

Ver 21.00 – Base Motion

2/17/2020

A steady state harmonic base excitation (motion) can be specified in this Ver 21.00. The bearings with station J = 0, with the exception of Floating Ring Bearing (see example 5 for more details), are connected to the base and the flexible supports with the non-zero stiffness and damping are also considered to be connected to the base, as shown in the Figures 1 and 2, and all the stations connected to the base are subject to the base excitation if specified. i.e., all the rotor/support stations connected to the ground are now considered to be connected to the base if base excitation is present. The foundation is neglected in the base motion analysis.



Fig. 1 – Single Base



Fig. 2 – **Multiple Bases**

For the steady state harmonic base excitation analysis, the system must be linear and bearings are linear bearings. This is a linear analysis.

The base motion inputs are entered in the Base Motion tab under Model – Data Editor, as shown in Figure 3. The inputs are described below:

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 Harmonics Base Motion Torsional/Axial									
1. Base Type: Single									
2. Steady State	Base Harmonic Motion:	xcitation Frequency is a	a function of Rotor Speed or a Cons	stant 🗨					
	Excitation Frequency (cp	om = wo + w1 * rpm + w	2 * rpm^2)						
	Wo: 6000	W1: 0	W2: 0						
ſ	- Amplitude Multiplier (A =	Ao + A1 * rpm + A2 * rpi	m^2)						
3.	Ao: 1	A1: 0	A2: 0						
	Steady State Harmonic	Base Motion: q = A* [d	qc * cos (wexc*t) + qs * sin(wexc*t)]					
	(qc,qs) are the	displacement amplitude	s in (cos,sin) components	-					
Exc	citation frequency wexc (ra	d/sec) = cpm * (2*pi/6	0). rpm = reference shaft speed,	rotor 1 speed					
		3 Stations connected t	o the Base: 1, 6, 7						
Direct	ion qc - cos	qs - sin	Comments						
<u>1 X-Di</u>	r 0.1	0	For Single Base						
2 Y-Di		0							
4 Theta	im U i-Y O	0							
	:	· · ·		_					
			Unit	t:(1) - Amplitude: inc	h, radian				
	orm.(1) - Amplitude, inch, radian								
<u>T</u> or K			<u>S</u> ave Save <u>A</u> s	Qlose	<u>H</u> elp				

Fig. 3 – Inputs for Base Motion (Single Base)

1) Base Type: The Base Type can be Single, as shown in Fig. 1, or Multiple as shown in Fig. 2.

Rotor Bearing System Data	×
Units/Description Material Shaft Elements Disks Avial Forces Static Loads Constraints Misalianments	Unbalance Bearings Supports Foundation User's Elements
	Base Type: Single
Steady State Base Harmonic Motion: Excitation Frequ	ency is a function Single an
Excitation Frequency (cpm = wo + w1*	rom + w2 * rom ''2)

For a Single Base model, all the stations connected to the same base are subject to the same base motion. For a Multiple Bases model, the stations connected to the different base can have different base motion in amplitude and phase, but the base excitation

frequency is the same for all the bases, only the amplitude and phase can be different. Each base has 4 degrees-of-freedom, as described in the lateral vibration model, i.e., two translations (X, Y) and two rations (Theta-X and Theta-Y). For a Single Base, the inputs are illustrated in Fig. 3. Fig. 4 shows a multiple bases model input. There is a "station reminder" automatically shown above the motion input. It shows the number of stations connected to the base and the station numbers. For a multiple bases model, the base motion for all the connected stations must be entered.

Roto	Rotor Bearing System Data X											
U Ax	Units/Description Material Shaft Elements Disks Unbalance Bearings Supports Foundation User's Elements Axial Forces Static Loads Constraints Misalignments Shaft Bow Time Forcing Harmonics Base Motion Torsional/Axial											
	Base Type: Multiple											
	Steady State Base Harmonic Motion: Excitation Frequency is a function of Rotor Speed or a Constant											
			- Excitation	n Frequency	(cpm = wo	+w1*npm	+ w2 * rpm ′	`2)				
			Wo:	6000	W1:	0	v	/2: 0				
			Amplitude	Multiplier (/	A = Ao + A1	* rpm + A2	* rpm^2) —			7		
			Ao:	I	A1:	0	4	2: 0				
		Б	Steady	State Harmo (qc,qs) are f uency wexo	onic Base M the displace c (rad/sec) =	otion: q = / ment amplit = cpm * (2*)	*[qc *cos udes in (cos pi/60). p	(wexc*t) + s,sin) comp m = referer	• qs * sin(we onents nce shaft sp	exc*t)]	1 speed	
					3 Station	ns connect	ed to the Ba	ise: 1, 6, 7	<	-		
		stn I	Xc-cos	Xs-sin	Yc-cos	Ys-sin	ThetaXc	ThetaXs	ThetaYc	ThetaYs	Comments	_
	1	1	0.1	0	0	0.2	0	0	0	0	For Multiple Bases	
	2	6	0.05	0	0	0.1	0	0	0	0		
	3	l	0.03	U	U	0.05	U	U	U	U		
	4											
	6											
	7		0		0	0					0	-
	Insert Row Delete Row Unit:(1) - Amplitude: inch, radian											
	Ī	or K						<u>S</u> ave	Save /	<u>\</u> s	Close <u>H</u>	<u>l</u> elp

Fig. 4 – Inputs for Base Motion (Multiple Bases)

Note that if the rotational displacements are specified in the base motion, the bearings connected to the base must have rotational stiffness and/or damping to transmit the base motion.

2) Excitation Frequency: The base motion frequency (excitation frequency) can be either a function of rotor speed or a constant frequency, or the excitation frequency varies at a constant rotor speed.

Rotor Bearing System Data X
Units/Description Material Shaft Elements Disks Unbalance Bearings Supports Foundation User's Elements Axial Forces Static Loads Constraints Misalignments Shaft Bow Time Forcing Harmonics Base Motion Torsional/Axial Base Type: Single
Steady State Base Harmonic Motion: Excitation Frequency is a function of Rotor Speed or a Constant Excitation Frequency (Excitation Frequency is a function of Rotor Speed or a Constant Excitation Frequency (Excitation Frequency varies at a Constant Rotor Speed Wo: 6000 W1: 0 W2: 0

If the excitation frequency is a function of rotor speed or a constant, the analysis is performed for a range of rotor speed, as illustrated in Fig. 5. If the excitation frequency varies at a constant rotor speed, the analysis is performed for a range of excitation frequency, as illustrated in Fig. 6.

otor Bearing System Data	×
Units/Description Material Shaft Elements Disks Unbalance Bearings Supports Foundation Avial Forces Axial Forces Static Loads Constraints Misalignments Shaft Bow Time Forcing Harmonics Base	ation User's Elements Motion Torsional/Axial
Base Type: Single	-
Excitation Frequency (cpm = wo + w1 * rpm + w2 * rpm^2) Wo: 6900 W1: 0 W2: 0	<u> </u>

Fig. 5 – Excitation frequency is a constant

Rotor Bearing System Data	×
Units/Description Material Shaft Elements Disks Unbalance Bearings Supports Found Axial Forces Static Loads Constraints Misalignments Shaft Bow Time Forcing Harmonics Bas	dation User's Elements e Motion Torsional/Axial
Base Type: Single	
Steady State Base Harmonic Motion: Excitation Frequency varies at a Constant Rotor Speed	•
Excitation Frequency (cpm)	
Start: 0 Stop: 1000 Increment. 10	

Fig. 6 – Excitation frequency varies at a constant rotor speed

3) Base Motion: The base motion is described as a steady state harmonic motion.

For the *i*th base:
$$z_i = A \times [z_{ci} \cos(\omega_{exc} t) + z_{si} \sin(\omega_{exc} t)]$$
 (1)
= $A \times |z| \cos(\omega_{exc} t - \phi)$

Note that the displacement expression uses a phase lag $(-\phi)$, and the force expression uses a phase lead.

where A is a speed dependent amplitude multiple. In general, the base motion is speed independent, therefore $A_0=1$, $A_1=A_2=0$. For a multiple base model, the base excitation frequency is the same, but the amplitude and phase can be different by specifying different cosine and sine components (z_c and z_s) of the motion. For every base motion, 4 degrees-of-freedom can be specified: two translations (x,y) and two rotations (θ_x , θ_y). Since the motion is transmitted through bearings to the rotor system. If rotational base motion is specified (θ_x , θ_y), then the bearing connected to this base must have the rotational stiffness and/or damping to transmit this base motion to the rotor system. Otherwise, the rotational base motion will be ignored.

4) Analysis: When performing the base motion analysis, analysis option 23, the rotor speed input depends on the excitation frequency type entered in the Base Motion Input. As said before, if the excitation frequency is a function of rotor speed or a constant, the analysis can be performed in a range of rotor speed, and if the excitation frequency varies at a constant rotor speed, the analysis is performed at a constant rotor speed, as illustrated in Fig. 7.



Fig. 7 – Rotor speed input for the base motion analysis

The results can be viewed from the Postprocessor in both text and graphic formats. Several examples are employed to illustrate the use of Base Motion Analysis. Mathematically, the absolute displacement of the rotor due to the base motion can be verified using the Steady State harmonic Excitation Analysis. It will be demonstrated in the following examples.



Example 1 – Single Degree-of-Freedom

For a single DOF system, a mass m is supported by a spring k and a damping c. The spring and damping connected to the base are subject to a base motion z(t).



The equation of motion of the mass can be obtained by applying the Newton's 2^{nd} law for the absolute displacement *x* is:

$$m\ddot{x} = F_k + F_c \tag{2}$$

where F_k and F_c are the spring and damping forces acting on the mass *m*.

$$F_k = -k(x-z) \tag{3}$$

$$F_c = -c\left(\dot{x} - \dot{z}\right) \tag{4}$$

i.e.,

$$m\ddot{x} = -k(x-z) - c(\dot{x} - \dot{z})$$
⁽⁵⁾

or

$$m\ddot{x} + c\dot{x} + kx = kz + c\dot{z} \tag{6}$$

For a harmonic base motion

$$z = z_c \cos(\omega_{exc}t) + z_s \sin(\omega_{exc}t)$$
⁽⁷⁾

Therefore, the equation of motion becomes:

$$m\ddot{x} + c\dot{x} + kx = (kz_c + c\omega_{exc}z_s)\cos\omega_{exc}t + (kz_s - c\omega_{exc}z_c)\sin\omega_{exc}t$$
(8)

Define the relative displacements with respect to the base motion z:

$$u = x - z \qquad \Rightarrow \qquad x = u + z \tag{9}$$

Substitution of Eq. (9) into Eq. (6), the equation of motion in the relative displacement form:

$$m\ddot{u} + c\dot{u} + ku = -m\ddot{z} \tag{10}$$

Case 1: BaseMotion_1a.rot

The first case is taken from "Applied Mechanical Vibrations" by David V. Hutton, page 84.

m = 8 Lb, k = 40 Lb/in, c = 0, $z_c = 0$, $z_s = 0.2$ in, and $\omega_{\text{exc}} = 115$ Hz (6900 cpm = 722.57 rad/sec)

The system undamped natural frequency is:

$$\omega_n = \sqrt{\frac{k}{m}} = \sqrt{\frac{40}{\frac{8}{386.088}}} = 43.94 \text{ rad/sec} = 419.57 \text{ cpm}$$

The frequency ratio is defined as below

$$\gamma = \frac{\omega_{exc}}{\omega_n} = 16.45$$

For this high frequency ratio, i.e., the excitation frequency is much higher than the system natural frequency, the inertia of the mass keeps it from moving much, so that the relative motion consists primarily of the base motion relative to the mass. The mass steady state vibration amplitude is 0.00074 in. The mass relative displacement to the base is 0.20074 in.

The related rotor-bearing model and base motion inputs and analysis inputs are shown below:

Pater Passing System Data
Axial Forces Static Loads Constraints Misalignments Shaft Bow Time Forcing Harmonics Base Motion Torsional/Axial
Units/Description Material Shaft Elements Disks Unbalance Bearings Supports Foundation User's Elements
Curture United (2) Engineering English (a in Uhf Uhm)
Description Context
1 Test Base Motion, taken from David V. Hutton, Page 84
3 System natural frequency = 43.94 rad/sec = 419.57 cpm
4 Base motion, z=0.2 sin(wt) in, w = 115 Hz = 6900 cpm = 722.57 rad/sec
5 frequency ratio = excitation freq/natural freq = 16.45
b Rotor Bearing System Data
Axial Forces Static Loads Constraints Misalignments Shaft Bow Time Forcing Harmonics Base Motion Torsional/Axial
Units/Description Material Shaft Elements Disks Unbalance Bearings Supports Foundation User's Elements
Material No. 1 Material: Trained Goal
Mass Density Elastic Modulus Shear Modulus Comments
1 U U U Dummy material for Shatt
Rotor Bearing System Data
Axial Forces Static Loads Constraints Misalignments Shaft Bow Time Forcing Harmonics Base Motion Torsional/Axial
Units/Description Material Shart Elements Disks Unbalance Bearings Supports Foundation User's Elements
Shaft: 1 of 1 Starting Station #: 1 Add Shaft Del Shaft Previous Next
Speed Ratio: 1 Avial Dietance: 0 Y Dietance: 0 Import * xls
Comment: Durning Shart
1 1 1 1 0 0.1 0 1 0 0 Dummy Shaft
2
Rotor Bearing System Data
Axial Forces Static Loads Constraints Misalignments Shaft Bow Time Forcing Harmonics Base Motion Torsional/Axial
Units/Description Material Shaft Elements UISKs Unbalance Bearings Supports Foundation User's Elements
Use Horizontal Scroll Barto scroll to the right for more data inputs if nacessary, or click the Full Table
Tune Che Mass Dis leastin Delevantin Cherry Cherry Cherry Lands D D Device
1 Rigid 1 8 0 0 0 0 0.2 0 1 0
2
3

Rotor Bearing System Data X											
Axial Force	s S	tatic Loads	Constrair	nts Misalign	ments Sha	aft Bow	Time Forcing	Harmonics	Base Moti	ion Torsional/	Axial
Units/Des	criptior	n Materia	Shaft	Elements I	Disks Ur	nbalance	Bearings	Supports	Foundation	User's Elem	ents
Bearing	: 1 of	1			Foundation		Add Brg	Del Brg	Previous	Next	
Station	Station I: 1 J: 0 Angle: 0										
Туре	e: 0-	Linear Const	ant Bearing)			•	·			
Commen	t:										
				Translation	al Bearing P	roperties					
Kx	c 40		Kxy:	0		Cxx: 0		Cxy: 0			
Ky	с 0		Куу:	40		Cyx: 0		Суу: 0			
Rotor Beari	ng Sys	tem Data									×
Units/Des	criptio	n Materia	I Shaft	Elements	Disks U	nbalance	Bearings	Supports	Foundation	User's Elem	ents
Axial Force	Axial Forces Static Loads Constraints Misalignments Shaft Bow Time Forcing Harmonics Base Motion Torsional/Axial										
x, y, theta x, and theta y: Fixed or None (0); Shear/Momnet: Release or None (0) Import *xls Export *xls											
	Stn	×	Ų	Theta x	Theta y	She	ar M	oment	Com	ments	
1	1	0	Fixed	Fixed	Fixed	0		0			
2	2	Fixed	Fixed	Fixed	Fixed	0		0			
3											

lotor Bearing System Data X									
Units/Description Material Shaft Elements Disks Unbalance Bearings Supports Foundation User's Elements Axial Forces Static Loads Constraints Misalignments Shaft Bow Time Forcing Harmonics Base Motion Torsional/Axial									
Base Type: Single									
Steady State Base Harmonic Motion: Excitation Frequency is a function of Rotor Speed or a Constant									
	Excitation F	requency (cpm = wo + v	w1 * rpm + w2 * rpm^2)						
	Wo: 69	00 W1: 0	W2: 0						
	Amplitude N	/ultiplier (A = Ao + A1 * n	pm + A2 * rpm^2)						
	Ao: 1	A1: 0	A2: 0						
	Steady St	ate Harmonic Base Moti	on:q = A* [qc * cos (wexc*t) + qs * sin(wexc*t)]					
	(q	c,qs) are the displaceme	ent amplitudes in (cos,sin) co	mponents					
	Excitation freque	ency wexc (rad/sec) = c	pm * (2*pi/60). rpm = refe	erence shaft speed, rotor 1 speed					
Γ		1 Statio	n connected to the Base: 1						
		qc - cos	gs - sin	Comments					
	Direction								
1	X-Dir	0	0.2						
1	X-Dir Y-Dir	0	0.2						
1 2 3	Virection X-Dir Y-Dir Theta-X	0 0 0	0.2 0 0						

Lateral Analysis Option & Run Time	Data	×
Analysis: 23-Base Steady State Har Shaft Element Effects	monic Motion (Excitation)	requency Domain X: 0
✓ Rotatory Inertia ✓ Shear Def Static Deflection Constrained Bearing Stations Critical Speed Analysis Spin/Whirl Ratio: 1 No. of Modes: 5 Brg Stiffness: Kxx @ rpm: Highest	Base Motion (Excitation) Analysis X Steady State Base Excitation Mass I RPM-Starting: Increment: 10 Increment: 10 Cancel	Jnbalance Unbalance Bow kew V(X,Y) V(Z) Loads Forcing griment a Maneuver
Whirl Speed and Stability Analysis RPM-Starting: 0 Ending: 0 Increment: 0	Steady State Synchronous Hesponse Analysis Steady State Harmon RPM-Starting: 100 Effects: RPM-Starting: 0 Ending: 300 Image: Const. Unbalance Ending: 10 Increment: 10 Image: Shaft Bow Increment: 10	0 Run
No. of Modes: 6 Aerodynamics - Q	Excitation Shaft: 1 Image: Disk Skew Excitation Shaft: 1 Image: Image: Disk Skew I	ame speed
Speed (RPM): C Accele	ration - X: 0 Y: 0 Turn Rate - X: 0 Y: 0	Ref Pos: 0

Fig. 9 – Input data for Example 1 Case 1 (BaseMotion_1a.rot)

The constraints are used to limit the system to be a single degree-of-freedom in the X direction only for the purposes of comparison and understanding the base motion.

The reason to run the analysis from 0 to 100 rpm with an increment of 10 rpm is primarily for the easy presentation of the results. For this simple system, all the system parameters are not dependent on the rotor speed, therefore the results are also independent of the speed.

The results, the absolute displacement and the relative displacement of the mass and the force transmitted to the base, from the Base Motion Analysis are shown below:







Fig. 10 – Outputs for Example 1 Case 1 (BaseMotion_1a.rot)

As said that the absolute displacement can be verified by using the Steady State Harmonic Excitation Analysis according to Eq. (8). The steady state harmonic excitation is a function of bearing coefficients (*k* and *c*) and base motion (*z* and ω_{exc}). However, the force transmitted to the base through the bearing cannot be verified using this analysis, since the relative displacement is not obtainable from the Steady State Harmonic Excitation Analysis without knowing the base motion.

The bearing transmitted force from Base Motion is:

$$F = k\left(x - z\right) + c\left(\dot{x} - \dot{z}\right) \tag{11}$$

The bearing transmitted force from the Steady State Harmonic Excitation is:

$$F = kx + c\dot{x} \tag{12}$$

The input and output for the steady state harmonic analysis are show below. Note that the force expression uses a phase lead (ϕ) and the displacement uses a phase lag.

Rotor Bearin	g System Da	ata						×		
Units/Desc Axial Forces	Units/Description Material Shaft Elements Disks Unbalance Bearings Supports Foundation User's Elements Axial Forces Static Loads Constraints Misalignments Shaft Bow Time Forcing Harmonics Base Motion Torsional/Axial									
Ste	Steady State Harmonic Excitation: Excitation Frequency is a function of Rotor Speed or a Constant									
	Exc	itation Fi	requency	/ (cpm = wo + w1 * rpi	m + w2 * rpm^2)————	_			
	v	Vo: 690)0	W1: 0	W2	2: 0				
	Amp	litude M	ultiplier (/	A = Ao + A1 * rpm + A	2 * rpm^2)					
	A	No: 1		A1: 0	A2	:: 0				
	9	Steady S	tate Harr	monic Excitation: Q =	A * Q * cos (we	exc*t + phase)				
	Excitatio	n freque	ncy wex	c (rad/sec) = cpm * ()	2*pi/60). and	A is the Amplitude	multiplier			
rpm = excitation shaft speed, rotor speed where the excitation applied										
	Ele(Stn)	Sub	Dir	Left Amp.	Left Ang.	Right Amp.	Right Ang.	Comments 🔺		
1	1	1	1	8	270	0	0			
2 3 4	$\frac{2}{3} = \frac{1}{3} = \frac{1}$									

Lateral Analysis Option & Run Time I	Data			×
Analysis: S - Steady State Harmonic Shaft Element Effects Rotatory Inertia Shear Defe	Excitation Response	RPM: 6900	Time Frequency Domain ant Speed: 6900 rpm	Gravity (g)
Static Deflection Constrained Bearing Stations Critical Speed Analysis Spin/Whirl Ratio: 1 No. of Modes: 5 Brg Stiffness: Kxx @ rpm: Highest	Critical Speed Map Spin/Whirl Ratio: 1 Bearing K - Min: 1000 Npts: 50 Max: 1e+009 Stiffness to be varied at Bearings: All Allow Bearings in Series	Time-Start: 0 End: 2.80382 Step: 2.12296 Suggested Tim Solution Met Newmark-be Initial Cs: No	A Mass Unbalance Const. Unbalance Const. Unbalance Se-005 Disk Skew Gravity (X,Y) Static Loads ta Misalignment Marine Maneuver	Y: -386.088 Z: 0 None zero Gz Vertical Rotor Design Comparison
Whirl Speed and Stability Analysis RPM-Starting: 0 Ending: 0 Increment: 0	Steady State Synchronous Responses RPM-Starting: 100 Ending: 300 Increment: 10	nse Analysis Effects: ✔ Mass Unbalance ✔ Const. Unbalance ✔ Shaft Bow	-Steady State Harmonic Excitation RPM-Starting: 0 Ending: 100 Increment: 10	Run
No. of Modes: 6 Aerodynamics - Q Steady Maneuvers (Base Constant Ti	Excitation Shaft: 1 F	 ✓ Disk Skew ✓ Misalignment Rate) 	Excitation Shaft: 1	Cancel
Speed (RPM): 0 Accele	eration - X: 0 Y: 0	Turn Rate - X: 0	Y: 0 Ref Pos	ε



Fig. 10 – Verification of Base Motion using the Steady State Harmonic Excitation Analysis

Case 2: BaseMotion_1b.rot

Since this simple system has a constant and speed independent natural frequency, let us consider a wide range of excitation frequency at a constant rotor speed to plot the response versus the frequency ratio. To limit the response amplitude at the resonance, frequency ratio =1, let us add a damping coefficients of c = 0.5 in the bearing. Then we have:

undamped natural frequency =
$$\omega_n = \sqrt{\frac{k}{m}} = \sqrt{\frac{40}{8/386.088}} = 43.94 \text{ rad/sec} = 419.57 \text{ cpm}$$

damping factor =
$$\zeta = \frac{c}{2m\omega_n} = \frac{0.5}{2 \times \frac{8}{386.088} \times 43.94} = 0.275$$

damped natural frequency = $\omega_d = \omega_n \sqrt{1 - \zeta^2} = 42.25 \text{ rad/sec} = 403 \text{ cpm}$

xial Forces	Static Loads	Constraints	Misalignments	Shaft Bow	Time Forcing	Harmonics	Base Motion	Torsional/A
Jnits/Descri	ption Materia	al Shaft Eler	nents Disks	Unbalance	e Bearings	Supports	Foundation	User's Eleme
Bearing: 1	1 of 1		Found	dation	Add Brg	Del Brg	Previous	Next
Station I:	1 J: 0	1			Angle: 0	_		
Type:	0- Linear Cons	tant Bearing				•		
Comment:								
			Translational Be	aring Propertie	s			
Kxx:	40	Kxy: 0		Cxx:	0.5	Cxy: 0		
Kyx:	0	Куу: 40		Сух:	0	Cyy: 0.5	5	
			Rotational Be	aring Propertie	es			
Kaa:	0	Kab: 0		Caa:	0	Cab: 0		
Kba:	0	Kbb: 0	_	Cba:	0	Cbb: 0		
					Unit:(2) - Kt:Lb	in, Ct:Lbf-s/i	n; Kr:Lbf-in/rad	, Cr:Lbf-in-s/rad
Tor K	1				Unit:(2) - Kt:Lb	i/in, Ct:Lbf-s/i	n; Kr:Lbf-in/rad	, Cr:Lbf-in-s/rac
<u></u> or K					Unit:(2) - Kt:Lb Save	i/in, Ct:Lbf-s/i Save <u>A</u> s	n; Kr:Lbf-in/rad	, Cr:Lbf-in-s/rac
<u>T</u> or K	System Data				Unit:(2) - Kt:Lb <u>S</u> ave	i/in, Ct:Lbf-s/i Save <u>A</u> s	n; Kr:Lbf-in/rad	, Cr:Lbf+in-s/rac
Tor K	System Data				Unit:(2) - Kt:Lb Save	i/in, Ct:Lbf-s/i	n; Kr:Lbf-In/rad	, Cr:Lbf-in-s/rad
Ior K or Bearing Jnits/Descrip xial Forces	System Data ption) Materia) Static Loads	al] Shaft Eler Constraints	nents Disks Misalignments	Unbalance Shaft Bow	Unit:(2) - Kt:Lb Save	i/in, Qt:Lbf-s/ii Save <u>A</u> s Supports]] Harmonics	n; Kr:Lbf-in/rad	Cr:Lbf-in-s/rac
<u>T</u> or K or Bearing Jnits/Descri xial Forces	System Data ption Materia Static Loads	al) Shaft Eler) Constraints	nents Disks Misalignments	Unbalance	Unit:(2) - Kt:Lb Save	i/in, Ct:Lbf-s/i Save <u>A</u> s Supports] Harmonics	n; Kr:Lbf-in/rad	Cr:Lbf-in-s/rac
Tor K or Bearing Jnits/Descrip xial Forces Steady S	System Data ption Materia Static Loads State Base Ham	al Shaft Eler Constraints nonic Motion:	nents Disks Misalignments Excitation Frequ	Unbalance Shaft Bow	Unit:(2) - Kt:Lb Save	Vin, Ct:Lbf+s/i Save <u>As</u> Supports Harmonics	n; Kr:Lbf-in/rad	Cr:Lbf-in-s/rac
Ior K or Bearing Jnits/Descrip xial Forces Steady S	System Data ption Materia Static Loads State Base Ham xcitation Freque	al Shaft Eler Constraints nonic Motion: ncy (cpm)	nents Disks Misalignments Excitation Frequ	Unbalance Shaft Bow uency varies at	Unit:(2) - Kt:Lb Save	i/in, Ct:Lbf+a/i Save <u>A</u> s Supports Harmonics	n; Kr:Lbf-in/rad	Cr:Lbf-in-s/rac

The relevant inputs are shown in Fig. 11 below:

Axial Forces	Static Loads	Constraints Misalignm	ents Shaft Bow Time Fo	rigis Supports Foundation Oser's Elements ricing Harmonics Base Motion Torsional/Axia
Steady	State Base Harmor	nic Motion: Excitation F	requency varies at a Consta	nt Rotor Speed
-	Excitation Frequency	, (com)		
	Start: 5	Stop: 100	0 Incremen	ıt. 5
	Amplitude I	Multiplier (A = Ao + A1 * r	pm + A2 * rpm^2)	
	Ao: 1	A1:) A2: 0	
	1			
	Steady St	tate Harmonic Base Mot	ion: q = A* [qc * cos (wexc*t) + qs * sin(wexc*t)]
	(a	ic.qs) are the displaceme	ent amplitudes in (cos,sin) co	mponents
_	Excitation freque	ency wexc (rad/sec) = o	cpm * (2*pi/60). rpm = refe	erence shaft speed, rotor 1 speed
		Station	is connected to the Base: 1	
		qc - cos	gs - sin	Comments
	Direction		0.0	
1	Direction X-Dir	0	0.2	
1	Direction X-Dir Y-Dir	0	0.2	
1 2 3	Direction X-Dir Y-Dir Theta-X	0	0.2	
1 2 3 4	Direction X-Dir Y-Dir Theta-X Theta-Y	0 0 0 0	02 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0	

Chaile Florence Florence		RPM: 6900	Time Frequency	
Rotatory Inertia V Shear De	formation 🔽 Gyroscopic 🔲 Gz	Constar	nt Speed: 6900 rpm	
Static Deflection Constrained Bearing Stations Critical Speed Analysis Spin/Whirl Ratio: 1 No. of Modes: 5 Brg Stiffness: Kxx @ rpm: Highest Whirl Speed and Stability Analysis	Critical Speed Map Sase Motion (Excitation) Analys Steady State Base Excitation RPM-Rotor: Excitation Freq cpm Start: 5 End: 1000 Inc: 5	Time-Start: 0 sis	Mass Unbalance Const. Unbalance Shaft Bow Disk Skew Gravity (XY) Gravity (Z) Static Loads Time Forcing Misalignment Marine Maneuver y State Harmonic Excitation	Y: -386.088 Z: 0 None zero G Vertical Roto Design Comparison
RPM-Starting: 0 Ending: 0 Increment: 0	Ending: 300 V Increment: 10 V	Mass Unbalance Const. Unbalance Shaft Row	Excitation Freq cpm Start: 5	Run
No. of Modes: 6 Aerodynamics - Q	Excitation Shaft: 1	Disk Skew Misalignment	End: 1000 Inc: 5	Cancel

Fig. 11 – Example 1 Case 2: Excitation frequency from 5 to 1000 cpm

The absolute and relative displacements of the mass and the force transmitted to the base versus the frequency ratio are shown in Fig. 12 below:





Fig. 12 – Base Motion Results for Example 1 Case 2

To change the graphic scales and headings, go to Options – Settings and macke necessary changes. To scale the X-axis from Excitation Frequency to Frequency Ratio (Exec Freq/natural Freq), multiplying a scale factor (1/Natural Freq = 1/419.57=0.00238) as shown below.

Base Motion - Amplitude and	d Phase vs. Frequency	Unknown X
Options Station X-axis Abso Redraw Settings	olute/Relative Absolute Displacement Station: 1, Sub-Station: 1	Title: Absolute Displacement X-Label: Frequency Ratio (Exc Freq/Natural Freq)
Print () 0 de Print to File Export Data 90 0 0.50 0.40 0.30 0.20 0.10 0.20	eg: Amp = 0.42530 phase = 14	Y-Label: Amplitudes Z-Label: Phases (Deg) Station: 1 Sub: Probe Angles (deg) - X (1): 0 Probe Y (2): Operating Speed Range: 1 to Operating Speed Range: 0 0 Label Amplification Factor: Major Axis (2) Mark AF lines Phase Display: • Academic Instrument (ADRE) Peak - Peak Phase Shift - X(1): 0 Y(2): Curve Fit Symbol ✓ Major Grid Minor Grid Text Color ✓ Manual X Scale: 0.00238 Amplitude Scale: 1
0.00 0.00 0.50 Freque	1.00 1.50 ncy Ratio (Exc Freq/Natura	Manual Scaling Data Xmin: 0 Ymin: 0 Zmin: 0 Xmax: 2.5 Ymax: 0.5 Zmax: 360 XDiv: 5 YDiv: 5 ZDiv: 4 Decimal Places for the Response Graphic Printout

As expected, the absolute displacement starts with the base motion at $\gamma =0$ and reaches the maximum absolute displacement before the resonance $\gamma =1$, and the absolute displacement equals to the base motion of 0.2 inches at $\gamma =0$, and $\sqrt{2}$. The absolute displacement decreases as the frequency ratio increases after the resonance. The relative displacement starts from zero and reaches the maximum relative displacement after the resonance and approaches to the base motion when the frequency ratio is very high. At very low frequency ratio, i.e., the excitation frequency is much less than the system natural frequency, the mass vibrates with the base and there is little relative motion between the mass and the base. At very high frequency ratio, the mass is nearly stationary and the relative motion is primary the base motion.

Again, the maximum absolute displacement, 0.4253 inches at 395 rpm can be verified by using the steady state harmonic excitation analysis. The excitation frequency is 395 cpm (41.36 rad/sec) and the excitation force, according to Eq. (8), is:

$$kz + c\dot{z} = k \left(z_c \cos \omega_{exc} t + z_s \sin \omega_{exc} t \right) + c \omega_{exc} \left(z_s \cos \omega_{exc} t - z_c \sin \omega_{exc} t \right)$$

= 40(0.2 sin $\omega_{exc} t$) + 0.5 × $\frac{395 \times 2\pi}{60}$ (0.2 cos $\omega_{exc} t$)
= 8 sin $\omega_{exc} t$ + 4.13643 cos $\omega_{exc} t$ = 9.00611 cos ($\omega_{exc} t$ - 62.659°)
= 9.00611 cos ($\omega_{exc} t$ + 297.341°)

The input and output are shown below:

Rotor Bearing System Data X											
Units/Description Material Shaft Elements Disks Unbalance Bearings Supports Foundation User's Elements Axial Forces Static Loads Constraints Misalignments Shaft Bow Time Forcing Harmonics Base Motion Torsional/Axial											
Steady State Harmonic Excitation: Excitation Frequency is a function of Rotor Speed or a Constant.											
	Wo: 3	95	W1: 0	W2	2: 0						
	Amplitude Ao: 1	Multiplier (A = Ao + A1 * rpm + / A1: 0	A2 * rpm^2) — A2	: 0						
Excit	Steady ation frequ	State Har Jency wex	monic Excitation: Q = c (rad/sec) = cpm *	= A * Q * cos (we (2*pi/60). and a	exc*t + phase) A is the Amplitude	e multiplier					
	rpm = e	xcitation s	haft speed, rotor spe	ed where the exc	citation applied						
Ele(Stn)	Sub	Dir	Left Amn	Left Ang	Bight Amp	Bight Ang	Comments				
1 1	1	1	9.00611	297.341	0	0					
2											
Amplitu	ide and l	Phase v	s. Frequency			_		:			



Fig. 13 – Steady State Harmonic Excitation at 395 cpm for Example 1 case 2

Example 2 - 2 Degrees-of-Freedom

The second example is a 2 DOF system, as shown below. For more details, see "Structural Dynamics" by Roy R. Craig, Jr., page 240.



 m_1 =8 lb, k_1 = 40 lb/in, c_1 = 0.2 lb-sec/in m_2 =15 lb, k_2 = 100 lb/in, c_2 = 0.1 lb-sec/in base motion: z_c =0, z_s = 0.2, ω_{exc} from 5 cpm to 1000 cpm

Base Motion

Fig. 14 – Two Degrees-of-Freedom System

The equation of motion:

$$\begin{bmatrix} m_1 & 0\\ 0 & m_2 \end{bmatrix} \begin{bmatrix} \ddot{x}_1\\ \ddot{x}_2 \end{bmatrix} + \begin{bmatrix} c_1 & -c_1\\ -c_1 & (c_1+c_2) \end{bmatrix} \begin{bmatrix} \dot{x}_1\\ \dot{x}_2 \end{bmatrix} + \begin{bmatrix} k_1 & -k_1\\ -k_1 & (k_1+k_2) \end{bmatrix} \begin{bmatrix} x_1\\ x_2 \end{bmatrix} = \begin{bmatrix} 0\\ k_2z+c_2\dot{z} \end{bmatrix}$$
(13)

Define the relative displacements with respect to the base motion *z*:

$$\begin{cases} u_1 \\ u_2 \end{cases} = \begin{cases} x_1 - z \\ x_2 - z \end{cases} \qquad \Longrightarrow \qquad \begin{cases} x_1 \\ x_2 \end{cases} = \begin{cases} u_1 \\ u_2 \end{cases} + \begin{cases} z \\ z \end{cases}$$
(14)

Substitution of Eq. (14) into Eq. (13), the equation of motion in the relative displacement form:

$$\begin{bmatrix} m_1 & 0 \\ 0 & m_2 \end{bmatrix} \begin{bmatrix} \ddot{u}_1 \\ \ddot{u}_2 \end{bmatrix} + \begin{bmatrix} c_1 & -c_1 \\ -c_1 & (c_1 + c_2) \end{bmatrix} \begin{bmatrix} \dot{u}_1 \\ \dot{u}_2 \end{bmatrix} + \begin{bmatrix} k_1 & -k_1 \\ -k_1 & (k_1 + k_2) \end{bmatrix} \begin{bmatrix} u_1 \\ u_2 \end{bmatrix} = -\begin{bmatrix} m_1 & 0 \\ 0 & m_2 \end{bmatrix} \begin{bmatrix} \ddot{z} \\ \ddot{z} \end{bmatrix} (15)$$

The response can be solved in either coordinate system (absolute or relative displacements). For a single base model, it is convenient to solve the equation of motion in the relative displacement, Eq. (15). However, for a multiple bases model, will be presented later, the absolute displacement, Eq. (13) will be used.

Again, this is also a simple model and the system parameters are independent from the rotor speed. The system natural frequencies are constant and not varied with the rotor speed.

The system natural frequencies and damping factors can be obtained from the whirl speed analysis:

*******	**********	Whirl Speed	d and Stability	Analysis ***	*******	******					

	* * * * * * * * * * * *	Frequency	* * * * * * * * * * * * *	Damping	Log.	Damping					
Mode	rpm	R/S	Hz	Coefficient	Decremen	t Factor					
1	321.291	33.6456	5.3549	-1.556	.291	0.046					
2	628.304	65.7958	10.472	-7.131	.681	0.108					
*******	* * * * * * * * * * * * * *	* * * * * * * * * * *	* * * * * * * * * * * * * * * *	* * * * * * * * * * * * *	*******	*******					

Undamped Natural Frequencies:

 $\omega_{n1} = 33.58 \text{ rad/sec} = 320.67 \text{ cpm}$ $\omega_{n2} = 66.38 \text{ rad/sec} = 633.8 \text{ cpm}$

Damped Natural Frequencies and Damping Factors:

$\omega_{n1} = 33.65 \text{ rad/sec} = 321.29 \text{ cpm}$	$\zeta_1 = 0.046$
$\omega_{n2} = 65.80 \text{ rad/sec} = 628.30 \text{ cpm}$	$\zeta_2 = 0.108$

Lateral Analysis Option & Run Time Analysis: 4 - Whirl Speed & Stability	Data Analysis	Transient Analysis - RPM: 6900	Time Frequency	Gravity (g)
Rotatory Inertia Shear Def	ormation 🔽 Gyroscopic 🛛 🗖 G	iz Cons	tant Speed: 6900 rpm	X: 0
Static Deflection Constrained Bearing Stations Critical Speed Analysis Spin/Whirl Ratio: 1 No. of Modes: 5 Brg Stiffness: Kxx @ rpm: Highest	Critical Speed Map Spin/Whirl Ratio: 1 Bearing K - Min: 1000 Npts: 50 Max: 1e+009 Stiffness to be varied at Bearings: All Allow Bearings in Serie	Time-Start: 0 End: 2.8038 Step: 2.1229 Suggested Tim Solution Mel Newmark-bu	Mass Unbalance Const. Unbalance Shaft Bow Be-005 Disk Skew Gravity (X,Y) e Step Gravity (Z) thod V Time Forcing attaine Maneuver	Y: -386.088 Z: 0 None zero Gz Vertical Rotor Design Comparison
Whirl Speed and Stability Analysis	- Steady State Synchronous Res RPM-Starting: 100	ponse Analysis Effects: Mass Unbalance	Steady State Harmonic Excitation RPM-Starting: 0	
Ending: 1000 Increment: 100	Ending: 300 Increment: 10	Const. Unbalance	Ending: 1000 Increment: 100	Run
No. of Modes: 6 Aerodynamics - Q	Excitation Shaft: 1	✓ Disk Skew✓ Misalignment	Excitation Shaft: 1	Cancel
Steady Maneuvers (Base Constant T Speed (RPM): 0 Accel	ranslational Acceleration and/or Te eration - X: 0 Y: 0	um Rate) Tum Rate - X: 0	Y: 0 Ref Po:	s: 0





Case 1: BaseMotion_2a.rot

The relevant inputs are shown below in Fig. 15. Note that in this model, the support stiffness and damping are entered as a bearing.

Avial Forces Static Loads Constraints Misalignments Shaft Bow Time Forcing Hamonics Base Motion Torsional/Avial Unter/Description Material Shaft Bements Disks Unbalance Bearings Supports Foundation User's Bements System Units: [2]-Engineering English (or.in. Lbf. Lbm) - - - - 1 Two degrees-of-Freedom System 2 Roy R. Caig, Jr., Page 240. -	Rotor Bearing System Data
Avail Forces State Loads Constraints Missignments Shaft Bow Time Forcing Hamonics Base Motion Consonal/Avail Unts/Description Material Shaft Blements Disks Unbalance Bearings Supports Foundation User's Elements System Units: (2) Engineeering English (6: In, Lt/s, Ltm) Description Context Image: State Loads User's Elements User's Elements Image: State Loads User's Elements User's Elements User's Elements Image: State Loads User's Elements Discinguity: State Loads Cana: J., Ray 20, 20, 21, 20, 21, 20, 21, 20, 21, 20, 21, 23, 23, 23, 23, 23, 23, 23, 23, 23, 23	
System Units: 21: Engineering English (p.m. Lt/, Ltm) I Two degrees-of-Freedom System 2 Roy R. Coig, Jr., Page 240. 3 m1=8 b, k1=40 lb/in, c1=0.2 lb-s/in 4 m2=15 b, k2=100 lb/in, c2=0.1 lb-s/in 5 mc2 6 zc=0, zs=0.2, excitation frequency (no, 5 cpm to 1000 cpm 7 The system undamped natural frequencies: 321, 634 cpm 9 Denoing Factors: 0.046 and 0.108 100 Static Loads Votor Bearing System Data X Axial Forces Static Loads Constraints Use Horizontal Scroll Bar to scroll to the right for more data inputs f necessary, or click the Full Table Full Table Type Mass Dial.nettia Plas 1 Rigid 1 8 0 1 Rigid 1 0 0 1 Rigid 1 8 1 0 1 Rigid 1 8 0 0 0 2 1 0 1 Rigid 1 8 0 0 0 0 2 1 <	Axial Forces Static Loads Constraints Misalignments Shaft Bow Time Forcing Harmonics Base Motion Torsional/Axial Units/Description Material Shaft Elements Disks Unbalance Bearings Supports Foundation User's Elements
System Units: [2]: Engineering English (s. in, Lif, Lim)] Image: Colspan="2">Description Context Image: Colspan="2">Two degrees-of-Freedom System 2 Roy R. Craig, Jr., Page 240. 3 m1=8 b, 14-40 bir, c1=0.2 b-s/in 4 m2=15 lb, k2=100 lb/in, c2=0.1 lb-s/in 5 m2 is connected to the base and subject to the base motion z 6 zc= 0.2, exclaintion frequencies: 321, 634 cpm 8 The system damped natural frequencies: 321, 628 cpm 9 Damping Factors: 0.046 and 0.108 Noter Bearing System Data X Axial Forces Static Loads Constraints Misalignments Shaft Bow Time Forcing Hamonics Base Motion Torsional/Axial Use Hontzontal Scroll Bar to scroll to the right for more data inputs if necessary, or click the Full Table Full Table Full Table 1 Type Stin Mass Dia.Inertia Polar Inertia SkewX SkewY Length ID OD Dersity<	inatenal Shar Denents Disks Chibalance Dealings Supports Foundation Oser's Denents
Description Context 1 Two degrees-of-Freedom System 2 Roy R. Craig, Jr., Page 240. 3 m1=8 b, 14-40 lbr(m, c1=0.2 bs-s/m) 4 m2=15 lb, k2=100 lbr(m, c2=0.1 lb-s/m) 5 m2 is connected to the base and subject to the base motion z 6 zc= 0.2, exclusion frequencies: 321, 634 cpm 7 The system damped natural frequencies: 321, 628 cpm 9 Damping Factors: 0.046 and 0.108 Noter Bearing System Data X Axial Forces Static Loads Constraints Misalgoments Use Horizontal Scroll Bar to scroll to the right for more data inputs if necessary, or click the Full Table Full Table 1 Type Static Loads Constraints Misalgoments Vaial Forces Static Loads Constraints Diskes Unbalance Bearings Supports Foundation User's Bements Use Horizontal Scroll Bar to scroll to the right for more data inputs if necessary, or click the Full Table Full Table I Type Static Loads Constraints Misalgoments Shaft Bow Time Forcing Harmonics Base Motion Torsional/Axial Next Next<	System Units: (2) - Engineering English (s, in, Lbf, Lbm)
1 Two degrees of Freedom System 2 Roy R, Craig, Jr., Page 240. 3 m1=8 b, k1=40 b/n, c1=0.2 b/s/n 4 m2=15 b, k2=100 b/n, c2=0.1 b/s/n 5 m2 is connected to the base and subject to the base motion z 6 zc=0, zs=0.2, excitation frequency fno, 5 cpm to 1000 cpm 7 The system undamped natural frequencies: 321, 634 cpm 8 The system damped natural frequencies: 321, 634 cpm 9 Damping Factors: 0.046 and 0.108 10 Xotor Bearing System Data Avial Forces Static Loads Constraints Msalignments Description Material Shaft Elements Diels Use Horizontal Scroll Barto scroll to the right for more data inputs if necessary, or click the Full Table Full Table 1 Rigid 1 8 0 0 0 0 2.3 3 Use Horizontal Scroll Barto scroll to the right for more data inputs if necessary, or click the Full Table Full Table Full Table 1 Rigid 1 8 0 0 0 0 0 0 2.3 3 Use Horizontal Scroll	Description Content
2 Roy R. Craig, Jr., Page 240. 3 ml=8 b, kl=40 b/n, cl=0.2 b/s/n 4 m2=15 b, k2=100 b/n, c2=0.1 b/s/n 5 m2 is connected to the base and subject to the base motion z 5 zc=0, zs=0.2, excitation frequency fro, 5 cpm to 1000 cpm 7 The system undamped natural frequencies: 321, 634 cpm 8 The system damped natural frequencies: 321, 628 cpm 9 Damping Factors: 0.046 and 0.108 100 Rotor Bearing System Data Avail Forces 9 Static Loads Constraints Misalignments 9 Unters/Description 10 Material 11 Rigid 12 Rigid 13 B 14 Rigid 15 0 16 Static Loads 17 Rigid 18 Next Static Loads 19 Rigid 10 DD 11 Rigid 12 Rigid 13 Rigid 14 Rigid 15 O	1 Two degrees-of-Freedom System
3 m1=8 b, k1=40 lb/n, c1=0.2 b-s/m 4 m215 b, k2=100 lb/n, c2=0.1 lb-s/m 5 m2 is connected to the base and subject to the base motion z 5 m2 is connected to the base and subject to the base motion z 7 The system undamped natural frequencies: 321, 634 cpm 8 The system damped natural frequencies: 321, 628 cpm 9 Damping Factors: 0.046 and 0.108 10 Natal Forces 8 tatic Loads Constraints Mail forces Static Loads Constraints Misaignments Shaft Bow Time Forcing Harmonics Base Motion Torsional/Akial Units/Description Material Shaft Bernets Disks Use Horizontal Scroll Barto scroll to the right for more data inputs if necessary, or click the Full Table 1 Rigid 1 1 Rigid 1 1 Rigid 1 2 0 0 0 3 1 8 0 0 2 Material Shaft Bernerts Disks 1 Rigid	2 Roy R. Craig, Jr., Page 240.
and 2 is connected to the base and subject to the base motion z 5 m 2 is connected to the base and subject to the base motion z 6 z = 0, z = 0, z, excitation frequency fro, 5 cpm to 1000 cpm 7 The system undamped natural frequencies: 321, 634 cpm 8 The system damped natural frequencies: 321, 628 cpm 9 Damping Factors: 0.046 and 0.108 Notor Bearing System Data X Axial Forces Static Loads Constraints Misalignments Shaft Bow Time Forcing Hamonics Base Motion Torsional/Axial Units/Description Material Shaft Elements Diaks Unbalance Bearings Supports Foundation User's Elements Use Horizontal Scroll Bar to scroll to the right for more data inputs if necessary, or click the Full Table Full Table I I I Rigid 1 8 0	3 m1=8 lb, k1=40 lb/in, c1=0.2 lb-s/in 4 m2=15 lb, k2=100 lb/in, c2=0.1 lb-s/in
E zc=0, zs = 0, 2, excitation frequency fro, 5 cpm to 1000 cpm 7 The system undamped natural frequencies: 321, 634 cpm 8 The system undamped natural frequencies: 321, 628 cpm 9 Damping Factors: 0.046 and 0.108 Rotor Bearing System Data X Axial Forces Static Loads Constraints Misalignments Shaft Bow Time Forcing Harmonics Base Motion Torsional/Axial Units/Description Material Shaft Elements Disks Unbalance Bearings Supports Foundation User's Elements Use Horizontal Scroll Bar to scroll to the right for more data inputs if necessary, or click the Full Table Full Table Image: Constraints Misalignments Shaft Bow Time Forcing Harmonics Base Motion Torsional/Axial Use Horizontal Scroll Bar to scroll to the right for more data inputs if necessary, or click the Full Table Full Table Image: Constraints Mass O O O O O O O O O Constraints Misalignments Shaft Bow Time Forcing Harmonics Base Motion Torsional/Axial Units/Description Material Shaft Elements <td>5 m2 is connected to the base and subject to the base motion z</td>	5 m2 is connected to the base and subject to the base motion z
7 The system undamped natural frequencies: 321, 634 cpm 8 The system damped natural frequencies: 321, 628 cpm 9 Damping Factors: 0.046 and 0.108 Rotor Bearing System Data X Axial Forces Static Loads Constraints Misalignments Shaft Bow Time Forcing Hamonics Base Motion Torsional/Axial Units/Description Material Shaft Bements Disks Unbalance Bearings Supports Foundation User's Elements Use Horizontal Scroll Bar to scroll to the right for more data inputs if necessary, or click the Full Table Full Table Full Table 1 Rigid 1 8 0 0 0.2 1 0 2 1 1 8 0 0 0.2 1 0 2 1 8 0 0 0 0.2 1 0 2 1 8 0 0 0 0.2 1 0 2 1 8 0 0 0 0.2 1 0 2 3 1 8 <td>6 zc= 0, zs = 0.,2, excitation frequency fro, 5 cpm to 1000 cpm</td>	6 zc= 0, zs = 0.,2, excitation frequency fro, 5 cpm to 1000 cpm
a The system damped natural nequencies: s21, 625 cplin g Damping Factors: 0.046 and 0.108 Rotor Bearing System Data X Axial Forces Static Loads Constraints Misalignments Shaft Bow Time Forcing Hamonics Base Motion Torsional/Avial Units/Description Material Shaft Bements Disks Unbalance Bearings Supports Foundation User's Elements Use Horizontal Scroll Bar to scroll to the right for more data inputs if necessary, or click the Full Table Full Table Full Table 1 Rigid 1 8 0 0 0 0.2 1 0 2 1 1 8 0 0 0.2 1 0 0 2 3 3 3 3 3 3 3 3 3 3 Avial Forces Static Loads Constraints Misalignments Shaft Bow Time Forcing Hamonics Base Motion Torsional/Avial Units/Description Material Shaft Bements Disks Unbalance Bearings Suports <	7 The system undamped natural frequencies: 321, 634 cpm
10 10 X Rotor Bearing System Data X Axial Forces Static Loads Constraints Misalignments Shaft Bow Time Forcing Hamonics Base Motion Torsional/Axial Units/Description Material Shaft Elements Disks Unbalance Bearings Supports Foundation User's Elements Use Horizontal Scroll Bar to scroll to the right for more data inputs if necessary, or click the Full Table Full Table Full Table 1 Rigid 1 8 0 0 0 0.2 1 0 2 3	9 Damping Factors: 0.046 and 0.108
Rotor Bearing System Data X Avial Forces Static Loads Constraints Misalignments Shaft Bow Time Forcing Harmonics Base Motion Torsional/Avial Units/Description Material Shaft Elements Disks Unbalance Bearings Supports Foundation User's Elements Use Horizontal Scroll Bar to scroll to the right for more data inputs if necessary, or click the Full Table Full Table Full Table Type Stn Mass Dia.Inertia Polar Inertia SkewX SkewY Length ID DD Density • 1 Rigid 1 8 0 0 0 0.2 0 1 0 2 3 - - 0 0 0.2 1 0 2 - <	
Avial Forces Static Loads Constraints Misalignments Shaft Bow Time Forcing Hamonics Base Motion Torsional/Axial Units/Description Material Shaft Elements Disks Unbalance Bearings Supports Foundation User's Elements Use Horizontal Scroll Bar to scroll to the right for more data inputs if necessary, or click the Full Table Full Table Full Table Type Stn Mass Dia.Inertia Polar Inertia SkewX SkewY Length ID OD Density ID 1 Rigid 1 8 0 0 0 0.2 1 0 ID 2 3 -	Rotor Bearing System Data X
Units/Description Material Shaft Elements Disks Unbalance Bearings Supports Foundation User's Elements Use Horizontal Scroll Bar to scroll to the right for more data inputs if necessary, or click the Full Table Full Table Full Table Type Stn Mass Dia.Inertia Polar Inertia SkewX SkewY Length ID OD Density 0 1 Rigid 1 8 0 0 0 0.2 0 1 0 2 3	Axial Forces Static Loads Constraints Misalignments Shaft Bow Time Forcing Hamonics Base Motion Torsional/Axial
Use Horizontal Scroll Bar to scroll to the right for more data inputs if necessary, or click the Full Table Type Stn Mass Dia.Inertia Polar Inertia SkewX SkewY Length ID OD Density A 1 Rigid 1 8 0 0 0 0.2 0 1 0 2 3	Units/Description Material Shaft Elements Disks Unbalance Bearings Supports Foundation User's Elements
Use Horizontal Scroll Bar to scroll to the right for more data inputs if necessary, or click the Full Table Type Stn Mass Dia.Inertia Polar Inertia SkewX SkewY Length ID OD Density I 1 Rigid 1 8 0 0 0 0 0.2 0 1 0 2 3	
Type Stn Mass Dia.Inertia Polar Inertia Skew/X Skew/Y Length ID OD Density A 1 Rigid 1 8 0 0 0 0.2 0 1 0 2 3 0 0 0 0 0.2 0 1 0 2 3 0 0 0 0 0.2 0 1 0 2 3 0 0 0 0 0.2 0 1 0 2 3 0 0 0 0 0.2 0 1 0 0 2 3 0 <t< td=""><td>Use Horizontal Scroll Bar to scroll to the right for more data inputs if necessary, or click the Full Table</td></t<>	Use Horizontal Scroll Bar to scroll to the right for more data inputs if necessary, or click the Full Table
1 Rigid 1 8 0 0 0 0 0.2 0 1 0 2 3 3 3 3 1 0 0 0 0.2 0 1 0 0 Rotor Bearing System Data X X X X X X X X X X X X X X X X X Y	Type Stn Mass Dia.Inertia Polar Inertia SkewX SkewY Length ID OD Density
Z 3 Rotor Bearing System Data X Axial Forces Static Loads Constraints Misalignments Shaft Bow Time Forcing Harmonics Base Motion Torsional/Axial Units/Description Material Shaft Elements Disks Unbalance Bearings Supports Foundation User's Elements Support: 1 of 1 Add Delete Previous Next Station I: Support Mass only, the K and C are included in the bearing 2	1 Rigid 1 8 0 0 0 0 0.2 0 1 0
Rotor Bearing System Data X Axial Forces Static Loads Constraints Misalignments Shaft Bow Time Forcing Hamonics Base Motion Torsional/Axial Units/Description Material Shaft Elements Disks Unbalance Bearings Supports Foundation User's Elements Support: 1 of 1 Add Delete Previous Next Station I: S Comment: Support Mass only, the K and C are included in the bearing 2 V V V M 15 0 0 15 0 0 0 K 0 0 0 0 0 0 0 0	
Axial Forces Static Loads Constraints Misalignments Shaft Bow Time Forcing Harmonics Base Motion Torsional/Axial Units/Description Material Shaft Elements Disks Unbalance Bearings Supports Foundation User's Elements Support: 1 of 1 Add Delete Previous Next Station I: Image: Comment: Support Mass only, the K and C are included in the bearing 2 Image: Comment: Support Mass only, the K and C are included in the bearing 2 Image: Mass only of the fourthead of the fourthead of the bearing 2 Image: Comment is a fourthead of the fourthead of	Rotor Bearing System Data
Axial Forces Static Loads Constraints Misalignments Shaft Bow Time Forcing Harmonics Base Motion Torsional/Axial Units/Description Material Shaft Elements Disks Unbalance Bearings Supports Foundation User's Elements Support: 1 of 1 Add Delete Previous Next Station I: Image: Support Mass only, the K and C are included in the bearing 2 Image: Support Mass only, the K and C are included in the bearing 2 Image: Support Mass only, the K and C are included in the bearing 2 Image: Support Mass only, the K and C are included in the bearing 2 Image: Support Mass only, the K and C are included in the bearing 2 Image: Support Mass only, the K and C are included in the bearing 2 Image: Support Mass only, the K and C are included in the bearing 2 Image: Support Mass only, the K and C are included in the bearing 2 Image: Support Mass only, the K and C are included in the bearing 2 Image: Support Mass only, the K and C are included in the bearing 2 Image: Support Mass only, the K and C are included in the bearing 2 Image: Support Mass only, the K and C are included in the bearing 2 Image: Support Mass only, the K and C are included in the bearing 2 Image: Support Mass only, the K and C are included in the bear on C and And C and And C and And And C and C and C and C and And C and C a	
Support: 1 of 1 Add Delete Previous Next Station I: Image: Support Mass only, the K and C are included in the bearing 2 Image: Support Mass only, the K and C are included in the bearing 2 Image: Support Mass only, the K and C are included in the bearing 2 Image: Support Mass only, the K and C are included in the bearing 2 Image: Support Mass only, the K and C are included in the bearing 2 Image: Support Mass only, the K and C are included in the bearing 2 Image: Support Mass only, the K and C are included in the bearing 2 Image: Support Mass only, the K and C are included in the bearing 2 Image: Support Mass only, the K and C are included in the bearing 2 Image: Support Mass only, the K and C are included in the bearing 2 Image: Support Mass only, the K and C are included in the bearing 2 Image: Support Mass only, the K and C are included in the bearing 2 Image: Support Mass only, the K and C are included in the bearing 2 Image: Support Mass only, the K and C are included in the bearing 2 Image: Support Mass only, the K and C are included in the bearing 2 Image: Support Mass only, the K and C are included in the bearing 2 Image: Support Mass only, the K and C are included in the bearing 2 Image: Support Mass only, the K and C are included in the bearing 2 Image: Support Mass only, the K and C are included in the bearing 2 Image: Support Mass only, the K and C are included in the bearing 2	Axial Forces Static Loads Constraints Misalignments Shaft Bow Time Forcing Harmonics Base Motion Torsional/Axial
Support: 1 of 1 Add Delete Previous Next Station I: Image: Comment: Support Mass only, the K and C are included in the bearing 2 Image: Comment: Support Mass only, the K and C are included in the bearing 2 Image: Comment: Support Mass only, the K and C are included in the bearing 2 Image: Comment:	Units/Description Material Shart Elements Disks Unbalance Bearings Supports Poundation User's Elements
Station I: Station I: Support Mass only, the K and C are included in the bearing 2 Comment: Support Mass only, the K and C are included in the bearing 2 xx xv vx M 15 0 0 15 C 0 0 0 0 K 0 0 0 0	Support: 1 of 1 Add Delete Previous Next
Station I: Support Mass only, the K and C are included in the bearing 2 Comment: Support Mass only, the K and C are included in the bearing 2 M 15 0 0 15 C 0 0 0 0 K 0 0 0 0	
Comment: Support Mass only, the K and C are included in the bearing 2 xx xy yx yy M 15 0 0 15 C 0 0 0 0 K 0 0 0 0	Station I: 3
xx xv vx vv M 15 0 0 15 C 0 0 0 0 K 0 0 0 0	Connects Report Managers the Kond Connected date the baseline 2
xx xy yx yy M 15 0 0 15 C 0 0 0 0 K 0 0 0 0	Comment: Support Mass only, the K and C are included in the bearing 2
M 15 0 0 15 C 0 0 0 0 K 0 0 0 0	xx xy yx yy
	<u>M 15 0 0 15</u>

Rotor Bearing	System Data						×		
Axial Forces Units/Descrip	Static Loads	Constraints Misalignments Shaft Elements Disks	Shaft Bow	Time Forcing Bearings	Harmonics Supports	Base Motion To Foundation Use	orsional/Axial er's Elements		
Bearing: 1	of 2	Found	ation	Add Brg	Del Brg	Previous	Next		
Station I:	1 J: 3			Angle: 0					
Туре:	0- Linear Consta	nt Bearing		-]				
Comment:									
		Translational Bea	ring Properties	1					
Kxx:	40	Kxy: 0	Cxx:	0.2	Cxy: 0				
Кух:	0	Куу: 40	Сух:	0	Суу: 0.2				
		Rotational Bea	aring Propertie	s			•		
Rotor Bearing	System Data						×		
Axial Forces Units/Descri	Static Loads	Constraints Misalignments Shaft Elements Disks	Shaft Bow	Time Forcing Bearings	Harmonics Supports	Base Motion T Foundation Use	orsional/Axial er's Elements		
Bearing: 2	2 of 2	Found	ation	Add Brg	Del Brg	Previous	Next		
Station I:	3 J: 0			Angle: 0					
Type:	0- Linear Consta	nt Bearing		•]				
Comment:	Suppprt K & C w	hich is connected to the BASE	E						
Translational Bearing Properties									
Kxx:	100	Kxy: 0	Cxx:	0.1	Cxy: 0				
Кух:	0	Кууу: 100	Cyx:	0	Cyy: 0.1				

Rotor Bea	otor Bearing System Data X												
Units/Do Axial For x, y, th	Units/Description Material Shaft Elements Disks Unbalance Bearings Supports Foundation User's Elements Axial Forces Static Loads Constraints Misalignments Shaft Bow Time Forcing Harmonics Base Motion Torsional/Axial x, y, theta x, and theta y: Fixed or None (0); Shear/Momnet: Release or None (0) Import *xls Export *xls												
	Stn	×	Ŷ	Theta x	Theta y	Shear	Moment	Comments					
1	1	0	Fixed	Fixed	Fixed	0	0						
2	2	Fixed	Fixed	Fixed	Fixed	0	0						
3	3	0	Fixed	Fixed	Fixed	0	0						
4													
5													
6													
7													

Rotor Bear	ring System Data					×					
Units/De Axial Ford	Units/Description Material Shaft Elements Disks Unbalance Bearings Supports Foundation User's Elements Axial Forces Static Loads Constraints Misalignments Shaft Bow Time Forcing Harmonics Base Motion Torsional/Axial										
	Base Type: Single										
Stea	Steady State Base Harmonic Motion: Excitation Frequency varies at a Constant Rotor Speed										
	Excitation Frequency	(cpm)									
	Start: 5	Stop: 100	00 Increr	ment. 5							
	Amplitude N	fultiplier (A = Ao + A1 *	rpm + A2 * rpm^2)								
	Ao: 1	A1.	D A2-	0							
			7.2.								
	Steady St	ate Harmonic Base Mot	ion:q = A* [qc * cos (we	<c*t) *="" +="" qs="" sin(wexc*t)<="" td=""><td>]</td><td></td></c*t)>]						
	(q	c,qs) are the displacem	ent amplitudes in (cos,sin)	components							
	Excitation freque	ency wexc (rad/sec) =	cpm * (2*pi/60). rpm =	reference shaft speed,	rotor 1 speed	_					
		1 Statio	on connected to the Base	: 3							
	Direction	qc - cos	qs - sin	Comr	nents						
1	X-Dir	0	0.2								
2	Y-Dir	0	0								
3	Theta-X	0	0								
4	Theta-Y	0	0								
				Uni	t:(2) - Amplitude: ir	nch, radian					
Te	or K		Save	e Save <u>A</u> s	Close	<u>H</u> elp					

Fig. 15 – Inputs for Example 2





Mass m_1 absolute and relative displacements (station 1)



Fig. 16 – Displacements for Mass m_1



Mass m_2 absolute and relative displacements (station 3)





The transmitted forces for bearing 1 and bearing 2 are shown below. The force transmitted through bearing 2 is acting on the base.



Fig. 18 – Forces Transmitted through Bearings

Again, the absolute displacements can be verified by using the steady state harmonic excitation analysis. The excitation acting on the mass m_2 (station 3) is:

$$kz + c\dot{z} = k(z_c \cos \omega_{exc}t + z_s \sin \omega_{exc}t) + c\omega_{exc}(z_s \cos \omega_{exc}t - z_c \sin \omega_{exc}t)$$
$$= (kz_c + c\omega_{exc}z_s)\cos \omega_{exc}t + (kz_s - c\omega_{exc}z_c)\sin \omega_{exc}t$$

For the excitation frequency of 320 cpm, the harmonic excitation is:

$$\left(0.1 \times \frac{320 \times 2\pi}{60} \times 0.2\right) \cos \omega_{exc} t + (100 \times 0.2) \sin \omega_{exc} t$$

The harmonic excitation input:

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 Harmonics Base Motion Torsional/Axial							
Steady State Harmonic Excitation: Excitation Frequency is a function of Rotor Speed or a Constant							
Excitation Frequency (cpm = wo + w1 * rpm + w2 * rpm^2) Vo: 320 W1: 0 W2: 0 Amplitude Multiplier (A = Ao + A1 * rpm + A2 * rpm^2)							
Ao: 1 A1: 0 A2: 0 Steady State Harmonic Excitation: Q = A * Q * cos (wexc*t + phase)							
Excitation frequency wexc (rad/sec) = cpm * (2*pi/60). and A is the Amplitude multiplier rpm = excitation shaft speed, rotor speed where the excitation applied							
Ele(Stn) Sub Dir Left Amp. Left Ang. Right Amp. Right Ang. Comments							
1 3 1 1 20.0112 271.919 0 0 2 3 4							

Fig. 19 – Harmonic Excitation at m_2 (station 3)

The results for the excitation frequency at 320 cpm can be verified. In order to shown the plots, we ran the steady state harmonic analysis for a speed range of 0-1000 rpm. The displacement results are:





Fig. 20 – Responses for the Harmonic Excitation

Case 2: BaseMotion_2b.rot

In this model, we can also move the bearing 2 data into the support tab, as shown in Fig. 21. The results are identical to the previous model and not repeated here.

Rotor Bearing System Data					×
Axial Forces Static Loads Constr Units/Description Material Sha	raints Misalignments Sh aft Elements Disks U	naft Bow Time Forcin Inbalance Bearings	ng Harmonics Supports	Base Motion	Torsional/Axial Jser's Elements
Support: 1 of 1		Add	Delete	Previous	Next
Station I: 3					
Comment: The K and C are now i	n this data input				
XX	ΧŲ	γx		γų	
M 15	0	0	0 15		
К 100	0	0		100	
Damping Input Format	t O Zeta - Damping Fa	actor Zeta-X	0.0253669		
C = Zeta * 2 * SQRT(M * F	 Typical Zeta = 0.000⁻ 	1 - 0.02 Zeta-Y	0.0253669		
			Unit:(2) - M	1: Lbm, C: Lbf-s/ir	ı, K: Lbf∕in
Tor K		<u>S</u> ave	Save <u>A</u> s	Close	<u>H</u> elp

Fig. 21 – Alternative inputs for Bearing 2

Example 3 – Multiple Degrees-of-Freedom

A multiple DOF system, as shown in Fig. 22, is used in this example. At the operating speed of 3,000 rpm, the first five natural frequencies are: 4,312 (backward), 4,358 (forward), 7,342 (backward), 7,619 (forward), and 100,684 (backward) rpm and their associated whirling modes are shown in Fig. 23.



Fig. 22 – Example 3







Fig. 23 – The first five modes at 3,000 rpm

Case 1: BaseMotion_3a.rot

A single base is assumed in this case. The base has a motion in Y direction and the excitation frequency is from 200 to 10,000 cpm with an increment of 50 cpm. This excitation frequency will excite the first two system natural frequencies and far below the third natural frequency. The base motion and the analysis input are shown below:

Rotor Bearing System Data X Units/Description Material Shaft Elements Disks Unbalance Bearings Supports Foundation User's Elements Axial Forces Static Loads Constraints Misalignments Shaft Bow Time Forcing Harmonics Base Motion Torsional/Axial Base Type: Single • • • • • • Steady State Base Harmonic Motion: Excitation Frequency varies at a Constant Rotor Speed • <th></th> <th></th>							
Units/Description Material Shaft Elements Disks Unbalance Bearings Supports Foundation User's Elements Axial Forces Static Loads Constraints Misalignments Shaft Bow Time Forcing Harmonics Base Motion Torsional/Axial Base Type: Single Image: Steady State Base Harmonic Motion: Excitation Frequency varies at a Constant Rotor Speed Image: Steady State Base Harmonic Motion: Excitation Frequency varies at a Constant Rotor Speed Image: Steady State Base Harmonic Motion: Image: Steady State Rotor Speed Image: Steady State Base Harmonic Motion: Image: Steady State Rotor Speed Image: Steady State Base Harmonic Base Motion: Image: Steady State Harmonic Base Motion: <	Rotor Bearing System Data						
Base Type: Single Steady State Base Harmonic Motion: Excitation Frequency varies at a Constant Rotor Speed Excitation Frequency (cpm) Start: 200 Stop: 10000 Increment. 50 Anplitude Multiplier (A = Ao + A1 * pm + A2 * pm^2) Ao: 1 A1: 0 A2: 0 Steady State Harmonic Base Motion: q = A* [qc * cos (wexc*t) + qs * sin(wexc*t)] (qc.qs) are the displacement amplitudes in (cos,sin) components Excitation frequency wexc (rad/sec) = cpm * (2*pi/60). rpm = reference shaft speed, rotor 1 speed Other colspan="2">Comments Lot on qc · cos qs · sin Comments 1 X-Dir 0 Other colspan="2">Steady State Harmonic Base Motion: q = A* [qc * cos (wexc*t) + qs * sin(wexc*t)] (qc.qs) are the displacement amplitudes in (cos,sin) components Excitation frequency wexc (rad/sec) = cpm * (2*pi/60). rpm = reference shaft speed, rotor 1 speed 2 Direction qc · cos qs · sin Comments 2 Otheret on o Single Ba	Units/Description Material Shaft Elements Disks Unbalance Bearings Supports Foundation User's Elements Axial Forces Static Loads Constraints Misalignments Shaft Bow Time Forcing Harmonics Base Motion Torsional/Axial						
Steady State Base Harmonic Motion: Excitation Frequency varies at a Constant Rotor Speed Excitation Frequency (cpm) Start: 200 Stop: 10000 Increment. 50 Amplitude Multiplier (A = Ao + A1 * rpm + A2 * rpm^2) Ao: 1 A1: 0 A2: 0 Steady State Harmonic Base Motion: g = A* [qc * cos (wexc*t) + qs * sin(wexc*t)] (qc.qs) are the displacement amplitudes in (cos.sin) components Excitation frequency wexc (rad/sec) = cpm * (2*pi/60). rpm = reference shaft speed, rotor 1 speed 2 Y-Dir 0.1 0 Single Base - Y direction 3 Iheta-X U U U 4 Theta-Y 0 0 0	Base Type: Single						
Excitation Frequency (cpm)Start:200Stop:10000Increment.50Amplitude Multiplier (A = Ao + A1 * pm + A2 * pm^2)Ao:1A1:0A2:0Ao:1A1:0A2:00Steady State Harmonic Base Motion: $q = A^* [qc * cos (wexc*t) + qs * sin(wexc*t)]$ (qc.qs) are the displacement amplitudes in (cos,sin) components Excitation frequency wexc (rad/sec) = cpm * (2*pi/60).pm = reference shaft speed, rotor 1 speed2 Stations connected to the Base: 3, 7DirectionQc - cosqs - sinComments1X-Dir0O index < 10	<td>Steady State Base Harmonic Motion: Excitation Frequency varies at a Constant Rotor Speed</td> <td>l</td>	Steady State Base Harmonic Motion: Excitation Frequency varies at a Constant Rotor Speed	l				
Stat: 200 Stop: 10000 Increment. 50 Amplitude Multiplier (A = Ao + A1 * rpm + A2 * rpm^2) Ao: 1 A1: 0 A2: 0 Ao: 1 A1: 0 A2: 0 0 Steady State Hamonic Base Motion: q = A* [qc * cos (wexc*t) + qs * sin(wexc*t)] (qc,qs) are the displacement amplitudes in (cos,sin) components Excitation frequency wexc (rad/sec) = cpm * (2*pi/60). rpm = reference shaft speed, rotor 1 speed 2 Stations connected to the Base: 3, 7 Direction qc - cos qs - sin Comments 1 X-Dir 0 0 2 Y-Dir 0.1 0 Single Base - Y direction 3 I heta-X 0 0 0	Excitation Frequency (cpm)	l					
Amplitude Multiplier (A = Ao + A1 * pm + A2 * pm ^2)Ao:1A1:0A2:0Steady State Hamonic Base Motion: $q = A^* [qc^* cos (wexc^*t) + qs^* sin(wexc^*t)]$ (qc,qs) are the displacement amplitudes in (cos,sin) componentsExcitation frequency wexc (rad/sec) = cpm * (2*pi/60).rpm = reference shaft speed, rotor 1 speed2 Stations connected to the Base: 3, 7Directionqc - cosqs - sinComments1X-Dir02Y-Dir0.13I heta-XU4T heta-Y0	Start: 200 Stop: 10000 Increment. 50						
Ao: 1 A1: 0 A2: 0 Steady State Harmonic Base Motion: q = A* [qc * cos (wexc*t) + qs * sin(wexc*t)] (qc,qs) are the displacement amplitudes in (cos,sin) components Excitation frequency wexc (rad/sec) = cpm * (2*pi/60). rpm = reference shaft speed, rotor 1 speed 2 Stations connected to the Base: 3, 7 Direction qc · cos qs · sin Comments 1 X-Dir 0 0 0 2 Y-Dir 0.1 0 Single Base · Y direction 3 I heta-X 0 0 0	Amplitude Multiplier (A = Ao + A1 * rpm + A2 * rpm^2)						
Steady State Hamonic Base Motion: q = A* [qc * cos (wexc*t) + qs * sin(wexc*t)] (qc,qs) are the displacement amplitudes in (cos,sin) components Excitation frequency wexc (rad/sec) = cpm * (2*pi/60). mpm = reference shaft speed, rotor 1 speed 2 Stations connected to the Base: 3, 7 Direction Q - cos	Ao: 1 A1: 0 A2: 0						
(qc.qs) are the displacement amplitudes in (cos,sin) components Excitation frequency wexc (rad/sec) = cpm * (2*pi/60). rpm = reference shaft speed, rotor 1 speed 2 Stations connected to the Base: 3, 7 Direction Q · cos qs · sin Comments 1 ×·Dir 0 Single Base · Y direction 3 Ineta-X U	Steady State Harmonic Base Motion: q = A* [qc * cos (wexc*t) + qs * sin(wexc*t)]	l					
Excitation frequency wexc (rad/sec) = cpm * (2*pi/60). rpm = reference shaft speed, rotor 1 speed 2 Stations connected to the Base: 3, 7 Direction Comments 1 X-Dir Comments 2 Y-Dir 0,1 O Single Base · Y direction 3 Ineta-X U U 4 Theta-Y 0 O	(qc,qs) are the displacement amplitudes in (cos,sin) components	L					
2 Stations connected to the Base: 3, 7 Direction qc - cos qs - sin Comments 1 X-Dir 0 0 2 Y-Dir 0.1 0 Single Base - Y direction 3 Theta-X U U 4 Theta-Y 0 0	Excitation frequency wexc (rad/sec) = cpm * (2*pi/60). pm = reference shaft speed, rotor 1 speed						
Direction qc - cos qs - sin Comments 1 X-Dir 0 0 2 Y-Dir 0.1 0 Single Base - Y direction 3 I heta-X U U U 4 T heta-Y 0 0 0	2 Stations connected to the Base: 3, 7	l					
1 X-Dir 0 0 2 Y-Dir 0.1 0 Single Base - Y direction 3 I heta-X U U 4 T heta-Y 0 0	Direction gc · cos gs · sin Comments	L					
2 Y-Dir 0.1 0 Single Base - Y direction 3 I heta-X U U 4 Theta-Y 0 0	1 X-Dir 0 0	L					
3 1 heta-X U U 4 Theta-Y 0 0	2 Y-Dir 0.1 0 Single Base - Y direction						
4 Theta-Y 0 0	3 IhetaX U U	ſ					
	4 Theta-Y 0 0						

Lateral Analysis Option & Run Time	Data	×
Analysis: 23- Base Steady State H. Shaft Element Effects ▼ Rotatory Inertia ▼ Shear Detection □ Constrained Bearing Stations Critical Speed Analysis Spin/Whirl Ratio: □ No. of Modes: ③ rpm: Highest	Transient Analysis Time Frequency formation ✓ Gyroscopic Gz Critical Speed Constant Speed: 7600 rpm Constant Speed: 7600 rpm Critical Speed Base Motion (Excitation) Analysis X Spin/Whit R Base Motion (Excitation) Analysis X Bearing K - Steady State Base Excitation Base Motion Npts: 0 Excitation Freq. cpm GK Stiffness to t Start: 200 Cancel Forcing Bearings: Find: 10000 Inc: 50 Cancel ne Maneuver	Gravity (g) X: 0 Y: -9806.64 Z: 0 None zero Gz Vertical Rotor Design Comparison
Ending: 0 Ending: 10000 Increment: 1000	RPM-Starting: 1000 Effects: RPM-Starting: 3000 Ending: 10000 I Mass Unbalance Ending: 3000 Increment: 1000 I Const. Unbalance Ending: 3000 Increment: 1000 I Shaft Bow Increment: 1	Run

Fig. 24 – The Base Motion and Analysis Input

The displacements (absolute and relative) at the disk (station 1) and bearings (stations 3 and 7) are shown in Fig. 25 below:








Fig. 25 – The Results for Base Motion



Forces transmitted through bearings to the base are:

Fig. 26 – The Force Transmitted to the Base

Although the bearings are isotropic and uncoupled in the X and Y directions in this example, as shown below, the X and Y motions are coupled through the gyroscopic effect. So, even with the base motion in the Y direction only, the responses occur at both X and Y directions with dominant Y displacement.

Rotor Bearing Sy	ystem Data	×
Axial Forces Units/Description	Static Loads Constraints Misalignments Shaft Bow Time Forcing Harmonics Base Motion T on Material Shaft Elements Disks Unbalance Bearings Supports Foundation Use	orsional/Axial er's Elements
Bearing: 1 of	f 2 Foundation Add Brg Del Brg Previous	Next
Station I: 3	J: 0 Angle: 0	
Type: 0)- Linear Constant Bearing	
Comment: T	Two identical bearings at stations 3 and 7	
	Translational Bearing Properties	
Kxx: 1	500 Kxy: 0 Cxx: 0.5 Cxy: 0	
Кух: 0	Куу: 1500 Сух: 0 Суу: 0.5	
	Rotational Bearing Properties	
Kaa: 0	Kab: 0 Caa: 0 Cab: 0	
Kba: 0	Kbb: 0 Cba: 0 Cbb: 0	
Rotor Bearing Sy	ystem Data	×
Axial Forces Units/Description	Static Loads Constraints Misalignments Shaft Bow Time Forcing Harmonics Base Motion Tion Material Shaft Elements Disks Unbalance Bearings Supports Foundation Use	orsional/Axial er's Elements
Bearing: 2 of	f 2 Foundation Add Brg Del Brg Previous	Next
Station I: 7	J: 0 Angle: 0	
Type: 0	- Linear Constant Bearing	
Comment:		

Notor bearing system bata				~
Axial Forces Static Loads Units/Description Material	Constraints Misalignmen Shaft Elements Disk:	ts Shaft Bow Time s Unbalance Bea	Forcing Harmonics Base M arings Supports Foundati	Notion Torsional/Axial
Bearing: 2 of 2	🗌 Fou	ndation Add E	Brg Del Brg Previo	ous Next
Station I: 7 J: 0		Angle	e: 0	
Type: 0- Linear Constar	nt Bearing		•	
Comment:				
	Translational B	earing Properties		
Кох: 2000	Kxy: 0	Cxx: 0.5	Cxy: 0	
Кух: 0	Куу: 2000	Cyx: 0	Суу: 0.5	
	Rotational E	Bearing Properties		
Kaa: 0	Kab: 0	Caa: 0	Cab: 0	
Kba: 0	Kbb: 0	Cba: 0	Cbb: 0	

Again, the absolute displacements can be verified using the Steady State Harmonic Excitation Analysis as described before. For comparison purposes, the excitation frequency at 4,350 cpm is selected. The excitation forces can then be calculated and entered in the harmonic excitation input, as shown below. The analysis is run at a constant rotor speed of 3,000 rpm. The results are also listed below.



Lateral Analysis Option & Run Time [Data			×
Analysis: 8 - Steady State Harmonic Shaft Element Effects Rotatory Inertia V Shear Defe	Excitation Response	Transient Analysis RPM: 7600 Const	Time Frequency Domain Domain	Gravity (g)
Static Deflection Constrained Bearing Stations Critical Speed Analysis Spin/Whirl Ratio: 1 No. of Modes: 3 Brg Stiffness: Kxx @ rpm: Highest	Critical Speed Map Spin/Whil Ratio: 1 Bearing K - Min: 175 Npts: 0 Max: 1.75e+008 Stiffness to be varied at Bearings: All Allow Bearings in Series	Time-Start: 0 End: 0.1 Step: 0.0001 Suggested Tim Solution Met Runge_Kutta Initial Cs: No	 Mass Unbalance Const. Unbalance Shaft Bow Disk Skew Gravity (X) Gravity (Z) thod Static Loads Time Forcing Misalignment Marine Maneuver 	Y: -3806.64 Z: 0 None zero Gz Vertical Rotor Design Comparison
Whirl Speed and Stability Analysis RPM-Starting: 0 Ending: 10000 Increment: 1000 No. of Modes: 8	Steady State Synchronous Response RPM-Starting: 1000 Ending: 10000 Increment: 1000 Excitation Shaft: 1	e Analysis Effects: Mass Unbalance Const. Unbalance Shaft Bow Disk Skew Micelingenent	- Steady State Harmonic Excitation RPM-Starting: 3000 Ending: 3000 Increment: 1 Excitation Shaft: 1	Run Cancel
Steady Maneuvers (Base Constant Tr Speed (RPM): 0 Accele	anslational Acceleration and/or Turn R- ration - X: 0 Y: 0	ate) Turn Rate - X: 0	✓ All Shafts with same speed Y: 0 Ref Port	s: 0

Fig. 27 – The Steady State Harmonic Excitation

Sha	aft	1	Spee	ed=	3000.00	rpm	=	314.	.16	R/S	=		50.00 1	Ηz	
* * * * *	****	* * * * * *	**** X	**** 5	Shaft El ====	ement = Y	Disp]	lacem =	nent	s ** Ell	***; ipt:	***** ical	****** Orbit 1	**** Data	* * * *
stn	sub	Ampli	tude	Phase	Ampl	itude	Phase	9		A	-	:	В		G
1	1	0.816E	-01	267.5	0.112	E+01	87.4	1	0.1	12E+	01	0.1	30E-03		94.
2	1	0.692E	-01	269.7	0.964	E+00	86.0)	0.9	66E+	00	0.4	48E-02		94.
3	1	0.570E	-01	272.9	0.810	E+00	84.1	L	0.8	12E+	00	0.8	/0E-02		94.
4	1	0.451E	-01	277.8	0.657	E+00	81.4	1	0.6	59E+	00	0.1	27E-01		94.
5	1	0.338E	-01	286.0	0.507	E+00)	0.5	08E+	00	0.1	64E-01		93.
6	1	0.239E	-01	301.7	0.363	E+00	69.0)	0.3	63E+	00	0.1	90E-01		92.
7	1	0.177E	-01	332.7	0.233	E+00	51.5	ō	0.2	33E+	00	0.1	73E-01		89.
* * * * *	* * * *	* * * * * *	* * * * *	* * * * * * *	* * * * * * * *	* * * * * *	* * * * * *	* * * * *	****	****	* * * *	* * * * *	* * * * * *	* * * *	* * * *
Eler	nent 	Inter	nal S	Shear H Left -	Forces a	nd Mor	ments	(Sem	ni-M	lajor Rig	Ax: ht -	is)			
Ele		She	ar		Moment			Shea	ar	2	ľ	Momen	t		
1		81.5	74		322.01		-	187.7	76		0	9119.	1		
2		187.	76		9119.1		4	153.2	22		3	30367			
3		773.	18		30367.		ŗ	553.8	38		-	13049			
4		553.	88		13049.		-	70.13	36		3	31195			
5		70.1	36		31195.		2	291.5	51		2	22154			
6		291.	51		22154.			378.6	51		0	.1314	7E-08		
****	****	* * * * * *	****	* * * * * * *	* * * * * * * *	* * * * * *	*****	****	****	****	***;	* * * * *	* * * * * * *	* * * *	****
ala ala ala ala al		ale ale ale ale ale ale			- ·	10			,			ala ala ala ala		1lll.	de de de de
****	* * * *	*****	× × × _	Linear	Bearing	/Suppo	ort Fo	orce	and	Mom	ent	****		~ ~ ~ ~	* * * *
str	ר ד	===== 7	X	=====	====	= Y	=====	=		EIT	ipti	ical	Orbit I D	Jata	~
T	J	Ampii	tuae	Pnase	Ampi	itude	Phase	9		А			В		G
3	0	0.864E	+02	264.3	0.123	E+04	75.5	5	0.1	23E+	04	0.1	32E+02		94.
Momer	nt	0.000E	+00	0.0	0.000	E+00	0.0)	0.0	00E+	00	0.0	00E+00		Ο.
7	0	0.356E	+02	326.2	0.470	E+03	45.0)	0.4	70E+	03	0.3	49E+02		89.
Momer	nt	0.000E	+00	0.0	0.000	E+00	0.0	C	0.0	00E+	00	0.0	00E+00		0.
* * * * *	****	* * * * * *	* * * * *	* * * * * * *	* * * * * * * *	* * * * * *	*****	****	****	****	***;	* * * * *	* * * * * * *	****	* * * *

The absolute displacements are identical to the results from the base motion analysis. However, the forces transmitted through bearings are not the same since the steady state harmonic excitation analysis did not include the base motion.

Case 2: BaseMotion_3b.rot

In this case, the Single Base is replaced by Multiple Base Option with the identical base motion, as shown in Fig. 28.

Rotor Bearing System Data	×									
Units/Description Material Shaft Elements Disks U Axial Forces Static Loads Constraints Misalignments St	Inbalance Bearings Supports Foundation User's Elements naft Bow Time Forcing Harmonics Base Motion Torsional/Axial									
B Steady State Base Harmonic Motion: Excitation Frequency	ase Type: Multiple varies at a Constant Rotor Speed									
Excitation Frequency (cpm)										
Start: 200 Stop: 10000	Increment. 50									
Amplitude Multiplier (A = Ao + A1 * rpm + A2 Ao: 1 A1: 0	*rpm^2) A2: 0									
Steady State Hamonic Base Motion: q = A (qc,qs) are the displacement amplit	* [qc * cos (wexc*t) + qs * sin(wexc*t)] Jdes in (cos,sin) components									
Excitation frequency wexc (rad/sec) = cpm * (2*p 2 Stations connec	ted to the Base: 3, 7									
stn I Xc-cos Xs-sin Yc-cos Ys-sin	ThetaXc ThetaXs ThetaYc ThetaYs Comments 🔺									
1 3 0 0 0.1 0 2 7 0 0 0.1 0										

Fig. 28 – Multiple Base

The results are identical to the Case 1 and not presented here. However, when plotting the relative displacements, one must select which base will be used for the relative displacement as shown in Fig. 29.



Fig. 29 – The Relative Displacement

Case 3: BaseMotion_3c.rot

In this case, both bearings are subject to different base motion, as shown in Fig. 30. Note that the base motion can have different amplitude and phase, but the same frequency. The first bearing (station 3) has a base motion in the Y direction only. The second bearing (station 7) has the base motion in both X and Y directions.

Roto	or Beari	ng Syst	em Data									×
U Av	nits/De dal Forc	scription es St	Material atic Loads	Shaft E Constraint	ements s Misalign	Disks l iments S	Unbalance haft Bow	Bearings Time Forcir	Suppor	rts Foun onic: Bas	edation User's E se Motion Torsion	lements nal/Axial
	Stear	lv State	Rase Harmo	ppic Motion	Excitation	Frequenci	Base Type:	Multiple	Rotor Speed	-	-	
	Excitation Frequency (cpm)											
		St	art: 200		Stop: 1	0000	Ir	ncrement.	50			
			Amplitude	Multiplier (/	A = Ao + A1	* rpm + A2	* rpm^2) —			7		
			Ao: 1		A1:	0	A	2: 0				
			Steady	State Harmo	onic Base M	otion: q = /	A*[qc *cos	(wexc*t) +	qs * sin(we	exc"t)]		
				(qc,qs) are t	he displace	ment amplit	udes in (cos	s,sin) comp	onents			
		Б	citation freq	uency wexc	(rad/sec)	= cpm * (2*	pi/60). rp	m = referer	ice shaft sp	eed, rotor	1 speed	
	[2 Statio	ons connec	ted to the B	Base: 3, 7				
		stn I	Xc-cos	Xs-sin	Yc-cos	Ys-sin	ThetaXc	ThetaXs	ThetaYc	ThetaYs	Comments	
	1	3	0	0	0.1	0	0	0	0	0		
	2	7	0	0.05	0.05	0.05	0	0	0	0		
	4											

Fig. 30 – The Base Motion

The absolute displacements for the disk and both bearings are shown in Fig. 31. The relative motions for both bearings are shown in Fig. 32. The forces transmitted through bearings are shown in Fig. 33.







Fig. 31 – The Absolute Displacements





Fig. 32 – The Relative Displacements





Fig. 33 – The Bearing Transmitted Forces

To verify the absolute displacements caused by the base motion, the steady state harmonic excitation analysis is again used. For comparison purposes, the frequency at 4,350 cpm is selected. The amplitudes and phases are entered accordingly as shown in Fig. 34.

The right hand side of the equation for the Steady State Harmonic Excitation:

$$\begin{cases} F_x \\ F_y \end{cases} = \begin{bmatrix} k_{xx} & k_{xy} \\ k_{yx} & k_{yy} \end{bmatrix} \begin{cases} z_x \\ z_y \end{cases} + \begin{bmatrix} c_{xx} & c_{xy} \\ c_{yx} & c_{yy} \end{bmatrix} \begin{cases} \dot{z}_x \\ \dot{z}_y \end{cases}$$
(13)

where

$$\begin{cases} z_x \\ z_y \end{cases} = \begin{cases} x_c \\ y_c \end{cases} \cos(\omega_{exc}t) + \begin{cases} x_s \\ y_s \end{cases} \sin(\omega_{exc}t)$$
$$\begin{cases} \dot{z}_x \\ \dot{z}_y \end{cases} = \omega_{exc} \left(\begin{cases} x_s \\ y_s \end{cases} \cos(\omega_{exc}t) - \begin{cases} x_c \\ y_c \end{cases} \sin(\omega_{exc}t) \right)$$

and

$$\begin{cases} F_{x} \\ F_{y} \end{cases} = \begin{cases} F_{xc} \\ F_{xc} \end{cases} \cos(\omega_{exc}t) + \begin{cases} F_{xs} \\ F_{ys} \end{cases} \sin(\omega_{exc}t)$$

Rot	or Bearir	ig System I	Data							Х
L A	Inits/Des kial Force	cription 1 s Static I	Material Loads	Shaft E Constrain	Elements Disks ts Misalignments	Unbalance Shaft Bow	Bearings Sum Time Forcing Har	monics Base	lation User's Elem e Motion Torsional/	ents Axial
	Ste	r Bearing System Data X its/Description Material Shaft Elements Disks Unbalance Bearings Supports Foundation User's Elements al Forces Static Loads Constraints Misalignments Shaft Bow Time Forcing Harmonics Base Motion Torsional/Axial Steady State Harmonic Excitation: Excitation Frequency is a function of Rotor Speed or a Constant Image: Constraints Image: Constraints Image: Constraints Excitation Frequency (cpm = wo + w1 * rpm + w2 * rpm^2) Image: Constraints Image: Constraints Image: Constraints More: 4350 W1: 0 W2: 0 Image: Constraints Areplitude Multiplier (A = Ao + A1 * rpm + A2 * rpm^2) Ao: 1 A1: 0 Image: Constraints Ac: 1 A1: 0 A2: 0 Image: Constraints Image: Constraints								
	Notor Bearing System Data X Units/Description Material Shaft Elements Disks Unbalance Bearings Supports Foundation User's Elements Axial Forces Static Loads Constraints Misalignments Shaft Bow Time Forcing Harmonics Base Motion Torsional/Axial Steady State Harmonic Excitation: Excitation Frequency is a function of Rotor Speed or a Constant Image: Constraints Image: Constraints									
		An	nplitude I Ao: 1	Multiplier (A = Ao + A1 * rpm + A A1: 0	A2 * rpm^2) —	2: 0			
		Excitat	Steady ion frequ	State Har ency wex	monic Excitation:Q = c (rad/sec) = cpm * (A * Q * cos (w (2*pi/60). and	vexc*t + phase) A is the Amplitude	multiplier		
			rpm = ex	citation s	haft speed, rotor spee	ed where the ex	citation applied			
		Ele(Stn)	Sub	Dir	Left Amp.	Left Ang.	Right Amp.	Right Ang.	Comments	
	1	3	1	2	151.719	8.634	0	0	Y dir	
	2	6	1	1	0	0	100.646	-83.503	X dir	
	3	6	1	2	0	0	142.335	-38.503	Y dir	
	4									
	5									
	6 1									

Fig. 34 – The Steady State Harmonic Excitation

Since the comparison is selected only in one frequency, the results are compared as below:

******	******	larmonic :	Response due	to Shaft	: (1) Excitat	ion ********	******
	* *	** Excita	tion Frequenc	y = 435	50.0 cpm	l ***	
Shaft	1 5	Speed=	3000.00 rpm	= 31	L4.16 R/S =	50.00 Hz	2
		-	-				
* * * * * * *	* * * * * * * * *	*******	Shaft Element	Displac	cements *****	******	*****
		X =====	==== Ү	=====	Ellipt	ical Orbit Da	ita
stn su	b Amplitu	ide Phase	Amplitude	Phase	A	В	G
	1		1				
1 1	0.165E+0	0 220.9	0.943E+00	92.1	0.948E+00	-0.128E+00	96.
2 1	0.132E+0	0 216.6	0.823E+00	91.5	0.826E+00	-0.107E+00	95.
31	0.100E+0	0 209.5	0.704E+00	90.6	0.705E+00	-0.873E-01	94.
4 1	0.711E-0)1 196.2	0.586E+00	89.3	0.586E+00	-0.680E-01	92.
51	0.504E-0)1 169.1	0.468E+00	87.5	0.468E+00	-0.498E-01	89.
6 1	0.495E-0)1 128.3	0.351E+00	84.4	0.352E+00	-0.341E-01	84.
7 1	0.692E-0)1 99.8	0.235E+00	78.2	0.244E+00	-0.246E-01	75.
******	*******	*******	*****	******	*******	*******	*****
******	**** Hai	monic Re	sponse due to	Base Mo	otion (Excita	tion) ******	*****
*****	**** Ha:	monic Re	sponse due to	Base M o	otion (Excita	tion) ******	*****
*****	**** Hai **	rmonic Re ** Excita	sponse due to tion Frequenc	Base M c y = 435	otion (Excita	tion) ******	*****
******	**** Hai	monic Re ** Excita	sponse due to tion Frequenc	Base Mo y = 435 = 31	50.0 cpm	tion) *******	*****
****** Shaft	**** Hai *; 1 \$	rmonic Re ** Excita Speed=	sponse due to tion Frequenc 3000.00 rpm	Base Mo y = 435 = 31	50.0 Cpm 14.16 R/S =	tion) ******* 1 *** 50.00 Hz	***** :
******* Shaft	**** Han ** 1 \$	cmonic Re ** Excita Speed=	sponse due to tion Frequenc 3000.00 rpm Shaft Element	Base M c y = 435 = 31 Displac	50.0 cpm 14.16 R/S =	tion) ****** 1 *** 50.00 Hz	******
****** Shaft ******	**** Hai ** 1 \$ ********	cmonic Re ** Excita Speed= ******** x =====	sponse due to tion Frequenc 3000.00 rpm Shaft Element ===== v	Base Mc y = 435 = 31 Displac =====	otion (Excita 50.0 cpm 14.16 R/S = cements ***** Ellipt	tion) ****** 50.00 Hz	****** : : : : : :
******* Shaft ******	***** Hai ** 1 \$ ********* ===== b Ampliti	cmonic Re ** Excita Speed= ******** X ====== ide Phase	sponse due to tion Frequenc 3000.00 rpm Shaft Element ===== Y Amplitude	Base Mc y = 435 = 31 Displac ===== Phase	btion (Excita 50.0 cpm 14.16 R/S = cements ***** Ellipt	50.00 Hz 50.00 Hz ical Orbit Da	****** ******* uta
******* Shaft ******* stn su	***** Hal ** 1 \$ ********* ===== b Amplitu	cmonic Re ** Excita Speed= ******* X ===== ude Phase	sponse due to tion Frequenc 3000.00 rpm Shaft Element ===== Y Amplitude	Base Mc y = 435 = 31 Displac ===== Phase	btion (Excita 50.0 cpm 14.16 R/S = cements ***** Ellipt A	50.00 Hz 50.00 Hz ical Orbit Da B	****** 2 ******* uta G
******* Shaft ******* stn su 1 1	***** Hal ** 1 \$ ********* ===== b Amplitu 0 165E+(x ===== x === x ==== x === x == x == x = x x = x =	sponse due to tion Frequenc 3000.00 rpm Shaft Element ===== Y Amplitude 0 943E+00	Base Mc y = 435 = 31 Displac ===== Phase 92 1	otion (Excita 50.0 cpm 14.16 R/S = cements ***** Ellipt A 0 948E+00	50.00 Hz 50.00 Hz ical Orbit Da B	****** 2 ****** uta G 96
******* Shaft ******* stn su 1 1 2 1	***** Hai 1 5 ************************************	x ===== x === x ==== x === x === x == x == x = x x == x = x x = x =	sponse due to tion Frequenc 3000.00 rpm Shaft Element ===== Y Amplitude 0.943E+00 0.823E+00	Base Mc y = 435 = 31 Displac ===== Phase 92.1 91 5	Dtion (Excita 50.0 cpm 14.16 R/S = cements ***** Ellipt A 0.948E+00 0 826E+00	50.00 Hz 50.00 Hz ical Orbit Da B -0.128E+00 -0 107E+00	****** : ita G 96. 95
******* Shaft ******* stn su 1 1 2 1 3 1	***** Hai 1 5 ************************************	cmonic Re ** Excita Speed= ********* X ===== ude Phase 00 220.9 00 216.6 00 200.5	sponse due to tion Frequenc 3000.00 rpm Shaft Element ==== Y Amplitude 0.943E+00 0.823E+00 0.704E+00	Base Mc y = 435 = 31 Displac ===== Phase 92.1 91.5 90.6	Otion (Excita 50.0 cpm 14.16 R/S = cements ***** Ellipt A 0.948E+00 0.826E+00 0.755E+00 0.755E+00	50.00 Hz 50.00 Hz ital Orbit Da B -0.128E+00 -0.107E+00 -0.873E-01	****** ******* ata G 96. 95. 94
******* Shaft ******* stn su 1 1 2 1 3 1 4 1	***** Hai 1 5 ************************************	cmonic Re ** Excita Speed= ********* X ===== ude Phase 00 220.9 00 216.6 00 209.5 01 196 2	sponse due to tion Frequenc 3000.00 rpm Shaft Element ==== Y Amplitude 0.943E+00 0.823E+00 0.704E+00 0.586E+00	Base Mc y = 435 = 31 Displac ===== Phase 92.1 91.5 90.6 89 3	Dtion (Excita 50.0 cpm 14.16 R/S = cements ***** Ellipt A 0.948E+00 0.826E+00 0.705E+00 0.586E+00	<pre>tion) ******* 50.00 Hz 50.00 Hz ical Orbit Da B -0.128E+00 -0.107E+00 -0.873E-01 -0.680E-01</pre>	****** ata G 96. 95. 94. 92
******* Shaft ******* stn su 1 1 2 1 3 1 4 1 5 1	***** Han ** 1 \$ ************************************	<pre>cmonic Re ** Excita Speed= ******* X ===== ude Phase 00 220.9 00 216.6 00 209.5 01 196.2</pre>	sponse due to tion Frequenc 3000.00 rpm Shaft Element ==== Y Amplitude 0.943E+00 0.823E+00 0.704E+00 0.586E+00 0.468E+00	Base Mc y = 435 = 31 Displac ===== Phase 92.1 91.5 90.6 89.3 87.5	Dtion (Excita 50.0 cpm 14.16 R/S = cements ***** Ellipt A 0.948E+00 0.826E+00 0.705E+00 0.586E+00 0.468E+00	<pre>tion) ******* 50.00 Hz 50.00 Hz ical Orbit Da B -0.128E+00 -0.107E+00 -0.873E-01 -0.680E-01 -0.498E-01</pre>	****** ata G 96. 95. 94. 92. 80
******* Shaft ******* stn su 1 1 2 1 3 1 4 1 5 1 6 1	***** Han 1 5 ************************************	<pre>cmonic Re ** Excita Speed= ******* X ===== ude Phase 00 220.9 00 216.6 00 209.5 01 196.2 01 169.1 01 122.1 </pre>	sponse due to tion Frequenc 3000.00 rpm Shaft Element ==== Y Amplitude 0.943E+00 0.823E+00 0.704E+00 0.586E+00 0.468E+00 0.251E+00	Base Mc y = 435 = 31 Displac ===== Phase 92.1 91.5 90.6 89.3 87.5 94.4	Otion (Excita 50.0 cpm 14.16 R/S = cements ***** Ellipt A 0.948E+00 0.826E+00 0.705E+00 0.586E+00 0.468E+00 0.252E+00	<pre>tion) ******* 50.00 Hz 50.00 Hz ical Orbit Da B -0.128E+00 -0.107E+00 -0.873E-01 -0.680E-01 -0.498E-01 -0.341E-01</pre>	****** ata G 96. 95. 94. 92. 89.
******* Shaft ******* stn su 1 1 2 1 3 1 4 1 5 1 6 1	***** Han 1 5 ************************************	<pre>cmonic Re ** Excita Speed= ******* X ===== ude Phase 00 220.9 00 216.6 00 209.5 01 196.2 01 169.1 01 128.3</pre>	sponse due to tion Frequenc 3000.00 rpm Shaft Element ==== Y Amplitude 0.943E+00 0.823E+00 0.704E+00 0.586E+00 0.468E+00 0.351E+00	Base Mc y = 435 = 31 Displac ===== Phase 92.1 91.5 90.6 89.3 87.5 84.4 782	<pre>btion (Excita 50.0 cpm 14.16 R/S = cements ***** Ellipt A 0.948E+00 0.826E+00 0.705E+00 0.586E+00 0.468E+00 0.352E+00 0.244E+00</pre>	<pre>tion) ******* 50.00 Hz 50.00 Hz ical Orbit Da B -0.128E+00 -0.107E+00 -0.873E-01 -0.680E-01 -0.498E-01 -0.341E-01 0.341E-01</pre>	****** ata G 96. 95. 94. 92. 89. 84. 75
******* Shaft ******* stn su 1 1 2 1 3 1 4 1 5 1 6 1 7 1	***** Han 1 5 ************************************	<pre>cmonic Re ** Excita Speed= ******* X ===== ude Phase 00 220.9 00 216.6 00 209.5 01 196.2 01 169.1 01 128.3 01 99.8</pre>	sponse due to tion Frequenc 3000.00 rpm Shaft Element ==== Y Amplitude 0.943E+00 0.823E+00 0.704E+00 0.586E+00 0.468E+00 0.351E+00 0.235E+00	Base Mc y = 435 = 31 Displac ==== Phase 92.1 91.5 90.6 89.3 87.5 84.4 78.2	Otion (Excita 50.0 cpm 14.16 R/S = cements ***** Ellipt A 0.948E+00 0.826E+00 0.705E+00 0.586E+00 0.468E+00 0.352E+00 0.244E+00	<pre>tion) ******* 50.00 Hz 50</pre>	****** ata G 96. 95. 94. 92. 89. 84. 75.

Whirling Direction

To fully understand the effect of the base motion, we need to also examine the precessions of the base motion and the rotor motion. In this Case 3, the base motion at station 3 is a straight line motion which can excite both forward and backward whirling modes. The base motion at station 7 is a backward precessional elliptical motion which tends to excite the backward precessional modes more. To view the base motion, there is a Tool in DyRoBeS which can help you visualize the base motion, as shown below:



Base Motion at Station 3:



Base Motion at Station 7:



Use the Animation Play option, you can visualize the motion better. Now, let us go back to examine the entire rotor response (absolute displacements) from the Base Motion Analysis at the excitation frequency of 200, 4312, 4358, 7342, and 7619 cpm.





In the graph, the properties of the max orbit are printed. The value a is the semi-major axis, and b is the semi-minor axis. The positive sign of the semi-minor axis indicates the orbit is a forward precession and negative sign indicates the backward precession. The **red arrow** represents the base motion. At very low excitation frequency (I.e., low frequency ratio), the rotor moves with the base and there is no relative movement between rotor and base. The rotor whirls in the forward precession for the stations 1 (max orbit) and 2. The station 3 is a straight line motion which is the same as the base motion. After the straight line motion, the rest of the rotor whirls in the backward precession, same as the station 7 base motion. So, the rotor is whirling in a so-called mixed precession.

At the excitation frequency of 4350 cpm, the entire rotor whirls in the backward precession at resonance. The rotor deflection shape is similar to the first mode. The rotor response is far larger than the base motion at or near resonance.



At the excitation frequency of 7500 cpm, the entire rotor whirls also in the backward precession. The rotor deflection shape is similar to the third mode.



To check the whirling direction for all the excitation frequency range, the easiest way is to plot the elliptical orbital axes (semi-major and semi-minor axes). The negative semi-minor axis indicates a backward whirl.

The orbital axes for the stations 1 and 7 are shown below. It shows that the station 1 starts with forward precessions at low excitation frequency and becomes backward precessions around 3400 cpm, then turns to forward precessions again after 8550 cpm. However, for station 7, it starts with backward precessions, and becomes forward precessions only between 4600 cpm and 4800 cpm.





Case 4: BaseMotion_3d.rot

In this case, change the base motion x_s from 0.05 to -0.05 at station 7. This will change the base motion at station 7 from the previous backward precession to forward precession. The rests of data are unchanged.

Elliptical Orb	oit Analys	sis)	×	🔳 Ro	tor Elliptic	al Orbit		_		×
X = Xc cos	(wt) +×s	sin(wt) = 🖂	cos (wt-pha	sex)	[Display		Options	s Anima	tion				
Y = Yc cos	(wt) + Ys	sin (wt) = [Y	cos(wt-phas	ey)		Cancel				Shaff F	Rotation: C	'CW		
_ Input Data	: Select o	one option—								Forwar	d Precess	sion		
()	Xc, Xs, 1	Yc, Ys	_	O KL ML P	ohase x, pł	nase y			0.10 ლოფი					
Xc: 0	— ×	(s: -0.05).05 Ph	ase X (deo	ı): 270			0.08	~	\neg		-	
Ye: 0.05	. v	<pre>(* 0.05</pre>	- Mt I	070710 Ph	- · ave Y (dec	ψ 4 5			0.06		×.		-	
10.05	,	s. [0.05	r		ase i (değ	JI: [45			0.04	\mathcal{N}	-N		-	
		Cale	culated Resu	lts					0.02	Λ	\square	. \ .		
Elliptical O	rbit Data-		Tw	o Circular Orbil	ts Data —		11		0.00					
Semi-Ma	ajor Axis:	0.0809017	F	orward Ampliti	ude: 0.0	559017		-	0.02		$ \rightarrow $	X		
Semi-Mir	nor Axis:	0.0309017		Phase Ar	ngle: 63.4	4349		-	0.04		\mathbf{X}			
Attitude	e Angle:	121.717	Ba	ckward Ampliti	ude: 0.03	25		-	0.00]	
Prec	cession:	Forward		Phase Ar	nde: 180)		-	.0 10 Europe					
	50331011.			T Hase Al	igic. [***		J		0.10					
	-												_	_
Datas Daasi		Data												V
Kotor Bearl	ing Syste	em Data												×
Units/De	scription	Materia	Shaft E	ements D	isks 🛛 l	Jnbalance	B	earings	Suppor	ts Four	dation	User's E	Elements	
Axial Forc	es Sta	atic Loads	Constraint	s Misalignm	nents S	haft Bow 🗎	Time	e Forcin	g Harmo	onics Ba	se Motion	Torsio	nal/Axia	al [
					E	Base Type:	Mut	tiple		-				
Stead	dy State	Base Harm	onic Motion:	Excitation F	Frequency	varies at a	a Con	nstant R	otor Speed	1	-			
	Excitati	ion Frequen	icy (cpm) —								1			
	Sta	art: 200		Stop: 10	000	_	Incre	ment [50					
		1200		0.000. [10										
		Amplitude	e Multiplier (/	A = Ao + A1 *	rpm + A2	*rpm^2)—				7				
		Ao:	1	A1:	0		A2:	0						
		'	~					,						
		Steady	State Harmo	onic Base Mot	tion: q = A	\" [qc " cos	s (we:	xc"t) +	qs "sin(we	exc"t)]				
	E.	oitation from	(qc,qs) are t	ne displacem	ent amplit	udes in (co	s,sin) om –) compo	onents	and rates	1 mood			
r		citation freq	luency wext	(au/sec) =	cpin (z j	pi/60). I	pin =		ce snan sp	eeu, rotor	rspeed	_		
				2 Station	ns connec	ted to the	Base	: 3, 7						
	stnl	Xc-cos	Xs-sin	Yc-cos	<u>Ys-sin</u>	ThetaXc	Th	ietaXs	ThetaYc	ThetaYs	Comn	nents	_ _	
	3 7	0	-0.05	U.I 0.05	0.05	0		0	U N	U N				
3	•		0.00	0.00	0.00	· · · · · ·			ÿ					
4														
5														
6													-	
				<u> </u>					:					
Ins	sert Row	Del	ete Row							Unit:(4)	Amplitude	: mm. ra	dian	
										0.10.(4)	- inplicado			
							_	,						
<u></u> o	or K						Save	е	Save /	<u>l</u> s	Close		<u>H</u> elp	

Now, at 200 cpm, again, at such low excitation frequency and low frequency ratio, the rotor moves with the base. It is still a mixed precession, however, the stations 1 and 2 before the bearing #1 (station 3) are backward precessions now, and after the straight line motion at station 3, the rotor whirls in the forward precession same as the station 7 base motion.

At 4350 cpm, the response is at and near resonance. The entire rotor whirls in the forward precession and the rotor response is far larger than the base motion. The rotor deflection shape is similar to the second mode. At 7500 cpm, the rotor whirls in the forward precession. The rotor deflection shape is similar to the fourth mode.





<u>Case 5</u>: BaseMotion_3e.rot

Let us consider the base motion is a purely forward circular motion as shown below:

Rotor Bearing System Data	X
	alance Rearinge Supports Foundation Line's Elements
Axial Forces Static Loads Constraints Misalignments Shaf	t Bow Time Forcing Harmonics Base Motion Torsional/Axia
Bas	e Type: Single
Steady State Base Harmonic Motion: Excitation Frequency va	aries at a Constant Rotor Speed
Excitation Frequency (com)	
Start: 200 Stop: 10000	Increment. 50
_ Amplitude Multiplier (A = Ao + A1 * rpm + A2 * rp	vm^2)
Ao: 1 A1: 0	A2: 0
Steady State Harmonic Base Motion: q = A* [qc * cos (wexc*t) + qs * sin(wexc*t)]
(qc,qs) are the displacement amplitude	es in (cos,sin) components
Excitation frequency wexc (rad/sec) = cpm * (2*pi/6	30). rpm = reference shaft speed, rotor 1 speed
2 Stations connected	i to the Base: 3, 7
Direction gc - cos gs	- sin Comments
1 X-Dir U.1 -U	Forward motion
3 Theta-X 0	0
4 Theta-Y 0	0
	Unit:(4) - Amplitude: mm, radian
<u>T</u> or K	Save Save As Close Help
Elliptical Orbit Analysis	X 💽 Rotor Elliptical Orbit — 🗆 X
X = Xc cos(wt) + Xs sin(wt) = Kl cos (wt-phasex)	Options Animation
Y = Yc cos (wt) + Ys sin (wt) = [Y] cos(wt-phasey) Cancel	Shaft Rotation: CCW
Input Data: Select one option	Forward Precession
• Xc, Xs, Yc, Ys • Xc, Xs, Yc, Ys • Xl, M, phase x, phase y	
Xc: 0.1 Xi: 0.141421 Phase X (deg): 315	0.12
Yc: 0.1 YI: 0.141421 Phase Y (deg): 45	0.08
Calculated Results	0.04
Elliptical Orbit Data	0.00 B
Semi-Major Axis: U.141421 Forward Amplitude: 0.141421	-0.04
Semi-Minor Axis: 0.141421 Phase Angle: 45	-0.12
Attitude Angle: 0 Backward Amplitude: 0	-0.16
Precession: Forward Phase Angle: 0	

Now, you already know the results. Yes, this base motion will only excite the forward modes and no backward precession will be present. Since the system is an isotropic system, the rotor response orbits will be purely forward circular orbits.











Case 6: BaseMotion_3f.rot

Consider a purely backward circular base motion in this example.

Poter Posring System Data
Kotor 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 Harmonics Base Motion Torsional/Axial
Base Type: Single
Steady State Base Harmonic Motion: Excitation Frequency varies at a Constant Rotor Speed
Start: 200 Stop: 10000 Increment. 50
Amplitude Multiplier (A = Ao + A1 * rpm + A2 * rpm^2)
Ao: 1 A1: 0 A2: 0
Steady State Harmonic Base Motion: g = A* [gc * cos (wexc*t) + gs * sin(wexc*t)]
(qc,qs) are the displacement amplitudes in (cos,sin) components
Excitation frequency wexc (rad/sec) = cpm * (2*pi/60). rpm = reference shaft speed, rotor 1 speed
2 Stations connected to the Base: 3, 7
Direction gc - cos gs - sin Comments
1 X-Dir 0.1 0.1 Backward Motion
2 Y-Dir 0.1 -0.1
A Theta-Y 0 0
Unit:(4) - Amplitude: mm, radian
Tor K Save As Close Help
Elliptical Orbit Analysis × 🗈 Rotor Elliptical Orbit – 🗆 🗙
X = Xc cos(wt) + Xs sin(wt) = KI cos (wt-phasex) Display Options Animation
Y = Yc cos (wt) + Ys sin (wt) = [Y] cos(wt-phasey)
Input Data: Select one option Lancel Shaft Rotation: CCW
Xc, Xs, Yc, Ys C Kl, Yl, phase x, phase y 0.20
Xe: 0.1 Xe: 0.1 XI: 0.141421 Phase X (deg): 45 0.16
YC: U.1 YS: U.1 IY: U.141421 Phase Y (deg): 315 0.08
Calculated Results 0.04
Elliptical Orbit Data
Semi-Major Axis: U.141421 Forward Amplitude: U -0.04
Semi-Minor Axis: 0.141421 Phase Angle: 0 -0.00
Attitude Angle: 0 Backward Amplitude: 0.141421 -0.16

Results are as expected.







Example 4 – Industrial Compressor (BaseMotion_4a.rot)

An industrial compressor, as shown below, is used in this example. The rotor assembly is supported by two bearings at stations 2 and 4. The compressor design speed is 35,000 rpm. The bearing #1 at station 2 is a 3-lobe bearing and the bearing #2 at station 4 is a tilting pad bearing. Bearing Type 15 is used in this example.



Fig. 35 – An Industrial Compressor

lotor Bearing System Data					>
Axial Forces Static Loads Constra Units/Description Material Shaft	ints Misalignments Shaft Bow Elements Disks Unbalanc	Time Forcing Bearings	Harmonics Supports	Base Motion	Torsional/Axial User's Elements
Bearing: 1 of 2	Foundation	Add Brg	Del Brg	Previous	Next
Station I: 2 J: 0	41 DI 4 TOI 4 SOD 4 ODINI		т		
Comment: High Speed Compressor	: (".LDI, ".TDI, ".FRB, ".GDI) Linear Bearing - Bearing at collar end - Us	ed by Rotor Exar] nple		
FileName: BaseMotion_4a_Brg1.LD	1			Ē	prowse
,					

Rotor Bearing System Data			×
Axial Forces Static Loads Constraints Units/Description Material Shaft El	Misalignments Shaft Bow ements Disks Unbalance	Time Forcing Harmonic Bearings Supports	s Base Motion Torsional/Axial Foundation User's Elements
Bearing: 2 of 2	Foundation	Add Brg Del Brg	Previous
Station I: 4 J: 0 Type: 15- Link BePerf Data File (*.	LDI, *.TDI, *.FRB, *.GDI) Linear /	Analysis	
Comment: High Speed Compressor Bea	aring - Test		
FileName: BaseMotion_4a_Brg2.TDI			Browse

At 35,000 rpm, the first 4 precessional modes are shown in Fig. 36. It shows that the base motion will most likely excite the 1^{st} and 2^{nd} modes.



Fig. 36 – The first 4 Precessional Modes

<u>Case 1</u>: BaseMotion_4a.rot

For verification purposes, only the 2^{nd} bearing at station 4 is subject to a base motion and the 1^{st} bearing at station 2 is not subject to any base motion. Therefore, two bases are utilized in this model. The base 1 is not moving and the base 2 has a harmonic motion in Y direction. The base motion is shown in Fig. 37. The base excitation only at station 4 (base 2) varies from 1000 cpm to 50,000 cpm with an increment of 500 cpm at a constant rotor speed of 35,000 rpm.



Fig. 37 – Base Motion

The absolute displacements at both bearings are shown in Fig. 38. The relative displacements are shown in Fig. 39. The bearing transmitted forces are shown in Fig. 40.





Fig. 38 – The Absolute Displacements due to Base Motion





Fig. 39 – The Relative Displacement due to Base Motion





Fig. 40 – The Transmitted Bearing Forces due to Base Motion

At low excitation frequency, 1000 cpm, again, the rotor moves with the base motion and there is little relative movement between the rotor and base. Also, the straight line base motion can excite both forward and backward precessions. In this case and at this low frequency, the rotor moves nearly straight line motion (b=0) which is the same as the base motion.

The maximum response occurs at the impeller side (station 7). Again, at low excitation frequency, the rotor moves with the base motion (straight line) and proceeds with a backward whirl, then reaches the resonance at 19,500 cpm. The motion becomes forward precession after 21,500 cpm, This is understandable since the 1^{st} mode at 18,233 cpm with a log. Decrement of 2.0667 is a backward mode and the 2^{nd} mode at 21,317 cpm with a log. Decrement of 2.4541 is a forward mode.

At station 4 where the base motion occurs, the motion starts from a straight line motion, then backward, and forward, and backward.








The bearing coefficients for the bearing 2 (station 4) at 35,000 rpm are calculated below:

Brg Coef	rg Coefficients									
Kxx	Kxy	Кух	Куу	Cxx	Cxy	Сух	Суу			
197434.	0.00000	0.00000	197434.	109.352	0.00000	0.00000	109.352			

Based on Eq. (13), we can calculate the equivalent harmonic excitation at the frequency of 22,500 cpm as shown in Fig. 41.

Rotor Beari	Rotor Bearing System Data								
Units/De: Axial Forc St	Units/Description Material Shaft Elements Disks Unbalance Bearings Supports Foundation User's Elements Axial Forces Static Loads Constraints Misalignments Shaft Bow Time Forcing Harmonics Base Motion Torsional/Axial Steady State Harmonic Excitation: Excitation Frequency varies at a Constant Rotor Speed Excitation Frequency (cpm) Start: 22500 Stop: 0 Increment. 0 Amplitude Multiplier (A = Ao + A1 * rpm + A2 * rpm^2) Ao: 1 A1: 0 A2: 0 Steady State Harmonic Excitation: Excitation: C = A * IOL * cos (were * + phase)								
	Excitat	Steady Steady	State Ham ency wext	nonic Excitation:Q = c (rad/sec) = com *	= A * Q * cos (we (2*pi/60). and	exc*t + phase) A is the Amplitude	multiplier		
	rpm = excitation shaft speed, rotor speed where the excitation applied								
	Ele(Stn)	Sub	Dir	Left Amp.	Left Ang.	Right Amp.	Right Ang.	Comments 🔺	
1	4	1	2	32460.1	52.538	0	0		
3									
4									

Fig. 41 – The Equivalent Harmonic Excitation at frequency of 22,500 cpm

The absolute displacements due to base motion and steady state harmonic excitation at the frequency of 22,500 cpm are identical as expected.

****	****	***** Ha: ***	cmonic Excita	Response due ration Frequency	to Shaft (1 y = 22500.) Excitati cpm	on ******** ***	*****
Sha	aft	1 Sp	eed=	35000.00 rpm	= 3665.1	9 R/S =	583.33 Hz	2
* * * * *	****	******	*****	Shaft Element	Displaceme	nts *****	* * * * * * * * * * * *	*****
		==== X	=====	= ==== Ү	=====	Ellipti	cal Orbit Da	ita
stn	suk	Amplitud	e Phase	e Amplitude	Phase	A	В	G
1	1	0.419E-01	134.7	0.421E-01	267.1 0	.543E-01	0.240E-01	135.
	2	0.396E-01	134.2	2 0.396E-01	267.9 0	.515E-01	0.220E-01	135.
	3	0.306E-01	131.4	0.297E-01	272.8 0	.402E-01	0.141E-01	136.
	4	0.217E-01	126.2	2 0.203E-01	282.2 0	.290E-01	0.615E-02	137.
2	1	0.174E-01	121.7	0.160E-01	290.9 0	.236E-01	0.221E-02	137.
	2	0.735E-02	78.6	0.101E-01	355.0 0	.102E-01	-0.725E-02	80.
	3	0.638E-02	55.0	0.116E-01	15.9 0	.127E-01	-0.366E-02	65.
3	1	0.108E-01	351.9	0.227E-01	49.6 0	.235E-01	0.879E-02	73.
	2	0.194E-01	333.5	0.375E-01	60.7 0	.375E-01	0.193E-01	88.

4 5 6	3 1 1 2 1	0.203E-01 0.350E-01 0.547E-01 0.827E-01 0.103E+00	332.4 311.9 290.9 275.5 268.8	0.392E-01 0.812E-01 0.153E+00 0.247E+00 0.311E+00	61.5 71.5 76.9 79.6 80.7	0.392E-01 0.833E-01 0.160E+00 0.259E+00 0.328E+00	0.203E-01 0.297E-01 0.293E-01 0.216E-01 0.139E-01	89. 104. 107. 108. 108.
7	2 1	0.114E+00 0.120E+00	266.3 265.3	0.344E+00 0.360E+00	81.0 81.2	0.362E+00 0.379E+00	0.998E-02 0.804E-02	108. 108.
* * * * *	* * * >	****	* * * * * * * * *	* * * * * * * * * * * *	* * * * * * * * *	* * * * * * * * * * * *	****	*****
****	****	**** Harmon *** H	nic Respo Excitatio	onse due to on Frequency	Base Mot : Z = 22500	ion (Excitat 0. cpm	:ion) ****** ***	*****
Sha	aft	1 Spee	ed= 350	000.00 rpm	= 3665	.19 R/S =	583.33 Hz	
****	****	* * * * * * * * * * * *	**** Sha	aft Element	Displacer	ments *****	*****	*****
		===== X	=====	==== Ү		Ellipti	cal Orbit Da	ita
stn	suk	o Amplitude	Phase	Amplitude	Phase	A	В	G
1	1	0.419E-01	134.7	0.421E-01	267.1	0.543E-01	0.240E-01	135.
	2	0.396E-01	134.2	0.396E-01	267.9	0.515E-01	0.220E-01	135.
	3	0.306E-01	131.4	0.297E-01	272.8	0.402E-01	0.141E-01	136.
	4	0.217E-01	126.2	0.203E-01	282.2	0.290E-01	0.615E-02	137.
2	1	0.174E-01	121.7	0.160E-01	290.9	0.236E-01	0.221E-02	137.
	2	0.735E-02	78.6	0.101E-01	355.0	0.102E-01	-0.725E-02	80.
	3	0.638E-02	55.0	0.116E-01	15.9	0.127E-01	-0.366E-02	65.
3	1	0.108E-01	351.9	0.227E-01	49.6	0.235E-01	0.879E-02	73.
	2	0.194E-01	333.5	0.375E-01	60.7	0.375E-01	0.193E-01	88.
	3	0.203E-01	332.4	0.392E-01	61.5	0.392E-01	0.203E-01	89.
4	1	0.350E-01	311.9	0.812E-01	71.5	0.833E-01	0.297E-01	104.
5	1	0.547E-01	290.9	0.153E+00	76.9	0.160E+00	0.293E-01	107.
	2	0.827E-01	275.5	0.247E+00	79.6	0.259E+00	0.216E-01	108.
6	1	0.103E+00	268.8	0.311E+00	80.7	0.328E+00	0.139E-01	108.
_	2	0.114E+00	266.3	0.344E+00	81.0	0.362E+00	0.998E-02	108.
7	1	0.120E+00	265.3	0.360E+00	81.2	0.379E+00	0.804E-02	108.
بالانات بالانات	ل بل بل با		L + + + + + + + + + + + + + + + + + + +		L + + + + + + + + + + + + + + + + + + +	+++++++++++++++++++++++++++++++++++++++	. + + + + + + + + + + + + + + + + + + +	باد باد باد باد باد با

Case 2: BaseMotion_4b.rot

In this case, both bases are subject to the same base motion as shown in Fig. 42. At rotor speed of 35,000 rpm, the bearing coefficients are:

Brg	rg Coefficients at 35,000 rpm										
No.	Kxx	Kxy	Kyx	Куу	Cxx	Cxy	Сух	Суу			
1	335633.	183353.	-297550.	477252.	124.990	-3.22163	-3.22163	168.538			
2	197434.	.00000	0.00000	197434.	109.352	0.00000	0.00000	109.352			

Again, for the comparison purposes, the equivalent steady state harmonic excitations at the frequency of 22,500 cpm are calculated as shown in Fig. 43. Note that, the base motion at station 2 only has the Y movement, but the steady state excitations exist in both X and Y directions due to the coupled bearing stiffness and damping coefficients at station 2. The absolute response for both base motion and steady state harmonic excitation are listed for comparison.

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 Harmonics Base Motion Torsional/Axial									
Base Type: Multiple									
Steady State Base Harmonic Motion: Excitation Frequency varies at a Constant Rotor Speed									
Excitation Frequency (cpm)									
Start: 1000 Stop: 50000 Increment. 500									
Amplitude Multiplier (A = Ao + A1 * rpm + A2 * rpm^2)									
Ao: 1 A1: 0 A2: 0									
Steady State Harmonic Base Motion: q = A* [qc * cos (wexc*t) + qs * sin(wexc*t)]									
(qc,qs) are the displacement amplitudes in (cos,sin) components									
Excitation frequency wexc (rad/sec) = cpm (2 pi/80). rpm = reference shart speed, rotor I speed									
2 Stations connected to the Base: 2, 4									
stn I Xc-cos Xs-sin Yc-cos Ys-sin ThetaXc ThetaXs ThetaYc ThetaYs Comments									
3									

Fig. 42 – Base Motion

Units/Description Material Shaft Elements Disks Unbalance Bearings Supports Foundation User's Elements Axial Forces Static Loads Constraints Misalignments Shaft Bow Time Forcing Harmonics Base Motion Torsional/Axial Steady State Harmonic Excitation: Excitation Frequency varies at a Constant Rotor Speed Excitation Frequency (cpm) Start: 22500 Stop: 0 Increment. 0 Anplitude Multiplier (A = Ao + A1 * rpm + A2 * rpm^2) Ao: 1 A1: 0 A2: 0 Steady State Harmonic Excitation: Q = A * Q * cos (wexc *t + phase) Excitation frequency wexc (rad/sec) = cpm * (2*pi/60). and A is the Amplitude multiplier rpm = excitation shaft speed, rotor speed where the excitation applied	Rotor Beari	ng System I	Data						×		
Steady State Harmonic Excitation: Excitation Frequency varies at a Constant Rotor Speed Excitation Frequency (cpm) Start: 22500 Amplitude Multiplier (A = Ao + A1 * rpm + A2 * rpm^2) Ao: 1 Ao: 1 Ao: 1 Steady State Harmonic Excitation: Q = A * Q * cos (wexc*t + phase) Excitation frequency wexc (rad/sec) = cpm * (2*pi/60). and A is the Amplitude multiplier rpm = excitation shaft speed, rotor speed where the excitation applied Ele(Sth) Sub Dir Left Amp ElefSth) Sub	Units/Des Axial Force	Units/Description Material Shaft Elements Disks Unbalance Bearings Supports Foundation User's Elements Axial Forces Static Loads Constraints Misalignments Shaft Bow Time Forcing Harmonics Base Motion Torsional/Axial									
Excitation Frequency (cpm) Start: 22500 Stop: 0 Increment. 0 Amplitude Multiplier (A = Ao + A1 * rpm + A2 * rpm^2) Ao: 1 A1: 0 A2: 0 Steady State Harmonic Excitation: Q = A * Q * cos (wexc*t + phase) Steady State Harmonic Excitation: Q = A * Q * cos (wexc*t + phase) Excitation frequency wexc (rad/sec) = cpm * (2*pi/60). and A is the Amplitude multiplier rpm = excitation shaft speed, rotor speed where the excitation applied	Steady State Harmonic Excitation: Excitation Frequency varies at a Constant Rotor Speed										
Start: 22500 Stop: 0 Increment. 0 Amplitude Multiplier (A = Ao + A1 * rpm + A2 * rpm^2) Ao: 1 A1: 0 A2: 0 Ao: 1 A1: 0 A2: 0 0 Steady State Harmonic Excitation: Q = A * Q * cos (wexc*t + phase) Excitation frequency wexc (rad/sec) = cpm * (2*pi/60). and A is the Amplitude multiplier rpm = excitation shaft speed, rotor speed where the excitation applied ElefStbl Sub Dir Left Amp. Left Amp. Bight Amp. Bight Amp. Comments.		Excitation Frequency (cpm)									
Amplitude Multiplier (A = Ao + A1 * rpm + A2 * rpm^2) Ao: 1 Ao: 1 Steady State Harmonic Excitation: Q = A * Q * cos (wexc*t + phase) Excitation frequency wexc (rad/sec) = cpm * (2*pi/60). and A is the Amplitude multiplier rpm = excitation shaft speed, rotor speed where the excitation applied Ele(Stn) Sub Dir Left Amp ElefStn) Sub		Start:	22500		Stop: 0	Inc	rement. 0				
Ao: 1 A1: 0 A2: 0 Steady State Harmonic Excitation: Q = A * Q * cos (wexc*t + phase) Excitation frequency wexc (rad/sec) = cpm * (2*pi/60). and A is the Amplitude multiplier rpm = excitation shaft speed, rotor speed where the excitation applied ElefStn) Sub Dir Left Ang Bight Ang Comments		Amplitude Multiplier (A = Ao + A1 * rpm + A2 * rpm^2)									
Steady State Harmonic Excitation: Q = A * Q * cos (wexc*t + phase) Excitation frequency wexc (rad/sec) = cpm * (2*pi/60). and A is the Amplitude multiplier rpm = excitation shaft speed, rotor speed where the excitation applied Ele(Stn) Sub Dir Left Amp. Left Amp. Bight Amp.			Ao: 1		A1: 0	A2	: 0				
Excitation frequency wexc (rad/sec) = cpm * (2*pi/60). and A is the Amplitude multiplier rpm = excitation shaft speed, rotor speed where the excitation applied Ele(Stn) Sub Dir Left Amp. Left Ang. Bight Amp. Bight Amp. Comments			Steady	State Harr	nonic Excitation: Q	= A * Q * cos (we	exc*t + phase)				
Fight Ang Comments		Excitat	tion frequ	ency wex	c (rad/sec) = cpm *	(2*pi/60). and	A is the Amplitude	multiplier			
📕 📔 Eleistri I. Sub I. Dir I. Lett Amp. I. Lett Ang. I. Bight Amp. I. Bight Ang. I. Comments 🛛 🐴 🗌			rpm = ex	citation sr	hant speed, rotor spe	ed where the exc	station applied	I I			
		Ele[Stn]	Sub	Dir	Left Amp.	Left Ang.	Right Amp.	Right Ang.	<u>Comments</u>		
		<u></u>	-	1	18351	357.629	U	U			
	2	<u> </u>		2	62085.8	39.7629	U	U			
<u>3</u> 4 1 2 32460.1 52.538 U U	3	4	1	2	32460.1	52.538	U	U			
	4										

Fig. 43 – Equivalent Harmonic Excitation

Sha	aft	1 Spee	ed= 35	000.00 rpm	= 3665	.19 R/S =	583.33 Hz	
* * * * ;	* * * *	* * * * * * * * * * *	**** Sh	aft Element	Displace	ments *****	* * * * * * * * * * * * *	*****
		===== X		==== Y	=====	Ellipt	ical Orbit Da	ta
stn	sub	Amplitude	Phase	Amplitude	Phase	A	В	G
1	1	0.229E-01	163.5	0.147E+00	353.1	0.149E+00	-0.377E-02	99.
	2	0.216E-01	163.4	0.144E+00	353.5	0.145E+00	-0.373E-02	98.
	3	0.163E-01	163.0	0.131E+00	355.2	0.132E+00	-0.344E-02	97.
	4	0.111E-01	162.0	0.119E+00	357.4	0.120E+00	-0.293E-02	95.
2	1	0.858E-02	160.9	0.114E+00	358.6	0.114E+00	-0.259E-02	94.
	2	0.144E-02	131.8	0.994E-01	2.9	0.994E-01	-0.112E-02	91.
	3	0.785E-03	42.0	0.964E-01	4.4	0.964E-01	-0.478E-03	90.
3	1	0.575E-02	345.5	0.872E-01	10.2	0.873E-01	0.239E-02	87.
	2	0.110E-01	340.6	0.792E-01	17.7	0.797E-01	0.661E-02	84.
	3	0.116E-01	340.3	0.784E-01	18.7	0.789E-01	0.715E-02	83.
4	1	0.198E-01	325.9	0.770E-01	40.0	0.772E-01	0.190E-01	86.
5	1	0.302E-01	306.2	0.103E+00	62.4	0.104E+00	0.269E-01	98.
	2	0.451E-01	290.6	0.149E+00	75.9	0.154E+00	0.249E-01	104.
6	1	0.563E-01	283.6	0.184E+00	81.1	0.191E+00	0.207E-01	106.
	2	0.621E-01	281.0	0.202E+00	83.1	0.210E+00	0.184E-01	106.
7	1	0.650E-01	279.9	0.211E+00	83.9	0.220E+00	0.172E-01	107.

**************************************	************** bit Data G
	G
stn sub Amplitude Phase Amplitude Phase A B	
1 1 0.229E-01 163.5 0.147E+00 353.1 0.149E+00 -0.377	E-02 99.
2 0.216E-01 163.4 0.144E+00 353.5 0.145E+00 -0.373	E-02 98.
3 0.163E-01 163.0 0.131E+00 355.2 0.132E+00 -0.344	E-02 97.
4 0.111E-01 162.0 0.119E+00 357.4 0.120E+00 -0.293	E-02 95.
2 1 0.858E-02 160.9 0.114E+00 358.6 0.114E+00 -0.259	E-02 94.
2 0.144E-02 131.8 0.994E-01 2.9 0.994E-01 -0.112	E-02 91.
3 0.785E-03 42.0 0.964E-01 4.4 0.964E-01 -0.479	E-03 90.
3 1 0.575E-02 345.5 0.872E-01 10.2 0.873E-01 0.239	E-02 87.
2 0.110E-01 340.6 0.792E-01 17.7 0.797E-01 0.661	E-02 84.
3 0.116E-01 340.3 0.784E-01 18.7 0.789E-01 0.715	E-02 83.
4 1 0.198E-01 325.9 0.770E-01 40.0 0.772E-01 0.190	E-01 86.
5 1 0.302E-01 306.2 0.103E+00 62.4 0.104E+00 0.269	E-01 98.
2 0.451E-01 290.6 0.149E+00 75.9 0.154E+00 0.249	E-01 104.
6 1 0.563E-01 283.6 0.184E+00 81.1 0.191E+00 0.205	E-01 106.
2 0 621E-01 281 0 0 202E+00 83 1 0 210E+00 0 184	E-01 106
$7 \ 1 \ 0 \ 650E = 01 \ 279 \ 9 \ 0 \ 211E + 00 \ 83 \ 9 \ 0 \ 220E + 00 \ 0 \ 173$	E = 01 = 100.
, 1 0.0001 01 2,5.5 0.2111,00 00.5 0.2201,00 0.172	



The responses at both bearings for the base motion are shown below;



Fig. 44 – Absolute and Relative Displacements at Bearings





Fig. 45 – The Transmitted Bearing Forces due to Base Motion

Case 3: BaseMotion_4c.rot

In Case 2, although Multiple Bases are used, two bases have the same base motion. So, in this case, a Single base model is used as shown in Fig. 46. The results for the base motion in this case are identical to the results in Case 2 and are not repeated here.

Rotor Bear	ing Syste	em Data						×		
Units/De Axial Ford	escription	Material atic Loads (Shaft Elements Di Constraints Misalignm	isks Unbalance ents Shaft Bow	Bearing: Time Forci	s Supports ng Harmonics	Foundation Base Motion	User's Elements		
				Base Type:	Single	•]			
Steady State Base Harmonic Motion: Excitation Frequency varies at a Constant Rotor Speed										
	Excitation Frequency (com)									
	Start: 1000 Stop: 50000 Increment. 500									
		Amplitude N	Multiplier (A = Ao + A1 *	rpm + A2 * rpm^2)-						
			J	-	// <u>2</u> . *					
		Steady St	ate Harmonic Base Mot	ion:q = A* [qc * co	s (wexc*t) +	qs * sin(wexc*t)]			
		(q	c,qs) are the displacem	ent amplitudes in (co	s,sin) comp	onents				
	Ex	citation freque	ency wexc (rad/sec) =	cpm * (2*pi/60). r	pm = referei	nce shaft speed,	rotor 1 speed	_		
			2 Station	is connected to the	Base: 2, 4					
	Dir	rection	qc - cos	qs - sin		Comr	nents			
1	>	<-Dir	0	0						
2	۱	/-Dir	0.1	0						
3	11	neta-X	U	0						
4	L Th	neta-Y	0	0						
						Uni	t:(2) - Amplitude:	inch, radian		
Ī	or K				<u>S</u> ave	Save <u>A</u> s	Close	<u>H</u> elp		

Fig. 46 – Base Motion – Single Base

Case 4: BaseMotion_4d.rot

In this case, bearing #2 (station 4) is connected to a support (station 8) as shown in Fig. 47. The base motion is acting on the stations 2 and 8.



Fig. 47 – System Model

Rotor Bearing System Data X										
Units/Des Axial Force	cription Material es Static Loads	Shaft Elements D Constraints Misalignm	isks Unbalance B nents Shaft Bow Tim	earings Supports e Forcing Harmonics	Foundation User's Elements Base Motion Torsional/Axial					
	Base Type: Single									
Stead	Steady State Base Harmonic Motion: Excitation Frequency varies at a Constant Rotor Speed									
[Excitation Frequence	y (cpm)								
	Start: 1000 Stop: 50000 Increment. 500									
Amplitude Multiplier (A = Ao + A1 * rpm + A2 * rpm^2)										
Ao: 1 A1: 0 A2: 0										
	Steady S	tate Harmonic Base Mot	tion: q = A* [qc * cos (we	xc*t) + qs * sin(wexc*t)]						
	(i	qc,qs) are the displacem	ent amplitudes in (cos,sin,) components	ter 1 mond					
	Excitation frequ	ency wexc (rad/sec) =	cpm (2 pi/60). rpm =	reference shart speed, r	otor I speed					
		2 Station	ns connected to the Base	: 2, 8						
	Direction	qc - cos	qs - sin	Comme	ents					
1	X-Dir	0	0	•						
2	Y-Dir	0.1	0	¢						
3	Theta-X	0	0	· · · · · · · · · · · · · · · · · · ·						
4	Theta-Y	0	0							

Fig. 48 – Base Motion

Rotor Bearing	System Data				×
Axial Forces Units/Descrip	Static Loads Constrain otion Material Shaft E	ts Misalignments Shaft Bow Gements Disks Unbalanc	Time Forcing Ha	armonics Base Motio pports Foundation	n Torsional/Axial User's Elements
Bearing: 1	of 3	Foundation	Add Brg D	el Brg Previous	Next
Station I:	2 J: 0				
Type:	15-Link BePerf Data File (LDI, *.TDI, *.FRB, *.GDI) Linear	Analysis 💌		
Comment:	High Speed Compressor Be	earing - Bearing at collar end - Us	ed by Rotor Example	•	1
FileName:	BaseMotion_4a_Brg1.LDI				Browse

Rotor Bearing System Data	×
Axial Forces Static Loads Constraints Misalignments Shaft Bow Time Forcing Harmonics Base Motion Units/Description Material Shaft Elements Disks Unbalance Bearings Supports Foundation	n Torsional/Axial User's Elements
Bearing: 2 of 3 Foundation Add Brg Del Brg Previous	Next
Station I: 4 J: 8	
Type: 15- Link BePerf Data File (*.LDI, *.TDI, *.FRB, *.GDI) Linear Analysis	
Comment: High Speed Compressor Bearing - Test	
FileName: BaseMotion_4a_Brg2.TDI	<u>B</u> rowse

Rotor Bearing System Data						×
Axial Forces Static Loads Units/Description Material	Constraints Misalignmen Shaft Elements Disk	nts Shaft Bow s Unbalance	Time Forcing Bearings	Harmonics Supports	Base Motion Foundation	Torsional/Axial User's Elements
Bearing: 3 of 3	Fou	Indation	Add Brg	Del Brg	Previous	Next
Station I: 8 J: 0			Angle: 0			
Type: 0- Linear Consta	nt Bearing		•]		
Comment:						
	Translational E	earing Properties				
Kxx: 300000	Кху: 0	Cxx:	3	Cxy: 0		
Кух: 0	Куу: 300000	Сух:)	Суу: 3		
	Rotational I	Bearing Properties	;			
Kaa: 0	Kab: 0	Caa:)	Cab: 0		
Kba: 0	кыр: 0	Cba:)	Cbb: 0		

Rotor Bearin	otor Bearing System Data											
Axial Force Units/Des	Axial Forces Static Loads Constraints Misalignments Shaft Bow Time Forcing Harmonics Base Motion Torsional/Axial Units/Description Material Shaft Elements Disks Unbalance Bearings Supports Foundation User's Elements											
Support: 1 of 1 Add Delete Previous Next Station I: 8 Comment: Bearing Housing Mass Only, Stiffness and Damping are in Bearing #3												
	,	xu	UX	00								
м	10	Ö	0	10	- 1							
С	0	0	0	0								
K	0	0	0	0								
C 0 0 0 0 Damping Input Format C Zeta-X: 0 C C - Damping Coefficient C Zeta - Damping Factor Zeta-X: 0 C = Zeta * 2 * SQRT(M * K), Typical Zeta = 0.0001 - 0.02 Zeta-Y: 0												

Fig. 49 – Bearing and support data

At the rotor speed of 35,000 rpm, the first five natural frequencies and modes are shown in Fig. 50.







Fig. 50 – The first five natural frequencies and modes

The absolute and relative displacements at stations 4 and 8, bearing #2 and its support, are shown in Fig. 51.









Fig. 51 – The Absolute and Relative Displacements at Stations 4 and 8

Again, let us examine the impeller station (station 7) where the maximum displacement occurs. It starts from with the base motion (a straight line motion), then backward precession when approaching the 1^{st} mode (backward mode), after 15,000 cpm, the motion becomes forward and reaches the maximum peak at 16,000 cpm. From the previous Whirl Speed/Stability Analysis (Fig. 50), it shows that the 2^{nd} mode (forward mode) has a slightly smaller damping (log. Decrement) than that of the 1^{st} mode (backward mode). The second peak occurs around 40,000 cpm and the motion is a backward precession. This can also be observed from the mode frequency and damping at mode #4.



Case 5: BaseMotion_4e.rot

This case is identical to the previous Case 4, except the base motion has entered as multiple bases. The results are identical to Case 4, and not repeated here.

Rotor Bear	ing Syst	em Data									×
Units/De Axial Forc	scription es St	Material atic Loads	Shaft El	ements s Misalign	Disks L ments Sł	Inbalance haft Bow	Bearings Time Forcir	Suppo ng Harm	onics Ba	ndation User's Ele se Motion Torsiona	ments al/Axial
					в	ase Type:	Multiple		-		
Stead	dy State	Base Harm	onic Motion:	Excitation	Frequency	varies at a	Constant F	Rotor Spee	d	•	
	Excitat	ion Frequen	cy (cpm) —							7	
	St	art: 1000		Stop: 5	0000	Ir	ncrement.	500			
		- Amplitude	Multiplier (A	, A = Ao + A1	* rom + A2	*rom^2)—		,			
		Ao: [Δ1·	0		2. 0				
					1.	· · · · ·	<u>.</u>				
		Steady	State Harmo	onic Base M	otion: q = A	(* [qc * cos	(wexc*t) +	qs * sin(we	exc*t)]		
	Б	citation freq	uency wexc	(rad/sec)	= cpm * (2*p	oi/60). np	m = referen	ice shaft sp	peed, rotor	1 speed	
				2 Stati	ons connec	ted to the E	ase: 2, 8				
	stn I	Xc-cos	Xs-sin	Yc-cos	Ys-sin	ThetaXc	ThetaXs	ThetaYc	ThetaYs	Comments	
1	2	0	0	0.1	0	0	0	0	0		
2	8	0	0	0.1	0	0	0	0	0		
4		· · · · · · · · · · · · · · · · · · ·			·						
5											
7											-
		1									_
Ins	sert Row	Dele	ete Row						Unit:(2) -	Amplitude: inch, radia	an
To	or K						<u>S</u> ave	Save	As	Close H	elp

Fig. 52 – Base Motion – Multiple Bases

Let us consider a steady state harmonic excitation with a frequency of 40,000 cpm acting on the station 2 and station 8 at the rotor speed of 35,000 rpm. At 35.000 rpm, the bearing coefficients are:

Brg	Coefficier	nts at 35.0	00 rpm					
Stn	Kxx	Kxy	Kyx	Куу	Cxx	Cxy	Сух	Суу
2	335633.	183353.	-297550.	477252.	124.990	-3.22163	-3.22163	168.538
4	197434.	0.00000	0.00000	197434.	109.352	0.00000	0.00000	109.352
8	300000.	0.00000	0.00000	300000.	3.00000	0.00000	0.00000	3.00000

Rotor Bearin	ig System I	Data							×			
Units/Des Axial Force	cription I s Static I	Material Loads	Shaft El Constraints	ements Disks s Misalignments	Unbalance Shaft Bow Ti	Bearings Supr me Forcing Har	monics Base	ation User's Elem Motion Torsional/	ents 'Axial			
Ste	Steady State Harmonic Excitation: Excitation Frequency varies at a Constant Rotor Speed											
	Excitation Frequency (cpm) Start: 40000 Stop: 0											
	Ar	nplitude I Ao: 1	Multiplier (A	A = Ao + A1 * rpm + A1: 0	A2 * rpm^2) A2	: 0						
	Excitat	Steady ion frequ	State Ham	nonic Excitation: Q =	= A * Q * cos (we (2*pi/60), and	exc*t + phase) A is the Amplitude	multiplier					
		rpm = ex	citation sh	aft speed, rotor spe	ed where the exc	itation applied						
	Ele(Stn)	Sub	Dir	Left Amp.	Left Ang.	Right Amp.	Right Ang.	Comments	-			
	2			18380	355.79	U 0	U 0					
2	2	1	2	30026	2 3986	0	0					
4			<u> </u>	30020	2.000	•	· · · ·					
5												
6												
7												
8												
9												
10									-			
Insert F	Row	<u>D</u> elete R	ow				Unit:(2) - A	mp:Lbf,Phase:deg				
Tor	ĸ					1 0		. 1				

Fig. 53 – Steady State Harmonic Excitation at 40,000 cpm

Again, the absolute displacements can be compared with the results from the base motion.

****	****	**** Harmo	nic Resp	onse due to	Base Mot	ion (Excita	tion) ******	*****
		***	Excitati	ion Frequency	q = 4000	0. cpm	***	
Sh	naft	1 Spe	ed= 35	5000.00 rpm	= 3665	.19 R/S =	583.33 Hz	Ζ
* * * *	****	******	**** St	naft Element	Displace	ments ****	******	*****
		===== X		==== Ү		Ellipt	ical Orbit Da	ata
str	n suk	Amplitude	Phase	Amplitude	Phase	A	В	G
1	1	0.241E+00	333.3	0.139E+00	298.6	0.269E+00	-0.709E-01	27.
	2	0.222E+00	332.3	0.125E+00	303.2	0.249E+00	-0.542E-01	28.
	3	0.148E+00	325.3	0.847E-01	334.8	0.170E+00	0.121E-01	30.
	4	0.810E-01	306.3	0.907E-01	20.4	0.978E-01	0.722E-01	56.
2	1	0.582E-01	282.8	0.111E+00	35.7	0.114E+00	0.522E-01	105.
	2	0.893E-01	204.0	0.190E+00	55.7	0.205E+00	-0.434E-01	113.
	3	0.104E+00	198.0	0.205E+00	57.7	0.222E+00	-0.616E-01	113.
3	1	0.154E+00	186.9	0.253E+00	62.5	0.271E+00	-0.118E+00	114.
	2	0.201E+00	181.5	0.293E+00	65.6	0.313E+00	-0.170E+00	114.
	3	0.206E+00	181.1	0.297E+00	65.9	0.316E+00	-0.175E+00	114.
4	1	0.216E+00	175.9	0.276E+00	69.2	0.290E+00	-0.197E+00	115.

5	1	0.125E+00	165.7	0.124E+00	76.4	0.125E+00	-0.124E+00	35.
	2	0.651E-01	38.1	0.129E+00	236.5	0.143E+00	-0.185E-01	116.
6	1	0.189E+00	13.0	0.312E+00	242.9	0.340E+00	-0.133E+00	115.
	2	0.254E+00	9.9	0.404E+00	243.9	0.438E+00	-0.190E+00	115.
7	1	0.287E+00	8.8	0.450E+00	244.3	0.487E+00	-0.219E+00	115.
* * *	Fl	exible Supp	ort Disp	lacements				
8		0.228E+00	194.0	0.355E+00	86.4	0.365E+00	-0.211E+00	107.
* * * *	***	* * * * * * * * * * *	* * * * * * * *	******	******	* * * * * * * * * * * *	* * * * * * * * * * * * *	* * * * * * *

Sha	aft	1 Spe	ed= 3	35000.00 rpm	= (3665.19	R/S	=	583.33	Hz
****	****	* * * * * * * * * *	*****	Shaft Element	Disp	Lacemen	ts **:	* * * * * *	* * * * * * * * *	* * * * * * * *
		===== X		==== Ү	=====	=	Ell:	iptica	al Orbit	Data
stn	sub	Amplitude	Phase	Amplitude	Phase	9	A		В	G
1	1	0.241E+00	333.3	0.139E+00	298.0	5 0.2	269E+(00 -0	0.708E-01	27.
	2	0.222E+00	332.3	0.125E+00	303.2	2 0.2	249E+(00 -0).542E-01	28.
	3	0.148E+00	325.3	0.847E-01	334.8	з о . :	170E+0	00 00).121E-01	30.
	4	0.810E-01	306.3	0.907E-01	20.4	4 0.1	978E-0)1 ().722E-01	56.
2	1	0.582E-01	282.8	0.111E+00	35.	7 0.1	114E+0	00 00).522E-01	105.
	2	0.893E-01	204.0	0.190E+00	55.	7 0.2	205E+(00 -0	0.434E-01	113.
	3	0.104E+00	198.0	0.205E+00	57.	7 0.2	222E+(00 -0).616E-01	113.
3	1	0.154E+00	186.9	0.253E+00	62.	5 0.2	271E+(0 - 0).118E+00	114.
	2	0.201E+00	181.5	0.293E+00	65.0	5 O.	313E+0	00 -0	0.170E+00	114.
	3	0.206E+00	181.1	0.297E+00	65.9	9 0.1	316E+(0 - 0).175E+00	114.
4	1	0.216E+00	175.9	0.276E+00	69.2	2 0.1	290E+(00 -0	0.197E+00	115.
5	1	0.125E+00	165.7	0.124E+00	76.4	4 O.I	125E+(00 -0	0.124E+00	35.
	2	0.651E-01	38.1	0.129E+00	236.5	5 0.1	143E+0	00 -0	0.185E-01	116.
6	1	0.189E+00	13.0	0.312E+00	242.9	9 0.1	340E+0	00 -0	0.133E+00	115.
	2	0.254E+00	9.9	0.404E+00	243.9	9 0.4	438E+(00 -0	0.190E+00	115.
7	1	0.287E+00	8.8	0.450E+00	244.3	3 0.4	487E+0	00 -0	0.219E+00	115.
* * *	Fle	xible Supp	ort Dis	splacements						
8		0.228E+00	194.0	0.355E+00	86.4	4 0.3	365E+(00 -0).211E+00	107.
****	****	* * * * * * * * * *	* * * * * * *	* * * * * * * * * * * * * * *	*****	******	* * * * * *	* * * * * *	* * * * * * * * *	* * * * * * * *

Example 5 – Turbocharger

An automobile turbocharger is used in this demonstration. All the automobile turbochargers with floating ring bearings are operated beyond the instability threshold in linear theory and nonlinear analysis is required. Currently, in Ver 21, the Base Motion Analysis is a linear analysis for a linear system. The floating ring bearing data is save in BePerf and read directly in Rotor program. Linearized bearing coefficients are calculated first before the base motion is performed. Since this is a linear analysis, it may not give you the accurate prediction of the rotor behavior, however, it certainly give you some idea on how the rotor will behave for the base motion with the specified excitations.

Case 1: BaseMotion_5a.rot

The rotor model and some inputs are shown below:



Rotor Bearing System Data X
Axial Forces Static Loads Constraints Misalignments Shaft Bow Time Forcing Harmonics Base Motion Torsional/Axial Units/Description Material Shaft Elements Disks Unbalance Bearings Supports Foundation User's Elements
Bearing: 1 of 2 Add Brg Del Brg Previous Next
Station I: 6 J: 11 K: 0
Type: 15- Link BePerf Data File (*.LDI, *.TDI, *.FRB, *.GDI) Linear Analysis ▼
Comment: BaseMotion_5a_Turbocharger Bearing - Compressor End
Base Notion_5a_FRB_Compressor_end.FRB Browse

Rotor Bearing System Data X
Axial Forces Static Loads Constraints Misalignments Shaft Bow Time Forcing Harmonics Base Motion Torsional/Axial Units/Description Material Shaft Elements Disks Unbalance Bearings Supports Foundation User's Elements
Bearing: 2 of 2 Add Brg Del Brg Previous
Station I: 7 J: 12 K: 0
Type: 15- Link BePerf Data File (*.LDI, *.TDI, *.FRB, *.GDI) Linear Analysis
Comment: BaseMotion_5a_Turbocharger Bearing - Turbine End
FileName: BaseNotion_5a_FRB_Turbine_end.FRB

Rotor Bear	ing Syst	em Data									×
Units/De Axial Ford	escription	Material atic Loads	Shaft E Constraint	lements s Misalign	Disks l ments SI	Unbalance haft Bow	Bearings Time Forci	s Suppo ng Harmo	rts Four pnics Ba	ndation User's E se Motion Torsion	lements nal/Axial
Stea	dy State Excitat Sta	Base Harmo ion Frequen art: 5000 Amplitude Ao: 1	onic Motion cy (cpm) — Multiplier (/	: Excitation Stop: 2 A = Ao + A1 A1:	E Frequency 0000 * rpm + A2 0	Base Type: varies at a lr * rpm^2) /	Multiple Constant F ncrement.	Rotor Speed		•	
	Steady State Harmonic Base Motion: q = A* [qc * cos (wexc*t) + qs * sin(wexc*t)] (qc,qs) are the displacement amplitudes in (cos,sin) components Excitation frequency wexc (rad/sec) = cpm * (2*pi/60). rpm = reference shaft speed, rotor 1 speed										
	stnl	Xc-cos	Xs-sin	Ye-cos	Ys-sin	ThetaXc	ThetaXs	ThetaYo	ThetaYs	Comments	
1	11	0.1	0.2	0.2	0.1	0	0	0	0	Comments	
2 3 4 5 6 7	12	0.1	0.2	0.2	0.1	0	0	0	0		
	sert Row	Dele	ete Row			·	Save	Save /	Unit:(4)	Amplitude: mm, rac	dian Help

Fig. 54 – Turbocharger Model

The base motion analysis is performed at a rotor speed of 125,000 rpm with excitation frequency from 5000 to 20,000 cpm.



Fig. 54 – Base Motion Analysis

The responses due to the base motion at some stations are shown below. To further understand the rotor behavior, a whirl speed analysis is performed at the rotor 125,000 rpm, it clearly shows that a precessional mode with a frequency of 14,401 cpm is excited by this base motion and the floating ring at the turbine end is nearly stationary and the ring at the compressor end is very active. The mode shape is also shown for reference.















