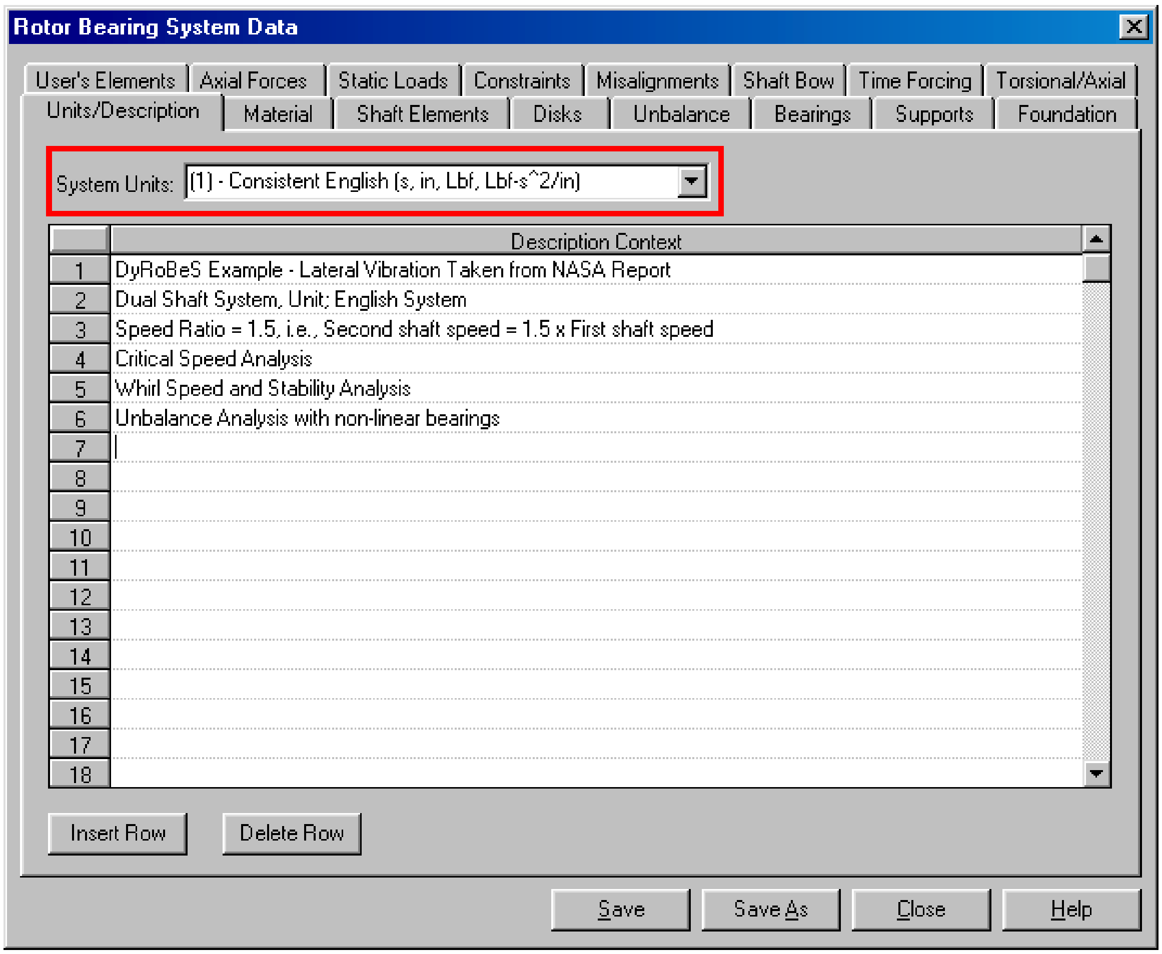
Data Utilization for Lateral, Torsional, and Axial Analysis

Folder	Lateral	Torsional	Axial
Units/Description	Yes	Yes	Yes
Material	Yes	Yes	Yes
Shaft Elements	Yes	Yes	Yes
Disks	Yes	Yes	Yes
Unbalance	Yes	No	No
Bearings	Yes	No	No
Supports	Yes	No	No
Foundation	Yes	No	No
User's Elements	Yes	No	No
Axial Forces	Yes	No	No
Static Loads	Yes	No	No
Constraints	Yes	No	No
Misalignments	Yes	No	No
Shaft Bow	Yes	No	No
Time Forcing Functions	Yes	No	No
Torsional/Axial Data			
Connectivity	No	Yes	Yes
Modal Damping	No	Yes	Yes
Steady State Excitation	No	Yes	Yes
Short Circuit Torque	No	Yes	No
Driving Torque	No	Yes	No
Load Torque	No	Yes	No

It should be noted that the same model will be used in lateral, torsional, and axial analyses, even though some of the inputs are not required for certain analyses and these entries will be ignored.

Description

The descriptions are used to describe the system to be modeled or the analysis to be performed. The purpose of using the description headers is to provide explanation for you or another person who might need to see or modify this data file. It is highly recommended, as a good engineering practice, to have adequate descriptions to document the model. These descriptions can also be displayed on the graphical output. Number of description lines shown in the model display is specified in the Graphics Settings under Model menu. The unit system is also selected in this tab.



Unit Systems

The data input is not restricted to a specific system of units. In addition to the consistent units of user's choice, four sets of system of units have been introduced in this version:

Unit = 0 => Consistent Units of User's Choice
Unit = 1 => Consistent English Units (sec, in, Lbf, Lbf-s^2/in)
Unit = 2 => Engineering English Units (sec, in, Lbf, Lbm)
Unit = 3 => Consistent SI Units (sec, m, N, kg)
Unit = 4 => Engineering Metric Units (sec, mm, N, kg)

For Unit=0, consistent units, it is essential that all of the input parameters be expresses in a consistent set of units of the user's choice. For Unit=1 and 3, these are two sets of consistent units, however, their units will be displayed on the input screen and in the output text files. For Unit=2 and 4, these are two sets of units that are commonly used in the engineering field. Since they are not consistent units, their input units are explicitly specified on the input screen. Users must pay attention to their units.

Units Systems	Consistent English Unit = 1	Engineering English Unit = 2	Consistent SI Unit = 3	Engineering Metric Unit = 4
Basic Quantities				
Time	Second (s)	Second (s)	Second (s)	Second (s)
Length	in	in	m	mm
Force	Lbf	Lbf	Newton (N)	Newton (N)
Mass	Lbf-s^2/in	Lbm	kg = N-s^2/m	kg
Inputs				
Material Properties				
Density	Lbf-s^2/in^4	Lbm/in^3	kg/m^3	kg/m^3
Modulus	Lbf/in^2 (psi)	Lbf/in^2 (psi)	N/m^2 (Pa)	N/mm^2 (MPa)
Shaft Elements				
Length, Diameter	in	in	m	mm
Disks				
Mass	Lbf-s^2/in	Lbm	kg	kg
Inertia	Lbf-s^2-in	Lbm-in^2	kg-m^2	kg-m^2
Skew Angle	degree	degree	degree	degree
Unbalance				
Imbalance (*me*)	Lbf-s^2	oz-in	kg-m	kg-mm
Angle	degree	degree	degree	degree
Flexible Supports				
Mass	Lbf-s^2/in	Lbm	kg	kg
Damping	Lbf-s/in	Lbf-s/in	N-s/m	N-s/mm
Stiffness	Lbf/in	Lbf/in	N/m	N/mm
Forces/Moments				
Forces	Lbf	Lbf	N	N

Moments/Torque	Lbf-in	Lbf-in	N-m	N-mm
Misalignment/Bow				
Deflection: x, y	in	in	m	mm
Theta: x, y	degree	degree	degree	degree
Time Forcing				
Force or Moment	Lbf Lbf-in	Lbf Lbf-in	N N-m	N N-mm
Time Constant	1/s	1/s	1/s	1/s
Excitation Freq.	rpm	rpm	rpm	rpm
ϕ - Phase	degree	degree	degree	degree
Bearings				
Stiffness – Kt	Lbf/in	Lbf/in	N/m	N/mm
Damping – Ct	Lbf-s/in	Lbf-s/in	N-s/m	N-s/mm
Stiffness – Kr	Lbf-in/rad	Lbf-in/rad	N-m/rad	N-mm/rad
Damping – Cr	Lbf-in-s/rad	Lbf-in-s/rad	N-m-s/rad	N-mm-s/rad
Length	in	in	m	mm
Lubricant Viscosity	Reyn (Lbf-s/in^2)	Reyn (Lbf-s/in^2)	Pal-second (N-s/m^2)	CentiPoise =1.0E03 * Pa-s
Lubricant Density	Lbf-s^2/in^4	Lbm/in^3	kg/m^3	kg/m^3
Pressure Drop Across seal	psi	psi	Pa	Bar =1.0E-05 * Pa
Linear PID + Low Pass Filter Active Magnetic Bearings				
Proportional Gain	Lbf/in	Lbf/in	N/m	N/mm
Integral Gain	Lbf/(in-s)	Lbf/(in-s)	N/(m-s)	N/(mm-s)
Derivative Gain	Lbf-s/in	Lbf-s/in	N-s/m	N-s/mm
Cut-Off Freq.	Hz	Hz	Hz	Hz
NonLinear Active Magnetic Bearings				
Proportional Gain	A/in	A/in	A/m	A/mm
Integral Gain	A/(in-s)	A/(in-s)	A/(m-s)	A/(mm-s)
Derivative Gain	A-s/in	A-s/in	A-s/m	A-s/mm
Force Constant	Lbf-in^2/A^2	Lbf-in^2/A^2	N-m^2/A^2	N-mm^2/A^2
Air Nominal Gap	in	in	m	mm
Current	A	A	A	A
Torsional				
Stiffness – K	Lbf-in/rad	Lbf-in/rad	N-m/rad	N-mm/rad
Damping – C	Lbf-in-s/rad	Lbf-in-s/rad	N-m-s/rad	N-mm-s/rad
Axial				
Stiffness – K	Lbf/in	Lbf/in	N/m	N/mm
Damping – C	Lbf-s/in	Lbf-s/in	N-s/m	N-s/mm

Gravity - g_o	386.088 in/s^2	386.088 in/s^2	9.8066 m/ s^2	9806.6 mm/s^2
Outputs				
Displacements	in	in	m	mm
Velocity	in/s	in/s	m/s	mm/s
Acceleration	in/s^2	in/s^2	m/s^2	mm/s^2
Rotations	rad	rad	rad	rad
Force	Lbf	Lbf	N	N
Moments/Torque	Lbf-in	Lbf-in	N-m	N-mm

The conversions between English and Metric units are list below for quick reference.

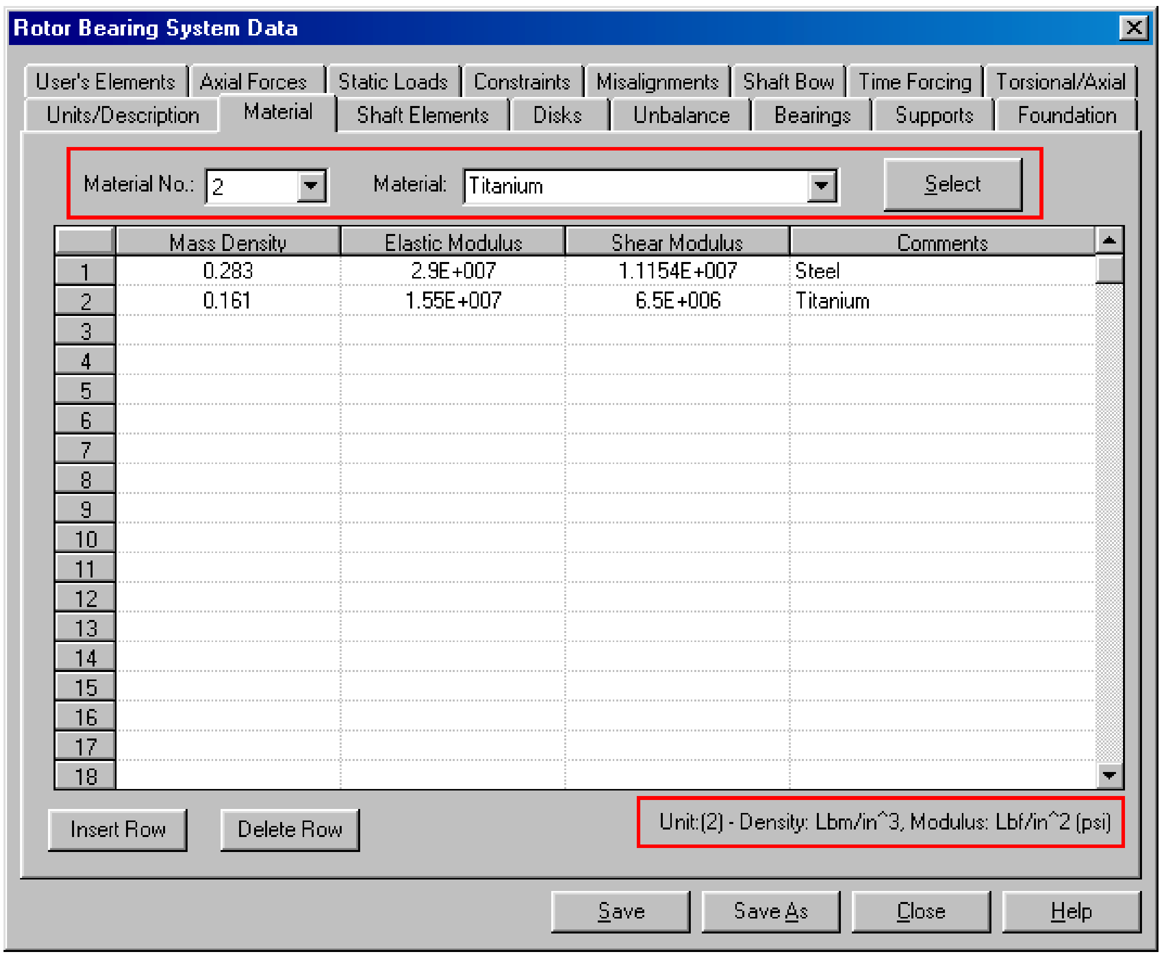
Unit	English	Metric (SI)	Conversions (* = multiply)
Time	second (s)	second (s)	
Length	in	Meter (m)	m = 0.025400 * in
Force	Lbf	Newton (N)	N = 4.448222 * Lbf
Mass	Lbf-s^2/in	kg = N-s^2/m	kg = 0.4535924 * Lbm = 175.1266 * Lbf-s^2/in
Density	Lbf-s^2/in^4	kg/m^3	kg/m^3 = 2.767990E+04 * Lbm/in^3 = 1.068688E+07 * Lbf-s^2/in^4
Inertia	Lbf-s^2-in	kg-m^2	kg-m^2 = 0.1129846 * Lbf-s^2-in
Moduli	Lbf/in^2 (psi)	N/m^2 (Pa)	Pa = 6.894757E+03 * psi
Gravity - g	386.088 in/s^2	9.8066 m/s^2	
Lateral Kt	Lbf/in	N/m	N/m = 175.1266 * Lbf/in
Lateral Ct	Lbf-s/in	N-s/m	N-s/m = 175.1266 * Lbf-s/in
Torsional K	Lbf-in/rad	N-m/rad	N-m/rad = 0.1129846 * Lbf-in/rad

Material Properties

The various shaft element materials used in the model are entered in this data entry form. Different colors are used to represent different materials in the system configuration plot. The colors are defined in the Graphic Settings under the Project menu. The material property number is used in the Shaft Elements data entry. Failure to specify a material will result in an error message. The material properties of steel are listed for reference:

Mass Density (ρ) = 7.329E-04 Lbf-s^2/in^4 = 7832 kg/m^3 = 0.283 Lbm/in^3
Elastic Modulus (E) = 29.0E+06 Lbf/in^2 = 20.0E+10 N/m^2 (Pascal)
Shear Modulus (G) = E / 2.6

You can type in the material properties for each material number or you can utilize the material library to fill in the material properties. If you want to use the library, specify the material number first, pick the material, then click *Select* to select the material. In the right bottom of the tab, the proper units for the specified unit system are displayed for reference.



Shaft Elements

The shafts of the system are numbered consecutively from 1 to *Ns* and the finite element stations of the model are numbered consecutively starting with 1 at the left end of shaft 1 and continuing to the last station at the right end of shaft *Ns*. The shafts are made up of Elements with the numbering for each shaft starts at the left end. Stations are located at the ends of the Elements. The term Station is commonly used in the rotordynamics instead of the term Node which is generally used in finite element literature because of the alternate meaning that Node has in the vibration mode shapes. Three types of elements are included in *DyRoBeS* and they are: Cylindrical Element, Conical (Tapered) Element, and User's Supplied Element.

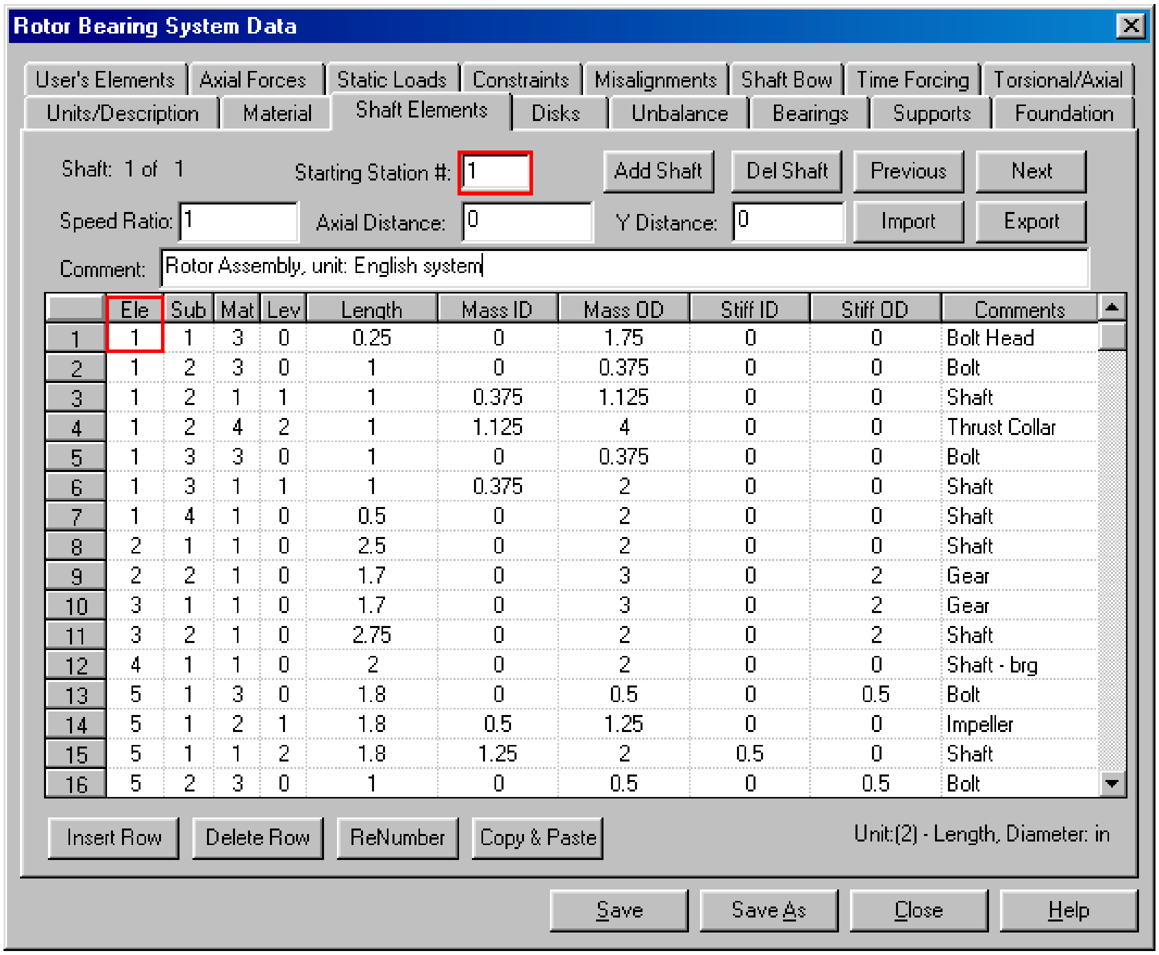
Element *i* is located immediately to the right of station *i*. Each element may possess several subelements (starting with 1 at the left of the element) thereby allowing for reasonable flexibility in modeling systems with several geometric discontinuities. Each subelement may possess several levels or layers. The use of subelement is strongly encouraged in the modeling. This will save tremendous computational time with little loss of accuracy in the result. However, when using subelements, it should be kept in mind that Disks and Bearings can only be placed at the ends of the elements (stations). Note that an element does not exist for the last station of each shaft. For multi-shaft systems, the station numbers are consecutive and the element numbers are not continuous.

The Shaft Elements page is shown below. The control buttons <***Add Shaft***>, <***Del Shaft***>, <***Previous***>, and <***Next***> allow you to add a new shaft data, delete an existing shaft, and switch the shaft data for multi-shaft systems. The <***Import***> and <***Export***> buttons allow you to import and export the shaft data to MS Excel file. You can manipulate the shaft data in MS Excel and then Import into ***DyRoBeS***. The <***Insert Row***> and <***Delete Row***> allow you to insert a new row or delete a row. <***ReNumber***> allows you to re-number the element and subelement numbers. A new element number is always started with a subelement number 1. <***Copy & Paste***> allows you to copy and paste row data. Standard *Windows* commands **<*Ctrl+C*>** and <***Ctrl+V***> can be used to copy and paste a single data field. In the right bottom of the tab, the proper units for the specified unit system are displayed for reference.

The following data fields are explained:

1. **Starting Station #**: The starting station (also element) number of the current shaft. Starting Station = 1 for shaft 1. This number is updated automatically and is used to remind the users of the starting element number of that particular shaft.

2. **Speed Ratio**: This field is used to calculate the speeds of the multi-shaft systems. Speed Ratio = 1 for shaft 1. Or you can simply input the shaft rotational speed, the program will calculate the ratios for you. Use zero (0) for non-rotating structure.



3. **Axial Distance**: The distance measured from the station 1 of shaft 1 to the starting station of the current shaft. It is used for geometric configuration plot only and it does not affect the numerical results. Distance = 0 for shaft 1.

4. **Y Distance**: Again, this value is used for geometric plot only. Zeros indicate that the shafts are concentric, non-zeros are used in the Torsional and Axial multi-branch systems to represent vertical offset caused by gears, etc.

5. **Comment**: Comments on the shaft.

6. **Ele**: Element number. The Element number in the first row must be equal to the Starting Station #.

7. **Sub**: Subelement number. Each element can contain a max of 20 subelements. Positive value represents a cylindrical element and negative value indicates that this subelement is a conical (tapered) element.

8. **Lev**: Level for the subelement. Each subelement can have a max of 5 levels (layers). Level zero (0) is the core data.

9. **Mat**: Material number. Mat = 0 for User Supplied Subelement.

10. **Length**: Subelement length. For the same subelement number with different levels, the subelement length should be the same.

11. **Mass ID**: Mass inner diameter (For conical element: left end inner diameter).

12. **Mass OD**: Mass outer diameter (For conical element: left end outer diameter).

13. **Stiff ID**: Stiffness inner diameter (For conical element: right end inner diameter).

14. **Stiff OD**: Stiffness outer diameter (For conical element: right end outer diameter).

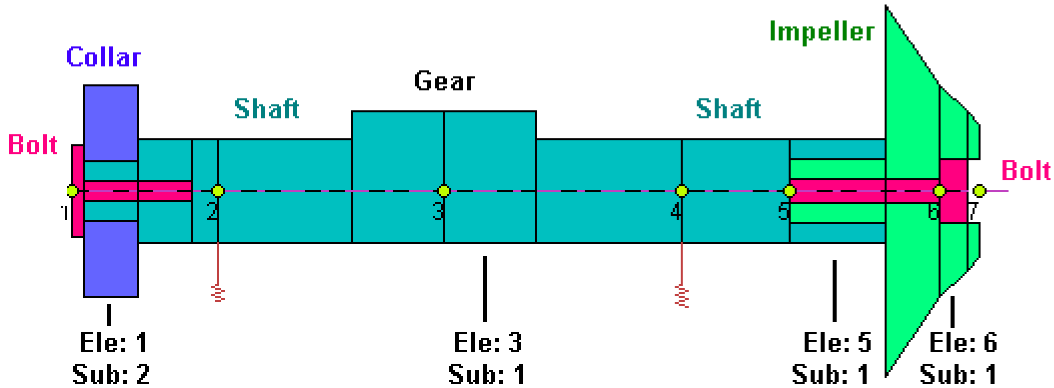
15. **Comments**: Subelement description.

For a standard cylindrical element, the Mass ID and OD are used for kinetic energy (mass, gyroscopic matrices) calculation and the Stiffness ID and OD are used for potential energy (stiffness matrix) calculation. If Stiffness OD = 0, then the Stiffness ID and OD will be reassigned to be equal to the Mass ID and OD. This option can save data entry time if you decide to use the same model for the kinetic energy and potential energy calculation. In the configuration plot, the upper half represents the Mass model and the lower half represents the Stiffness model.

However, for a conical element, the Mass ID and OD are the LEFT end inner and outer diameters and the Stiffness ID and OD are the RIGHT end inner and outer diameters. The mass model and stiffness model are using the same geometry.

Example 1: Single shaft system

A single shaft model and the associated shaft data are shown below:

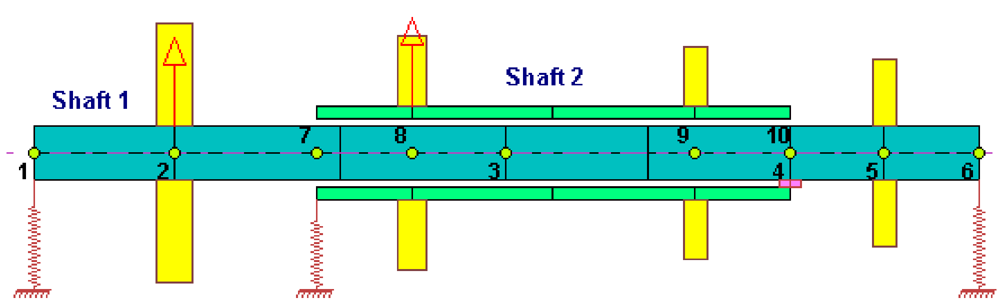


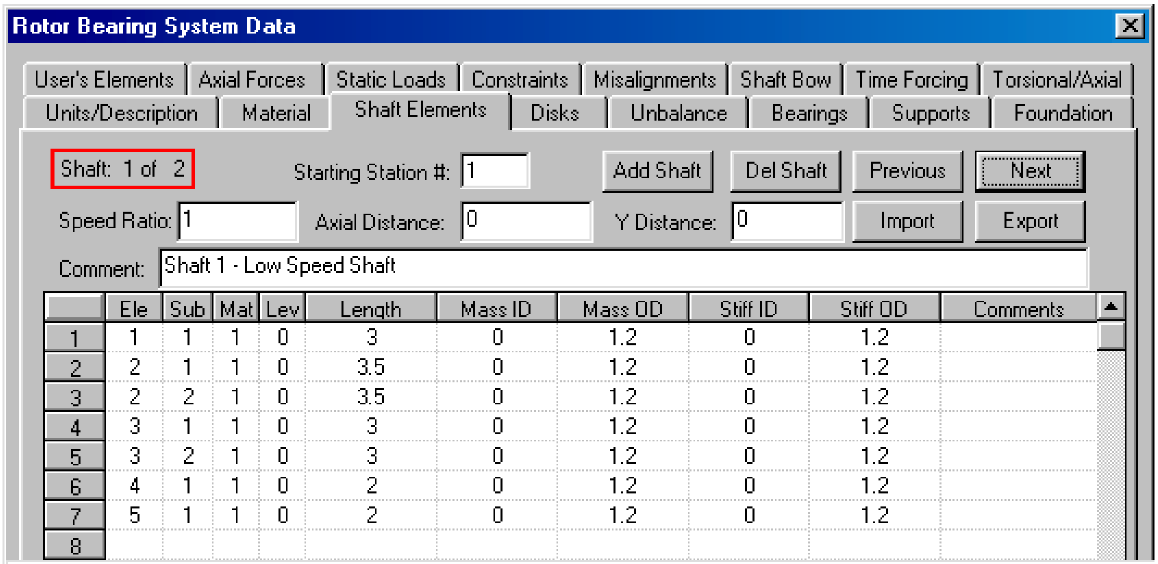
	Ele	Sub	Mat	Lev	Length	Mass ID	Mass OD	Stiff ID	Stiff OD	Comments
1	1	1	3	0	0.25	0	1.75	0	0	Bolt Head
2	1	2	3	0	1	0	0.375	0	0	Bolt
3	1	2	1	1	1	0.375	1.125	0	0	Shaft
4	1	2	4	2	1	1.125	4	0	0	Thrust Collar
5	1	3	3	0	1	0	0.375	0	0	Bolt
6	1	3	1	1	1	0.375	2	0	0	Shaft
7	1	4	1	0	0.5	0	2	0	0	Shaft
8	2	1	1	0	2.5	0	2	0	0	Shaft
9	2	2	1	0	1.7	0	3	0	2	Gear
10	3	1	1	0	1.7	0	3	0	2	Gear
11	3	2	1	0	2.75	0	2	0	2	Shaft
12	4	1	1	0	2	0	2	0	0	Shaft - brg
13	5	1	3	0	1.8	0	0.5	0	0.5	Bolt
14	5	1	2	1	1.8	0.5	1.25	0	0	Impeller
15	5	1	1	2	1.8	1.25	2	0.5	0	Shaft
16	5	2	3	0	1	0	0.5	0	0.5	Bolt
17	5	-2	2	1	1	0.5	7	0.5	4	Impeller
18	6	1	3	0	0.5	0	1.25	0	0	Bolt Head
19	6	-1	2	1	0.5	1.25	4	1.25	3	Impeller
20	6	-2	2	0	0.25	1.25	3	1.25	2.5	Impeller
21										

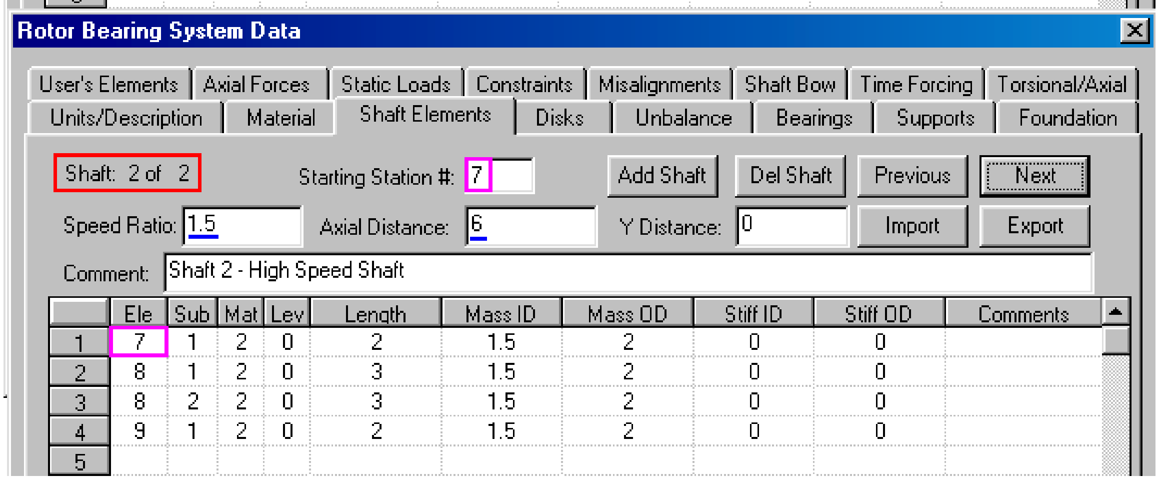
The model shown above has six (6) elements (7 stations). The substations between the major stations are not numbered. The different colors in the shaft elements represent the different material properties. A thrust collar in the left hand side and an impeller in the right hand side are attached to the shaft through bolts. Element 1, Subelement 2, and Element 5, Subelement 1, have three levels. Element 1, Subelement 3, Element 5, Subelement 2, and Element 6, Subelement 1, have two levels. As can be seen from the figure, the bearings are located at the major stations 2 and 4. A bearing cannot be applied at a substation. It is also observed that the rotor (gear portion) is not symmetric about the shaft centerline. The profile above the shaft centerline represents the rotor mass distribution, whereas the distribution below the centerline represents the rotor stiffness distribution.

Example 2: Dual shafts system

A dual shafts model and the associated shaft data are shown below:



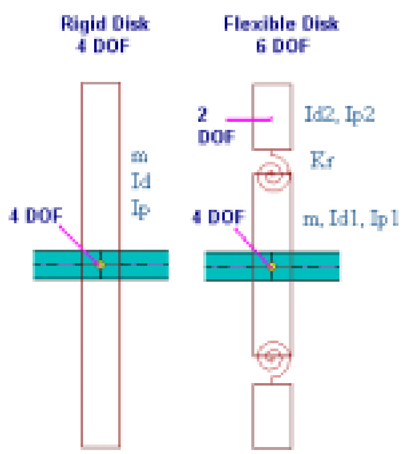


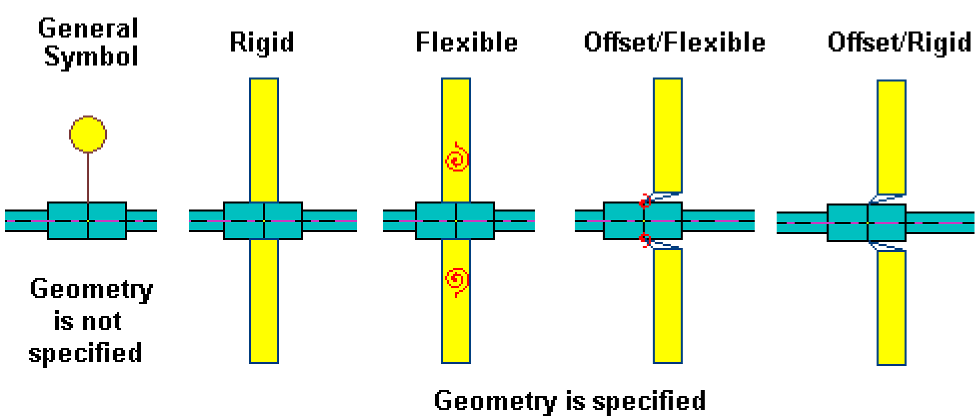


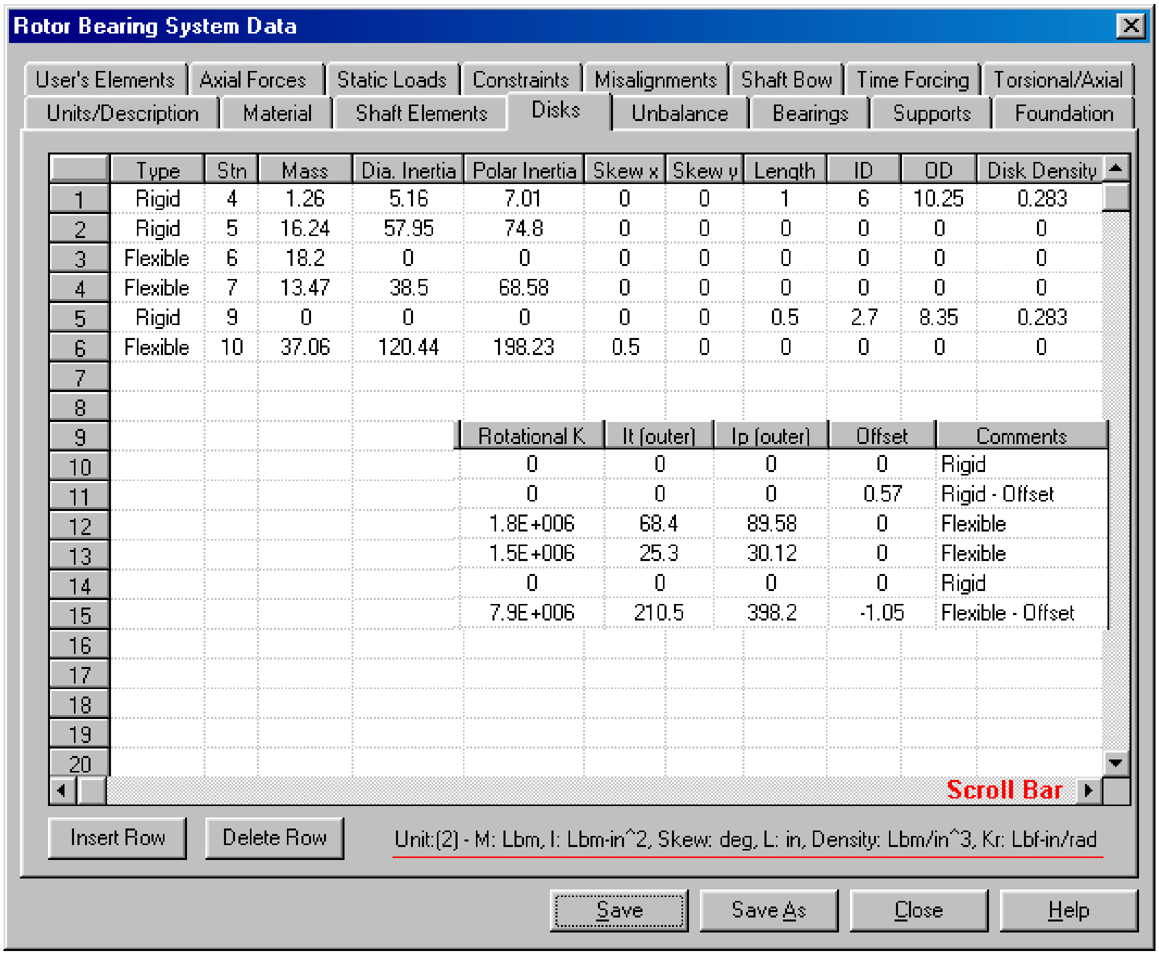
The shaft 1 starts from station 1 to station 6 and shaft 2 is from station 7 to station 10. Note that an element does not exist for the last station of each shaft. The shaft 2 speed is 1.5 times the shaft 1 speed.

Rigid/Flexible Disks

Impeller, fan, turbine blades, collar, coupling hub, etc, can all be modeled as disks. A concentrated disk can be located at any finite element station. Disks cannot be placed at a substation. Multiple disks are allowed at the same station. For a rigid disk, there are four-degrees-of-freedom (dof), 2 translational and 2 rotational displacements. These dofs are the same as the dofs of the finite element station which the disk is attached to. However, for a flexible disk, two additional rotational dofs are introduced, that is, there is a total of 6 dofs for each flexible disk. The diametral and polar moment of inertias for the inner and outer disks are typically carefully adjusted to match the first disk diametral resonant frequency. Since the outer disk has only 2 rotational dofs and no translational dofs, it only possess the moments of inertias. All the mass is lumped into the inner disk. The flexible disk option can be important for large overhung rotors, such as large gas turbines where the disk flexibility must be taken into consideration. Depending on the attachment method, the disk can also be offset from the attached station. The symbols used to represent the disk are shown below:







	Type	Stn	Mass	Dia. Inertia	Polar Inertia	Skew x	Skew y	Length	ID	OD	Disk Density
1	Rigid	4	1.26	5.16	7.01	0	0	1	6	10.25	0.283
2	Rigid	5	16.24	57.95	74.8	0	0	0	0	0	0
3	Flexible	6	18.2	0	0	0	0	0	0	0	0
4	Flexible	7	13.47	38.5	68.58	0	0	0	0	0	0
5	Rigid	9	0	0	0	0	0	0.5	2.7	8.35	0.283
6	Flexible	10	37.06	120.44	198.23	0.5	0	0	0	0	0

Rotational K	It (outer)	Ip (outer)	Offset	Comments
0	0	0	0	Rigid
0	0	0	0.57	Rigid - Offset
1.8E+006	68.4	89.58	0	Flexible
1.5E+006	25.3	30.12	0	Flexible
0	0	0	0	Rigid
7.9E+006	210.5	398.2	-1.05	Flexible - Offset

The input data are explained below:

1. **Type**: **R**igid or **F**lexible

2. **Stn**: Station number where the disk is located.

3. **Mass**: Disk mass.

4. **Dia. Inertia**: Diametral (transverse) moment of inertia. For flexible disk, it is the inner disk diametral inertia..

5. **Polar Inertia**: Polar moment of inertia. For flexible disk, it is the inner disk polar inertia.

6. **Skew x**: Disk skew angle about x axis in degree.

7. **Skew y**: Disk skew angle about y axis in degree.

8. **Length, ID, OD**: These values are used to graphically display the disk and may be used for the additional mass properties if the Disk Density is not zero. If Length and

OD are zero, then the disk is represented by a circle and a straight line connected to the station. If the Length and OD are not zero, the disk is plotted based on the given length, ID and OD.

9. **Density**: Disk density. For a non-zero density, additional mass properties calculated based on the disk geometry (length, ID, and OD) will be added into the specified mass properties (data fields, 3,4, and 5). Note: for flexible disks, these additional mass properties will be added into the inner disk properties.

10. **Rotational K**: Rotational stiffness used to connect the inner and outer disks. Used only when the disk is flexible.

11. **Id (outer)**: Diametral (transverse) moment of inertia of the outer disk. Used only when the disk is flexible.

12. **Ip (outer)**: Polar moment of inertia of the outer disk. Used only when the disk is flexible.

13. **Offset**: Non-zero value for the offset disk. Positive value if the disk is offset to the right and negative value if the disk is offset to the left.

14. **Comment**: Disk description.

The disk skew angles due to assembly are entered in this folder. However, the total disk skew angles are the combination of the skew caused by assembly and the skew caused by Shaft Bow. For flexible disks, the skew angles are applied on both inner and outer disks. A convenient tool for the calculation of mass properties of a homogeneous solid is provided under Tools menu. You can use this tool to calculate the mass properties of a cylindrical or tapered disk.

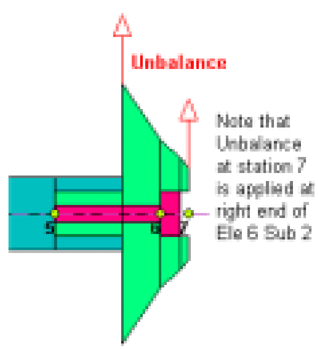
The scroll bar allows you to scroll the data. In the right bottom of the screen, the proper units for the specified unit system are displayed for reference.

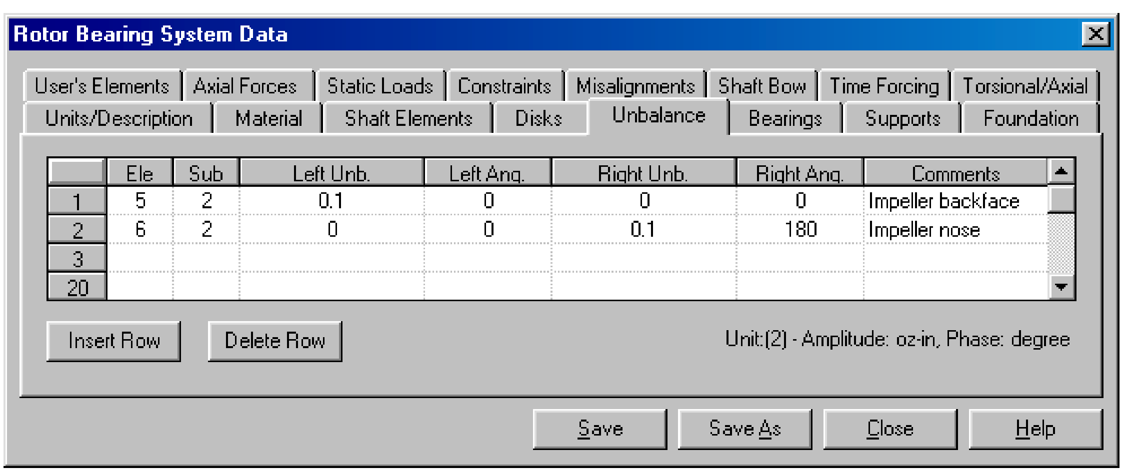
Unbalance

The unbalances of a rotating assembly are usually determined by using the multi-plane balancing machines. These unbalances are discrete and located at different planes with a magnitude of (*mass* * *eccentricity*). The unbalance planes may be located at the ends of each subelement in this program. These unbalance forces are assumed to be discrete and independent. Multiple unbalances are allowed at the same location.

For an unbalanced disk at station "*i*" with an unbalance "*me*", this unbalance can be placed at the left end of element "*i*" with a magnitude of "*me*". However, precautions must be taken for the unbalanced disk located at the right end (last station) of each shaft. Since there is no element number corresponding to the last station number on a shaft (explained in the Shaft Elements), this unbalance can be placed at the right end of the last subelement. In the right bottom of the screen, the proper units for the specified unit system are displayed for reference.

1. **Ele**: Element number.
2. **Sub**: Subelement number.
3. **Left Unb**: Left end unbalance amplitude (*me*).
4. **Left Ang**: Left end unbalance phase angle measured from X axis (degree).
5. **Right Unb**: Right end unbalance amplitude.
6. **Right Ang**: Right end unbalance phase angle.
7. **Comment**: Description.

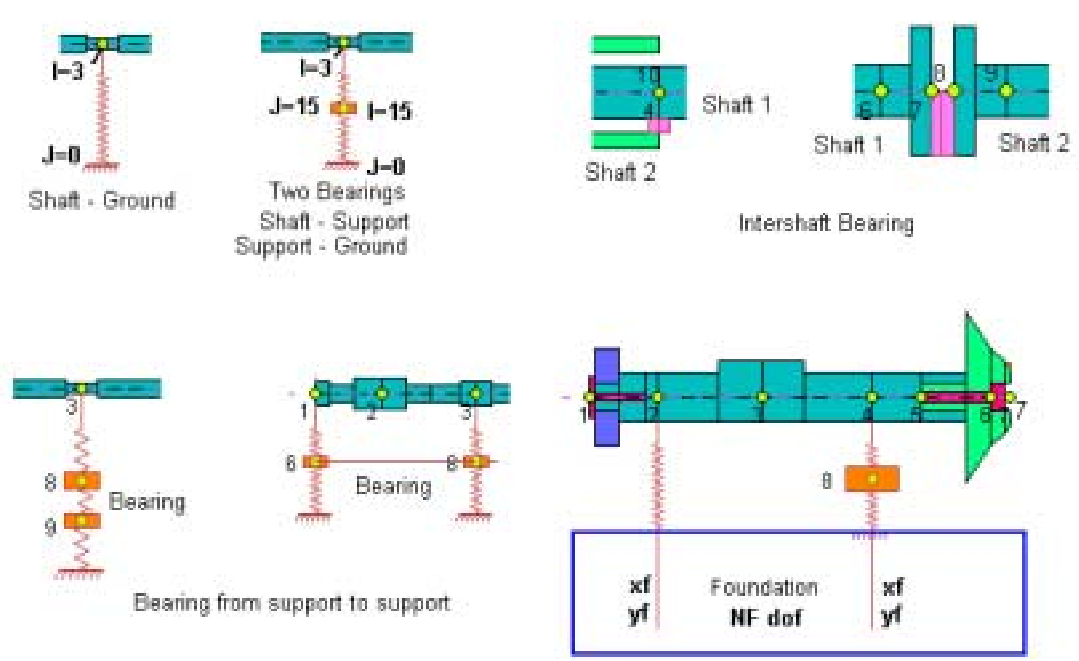




Bearings

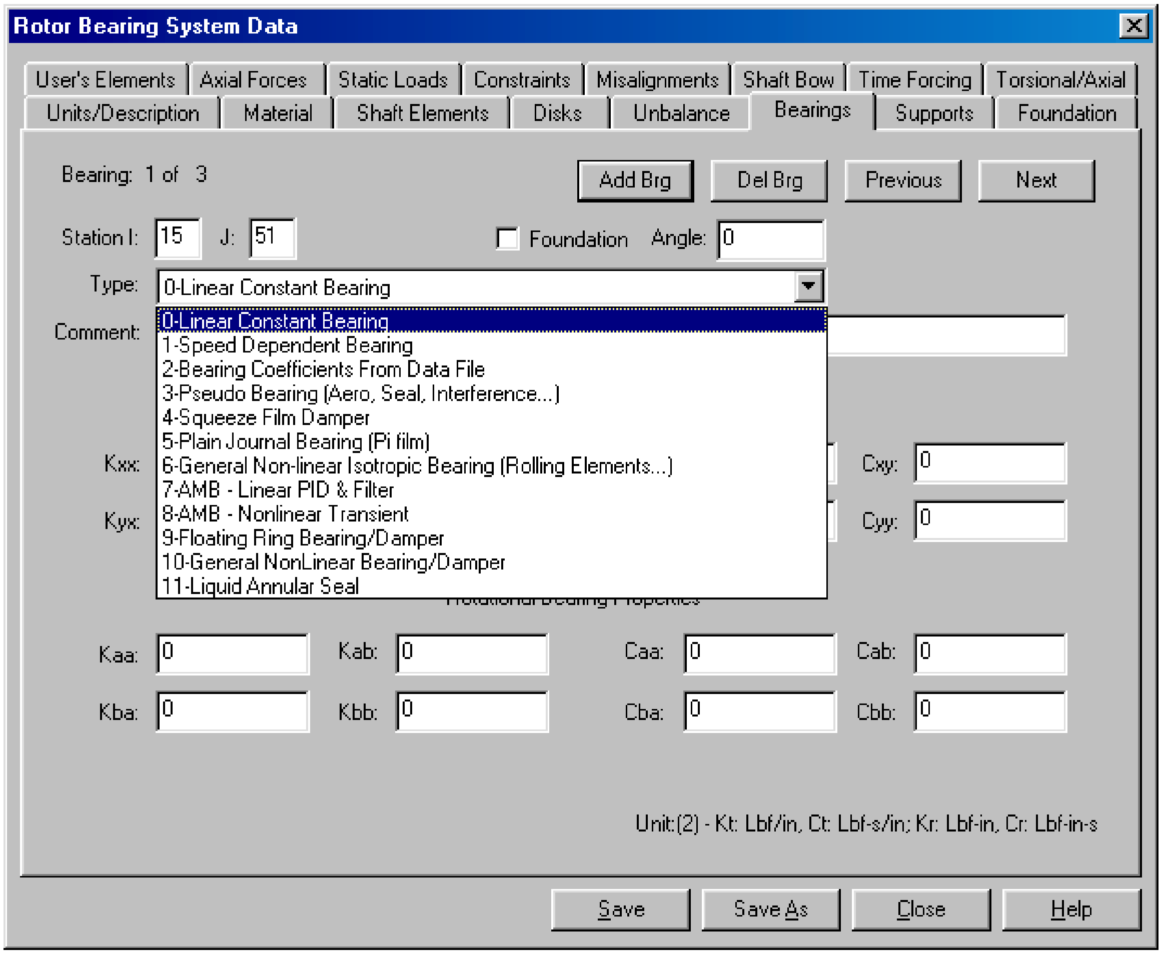
All the bearing/damper/seals/support forces acting on, or interacting between, the rotating assemblies and non-rotating structures fall into this category. The "bearing" can be of any type, such as linear/nonlinear, real/pseudo, fluid film, rolling elements, or active magnetic bearings, and aerodynamic forces, seals, rubbing, etc. Nonlinear bearings can only be used in the time transient analysis, with the exception of squeeze film dampers and generalized non-linear isotropic bearing. Squeeze film dampers and non-linear isotropic bearings can be analyzed in both the steady state synchronous response analysis and time transient analysis. Different types of bearings or even same type bearing can be at the same finite element station depending upon the modeling technique. Numerous predefined bearing types are provided in the program. If you like to define your own bearing type, please contact the program author for implementation.

Bearing is an interconnection component, which connects two finite element stations (station I and station J). Several configurations are shown below:

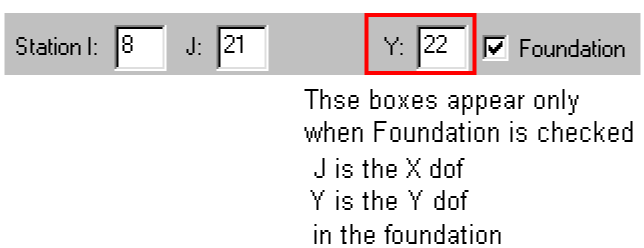


Some common input data are explained:

Station I and **Station J**: A bearing connects two stations. Station I cannot be zero. Station J = 0 if it is the rigid ground. J can also be a connecting station number of an intershaft bearing in a multi-shaft system or the flexible bearing support station number for a flexible support system.



Foundation: If the foundation box is checked, this bearing is connected to the foundation. The foundation data is provided under Foundation tab. See Foundation for more detail. If Foundation is checked, additional boxes appear in the screen. Then, J becomes the X degree-of-freedom in the foundation and Y is the Y degree-of-freedom in the foundation. The bearing connects x, y coordinates in the station I to J (X) and Y in the foundation, as shown below:



Angle: Degree measured from the global fixed coordinate system to the local coordinate system where the bearing coefficients are defined. The angle is measured in the counterclockwise direction. The dynamic characteristics of the bearings are usually defined (specified) in the local coordinate system, therefore, a coordinate transformation is performed by the program to convert the bearing stiffnesses and dampings in the local coordinate system to the stiffnesses and dampings in the global coordinate system. In *DyRoBeS*, it is recommended that this transformation be performed in *BePerf* for computational efficiency.

Comment: Description of this bearing.

Types: Currently, the following types of bearings are supported in the program and they are explained in the following sessions.

Linear constant bearing
Speed dependent bearing
Bearing from external data file
Pseudo bearing
Squeeze film damper
Plain journal bearing
Generalized non-linear isotropic bearing
Active magnetic bearing
Floating ring bearing
General non-linear polynomial bearing
Liquid annular seal

Again, in the right bottom of the screen, the proper units for the specified unit system are displayed for reference.

Linear Bearing

This option is used to specify linear, speed independent bearing coefficients. The linear bearing forces are of the form:

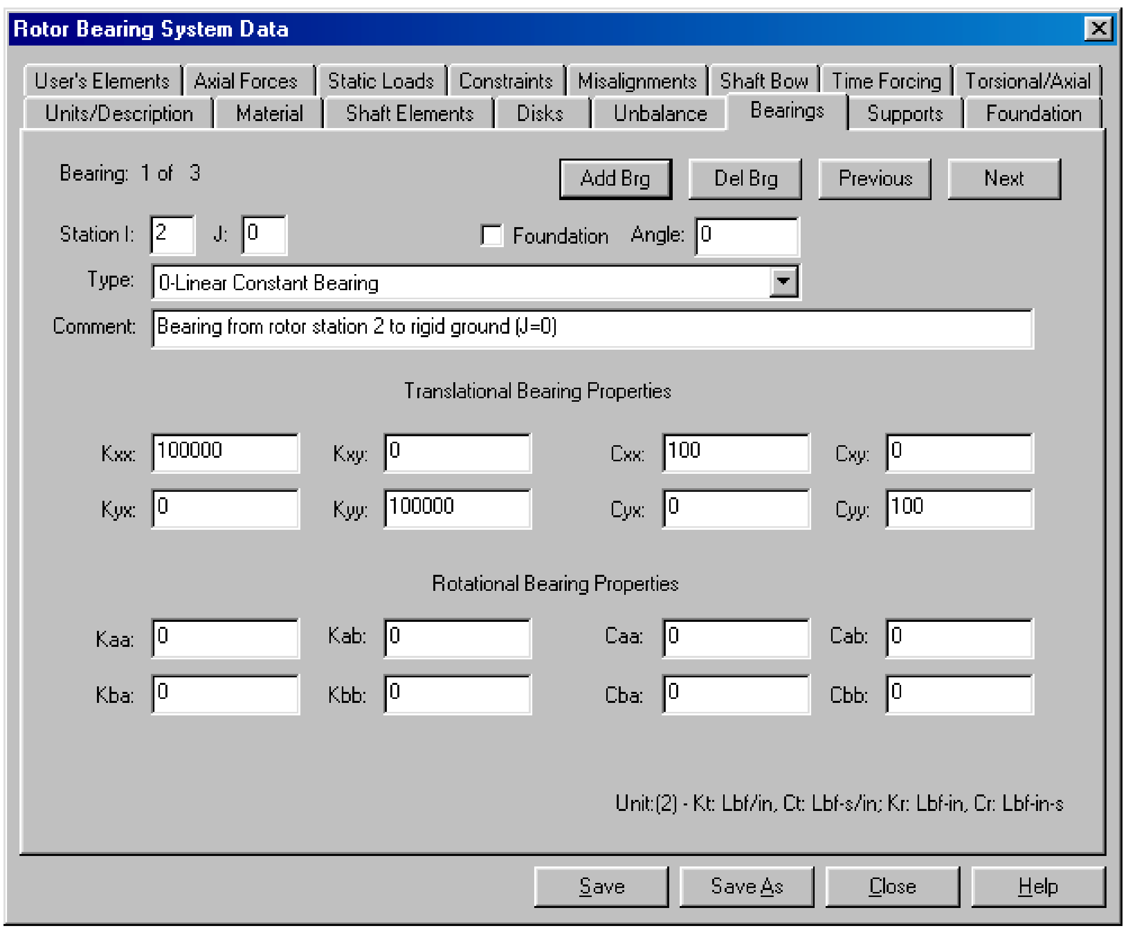
$$\begin{Bmatrix} F_x \\ F_y \\ M_x \\ M_y \end{Bmatrix} = - \begin{bmatrix} K_{xx} & K_{xy} & 0 & 0 \\ K_{yx} & K_{yy} & 0 & 0 \\ 0 & 0 & K_{\alpha\alpha} & K_{\alpha\beta} \\ 0 & 0 & K_{\beta\alpha} & K_{\beta\beta} \end{bmatrix} \begin{Bmatrix} x \\ y \\ \theta_x \\ \theta_y \end{Bmatrix} - \begin{bmatrix} C_{xx} & C_{xy} & 0 & 0 \\ C_{yx} & C_{yy} & 0 & 0 \\ 0 & 0 & C_{\alpha\alpha} & C_{\alpha\beta} \\ 0 & 0 & C_{\beta\alpha} & C_{\beta\beta} \end{bmatrix} \begin{Bmatrix} \dot{x} \\ \dot{y} \\ \dot{\theta}_x \\ \dot{\theta}_y \end{Bmatrix}$$

or in matrix form:

$$\mathbf{Q} = -\mathbf{K}\mathbf{q} - \mathbf{C}\dot{\mathbf{q}}$$

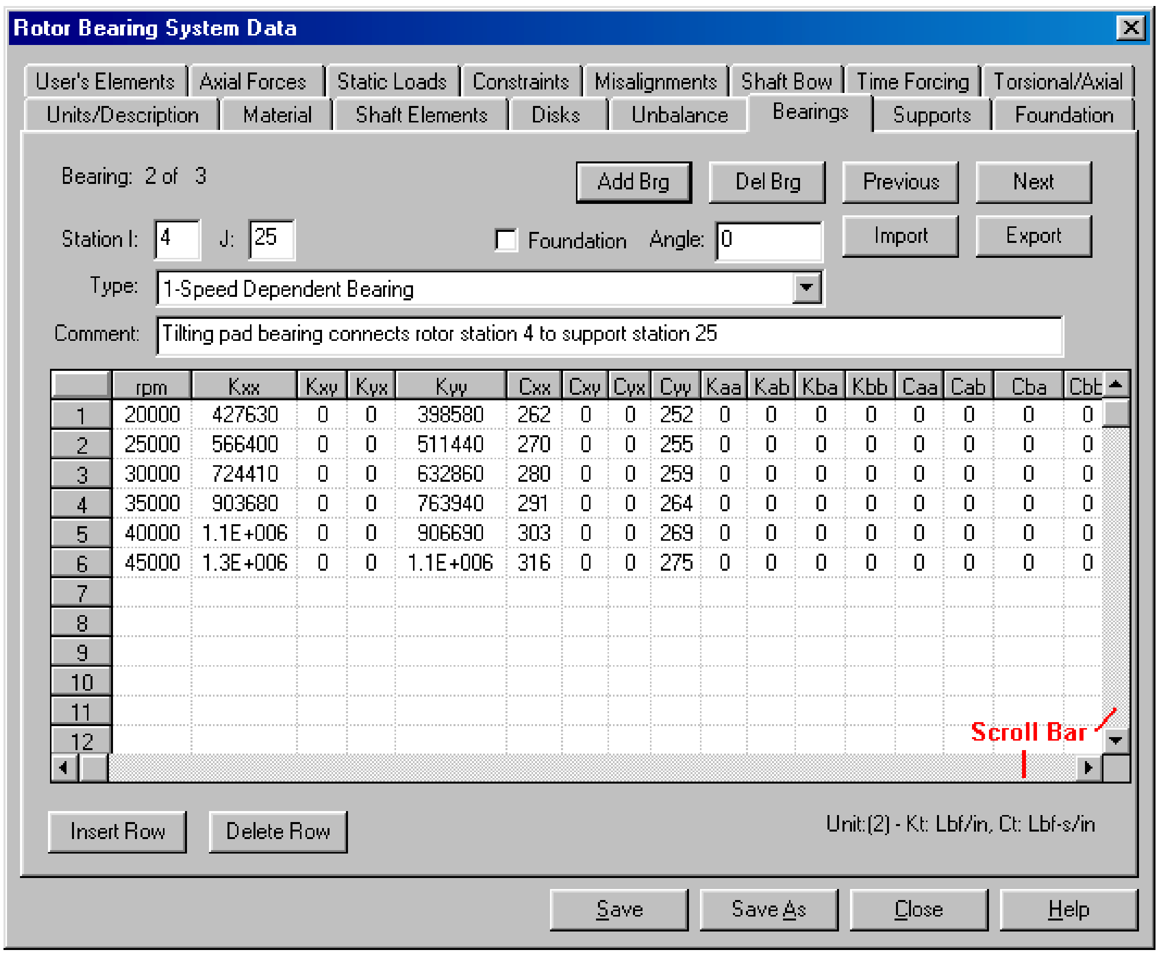
For bearings connecting station I and J, the bearing model becomes:

$$\begin{Bmatrix} \mathbf{Q}_i \\ \mathbf{Q}_j \end{Bmatrix} = -\begin{bmatrix} \mathbf{K} & -\mathbf{K} \\ -\mathbf{K} & \mathbf{K} \end{bmatrix} \begin{Bmatrix} \mathbf{q}_i \\ \mathbf{q}_j \end{Bmatrix} - \begin{bmatrix} \mathbf{C} & -\mathbf{C} \\ -\mathbf{C} & \mathbf{C} \end{bmatrix} \begin{Bmatrix} \dot{\mathbf{q}}_i \\ \dot{\mathbf{q}}_j \end{Bmatrix}$$



Speed Dependent Bearing

This option allows you to specify speed dependent linearized bearing coefficients. These coefficients are usually obtained from bearing performance programs or experiments. Sixteen bearing dynamic coefficients must be provided for each shaft rotational speed. The rotational speed of shaft 1 is used for the case of multi-shaft systems. If the number of data (speed) points is greater than or equal to 3, a spline function is used in the program to interpolate the coefficients for the shaft speeds requested in the analysis that are not given in the data points. If the number of data (speed) points is equal to 2, a linear function is used to obtain the coefficients for the shaft speeds that are not given in the data points. If there is only one point in the data, then it will be treated as a linear constant bearing. The use of spline function allows a small number of needed data points. Since the spline function is used in the interpolation, the data must be entered in the increasing order according to the speed value.



Bearing from External Data File

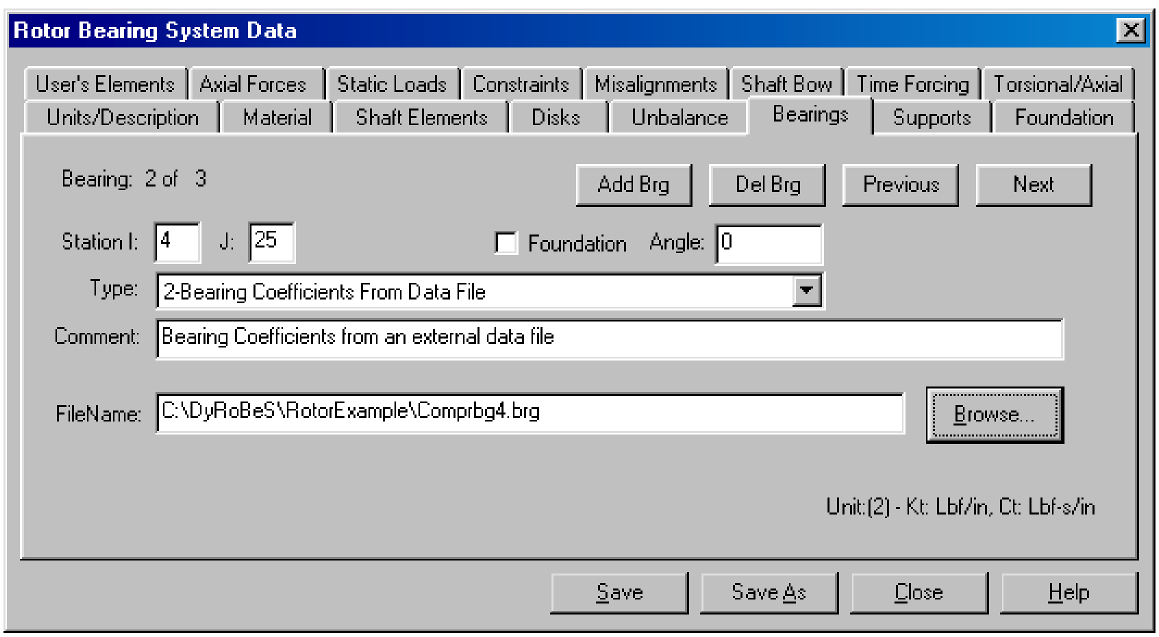
This option allows the analysis program to import bearing coefficients from an external data file. The data filename must include the full path. It is recommended to use ***Browse*** button to select the file. The external bearing data file must be in the following ASCII format:

number of speed points, *N*
repeat *N* times with the following data

Speed (rpm)   Kxx, Kxy, Kyx, Kyy, Cxx, Cxy, Cyx, Cyy

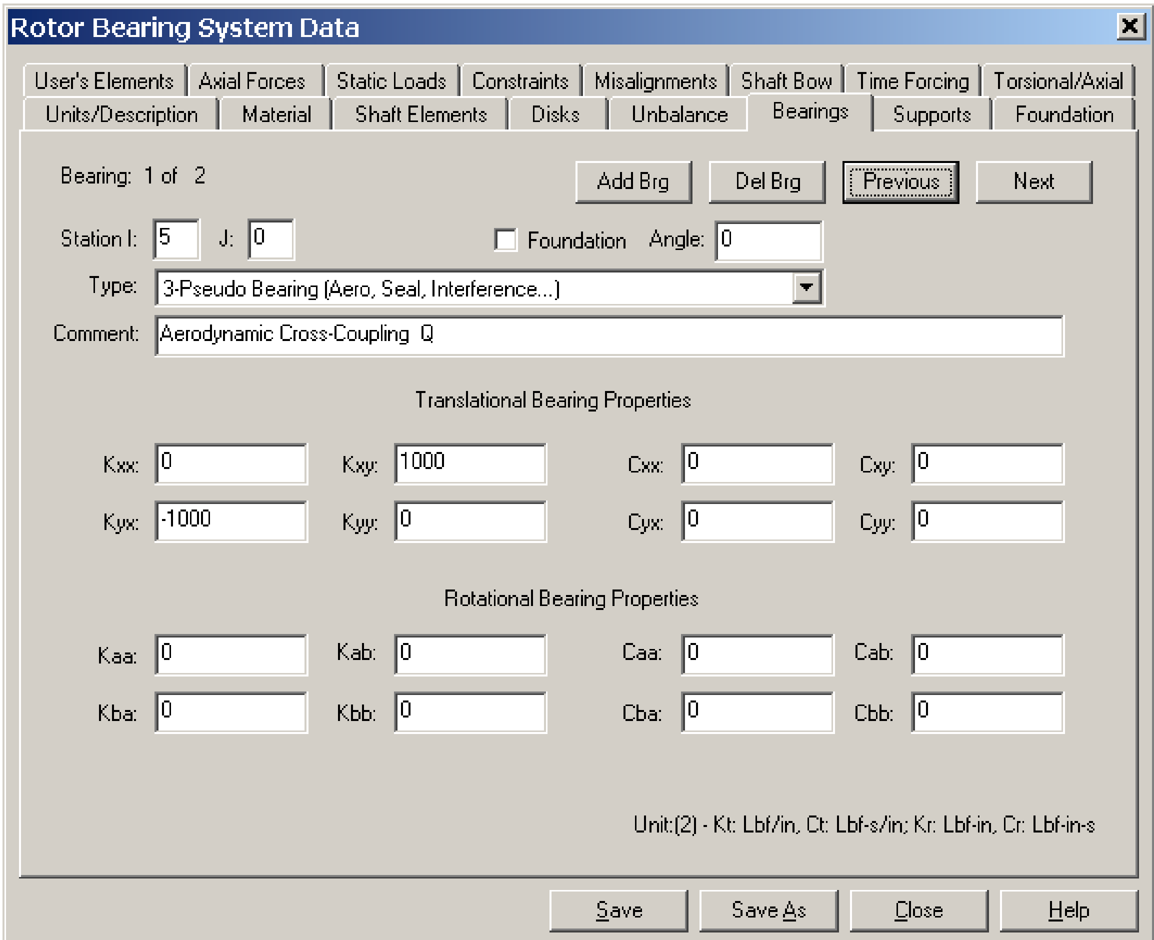
The rotational speed of shaft 1 is used for the case of multi-shaft systems. Again, a spline function is used in the program to interpolate the bearing coefficients for the shaft speeds requested in the analysis that are not given in the input data. The data must be entered in the increasing order according to the speed value. Example:

```
9
 5000  .1832E+06  .1552E+06  -.1603E+06  .1885E+06  672   3    3   689
10000  .3628E+06  .3035E+06  -.3301E+06  .3920E+06  665   3    3   703
15000  .5316E+06  .4536E+06  -.4974E+06  .5726E+06  660   6    6   706
20000  .6935E+06  .6038E+06  -.6649E+06  .7387E+06  657   8    8   707
25000  .8557E+06  .7483E+06  -.8416E+06  .9170E+06  654   8    8   712
30000  .1021E+07  .8852E+06  -.1030E+07  .1117E+07  652   4    4   721
35000  .1190E+07  .1013E+07  -.1233E+07  .1342E+07  650  -5   -5   732
40000  .1364E+07  .1132E+07  -.1450E+07  .1596E+07  647  -10  -10  745
45000  .1544E+07  .1242E+07  -.1682E+07  .1879E+07  645  -15  -15  759
```



Pseudo Bearing

This option allows you to input the *bearing like* forces in the form of stiffnesses and dampings. The bearing coefficients are entered in the same format as **linear bearing** option and are treated in the same way as the linear bearings. However, these coefficients are ignored in the Critical Speed Map Analysis.



Squeeze Film Damper

Squeeze film dampers can be modeled with or without centering springs. The centering spring is assumed to be isotropic. For the nonlinear centering spring, a generalized non-linear isotropic bearing can be used in parallel or in series with the squeeze film damper. In the steady state synchronous response analysis, centered circular orbits are assumed. The general motion of a plain fluid film journal bearing or a squeeze film damper is governed by the Reynolds equation which is derived from the Navier-Stokes equation. The fluid film forces acting on the journal are determined by application of boundary conditions and integration of pressure distribution. The general incompressible laminar Reynolds equation is given by:

$$\frac{1}{R^2}\frac{\partial}{\partial\theta}\left(\frac{h^3}{\mu}\frac{\partial P}{\partial\theta}\right)+\frac{\partial}{\partial Z}\left(\frac{h^3}{\mu}\frac{\partial P}{\partial Z}\right)=6\left(\omega_b+\omega_j-2\dot{\phi}\right)\frac{\partial h}{\partial\theta}+12\frac{\partial h}{\partial t}$$

where

ω_j = journal rotational speed

ω_b = bearing rotational speed

$\dot{\phi}$ = precession of the line of centers (whirl speed)

For a squeeze film damper, the damper is free to precess, but not rotate. I.e., the journal and bearing speeds are zero. Furthermore, the last term ($\partial h/\partial t$) vanishes at steady state condition. For the transient analysis, short bearing and π film assumptions are utilized. For the steady state response, the following table summarizes the equivalent stiffness and damping for the cases of circular synchronous motion about the origin and pure radial motion with no precession for the conditions of cavitation (π film) and no cavitation (2π film).

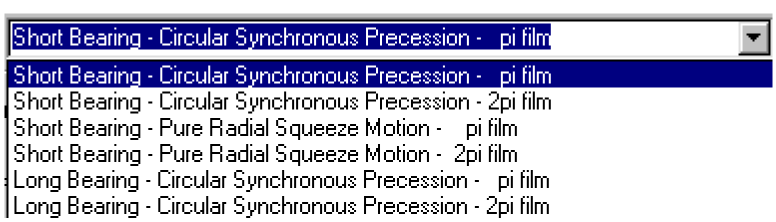
Bearing	Film	Motion	Stiffness	Damping
Short Bearing	π film	Circular Synchronous Precession	$\frac{2\mu R L^3 \varepsilon \omega}{C^3\left(1-\varepsilon^2\right)^2}$	$\frac{\mu R L^3 \pi}{2C^3\left(1-\varepsilon^2\right)^{3/2}}$
	2π film		0	$\frac{\mu R L^3 \pi}{C^3\left(1-\varepsilon^2\right)^{3/2}}$
	π film	Pure Radial Squeeze Motion	0	$\frac{\mu R L^3 \pi\left(2\varepsilon^2+1\right)}{2C^3\left(1-\varepsilon^2\right)^{5/2}}$

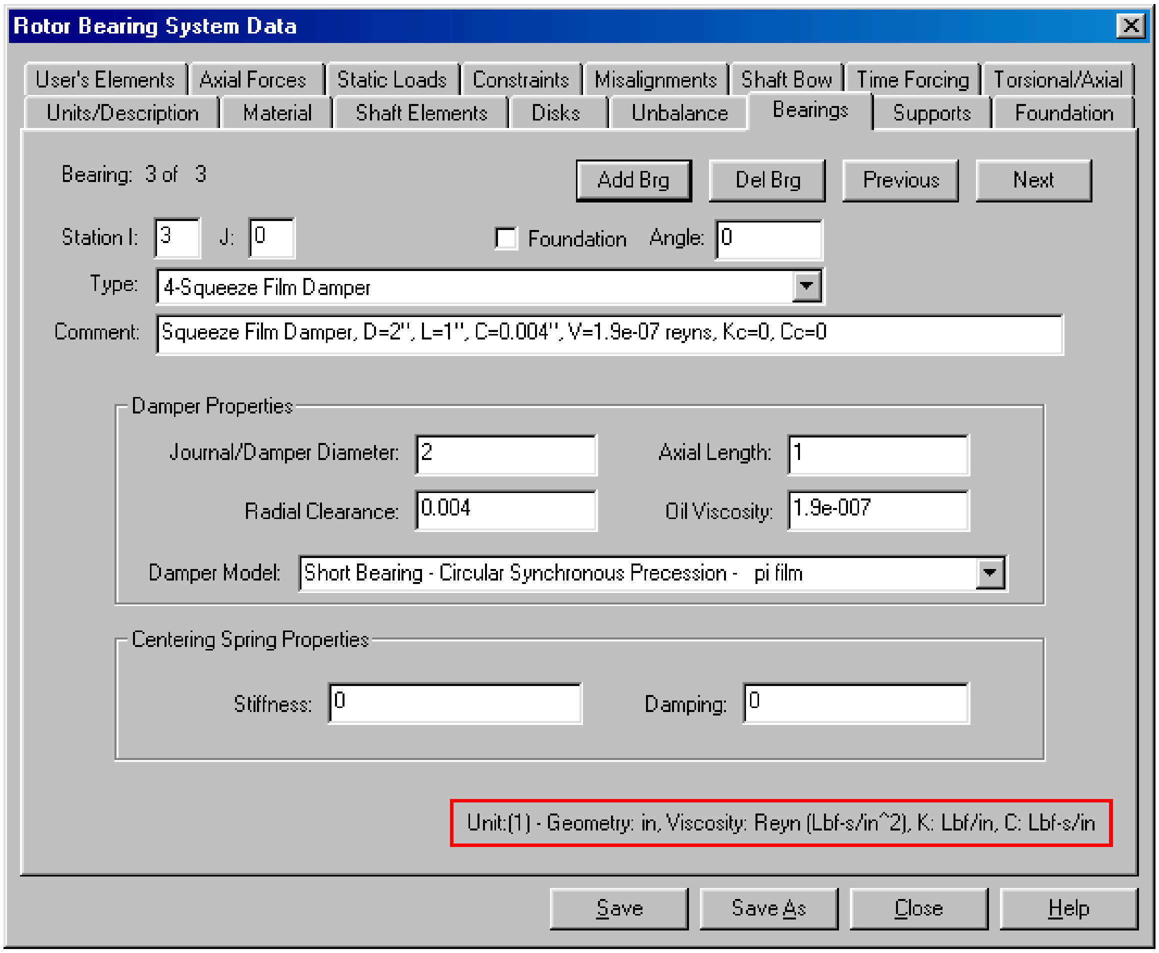
	2π film		0	$\frac{\mu R L^3 \pi (2\varepsilon^2 + 1)}{C^3 (1-\varepsilon^2)^{5/2}}$
Long Bearing	π film	Circular Synchronous Precession	$\frac{24\mu R^3 L \varepsilon \omega}{C^3 (2+\varepsilon^2)(1-\varepsilon^2)}$	$\frac{12\mu R^3 L \pi}{C^3 (2+\varepsilon^2)(1-\varepsilon^2)^{1/2}}$
	2π film		0	$\frac{24\mu R^3 L \pi}{C^3 (2+\varepsilon^2)(1-\varepsilon^2)^{1/2}}$

Where R = damper radius
L = damper axial length
C = radial clearance
ω = whirl speed
μ = oil viscosity
ε = eccentricity ratio

Note that for the circular synchronous motion, the equivalent stiffness term is a highly nonlinear function of eccentricity and may lead to a nonlinear jump phenomenon under high rotor unbalance. Caution must be taken while designing the damper, since it can significantly either improve or degrade the dynamic characteristics of the rotor system.

The data fields are self-explanatory. In the right bottom of the screen, the proper units for the specified unit system are displayed for reference.



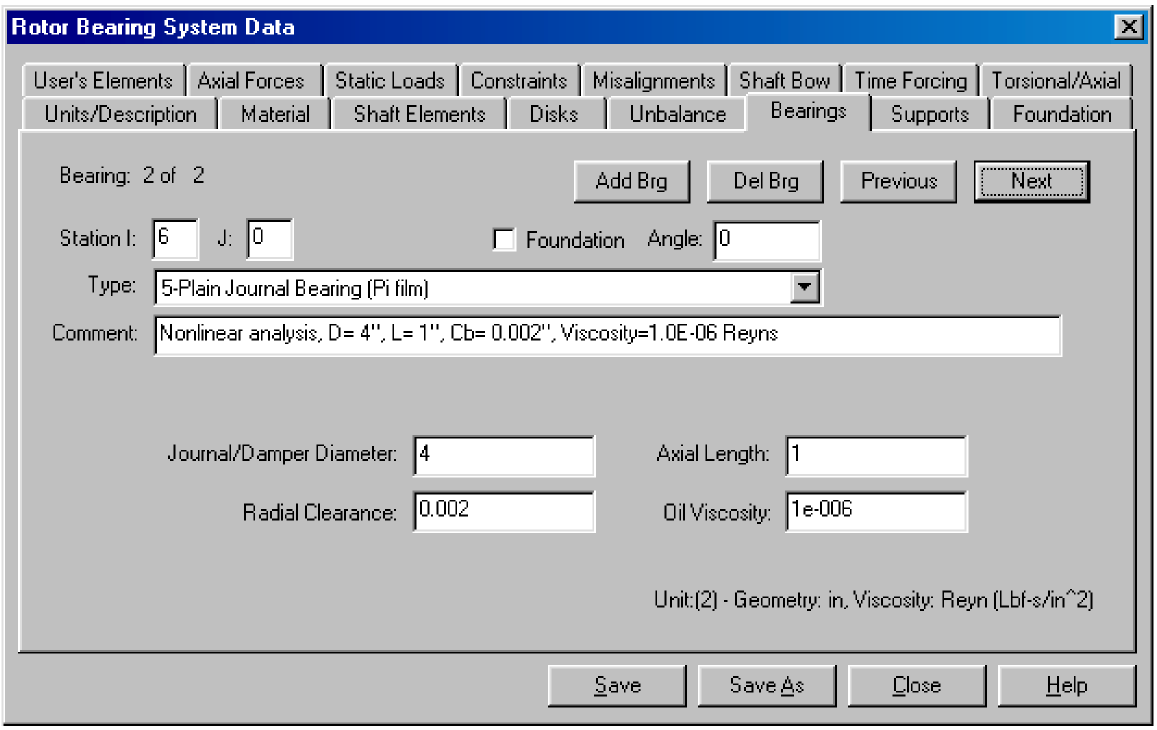

Rotor Bearing System Data
User's Elements
Axial Forces
Static Loads
Constraints
Misalignments
Shaft Bow
Time Forcing
Torsional/Axial
Units/Description
Material
Shaft Elements
Disks
Unbalance
Bearings
Supports
Foundation
Bearing: 3 of 3
Add Brg
Del Brg
Previous
Next
Station I: 3
J: 0
Foundation
Angle: 0
Type: 4-Squeeze Film Damper
Comment: Squeeze Film Damper, D=2", L=1", C=0.004", V=1.9e-07 reyns, Kc=0, Cc=0
Damper Properties
Journal/Damper Diameter: 2
Axial Length: 1
Radial Clearance: 0.004
Oil Viscosity: 1.9e-007
Damper Model: Short Bearing - Circular Synchronous Precession - pi film
Centering Spring Properties
Stiffness: 0
Damping: 0
Unit:(1) - Geometry: in, Viscosity: Reyn (Lbf-s/in^2), K: Lbf/in, C: Lbf-s/in
Save
Save As
Close
Help

Plain Journal Bearing

A plain journal bearing model based on π film short bearing theory is provided. The incompressible laminar Reynolds equation for the short bearing theory is:

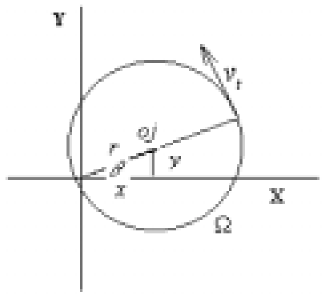
$$\frac{\partial}{\partial Z}\left(\frac{h^3}{\mu}\frac{\partial P}{\partial Z}\right) = 6\ \omega_j \frac{\partial h}{\partial \theta} + 12\frac{\partial h}{\partial t}$$

The data fields are self-explanatory. In the right bottom of the screen, the proper units for the specified unit system are displayed for reference.



Generalized Non-Linear Isotropic Bearings

Two types of the generalized non-linear isotropic bearing are provided in this bearing option. This option replaces the previous rolling element bearing with clearance.



(x, y) are shaft displacements and $r = \sqrt{x^2 + y^2}$. The tangential velocity of the shaft at the contact point

$$v_t = R\,\Omega + (-\dot{x}\sin\theta + \dot{y}\cos\theta) = R\,\Omega + \left(\frac{-\dot{x}y + \dot{y}x}{r}\right)$$

$(-F_r)$ is the radial restoring force acting on the shaft due to radial displacement, $(-F_t)$ is the tangential force due to Coulomb Friction:

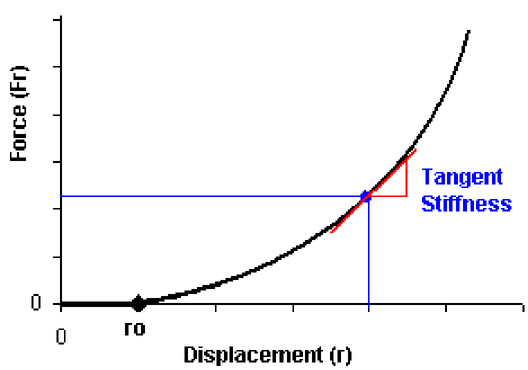
$$-F_t = \mu\,(\text{-}F_r)\,sign(v_t)$$

The total forces action on the shaft due to displacement (r), friction (μ), and linear damping (C) are:

$$F_x = (-F_r)\cos\theta - (-F_t)\sin\theta - C\dot{x}$$
$$F_y = (-F_r)\sin\theta + (-F_t)\cos\theta - C\dot{y}$$

Two types of equations are provided for the radial force and they are:

Case 1: Continuous Force-Displacement Curve



When $r < r_0$ (deadband or gap)

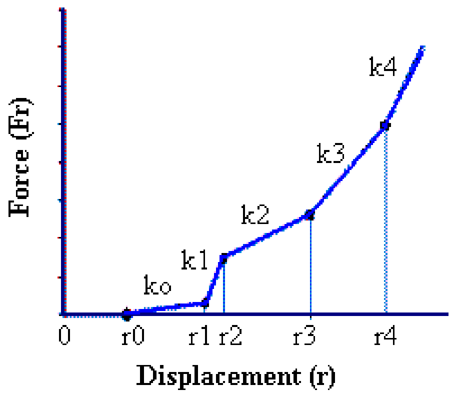
$F_r = 0,\ F_t = 0,\ F_x = 0,\ F_y = 0$ No forces are action on the shaft

When $r_0 \le r$

$$F_r = k_0 (r - r_0)^{a_0} + k_1 (r - r_0)^{a_1} + k_2 (r - r_0)^{a_2} + k_3 (r - r_0)^{a_3} + k_4 (r - r_0)^{a_4}$$
$$F_t = \mu\, F_r\ sign(v_t)$$

Note that r_0 can be zero if no gap or deadband exists.

Case 2: Piecewise linear curves



where k_i is the slope from r_i to r_{i+1}

When $r < r_0$ (deadband or gap)

$F_r = 0,\ F_t = 0,\ F_x = 0,\ F_y = 0$ No forces are action on the shaft

When $r_0 \le r < r_1$

$$F_r = k_0\ (r - r_0)$$
$$F_t = \mu_0\ F_r$$

When $r_1 \le r < r_2$

$$F_r = k_0\ (r_1 - r_0) + k_1\ (r - r_1)$$
$$F_t = \mu_1\ F_r$$

When $r_2 \le r < r_3$

$$F_r = k_0\,(r_1 - r_0) + k_1\,(r_2 - r_1) + k_2\,(r - r_2)$$
$$F_t = \mu_2\, F_r$$

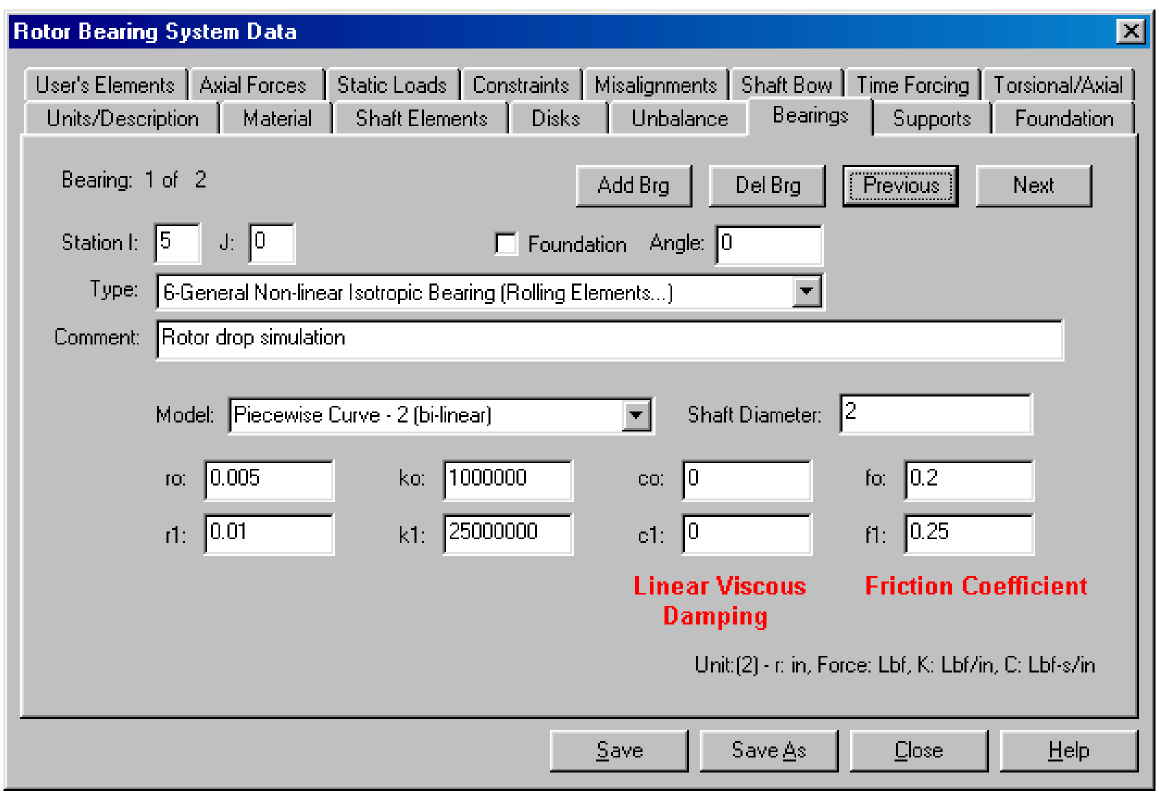
When $r_3 \le r < r_4$

$$F_r = k_0\,(r_1 - r_0) + k_1\,(r_2 - r_1) + k_2\,(r_3 - r_2) + k_3(r - r_3)$$
$$F_t = \mu_3\, F_r$$

When $r_4 \le r$

$$F_r = k_0\,(r_1 - r_0) + k_1\,(r_2 - r_1) + k_2\,(r_3 - r_2) + k_3(r_4 - r_3) + k_4(r - r_4)$$
$$F_t = \mu_4\, F_r$$

A linear rolling element bearing with clearance (deadband) can be modeled in this case.



Active Magnetic Bearing

Two options are used to model the active magnetic bearing. The linear Proportional-Integral-Derivative controller with low pass filter is used in the steady state analysis (Stability and Forced Response Analyses). The nonlinear active magnetic bearing requires more input data and is used in the non-linear transient analysis. For both options, the sensor stations may be different from the bearing stations (sensor non-collocation) and the model may be different for the two bearing axes.

Active Magnetic Bearing 1 - Linear PID controller with low pass filter

This bearing is modeled as a PID controller in series with a unity gain, first order low pass filter (generally used to model the amplifier). Two additional degrees of freedom will be added to each of the x and y equations to model the controller states for each bearing. However, these two additional degrees of freedom will not be available for displaying in the post-processor. The output of the PID controller at each axis is:

$$C_p x_s + C_i \int x_s dt + C_d \dot{x}_s$$

Where x_s is the displacement at sensor location. The control force at each direction in the S-domain is:

$$F = \left(C_p + C_i \frac{1}{s} + C_d s \right) \left(\frac{2\pi\ f_c}{s + 2\pi\ f_c} \right) x_s$$

Active Magnetic Bearing 2 - Non-Linear Transient Analysis

This bearing is a standard PID controlled active magnetic bearing with sensor non-collocation, gap non-linearity and current saturation effects for the transient analysis only. The control current is determined from the following expression:

$$i_c = C_p x_s + C_i \int x_s dt + C_d \dot{x}_s$$

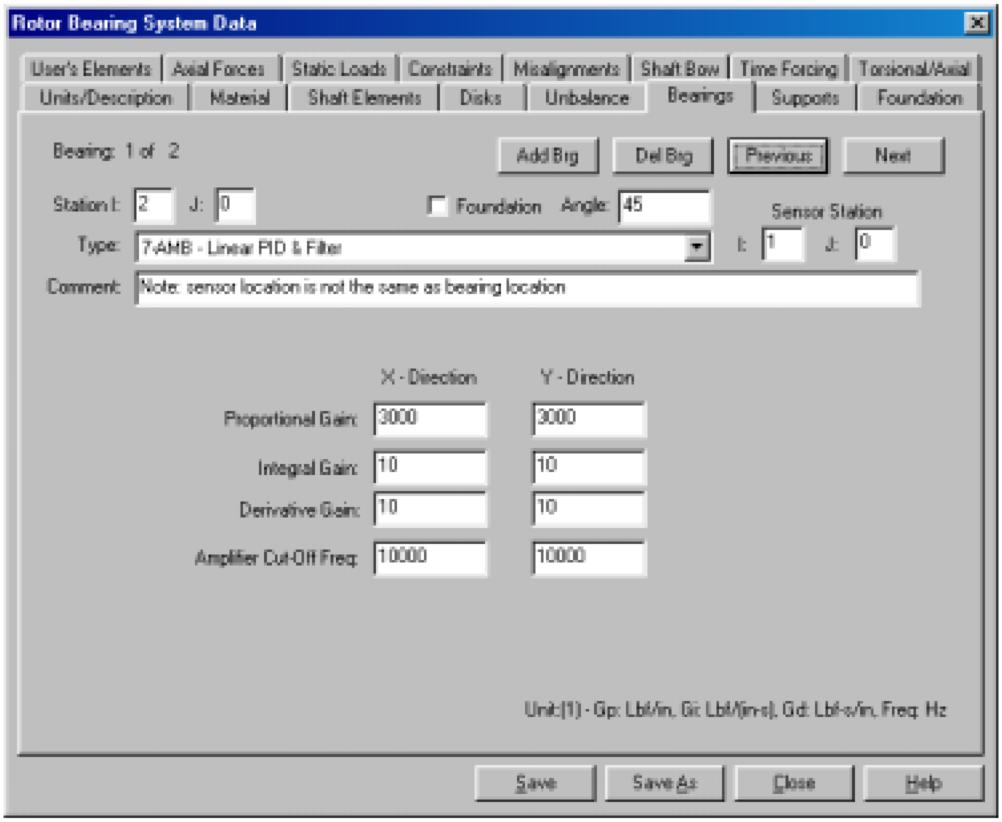
The currents supplied to the magnetic bearing are determined from the following:

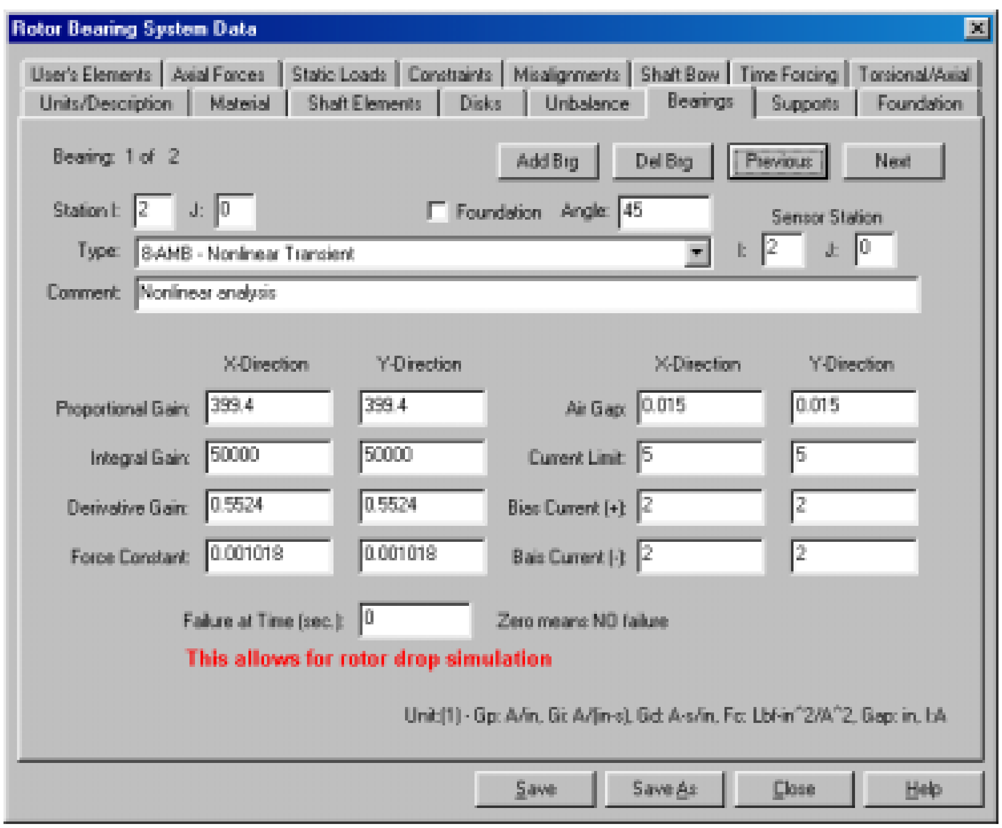
$$i_1 = i_{b,p} - i_c \qquad\qquad i_2 = i_{b,n} + i_c$$

$$\text{if } \ i < 0, \quad i = 0; \qquad \text{if } \ i > i_{\text{limit}}, \quad i = i_{\text{limit}}$$

The force in the magnetic bearing is:

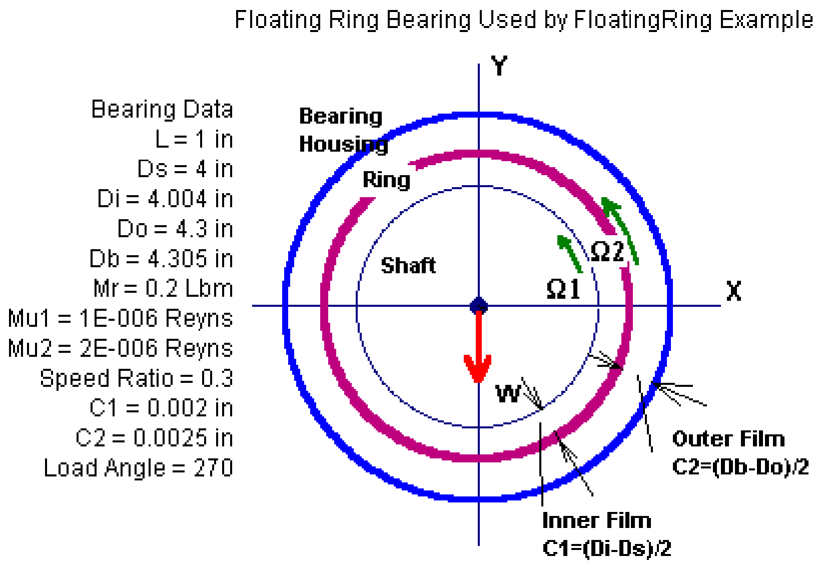
$$F = F_c \cdot \left[\left(\frac{i_1}{h_1} \right)^2 - \left(\frac{i_2}{h_2} \right)^2 \right] \quad \text{where} \quad h_1 = gap - x_b \ \text{ and } \ h_2 = gap + x_b$$

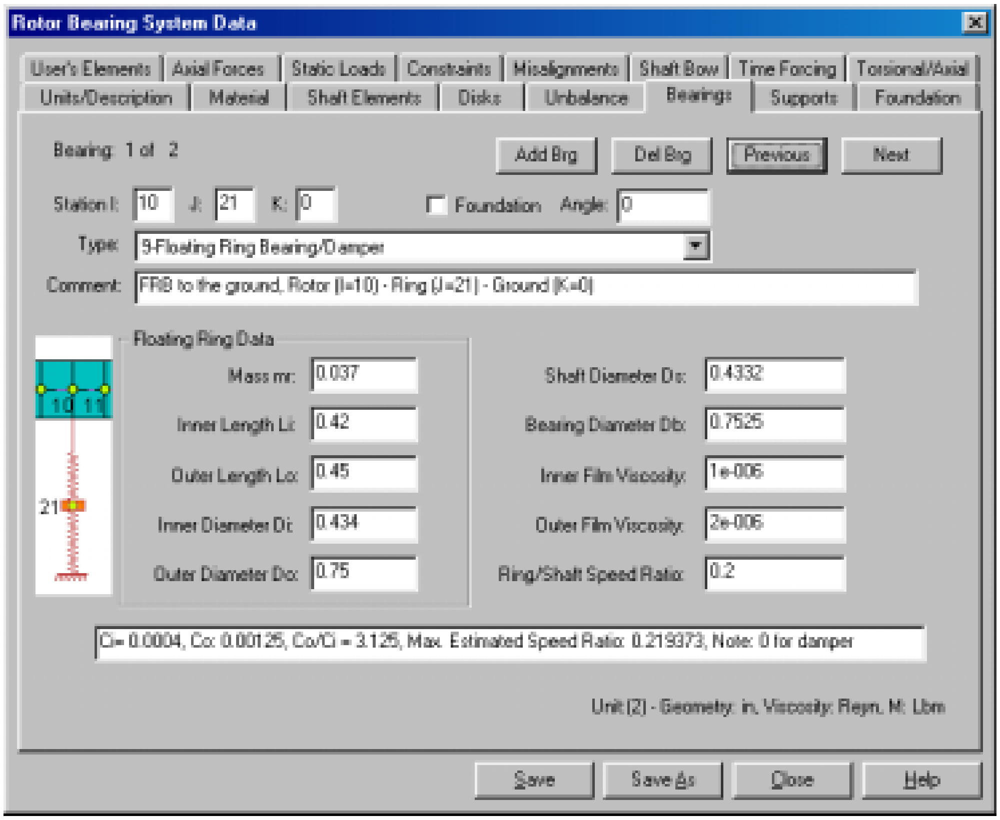

Rotor Bearing System Data
User's Elements | Axial Forces | Static Loads | Constraints | Misalignments | Shaft Bow | Time Forcing | Torsional/Axial
Units/Description | Material | Shaft Elements | Disks | Unbalance | Bearings | Supports | Foundation
Bearing: 1 of 2
Add Brg
Del Brg
Previous
Next
Station I: 2 J: 0
Foundation
Angle: 45
Sensor Station
I: 1 J: 0
Type: 7-AMB - Linear PID & Filter
Comment: Note: sensor location is not the same as bearing location
X - Direction
Y - Direction
Proportional Gain: 3000 3000
Integral Gain: 10 10
Derivative Gain: 10 10
Amplifier Cut-Off Freq: 10000 10000
Unit:(1) - Gp: Lbf/in, Gi: Lbf/(in-s), Gd: Lbf-s/in, Freq: Hz
Save
Save As
Close
Help

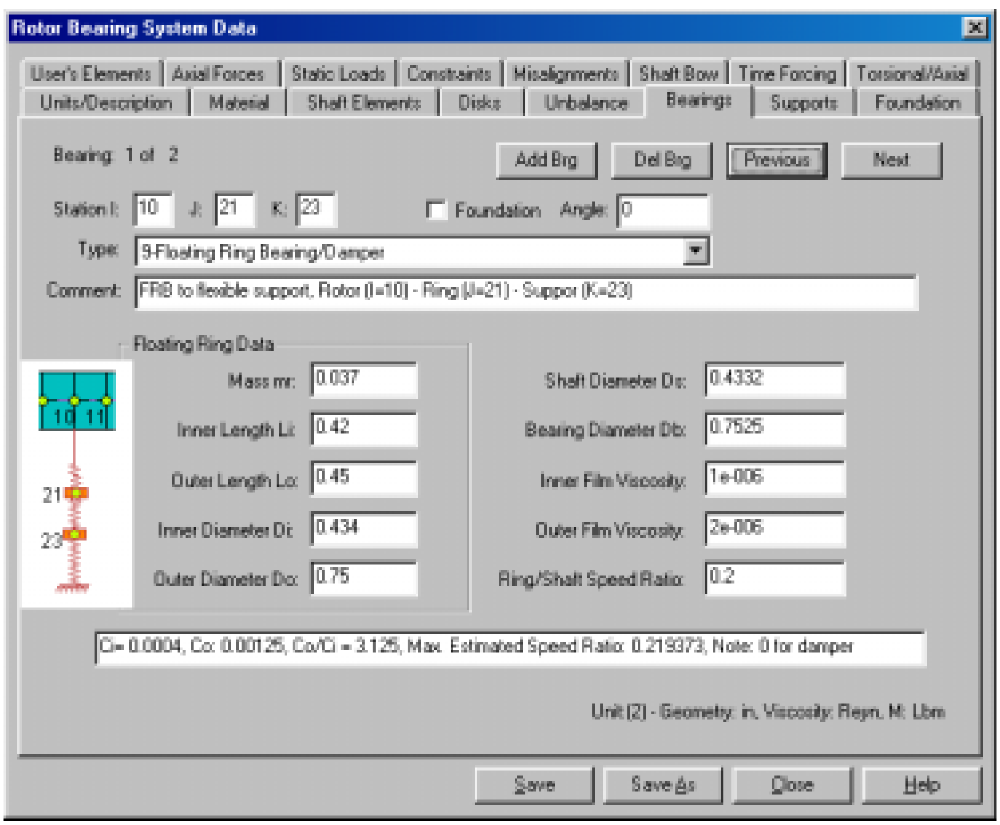

Rotor Bearing System Data
User's Elements | Axial Forces | Static Loads | Constraints | Misalignments | Shaft Bow | Time Forcing | Torsional/Axial
Units/Description | Material | Shaft Elements | Disks | Unbalance | Bearings | Supports | Foundation
Bearing: 1 of 2
Add Brg
Del Brg
Previous
Next
Station I: 2 J: 0
Foundation
Angle: 45
Sensor Station
I: 2 J: 0
Type: 8-AMB - Nonlinear Transient
Comment: Nonlinear analysis
X-Direction
Y-Direction
Proportional Gain: 399.4 399.4
Integral Gain: 50000 50000
Derivative Gain: 0.5524 0.5524
Force Constant: 0.001018 0.001018
X-Direction
Y-Direction
Air Gap: 0.015 0.015
Current Limit: 5 5
Bias Current (+): 2 2
Bais Current (-): 2 2
Failure at Time (sec.): 0
Zero means NO failure
This allows for rotor drop simulation
Unit:(1) - Gp: A/in, Gi: A/(in-s), Gd: A-s/in, Fc: Lbf-in^2/A^2, Gap: in, I:A
Save
Save As
Close
Help

Floating Ring Bearing

Floating Ring Bearing can be treated as two fluid film bearings in series. The inner film has two rotating surface (shaft and ring). The outer film bearing has only one rotating surface (ring). Additional two degrees of freedom are introduced for each floating ring bearing due to its ring mass. The ring mass station is a support station which is automatically created when floating ring bearing is selected. The ring mass cannot be zero to ensure the mass matrix being positive definite. The Station I is the station at the rotor, Station J is the ring station, and Station K is the support station. If K=0, the floating ring bearing is connected to the ground. If K is not zero, then a support must be created by using the **Support** tab.

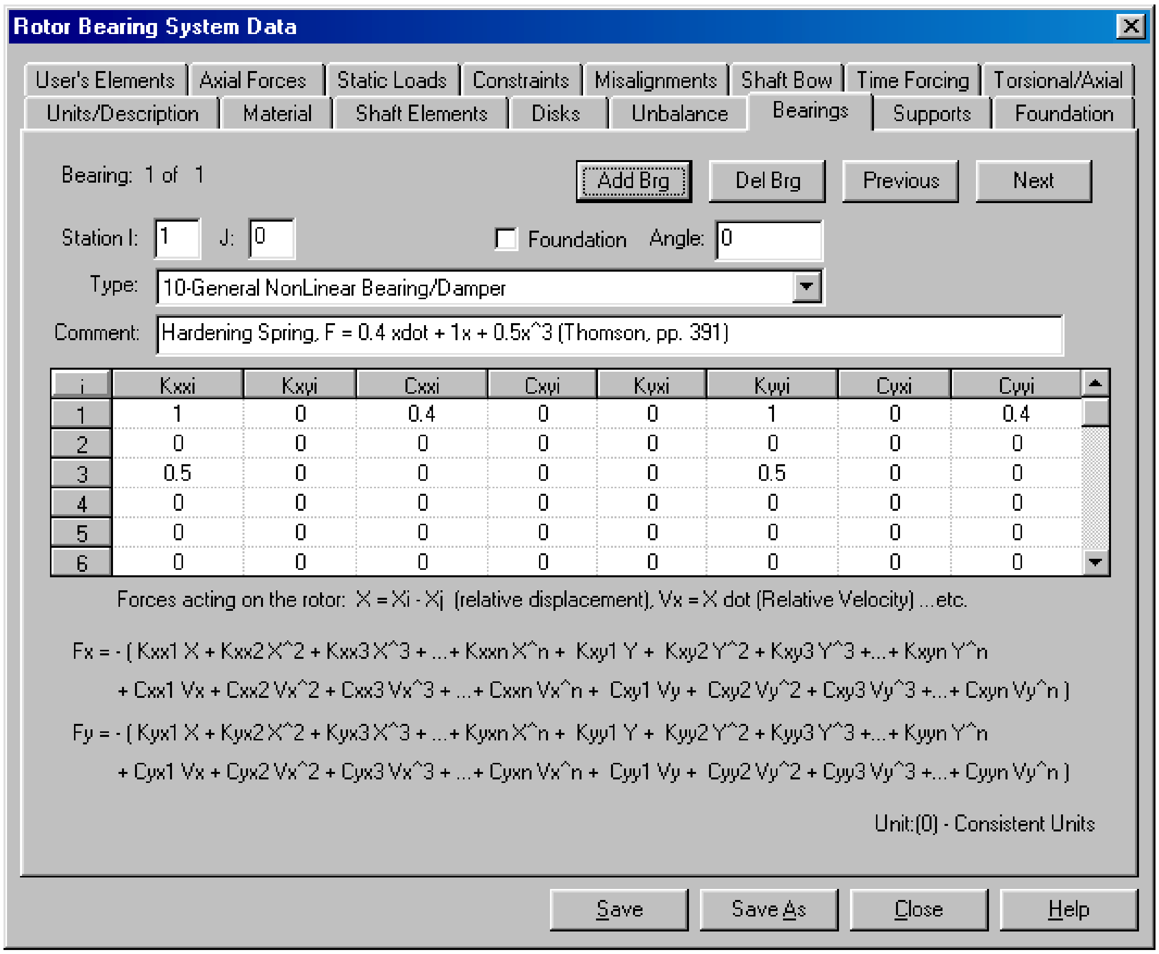



Rotor Bearing System Data
User's Elements
Axial Forces
Static Loads
Constraints
Misalignments
Shaft Bow
Time Forcing
Torsional/Axial
Units/Description
Material
Shaft Elements
Disks
Unbalance
Bearings
Supports
Foundation
Bearing 1 of 2
Add Brg
Del Brg
Previous
Next
Station I: 10 J: 21 K: 0
Foundation
Angle: 0
Type: 9-Floating Ring Bearing/Damper
Comment: FRB to the ground, Rotor (I=10) - Ring (J=21) - Ground (K=0)
Floating Ring Data
Mass mr: 0.037
Inner Length Li: 0.42
Outer Length Lo: 0.45
Inner Diameter Di: 0.434
Outer Diameter Do: 0.75
Shaft Diameter Ds: 0.4332
Bearing Diameter Db: 0.7525
Inner Film Viscosity: 1e-006
Outer Film Viscosity: 2e-006
Ring/Shaft Speed Ratio: 0.2
10 11
21
Ci= 0.0004, Co: 0.00125, Co/Ci = 3.125, Max. Estimated Speed Ratio: 0.219373, Note: 0 for damper
Unit (2) - Geometry: in, Viscosity: Reyn, M: Lbm
Save
Save As
Close
Help


Rotor Bearing System Data
User's Elements
Axial Forces
Static Loads
Constraints
Misalignments
Shaft Bow
Time Forcing
Torsional/Axial
Units/Description
Material
Shaft Elements
Disks
Unbalance
Bearings
Supports
Foundation
Bearing 1 of 2
Add Brg
Del Brg
Previous
Next
Station I: 10 J: 21 K: 23
Foundation
Angle: 0
Type: 9-Floating Ring Bearing/Damper
Comment: FRB to flexible support, Rotor (I=10) - Ring (J=21) - Suppor (K=23)
Floating Ring Data
Mass mr: 0.037
Inner Length Li: 0.42
Outer Length Lo: 0.45
Inner Diameter Di: 0.434
Outer Diameter Do: 0.75
Shaft Diameter Ds: 0.4332
Bearing Diameter Db: 0.7525
Inner Film Viscosity: 1e-006
Outer Film Viscosity: 2e-006
Ring/Shaft Speed Ratio: 0.2
10 11
21
23
Ci= 0.0004, Co: 0.00125, Co/Ci = 3.125, Max. Estimated Speed Ratio: 0.219373, Note: 0 for damper
Unit (2) - Geometry: in, Viscosity: Reyn, M: Lbm
Save
Save As
Close
Help

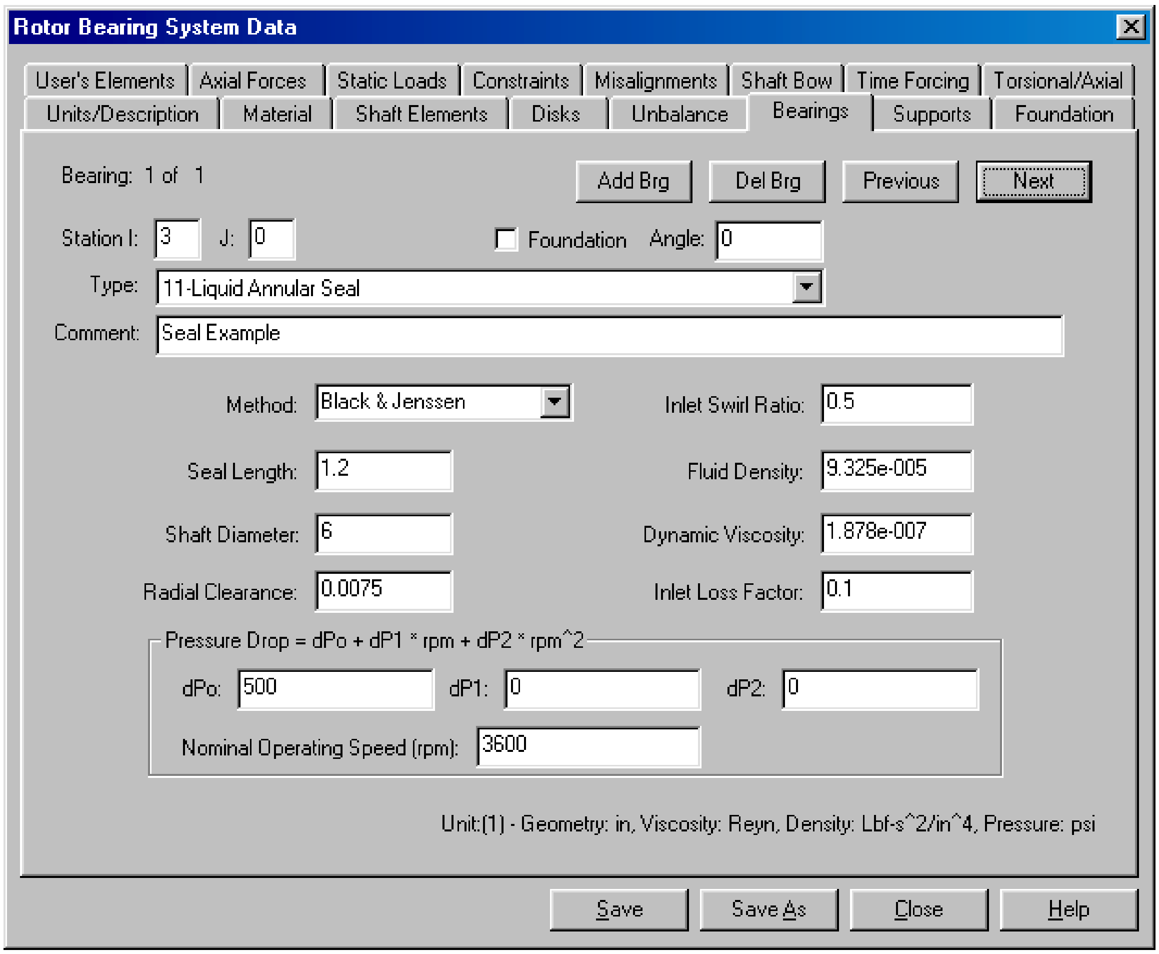
General Non-Linear Polynomial Bearing

This is a general non-linear bearing. The bearing characteristics is modeled as a polynomial as shown below:



Liquid Annular Seal

The liquid annular seals used in the pumps are known to raise the "dry" critical speeds by a considerable amount. The mathematical model of the liquid annular seal is similar to the bearing model. The dynamic coefficients are calculated from the given seal data and pressure drop. Two models are available: one is based on Black & Jenssen and the other is based on Childs (1983).



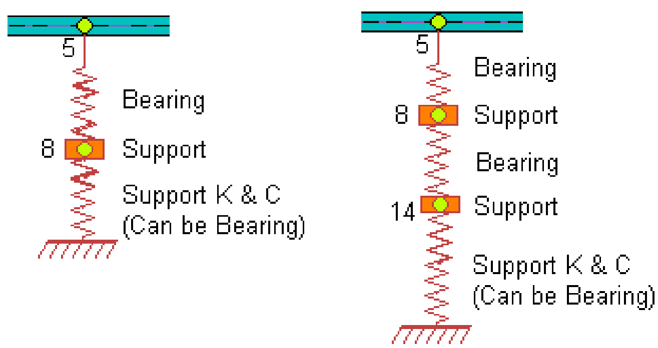
Flexible Supports

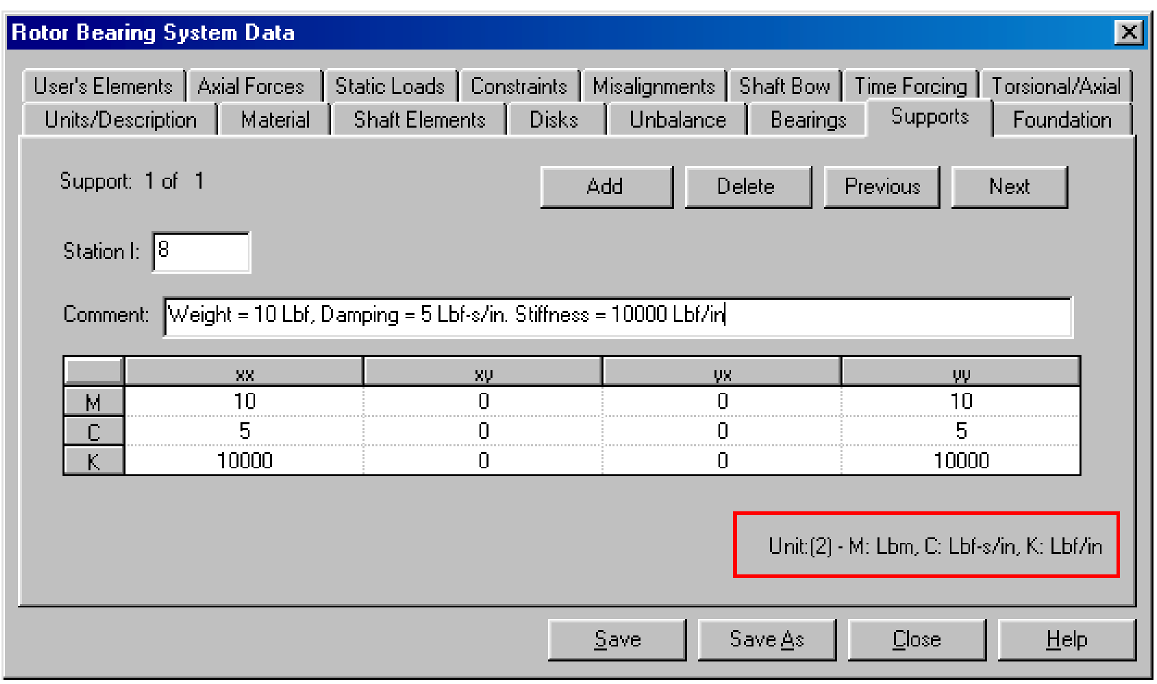
Two translational displacements are used to describe the motion of a flexible support, i.e. two degrees-of-freedom at each support station. A support is connected to a rigid ground through the support stiffness and damping. Note that the support stiffness and damping can be zero if the support is not connected to the rigid ground; however, the support mass cannot be zero. The flexible supports are considered to be non-rotating components with the exception of floating ring bushing. The rotational displacements (slopes) are constrained automatically in the modeling process.

Station I: Support station number. Note that this station has to connected to the rotor station or another support by a bearing.

Comment: Description of this support.

Coefficients: Mass (M), Damping (C), and Stiffness (K) Coefficients.



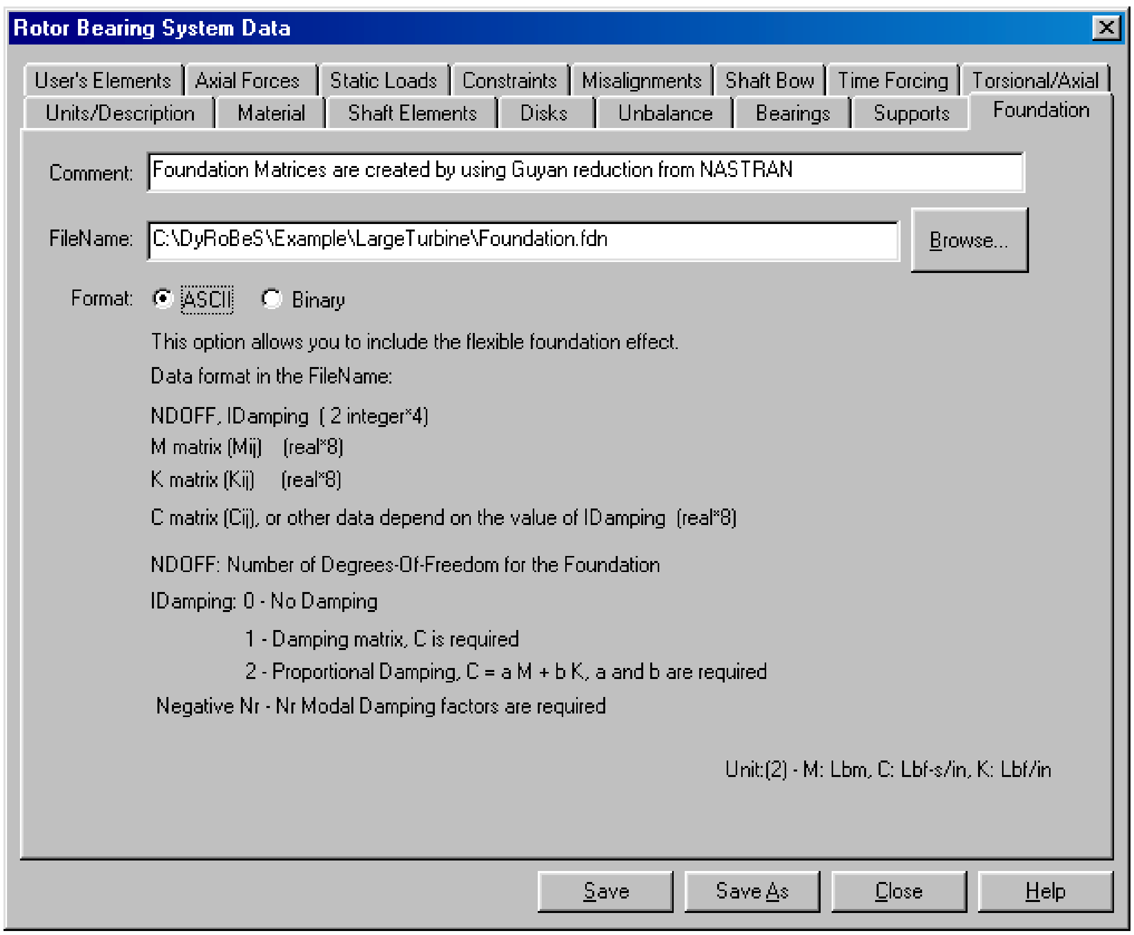


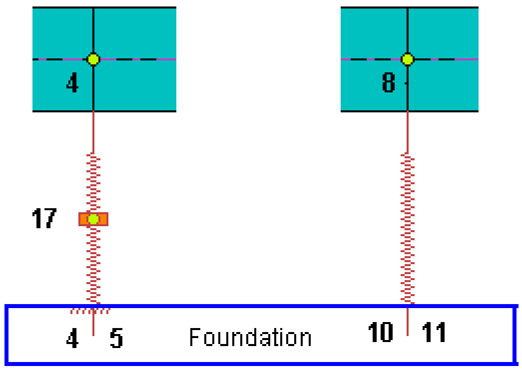
Foundation

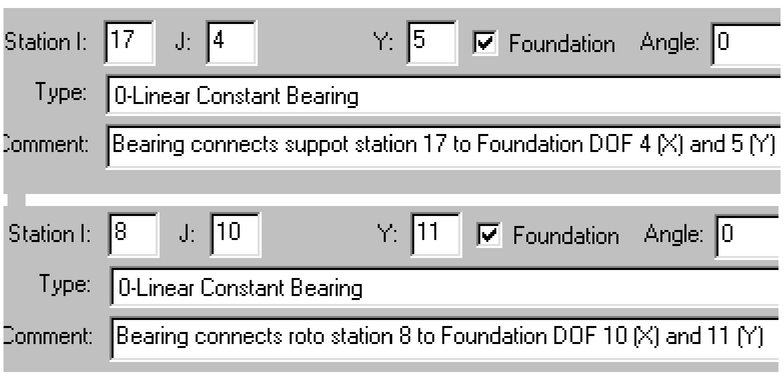
In contrast to a two (2) degrees-of-freedom flexible support, a foundation can possess NDOFF degrees-of-freedom and NDOFF >= 2. If not specified, foundation is considered to be rigid. The foundation matrices can be created by using general Finite Element Programs, such as NASTRAN or ANSYS. The foundation is connected to the rotor assembly by bearings. The foundation box needs to be checked in the bearing connected to the foundation. The J and Y are the coordinate entries in the foundation matrices. When foundation is included, one should always check the ASCII output from Lateral Vibration Model Summary, which includes the modal analysis for the foundation alone. This can be used to verify the foundation data. However, for static deflection and critical speed analysis, foundation is assumed to be rigid.

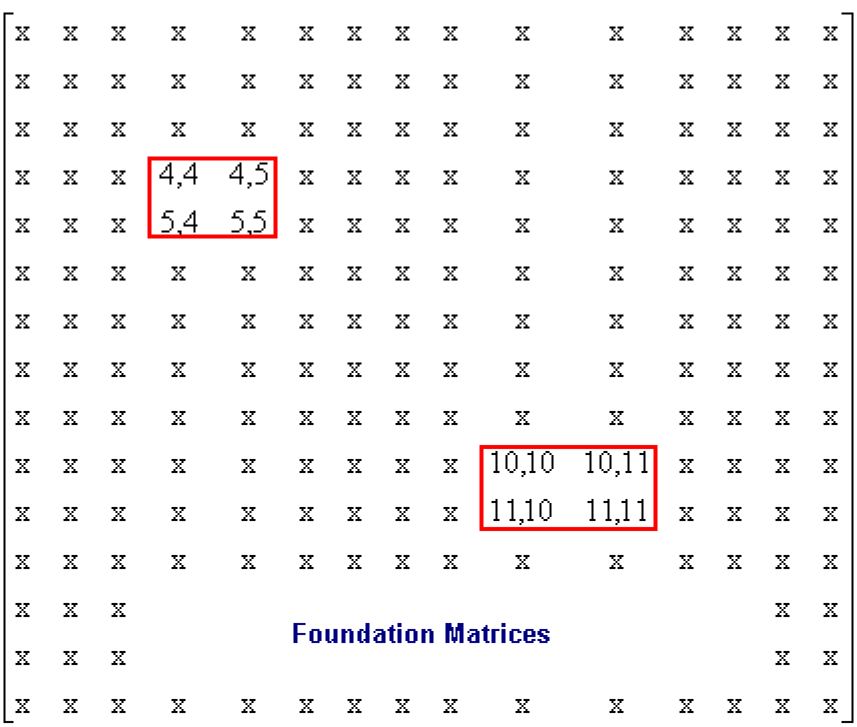
```
****************************** Foundation Data ******************************
 C:\DyRoBeS\Example\Foundation.fdn
 Foundation DOF = 15
************************  Foundation Modal Analysis  ***********************

  Mode   Damping Factor   Damping Coef.     Damped Freq.(R/S)       Hz
    1     .15534E-01       -96.522            6212.8             988.81
    2     .69470E-02       -96.522            13894.             2211.2
    ::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::
   15     .21968E-01       -965.22            43926.             6991.1
*****************************************************************************
```



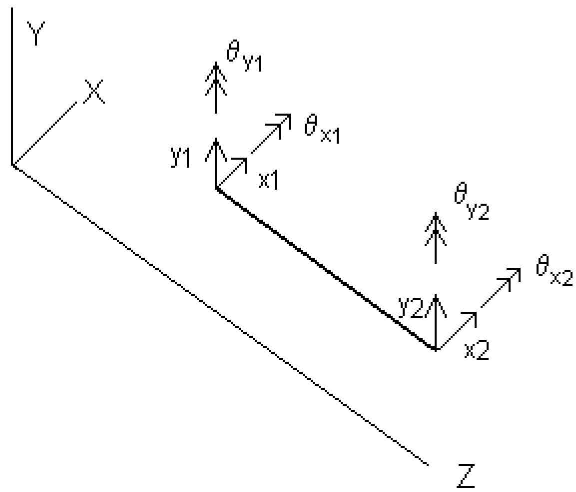

4
8
17
4
5
Foundation
10
11


Station I: 17 J: 4 Y: 5 Foundation Angle: 0
Type: 0-Linear Constant Bearing
Comment: Bearing connects suppot station 17 to Foundation DOF 4 (X) and 5 (Y)
Station I: 8 J: 10 Y: 11 Foundation Angle: 0
Type: 0-Linear Constant Bearing
Comment: Bearing connects roto station 8 to Foundation DOF 10 (X) and 11 (Y)


4,4 4,5
5,4 5,5
10,10 10,11
11,10 11,11
Foundation Matrices

User's Elements

This option allows you to specify your own subelement matrices. An element is assumed to be isotropic, with the (X-Z) and (Y-Z) planes having identical dynamic properties. The rotor shaft centerline is located along the Z-axis. Since the element is isotropic, only the stiffness matrix in the X-Z plane is required. The coordinates for a typical element are shown in the following figure.



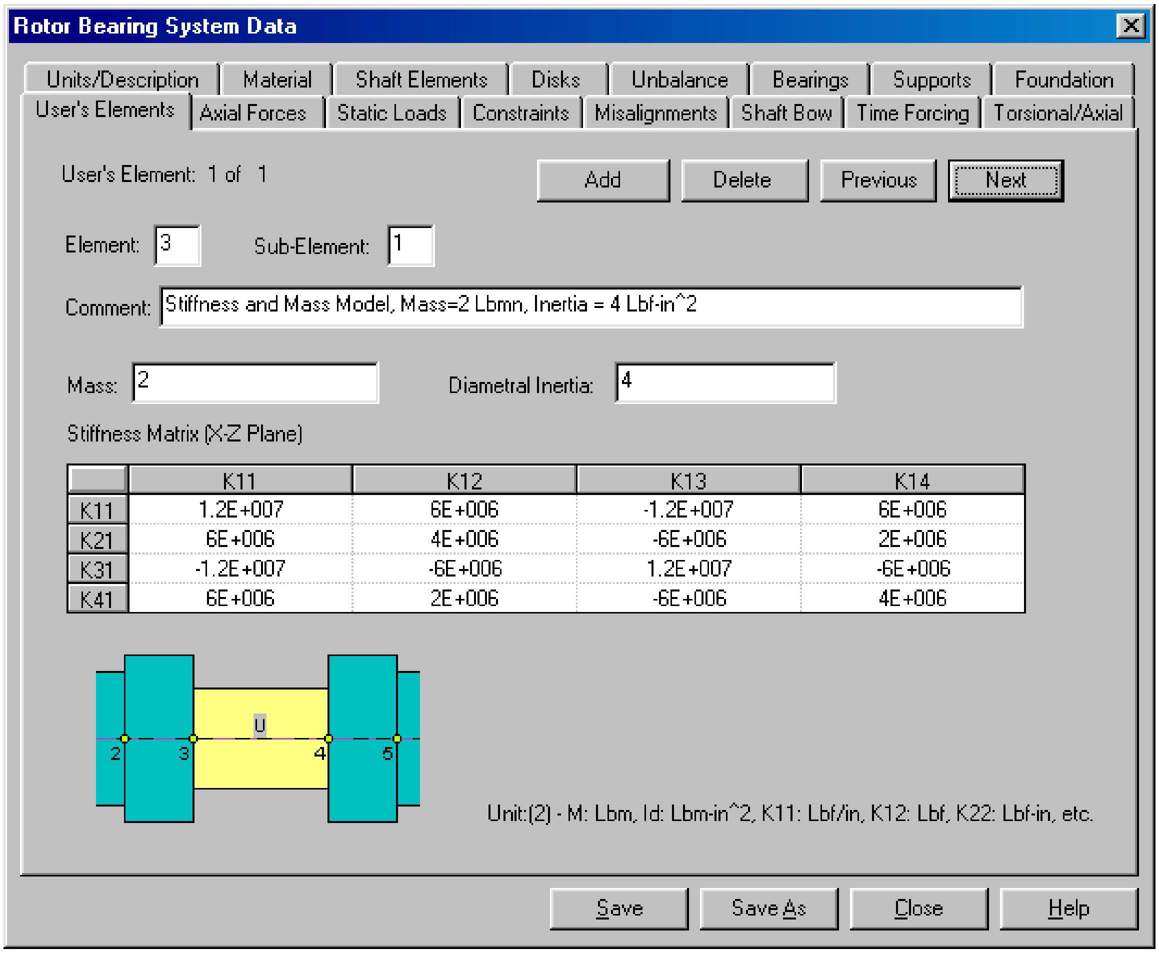
The element total mass and diametral moment of inertia are used to establish the mass matrix. The mass matrix in the (X-Z) plane will be:

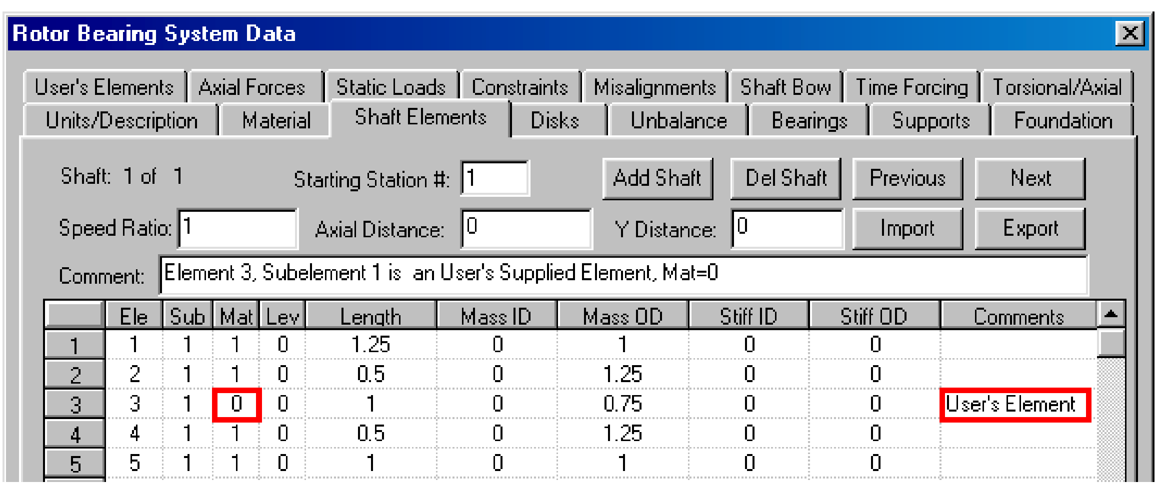
$$\begin{bmatrix} m/2 & 0 & 0 & 0 \\ 0 & I_d/2 & 0 & 0 \\ 0 & 0 & m/2 & 0 \\ 0 & 0 & 0 & I_d/2 \end{bmatrix} \quad \text{for} \quad \begin{Bmatrix} \ddot{x}_1 \\ \ddot{\theta}_{y1} \\ \ddot{x}_2 \\ \ddot{\theta}_{y2} \end{Bmatrix}$$

The user supplied (4x4) stiffness matrix in the (X-Z) plane will be:

$$\begin{bmatrix} K_{11} & K_{12} & K_{13} & K_{14} \\ K_{21} & K_{22} & K_{23} & K_{24} \\ K_{31} & K_{32} & K_{33} & K_{34} \\ K_{41} & K_{42} & K_{43} & K_{44} \end{bmatrix} \quad \text{for} \quad \begin{Bmatrix} x_1 \\ \theta_{y1} \\ x_2 \\ \theta_{y2} \end{Bmatrix}$$

The stiffness matrix is symmetric, only the upper half is used in the formulation of the element stiffness matrix. The Material Number in the Shaft Elements data page should be set to 0 for User Supplied Elements.

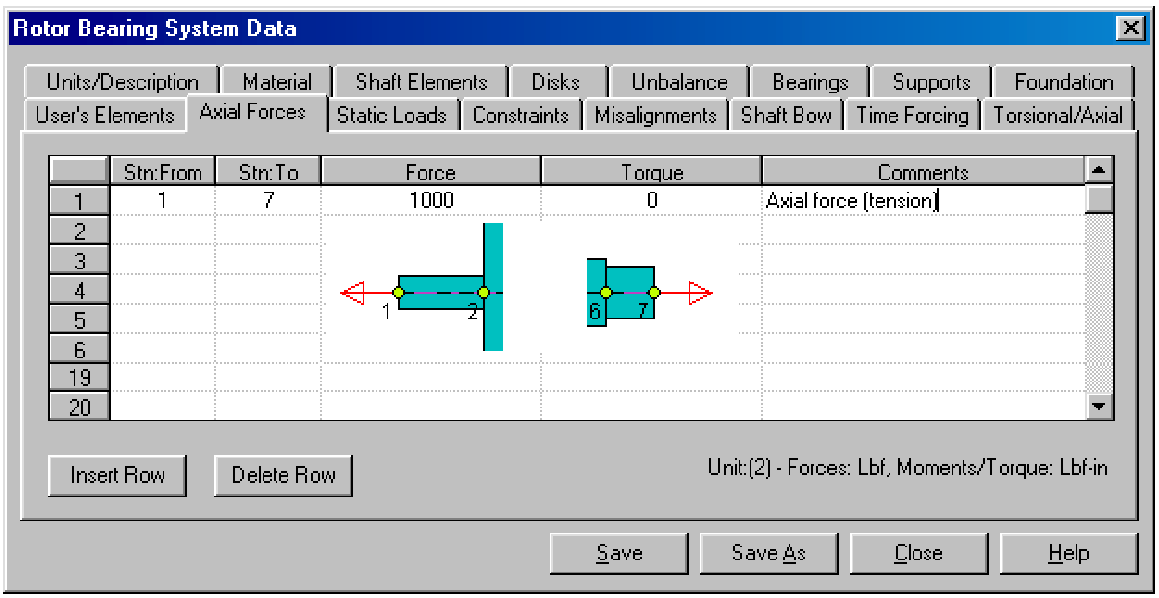

Rotor Bearing System Data
Units/Description | Material | Shaft Elements | Disks | Unbalance | Bearings | Supports | Foundation
User's Elements | Axial Forces | Static Loads | Constraints | Misalignments | Shaft Bow | Time Forcing | Torsional/Axial
User's Element: 1 of 1
Add | Delete | Previous | Next
Element: 3 Sub-Element: 1
Comment: Stiffness and Mass Model, Mass=2 Lbmn, Inertia = 4 Lbf-in^2
Mass: 2 Diametral Inertia: 4
Stiffness Matrix (X-Z Plane)
K11 K12 K13 K14
K11 1.2E+007 6E+006 -1.2E+007 6E+006
K21 6E+006 4E+006 -6E+006 2E+006
K31 -1.2E+007 -6E+006 1.2E+007 -6E+006
K41 6E+006 2E+006 -6E+006 4E+006
U
2 3 4 5
Unit:(2) - M: Lbm, Id: Lbm-in^2, K11: Lbf/in, K12: Lbf, K22: Lbf-in, etc.
Save | Save As | Close | Help


Rotor Bearing System Data
User's Elements | Axial Forces | Static Loads | Constraints | Misalignments | Shaft Bow | Time Forcing | Torsional/Axial
Units/Description | Material | Shaft Elements | Disks | Unbalance | Bearings | Supports | Foundation
Shaft: 1 of 1 Starting Station #: 1 Add Shaft | Del Shaft | Previous | Next
Speed Ratio: 1 Axial Distance: 0 Y Distance: 0 Import | Export
Comment: Element 3, Subelement 1 is an User's Supplied Element, Mat=0
Ele Sub Mat Lev Length Mass ID Mass OD Stiff ID Stiff OD Comments
1 1 1 1 0 1.25 0 1 0 0
2 2 1 1 0 0.5 0 1.25 0 0
3 3 1 0 0 1 0 0.75 0 0 User's Element
4 4 1 1 0 0.5 0 1.25 0 0
5 5 1 1 0 1 0 1 0 0

Axial Force and Torque

This option allows you to include the axial forces and torques effects in the model. Note that this option is used for the lateral vibration only. For axial force, tension is defined to be positive in magnitude and compression is defined to be negative. For axial torque, Right Hand Rule is used for the sign convention. A positive axial torque vector points in the positive outward normal direction at the boundary element.

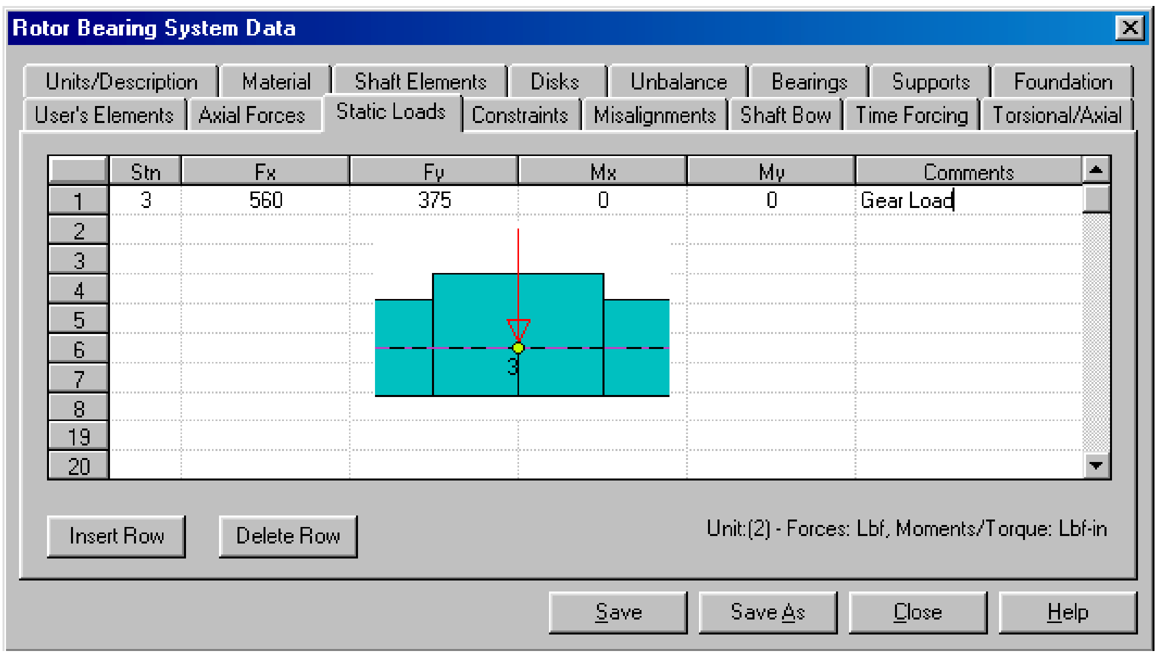
1. **Stn From**: Left starting station number.
2. **Stn To**: Right ending station number.
3. **Force**: Axial force value.
4. **Torque**: Axial torque.value.
5. **Comment**: Description.



Static Loads

The static loads are used in the Static Deflection Analysis and Transient Analysis. The static loads are externally applied loads, such as gear loads. The gravity loads are specified in the run time data folder.

1. **Stn**: Station number where the static loads are applied.
2. **Fx**: Force in the X direction.
3. **Fy**: Force in the Y direction.
4. **Mx**: Moment about the X direction.
5. **My**: Moment about the Y direction.
6. **Comments**: Description.

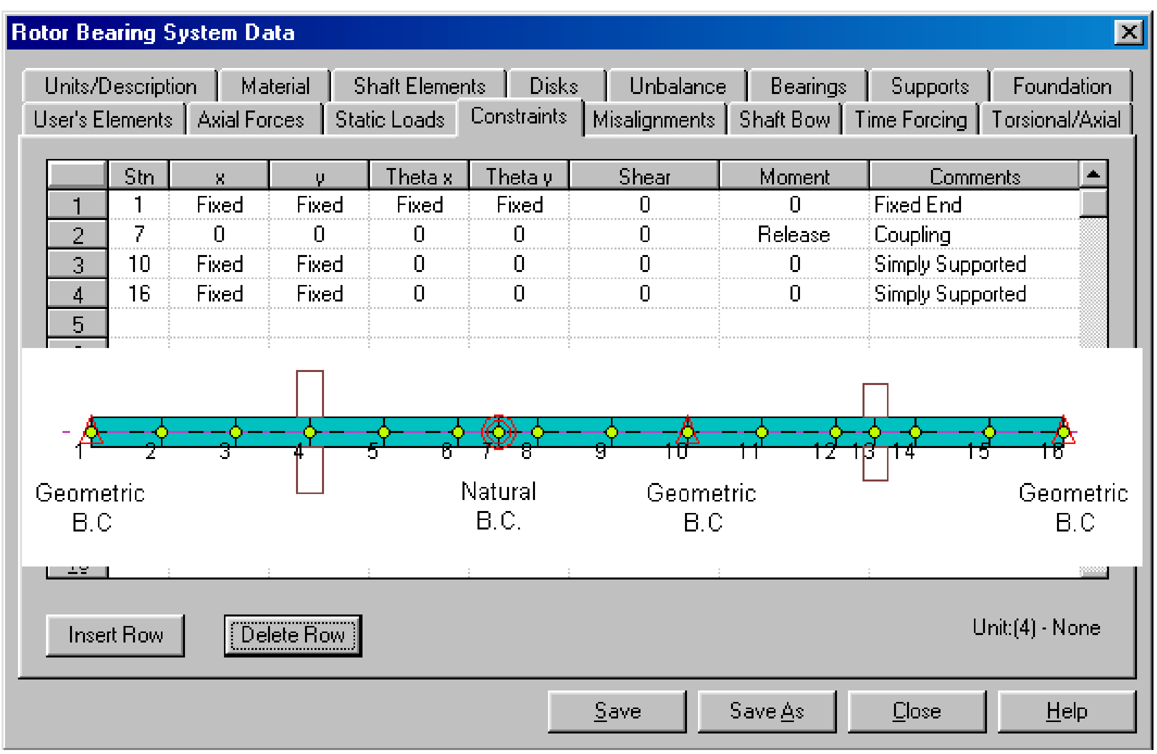


Constraints

This option allows you to model the geometric and natural boundary conditions. Note that this option is used for the lateral vibration only. For the axial and torsional vibrations, the constraints are entered under the Connectivity of Torsion/Axial folder. In the practice of rotordynamics, the geometric constraints are seldom used. They are provided in the program for the theoretical verification with many close form solutions. The natural boundary conditions (Shear/Moment Release) are used mainly for the simulation of a spline or a flexible coupling with moment release.

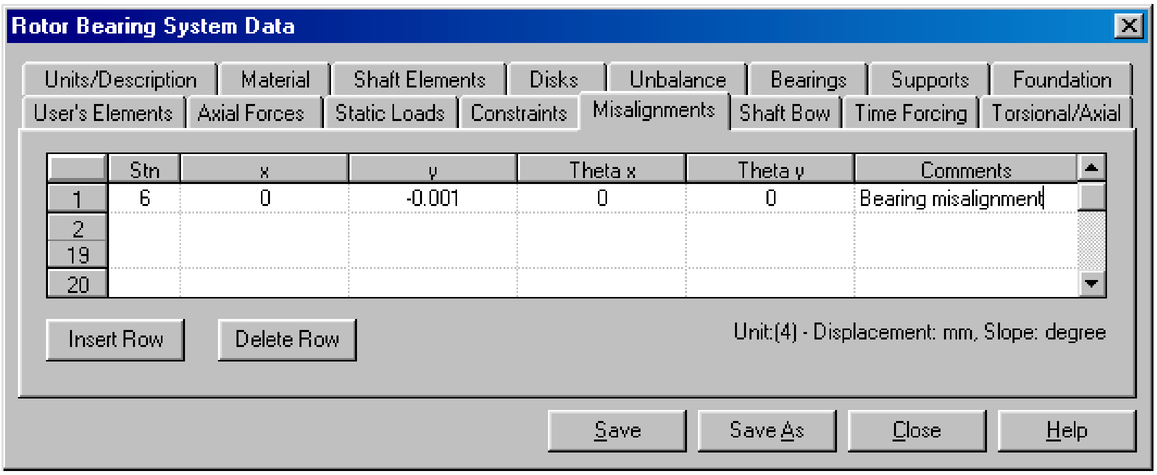
1. **Stn**: Station number where the constraint is imposed.
2. **x**: Translational displacement in the X axis (**F**ixed/**0**-None).
3. **y**: Translational displacement in the Y axis (**F**ixed/**0**-None).
4. **Theta x**: Rotational displacement about X axis (**F**ixed/**0**-None).
5. **Theta y**: Rotational displacement about Y axis (**F**ixed/**0**-None).
6. **Shear**: Shear force release (**R**elease/**0**-None).
7. **Moment**: Moment release (**R**elease/**0**-None).
8. **Comment**: Description.

If both geometric and natural constraints are applied at the same finite element station, the natural boundary conditions are ignored.



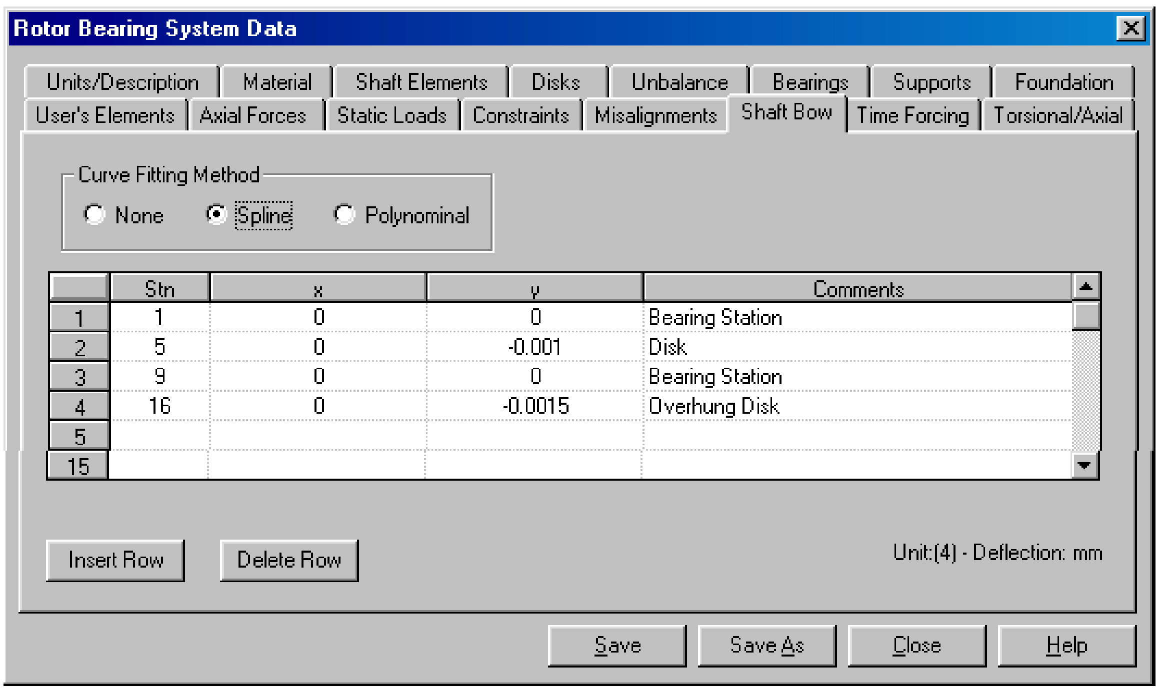
Misalignments

At the present time, the misalignments are used only in the Static Deflection and Constraint Force Calculation.



Shaft Bow

This option allows you to model the shaft residual bow effect. The shaft bow generates synchronous excitation with speed independent magnitude. Since it is not feasible and not practical to input the residual shaft bow (displacements and slopes) for all the finite element stations, two curve fitting options are provided in the program. By selecting **None**, the unspecified displacements and slopes are set to be zero. By selecting **Spline** or **Polynomial**, the unspecified displacements are interpolated or extrapolated from the given displacements and the slopes are derived from the displacements. The disk skew caused by the shaft bow is added to the total disk skew angle.



Time Forcing Functions

This option allows you to model almost any type of excitation forces/moments, such as synchronous (unbalance, blade loss, etc.), non-synchronous (gear mesh, etc.), any harmonics, step, constant, impulse, etc. The excitation is applied when $t_1 \le t < t_2$. Multiple excitations can be applied at the same station. The combination of various types of excitation allows you to model almost any forms of excitation.

1. **Stn**: Station number where the excitation is applied.
2. **Dir**: Coordinate at which the excitation is applied. 1 – force in x direction, 2- force in y direction, 3 – moment about x axis, 4 – moment about y axis.
3. **Type**: Excitation type. Various types are defined below.
4. **Start (t1)**: Starting time at which the excitation is applied.
5. **Stop (t2)**: Stop time at which the excitation is ended.
6. **Par 1, 2, 3, 4**: Parameters used to define the excitation. They are defined below.
7. **Comment**: Description.

Various types of excitations are defined below. Note that the excitation is applied when $t_1 \le t < t_2$.

Type = 0 Exponentially Decay Force

$$F = F_m \, e^{(-\lambda (t-t_1))} \cos(\omega_{exc}(t-t_1)+\phi)$$

where, $F_m = \text{Par1}$, $\lambda = \text{Par 2}$, $\omega_{exc} = \text{Par 3 (rpm)}$, $\phi = \text{Par4 (degree)}$ are the input parameters. By properly adjusting these parameters, the excitation can be in many other forms. For example:

if $\lambda = 0$	the force is a purely harmonic force.
If $\lambda = 0,\ \omega_{exc} = 0,\ \phi = 0$	the force is a step constant

Type = 1 Purely Harmonics

$$F = F_c \ \cos(\omega_{exc}(t-t_1)) + F_s \ \sin(\omega_{exc}(t-t_1))$$

where, $F_c = \text{Par1}$, $F_s = \text{Par2}$, $\omega_{exc} = \text{Par 3 (rpm)}$.

Type = 2 Step Constant

$$F = F_0$$

where, $F_0 = \text{Par1}$. If t2 = t1, or the time interval is very small, then the excitation becomes impulse force. Caution must be taken in the case of the impulse excitation, that is, t1 must be in the discrete time point.

Type = 3 Linear function

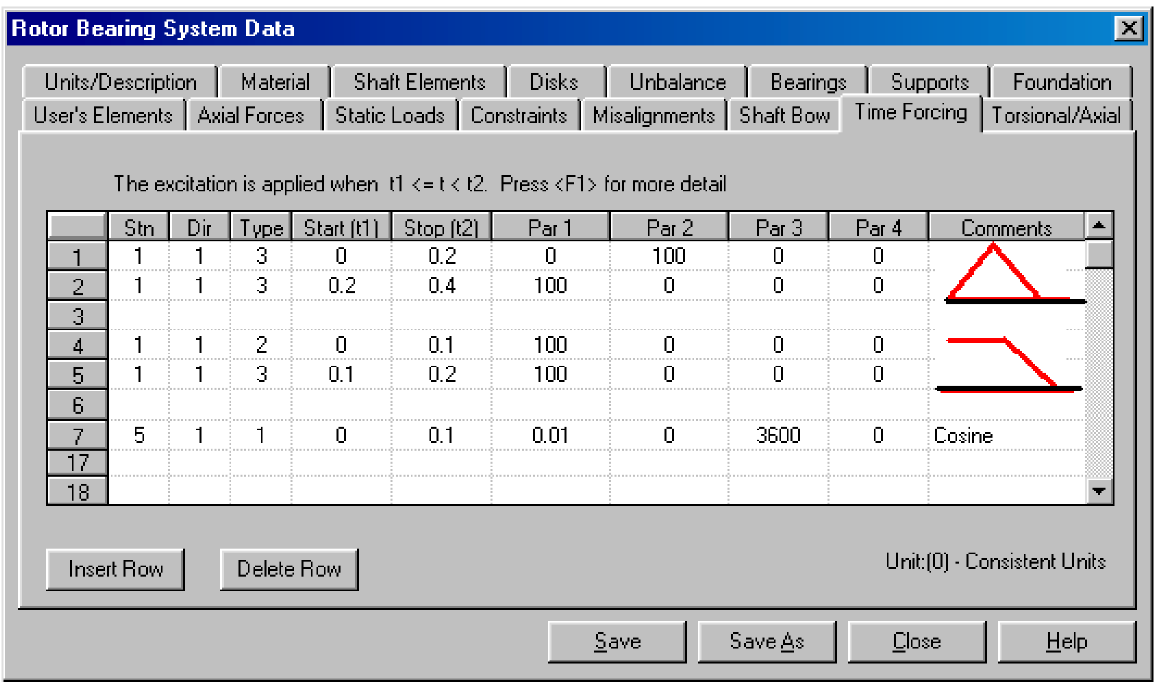
$$F = F_1 \ \text{at} \ t_1 \quad , \text{and} \quad F = F_2 \ \text{at} \ t_2$$

where, $F_1 = \text{Par1}$, and $F_2 = \text{Par2}$

Type = 4 Polynomial function

$$F = F_0 + F_1(t - t_1) + F_2(t - t_1)^2 + F_3(t - t_1)^3$$

where, $F_0 = \text{Par1}$, $F_1 = \text{Par2}$, $F_2 = \text{Par3}$, $F_3 = \text{Par4}$

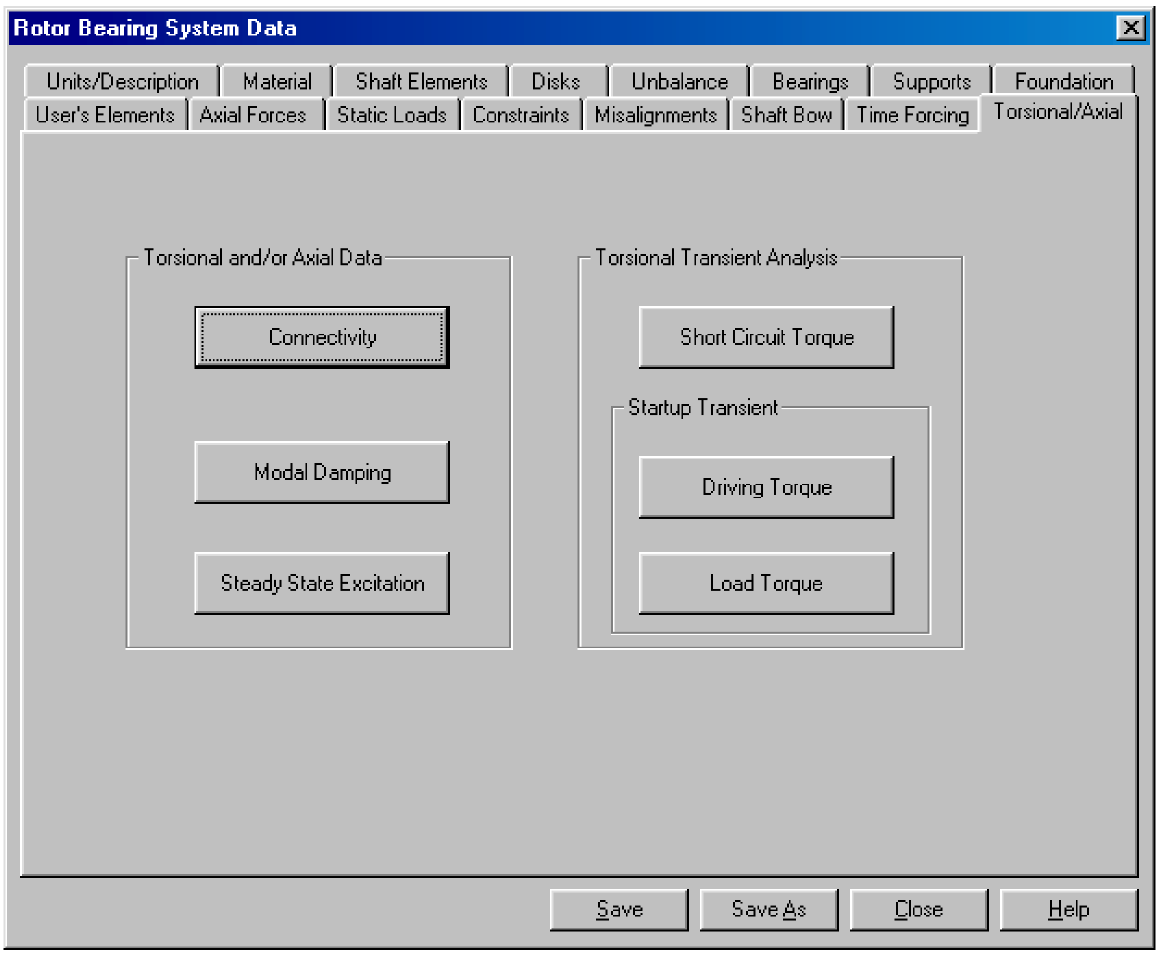


	Stn	Dir	Type	Start (t1)	Stop (t2)	Par 1	Par 2	Par 3	Par 4	Comments
1	1	1	3	0	0.2	0	100	0	0	
2	1	1	3	0.2	0.4	100	0	0	0	
3										
4	1	1	2	0	0.1	100	0	0	0	
5	1	1	3	0.1	0.2	100	0	0	0	
6										
7	5	1	1	0	0.1	0.01	0	3600	0	Cosine
17										
18										

Torsional/Axial Data

This folder allows you to input the additional data required for Torsional and/or Axial vibrations. The buttons for Connectivity, Modal Damping, and Steady State Excitation are for torsional or axial vibration. The buttons for Short Circuit Torque, Driving Torque, and Load Torque are only for torsional transient analysis.

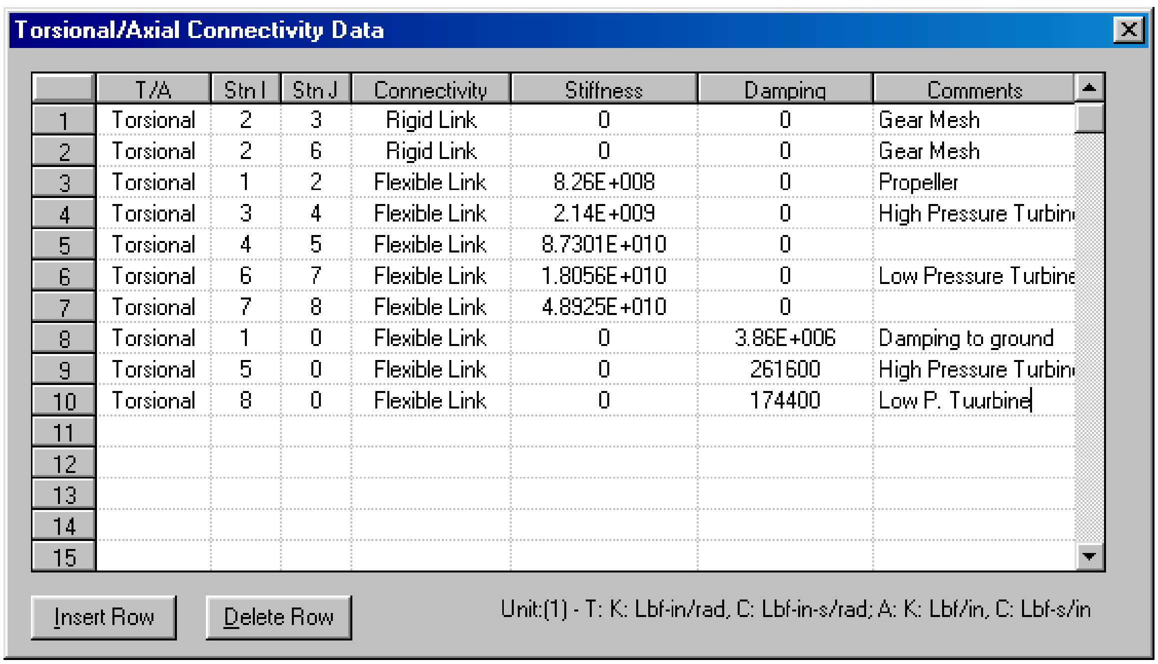
The Connectivity allows you to input the linear stiffness and damping or constraints. The Modal Damping allows you to input the damping factors, if the direct damping is not available. The Steady State Excitation allows you to input the steady state excitations. The Short Circuit Torque allows you to input the short circuit torques or any other excitations with the similar torque expression. The Driving Torque and Load Torque are the torques required for the Torsional Transient Startup Analysis.



Torsional/Axial Connectivity Data

This option allows you to input the connectivity and constraints for the torsional and/or axial vibration data. For torsional and axial vibrations, the system can be continuous by using the shaft elements and/or discrete by using the external connectivity, or the combination of continuous and discrete model. The discrete data is entered in this option. The connectivity links station I and station J.

1. **T/A**: **T**orsional or **A**xial vibration.
2. **Stn I**: Station number I.
3. **Stn J**: Station number J. If J = 0, station I is connected to the rigid ground.
4. **Connectivity**: **R**igid or **F**lexible Link. Rigid link indicates that the displacements at Station I and Station J are identical (for example, rigid gear meshes). Flexible link indicates that the stations I and J are connected by the external stiffness and damping.
5. **Stiffness**: Used in Flexible Link to connect station I and station J.
6. **Damping**: Used in Flexible Link to connect station I and station J.
7. **Comment**: Description.


Torsional/Axial Connectivity Data

	T/A	Stn I	Stn J	Connectivity	Stiffness	Damping	Comments
1	Torsional	2	3	Rigid Link	0	0	Gear Mesh
2	Torsional	2	6	Rigid Link	0	0	Gear Mesh
3	Torsional	1	2	Flexible Link	8.26E+008	0	Propeller
4	Torsional	3	4	Flexible Link	2.14E+009	0	High Pressure Turbin
5	Torsional	4	5	Flexible Link	8.7301E+010	0	
6	Torsional	6	7	Flexible Link	1.8056E+010	0	Low Pressure Turbine
7	Torsional	7	8	Flexible Link	4.8925E+010	0	
8	Torsional	1	0	Flexible Link	0	3.86E+006	Damping to ground
9	Torsional	5	0	Flexible Link	0	261600	High Pressure Turbin
10	Torsional	8	0	Flexible Link	0	174400	Low P. Tuurbine
11							
12							
13							
14							
15							

Insert Row Delete Row Unit:(1) - T: K: Lbf-in/rad, C: Lbf-in-s/rad; A: K: Lbf/in, C: Lbf-s/in

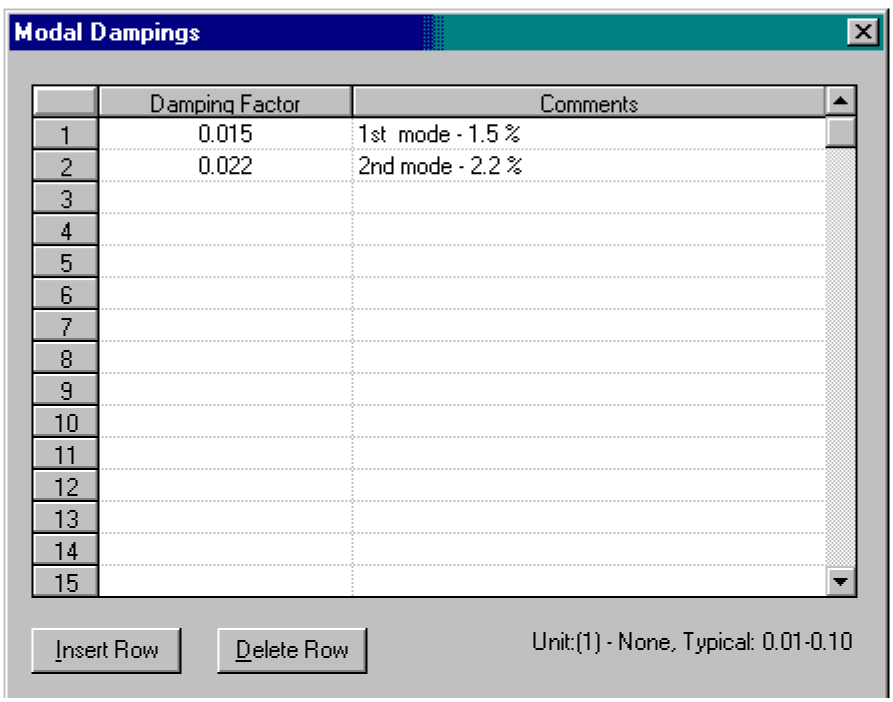
Torsional/Axial Modal Damping

This option allows you to input the modal damping factors, if the direct damping is not available. In general, the torsional damping for a geared train system is not readily available from the element level. The torsional modal damping factors for systems with dry type couplings have been reported in the range of 1-5 percent. For systems with resilient rubber couplings, the modal damping of the coupling modes, where the motions are dominated by the coupling, can go up to 6-10 percent. For practical purpose, only the first several modes are of interest, modal truncation is employed to approximate the physical damping. The modal damping factor is ratio of the actual modal damping to the critical modal damping for a given mode. If the modal damping factor is equal to one (1), the associated mode is said to be critically damped. Typical value is between 0.01 (1 percent) to 0.1 (10 percent). The definition of modal damping factor is:

$$\xi_r = \frac{C_r}{2J_r\omega_r} \qquad r = \text{mode of interest}$$

where

C_r, J_r, ω_r are modal damping, modal mass/inertia, and natural frequency



Torsional/Axial Steady State Excitations

This option allows you to input the torsional and/or axial steady state excitations. For torsional vibration, the excitation is torque. For axial vibration, the excitation is force. The excitation frequency can be a second order polynomial function of rotor speed. By adjusting the frequency coefficients, the excitation frequency can be a constant, synchronous, or non-synchronous excitation. The torque/force multiplier provides the flexibility of including the frequency into the torque/force amplitude. By adjusting the multiplier coefficients, the excitation amplitude can be a constant, first order, or second order of the frequency (speed).

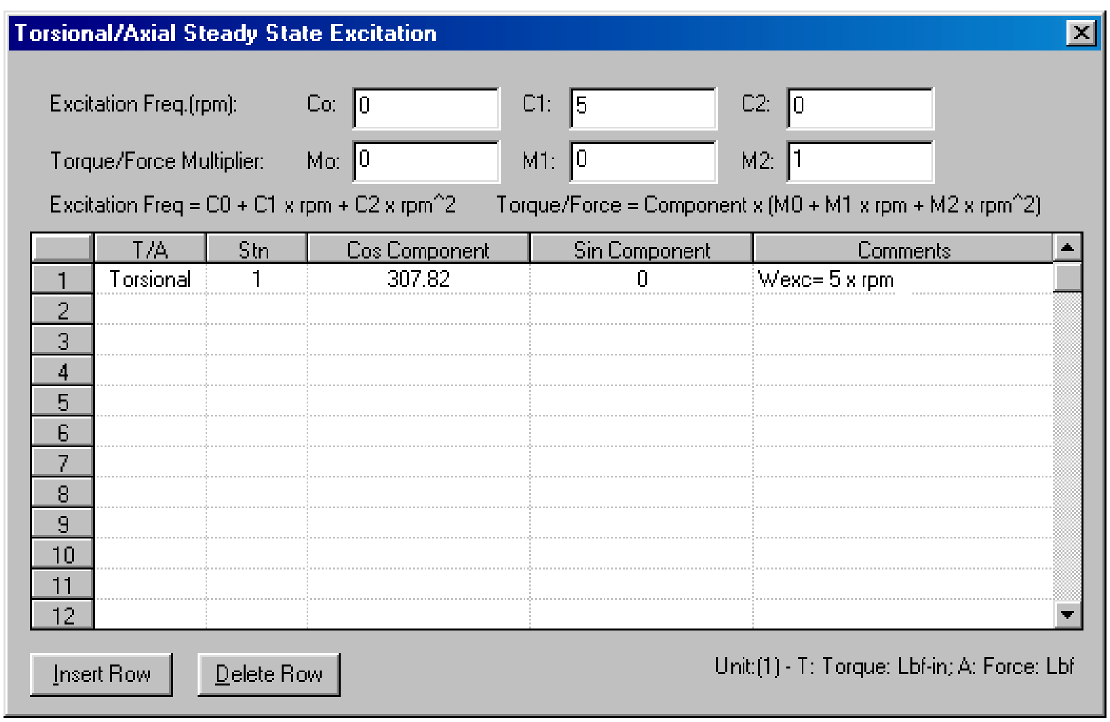
$$\omega_{exc} = \left(C_0 + C_1\,\Omega + C_2\,\Omega^2\right) \times \; (2\pi / 60)$$

$$T = \; \left(T_c \cos(\omega_{exc} t) + T_s \sin(\omega_{exc} t)\right) \; \times \; T_{multiplier}$$

$$T_{multiplier} \; = \; M_0 \; + \; M_1\,\Omega \; + \; M_2\,\Omega^2$$

where Ω is the rotor speed (rpm), C_0, C_1, C_2: are Frequency coefficients, and M_0, M_1, M_2: are Torque/force multiplier coefficients.

1. **T/A Option**: **T**orsional or **A**xial vibration.
2. **Stn I**: Station number where the excitation is applied.
3. **Cos Component**: *Tc*, Cosine component of the excitation amplitude.
4. **Sin Component**: *Ts*, Sine component of the excitation amplitude.
5. **Comment**: Description.



Torsional Short Circuit Torque

This option allows you to input the short circuit torques for torsional transient analysis. Although it is implemented for "short circuit" transient analysis, it is NOT limited by the short circuit torques. Any excitations with the following expression can be used in this transient analysis:

$$T = T_{rated}\left[T_0\, e^{-a_0 t} + T_1\, e^{-a_1 t}\sin(\omega t + \phi_1) + T_2\, e^{-a_2 t}\sin(2\omega t + \phi_2)\right]$$

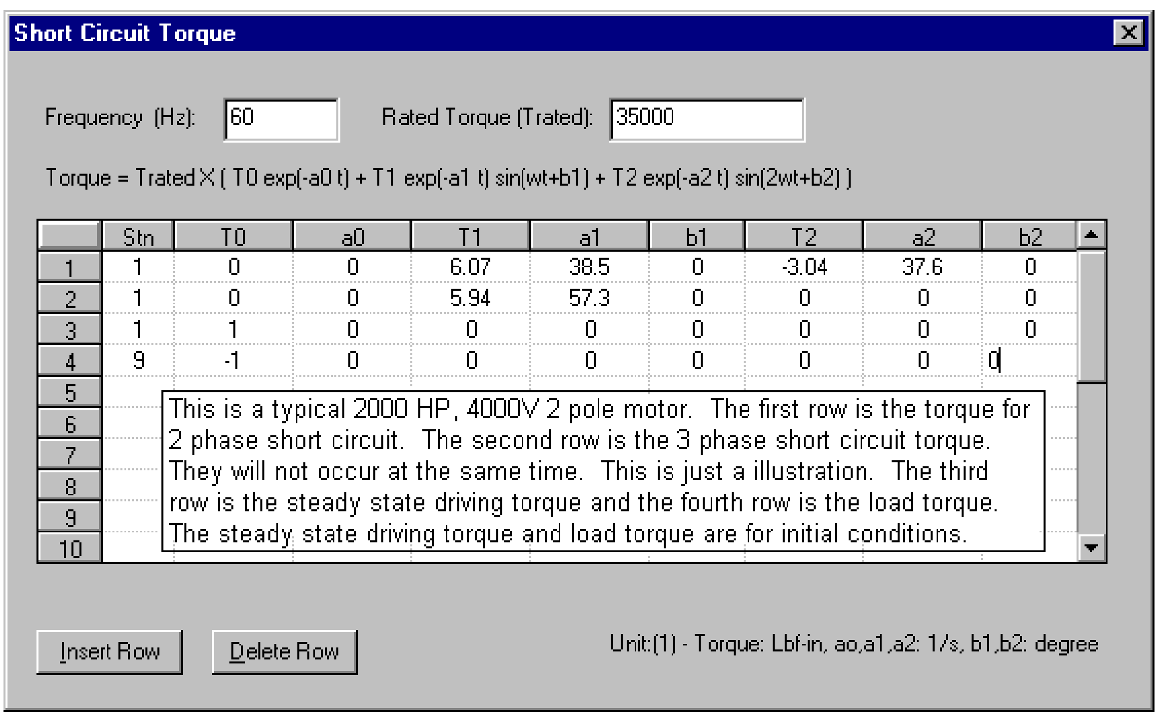
where

T_{rated}, T_0, T_1, T_2	are rated torque, and torque components.
a_0, a_1, a_2	are time constants.
ϕ_1, ϕ_2	are phase angles (degree).

The following figure shows the transient torques for a typical 2000 Hp, 4000V, 2 pole, 60 Hz motor. Please note that the 2-phase short circuit and 3-phase short circuit do not occur at the same time. They are listed simultaneously here only for reference purposes. The steady state driving torque and load torques are also entered in this form. The steady state driving torque and load torques have effects on the initial conditions (acceleration).

The torque and horsepower are related by:

$$T_{Lbf-in} = \frac{12\times 33000\times hp}{2\pi\times rpm} = \frac{63025\times hp}{rpm}$$



	Stn	T0	a0	T1	a1	b1	T2	a2	b2
1	1	0	0	6.07	38.5	0	-3.04	37.6	0
2	1	0	0	5.94	57.3	0	0	0	0
3	1	1	0	0	0	0	0	0	0
4	9	-1	0	0	0	0	0	0	0
5									
6									
7									
8									
9									
10									

Torsional Driving Torque

The Torsional Driving Torque and Load Torque are used for torsional startup analysis. It is known that the synchronous motors produce oscillating torques with excitation frequency equal to twice the slip frequency during startup and they can cause serious failure if the system is not properly designed. Induction motors also produce the oscillating torques at start; however, the torque amplitude exponentially decays and the excitation frequencies are equal to the line frequency and twice the line frequency. The data fields are self-explanatory. The synchronous speed (rpm) can be automatically calculated by specifying the number of poles or can be input independently.

$$N_{syn} = \frac{120 \times LineFrequency\,(\mathrm{Hz})}{No.\,of\;\;Poles}\ \ \mathrm{rpm}$$

The synchronous motor driving torque at any instant during startup has the form:

$$T = T_{avg} + T_{osc}\sin(\omega_{exc} t)$$

where T_{avg}, T_{osc} are the average and oscillating torques. They are provided by the motor manufacturers as a function of motor speed in percentage with respect to the rated torque. The excitation frequency of the pulsating torque is equal to twice the slip frequency.

$$\omega_{exc} = 2\pi \times 2 \times Line\ Frequency\ \times \left(\frac{Synchronous\ Speed - Motor\ Speed}{Synchronous\ Speed} \right)$$

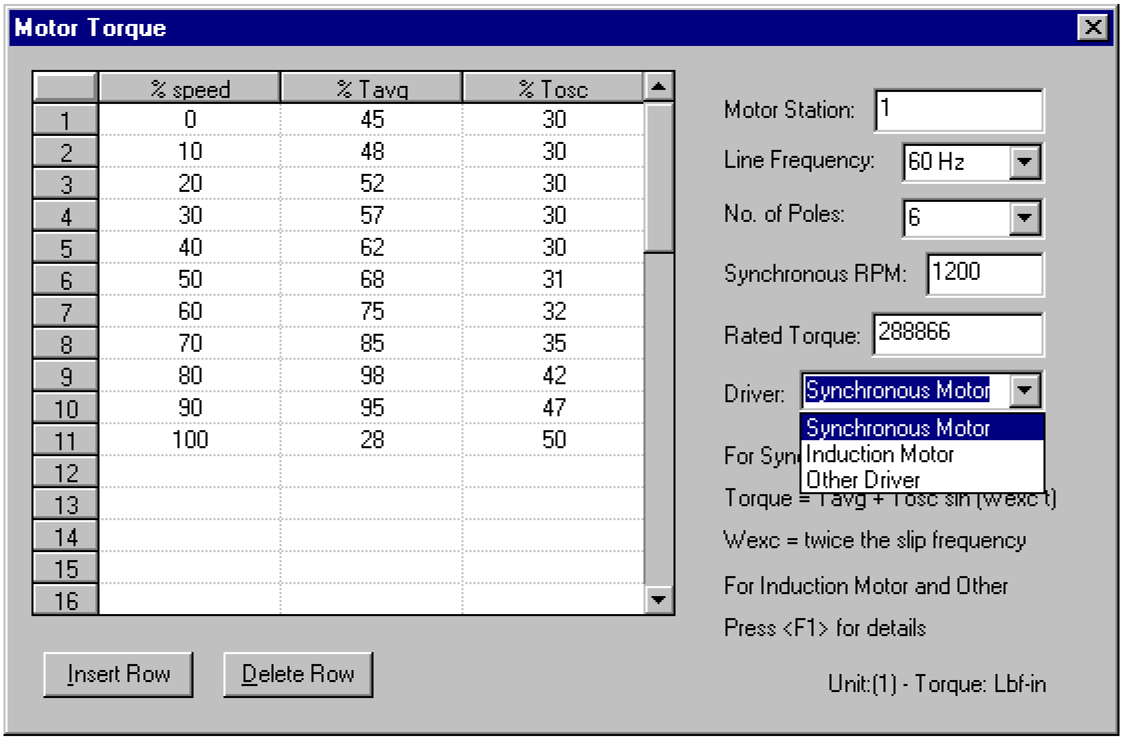
The induction motor driving torque has the form:

$$T = T_{avg} + T_{osc}$$

where the average torque is given in the same way as the synchronous motor input. The oscillating torque is given in the following expression:

$$T_{osc} = T_{rated}\ \left[T_0\ e^{-a_0 t} + T_1\ e^{-a_1 t}\sin(\omega t + \phi_1) + T_2\ e^{-a_2 t}\sin(2\omega t + \phi_2) \right]$$

where the parameters T_0, a_0, T_1, a_1, ϕ_1, T_2, a_2, ϕ_2 are entered in the Tosc column in the above sequence. Therefore, for an induction motor, the average torque data (Tavg) should at least requires 8 points.

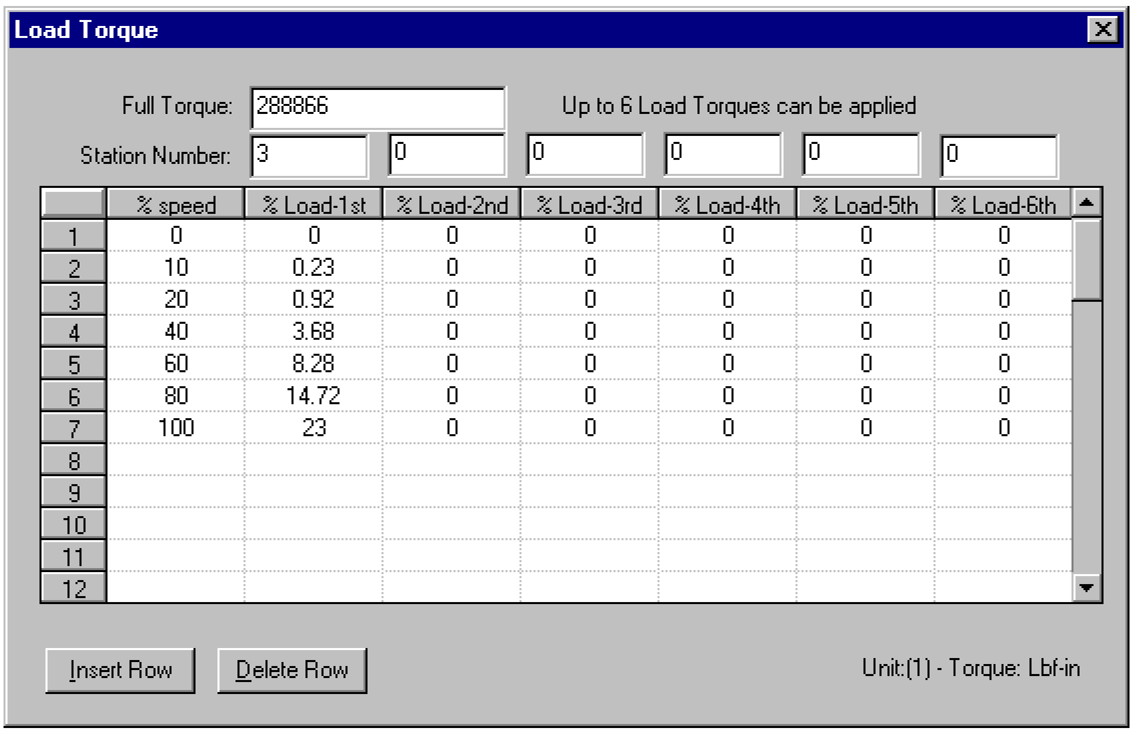

Motor Torque
% speed
% Tavg
% Tosc
1 0 45 30
2 10 48 30
3 20 52 30
4 30 57 30
5 40 62 30
6 50 68 31
7 60 75 32
8 70 85 35
9 80 98 42
10 90 95 47
11 100 28 50
12
13
14
15
16
Insert Row
Delete Row
Motor Station: 1
Line Frequency: 60 Hz
No. of Poles: 6
Synchronous RPM: 1200
Rated Torque: 288866
Driver: Synchronous Motor
Synchronous Motor
Induction Motor
Other Driver
Wexc = twice the slip frequency
For Induction Motor and Other
Press <F1> for details
Unit:(1) - Torque: Lbf-in

Torsional Load Torque

The load torques include compressor stage power, gear power loss, oil pump, etc. Up to six loads can be input in the analysis. It is common to specify the load torque as a function of speed in percentage. The torques are input in their actual (true) values, not the equivalent torques. The program converts the true torques to the equivalent torques and performs the analysis. The output vibratory torque can be specified either in true or equivalent values.

$$Equivalent\ Torque\ =\ Actual\ Torque \times n$$

where n is the speed ratio.



	% speed	% Load-1st	% Load-2nd	% Load-3rd	% Load-4th	% Load-5th	% Load-6th
1	0	0	0	0	0	0	0
2	10	0.23	0	0	0	0	0
3	20	0.92	0	0	0	0	0
4	40	3.68	0	0	0	0	0
5	60	8.28	0	0	0	0	0
6	80	14.72	0	0	0	0	0
7	100	23	0	0	0	0	0
8							
9							
10							
11							
12							