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National Aeronautics and Space Administration
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ATD Project Manager

UNITED TECHNOLOGIES
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RESUME:

Pratt & Whitney (P&W) is contracted under NASA Contract NAS8-36801 to develop alternate high-pressure fuel and oxidizer turbopumps for the Space Shuttle Main Engine (SSME). This document presents the results of the HPOTP rotordynamic baseline and parametric analyses.

The analyses presented in this report include both detailed parametric sensitivity studies, in combination with a thorough baseline analysis. The sensitivity studies quantified the impact extreme input parameter variations would have on rotordynamic response. Taguchi statistical methods were utilized throughout the report to accomplish these goals.

The following conclusions are supported from the results of this analysis:

a. The ATD HPOTP has 2X critical speed margin relative to the fundamental rotor bending mode (i.e., satisfy 20% DVS criteria).

b. Subcritical operation is predicted for baseline conditions and nonlinear tolerances, including bearing deadband. The first rotor mode is predicted to occur at 30,000 RPM (124% of FPL).

c. The ATD HPOTP has adequate rotordynamic stability margin from both linear and nonlinear studies (OSI exceeds 40K RPM with 0.24 LOG-DEC value at 109% RPL).

d. Acceptable housing accelerations and bearing loads are predicted.

e. All DVS rotordynamic criteria are satisfied.

APPROVED BY: _____ _____
(First Level Supervisor) (Second Level Supervisor)
D. A. Lewis

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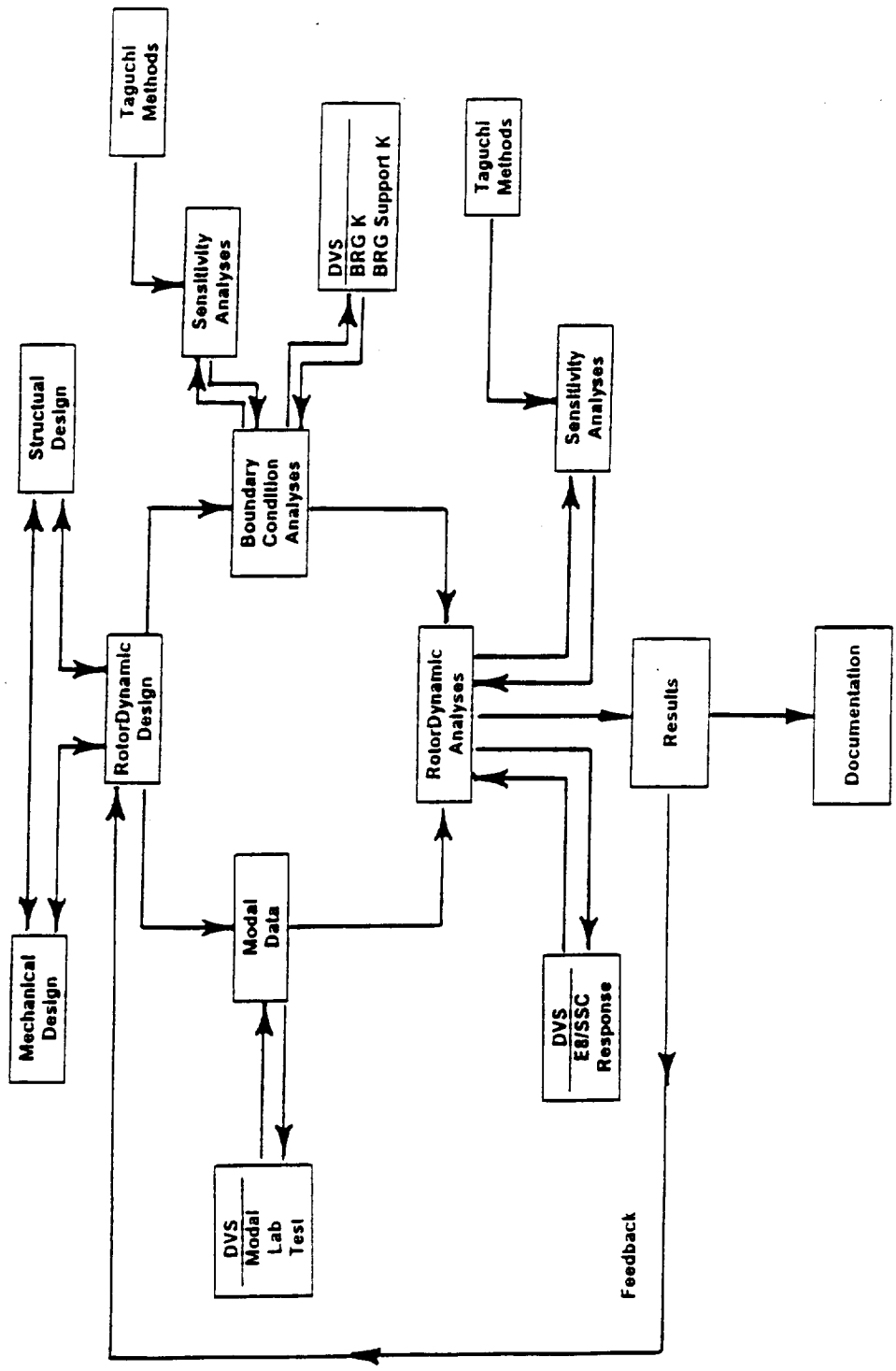

Figure 1. Design Verification System Flowchart: Rotordynamic Analyses

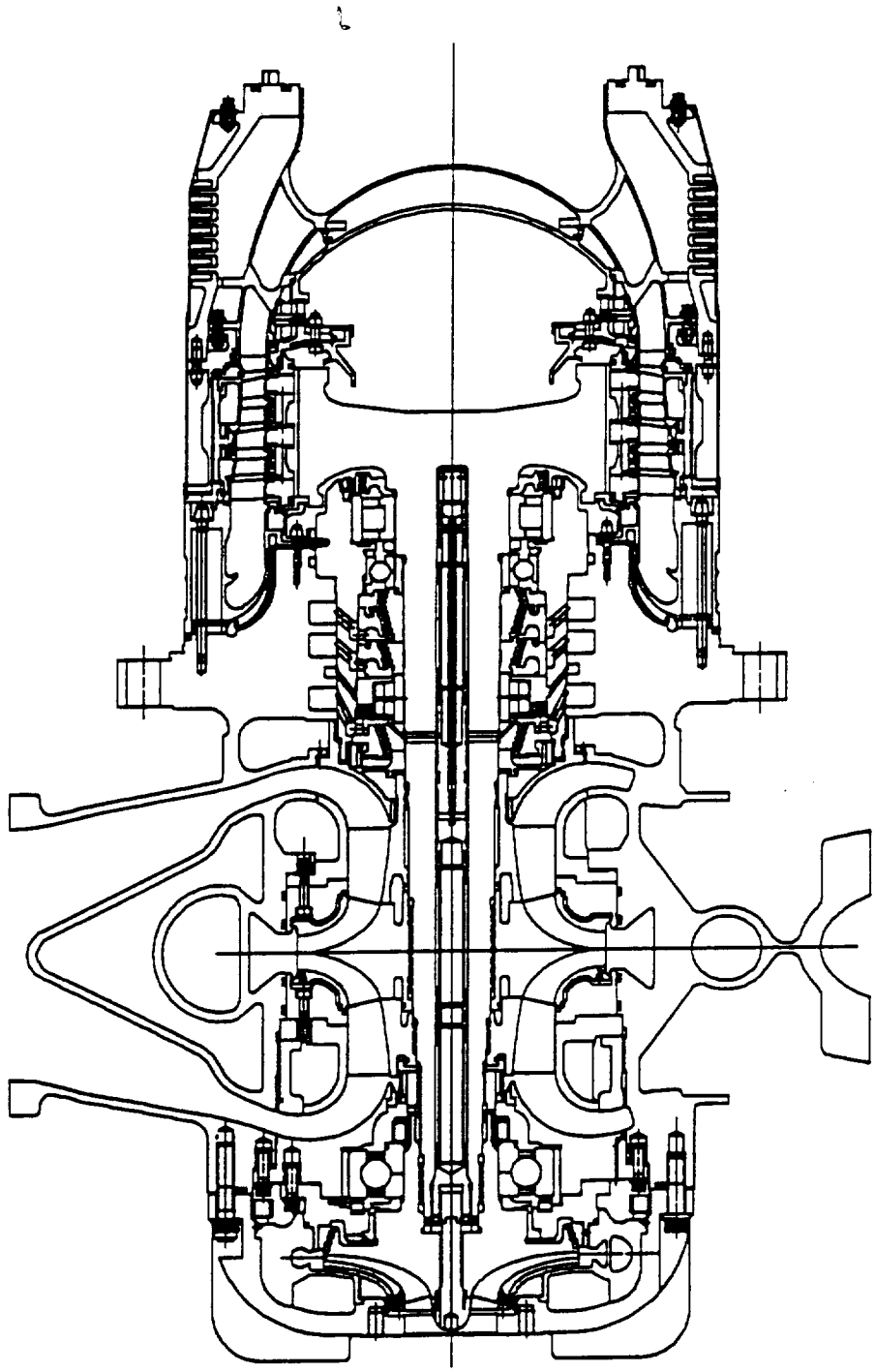

Figure 2. SSME/ATD HPOTP Assembly

1.0 INTRODUCTION

The following documents the SSME ATD HPOTP rotordynamic analyses. This document includes critical speed, stability and forced response due to excitation forces. The models include both rotor and housing dynamics and are intended to replicate the ATD HPOTP production configuration.

Data from several disciplines within Pratt and Whitney were utilized in support of this effort. The most recent verified values from these various groups were used. Where possible these values have been correlated to actual SSME ATD HPOTP test data. The ATD HPOTP has completed several tests up to 111% RPL with LOX cryogen (118% with LN2 cryogen) giving confidence in these values.

Results from a thorough rotordynamic baseline analysis are presented in this document. In addition, a Taguchi parametric sensitivity study was also conducted. NASA/MSFC and Pratt and Whitney rotordynamics jointly developed the study plan including both the significant rotordynamic boundary condition variables and the ranges examined. The parametric sensitivity study consisted of two parts: (1) a boundary condition sensitivity study and (2) rotordynamic sensitivity study. The extreme values from the boundary condition studies were utilized in the rotordynamic sensitivity study. Detailed results from both parts of the parametric sensitivity study are included in this report.

2.0 METHODS

Analytical and procedural methods are presented for the BOUNDARY CONDITIONS ANALYSES, ROTORDYNAMIC ANALYSES, and STATISTICAL METHODS used for assessing parameter input influences and combining the parameter inputs for presenting minimum, nominal and maximum conditions for the range of input variations considered.

2.1 Boundary Conditions

2.1.1 Aeromechanical Force Coefficients

A destabilizing force is generated on the turbine wheel due to changing blade tip clearance and changing efficiency of the blade to extract work as the rotor whirls (Reference 4. on page 131). This force is speed dependent as torque varies with speed. The force direction illustrated in Figure 3 is the same as the whirl velocity. Thus, the force contributes only a cross-coupled stiffness term and has no effect on critical speed.

The destabilizing force is expressed by;

$$\begin{Bmatrix} Fx \\ Fy \end{Bmatrix} = \begin{bmatrix} k & 0 \\ -k & 0 \end{bmatrix} \begin{Bmatrix} X \\ Y \end{Bmatrix} \; ; k = \frac{\beta T}{D_p H} \tag{1.0}$$

where: T = Turbine Torque
Dp = Blade Pitch Diameter
H = Blade Height
β = Coefficient of change in turbine efficiency

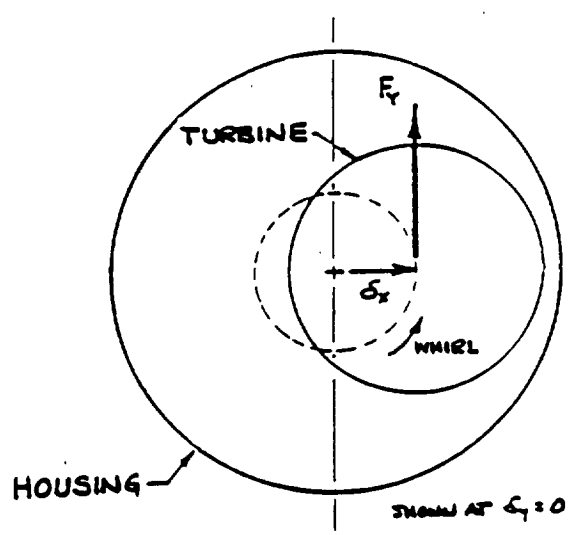

Figure 3. Aeromechanical Force Diagram: Destabilizing force is in direction of Whirl

2.1.2 Hydromechanical Force Coefficients

Dynamic forces generated by turbopump impeller-diffusers are modeled in equation (2.0). This model is the result of NASA funded research and testing by the California Institute of Technology.

$$-\begin{Bmatrix} Fx \\ Fy \end{Bmatrix} = \bar{C}\begin{bmatrix} M & m \\ -m & M \end{bmatrix}\begin{Bmatrix} \ddot{X} \\ \ddot{Y} \end{Bmatrix} + \bar{C}\omega\begin{bmatrix} C & c \\ -c & C \end{bmatrix}\begin{Bmatrix} \dot{X} \\ \dot{Y} \end{Bmatrix} + \bar{C}\omega^2\begin{bmatrix} K & k \\ k & K \end{bmatrix}\begin{Bmatrix} X \\ Y \end{Bmatrix} \tag{2.0}$$

$$\bar{C} = \pi\rho bR^2 \tag{2.1}$$

where; p = fluid density
b = fluid exit width (axial)
R = fluid exit radius
w = rotor spin speed

The nondimensional test data of Reference 5. on page 131. Table 1, is symmetric, which allows the simplified model of equation 2.0.

Thus,

$$\begin{aligned} K &= (Kxx + Kyy)/\,2 & k &= (Kyx + Kxy)/\,2 \\ C &= (Cxx + Cyy)/\,2 & c &= (Cyx + Cxy)/\,2 \\ M &= (Mxx + Myy)/\,2 & m &= (Myx + Mxy)/\,2 \end{aligned} \tag{2.2}$$

The nondimensional force coefficients of Reference 5. on page 131 have been dimentionalized by the model of equation 2.0. with force directions illustrated in Figure 4 on page 5. The direct stiffness coefficient "K" is negative and has the effect of reducing the critical speed. The cross-coupled stiffness coefficient "k" causes a force in the same direction as rotor whirl and is destabilizing.[1] The direct damping coefficient "C" acts as a whirl restoring force in the opposite direction as "k" and is stabilizing. These last two terms, "k" and "C" can be equated in a general term to scale the relative effectiveness of stability. This "whirl ratio" is expressed as, $k/C\omega$.

---

[1] The cross-coupled nondimensional force coefficient "k" from Reference 5. on page 131 has been multiplied by 2x in this report, based on the results of Dr. Dara Childs' previous Rocketdyne studies.

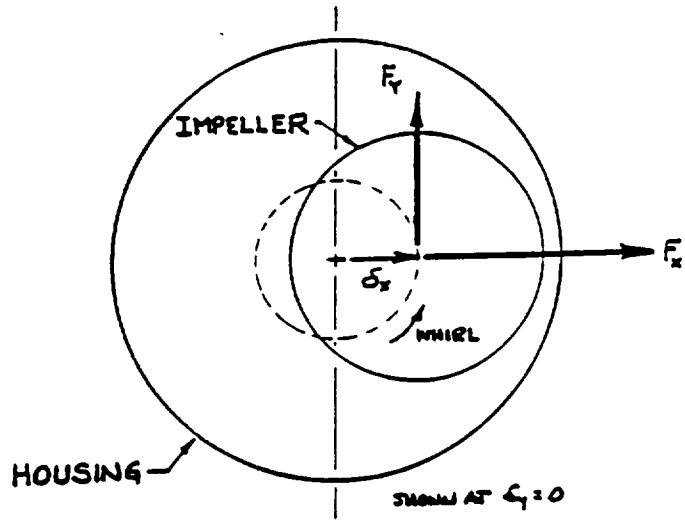

Figure 4. Hydromechanical Force Diagram

2.1.3 Structural Damping

Structure damping provides a constant energy dissipation per cycle of oscillation. Rocketdyne modal test showed casing modes to have about 3% to 6% equivalent viscous damping and the rotor modes to have about 0.6% (Reference 3. on page 131). Based on this information and Pratt & Whitney studies of the XLR129 & 350K high pressure turbopump, a nominal critical damping ratio of 3% was used for housing structural damping and 0.6% for the rotor.

2.1.4 Damper Seal Coefficients

A damper seal program developed by Dr. Dara Childs (Texas A&M) is used to define dynamic coefficients of high pressure annular seals. The program is capable of modeling annular seal geometry, flow properties and surface treatments. The solution procedure allows tapered clearances and different surface-roughness treatment on the stator or rotor seal elements. Output includes seal direct and cross-coupled stiffness, direct and cross-coupled damping and direct inertia.

2.1.5 Gas Labyrinth Seals

Calculations for labyrinth seal coefficients of the turbine interstage seals and interpropellant seals, were made with codes from Dr. Dara Childs (Turbomachinery Laboratories, Texas A&M) and are based on Scharrer's analysis (Reference 10. on page 131).

2.1.6 Component Side Loads

Static rotor side loads are used for the nonlinear analysis which include impeller and turbine component side loads. Circumferential pressure gradients are created from discharge hardware asymmetry, resulting in static load vectors. The impeller and turbine component side loads have been substantiated by hydromechanical and aeromechanical flow rigs within the Mechanical Component Design Group (12. on page 132).

2.1.7 Bearing Radial Dynamic Stiffness

Ball bearing load-deflection plots are generated using "Jones V" rigid ring analysis program based on formulation by A. B. Jones. The ball bearing model includes the outer race, balls and inner race. Effects of bearing carrier and back-up support are not included in the ball bearing springrate calculations.

Roller bearing load-deflection plots are generated using a flexible ring version; Jones IV. The roller bearing model includes the outer race, rollers and inner race. A thin shell theory is used for influence coefficients of the bearing race support.

Traditional A. B. Jones results for radial bearing springrates are defined by the slope of the tangent for a given radial load on the load-deflection curve (Figure 5). Pratt & Whitney experience has shown that the tangent springrate theory over estimates actual dynamic springrates by approximately 50% for ball bearings with loads similar to the ATD application. More accurate results are obtained using the effective or secant slope on the load-deflection curve shown in (Figure 5).

Bearing springrates for the SSME ATD turbopumps have been calculated using the secant method. Springrates are calculated vs speed using the resultant static side loads. Bearing parameters used in the bearing stiffness calculation do not include deadband clearance but are included later in the nonlinear analysis.

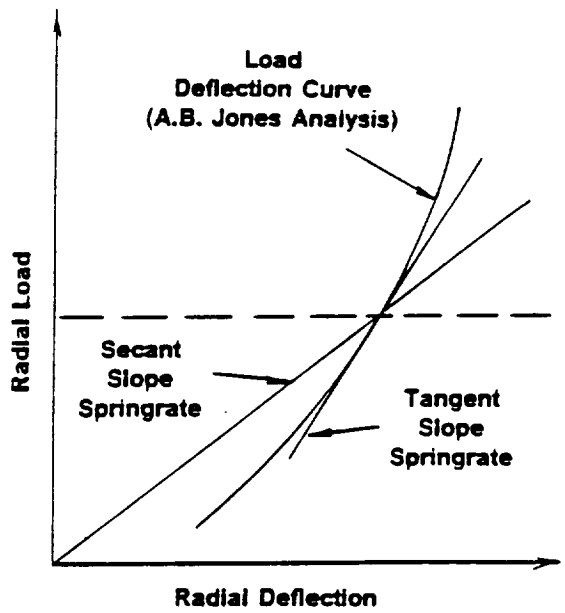

Figure 5. A.B. Jones Bearing Springrate Diagram: Load-Deflection Curve using secant method for prediction of bearing stiffness for a given radial load.

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2.1.8 Rotor Imbalance

Eccentric mass distribution is a major source of synchronous rotor excitation for the forced response analyses. This mass imbalance has been calculated for analytical input to simulate actual detail part, subassembly and full assembly imbalance. A 2X increase in the pump subassembly imbalance is added to provide conservative margins for reassembly residual and 'hydraulic imbalance'.

The rotor imbalance distribution used in the rotordynamic forced response analysis is tabulated in Table 1 on page 9. The distribution is constructed in two parts; pump and turbine subassembly, to simulate the actual hardware assembly procedures. The pump subassembly mass distribution is assumed to have worse case eccentricity of 0.0005 inch. The sum is distributed at location 2, 3 & 5 of Figure 6 on page 9. Corrections are made in stations 1 & 4 (Pump subassembly correction planes) to simulate the rotor after balance correction procedures, and residual moment imbalances. The original imbalance is again distributed at stations 2,3 & 5 (2X) to account for reassembly residual imbalance. Actual reassembly imbalance measurements have been approximately 1/3 of the analytical values of this distribution.

Turbine imbalance is significantly less than pump imbalance, as the turbine disk is integral with the shaft and rotor journals and is mass corrected at the detail part level. The imbalance distribution for the turbine subassembly represents the turbine blades, interstage seals and accompanying attachment parts. Actual reassembly imbalance measurements are 0.01-0.03 oz-in.

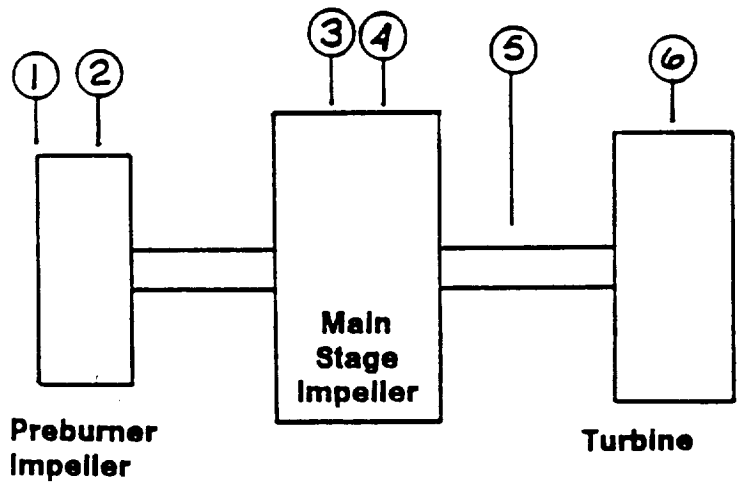

Figure 6. Rotor Imbalance Distribution Diagram

Location	Rotor Station	Axial Location (inch)	Imbalance (oz-in)	Angular Phase (degrees)
1	02	0.880	0.051	180
2	05	2.430	0.174	0
3	15	8.670	0.442	0
4	16	9.390	0.311	180
5	26	15.150	0.054	0
6	39	22.290	0.025	0

Table 1. Rotor Imbalance Distribution

2.2 Rotordynamic Analyses

2.2.1 Critical Speeds

Critical speeds are defined as rotational speeds of the rotor which are coincident with one of the natural vibratory modes of the rotor system. A critical speed analysis yields both the speed (frequency) of the coincidence and the normalized mode shapes of the rotor system.

Classical critical speed analysis involves solving an Eigenvalue problem. Pratt and Whitney conducts classical critical speed analyses using a transfer matrix approach to define the state variable matrices and then an iterative process to solve the determinant. The critical speed analysis utilizes only the direct stiffness component of the rotor interface coefficients (i.e., no inertia, damping or cross-coupled stiffness terms).

Once the determinant search is completed and the critical speed is known, normalized mode shapes can be extracted from the displacement state variables. These mode shapes yield insight into the relative rotor to housing motion, however since this is an Eigenvalue analysis, only relative deflections are resolved.

2.2.2 Linear Stability

A rotor system is said to be stable when following a small disturbance, the system response tends to return to its equilibrium position. The means of quantifying the stability margin of a system vary, however all relate to a measure of the system's relative damping. Some of the more popular quantifiers include: OSI (Onset Speed of Instability), LOG-DEC (logarithmic decrement), or critical damping ratio.

The linear stability analysis conducted on the ATD HPTP's involve a complex Eigenvalue analysis: the complex part contains frequency information, while the real part contains system damping information. The analysis was conducted using Pratt and Whitney's CANCER code, developed by Dr. Dara Childs. This analysis utilized all rotordynamic boundary condition coefficients (i.e, direct and cross-coupled damping, stiffness and inertia) and constant modal damping for the housing modes.

The stability analysis results are presented in terms of LOG-DEC; the decay rate of the system. Since the rotordynamic coefficients vary with speed, the stability results are presented as a function of speed. Also, recall the stability of a given mode is independent of the other modes and therefore the LOG-DEC value describes only a specific mode. For completeness additional analyses were conducted to determine the OSI.

2.2.3 Forced Response

Forced response analysis is the response of the rotor system to rotor unbalance. The output includes bearing loads, rotor to housing deflection, and housing acceleration levels. Experience gained from the current Rocketdyne SSME HPTP's has shown HPTP rotordynamic response is potentially sensitive to certain nonlinear aspects. For this reason, forced response analyses documented in this report include nonlinear effects.

The analysis was conducted using Pratt and Whitney's nonlinear CANCER code, developed by Dr. Dara Childs. The code accounts for both bearing deadband and static side loads; the two significant rotordynamic nonlinear interactions. Pratt and Whitney's nonlinear code is incapable of modeling inertia terms. In order to compensate for this deficiency, cross-couple damping terms were compensated.

The accuracy of the nonlinear model was confirmed by deleting the bearing deadband and static side loads (nonlinearities) and comparing the results with the linear model. The nonlinear model utilized a ramp rate of 100000 rpm/sec (w/20000 integration points) to avoid numerical instability yet adequately excite the rotor. This ramp rate is not intended to duplicate the ramp rate of the SSME. Comparisons of the linear and linearized nonlinear model showed good agreement.

2.3 Design of Experiments (Taguchi Methods)

A statistical technique was used for 1) assessing input parameter sensitivities and 2) calculating parameter combinations to produce minimum and maximum outputs. The technique is commonly used in manufacturing applications to make multiple parameter variations simultaneously, in a symmetric setup of a limited amount of experiments or runs. Data can then be extracted from the matrix of each parameter to calculate a "response table". An optimum combination is then found and represents the "Paper Champ" minimum and/or maximum output value. Confirmation test or runs are then made to verify the findings. These methods allow identification of individual parameter sensitivities, optimum values, and parameter interactions that may not be found with "on-at-a-time" parameter variation methods and greatly reduces the labor involved.

A simplified example is presented in Appendix B of a static stress calculation for a fixed beam with option length, load angle, thickness and width. Stress is calculated at the base of the beam, with the goal of minimizing the principal value. Input parameter are considered that have or thought to have an influence on the stress. These "factors" are tabulated with their allowable variations (e.g. Load Angle, by design, may vary from 30 to 45 degrees, etc). Even if little is known about a parameter influence, it can be added to the test matrix. Color is added in this example for illustration purposes, as it obviously has no influence on stress. Six factors are identified with two level variation.

This matrix would require 128 calculations (or measurements) to examine every combination of input values and identify the minimum stress (ignoring other methods of calculating minimum stress for this simple example). Using a L8 array to make multiple parameter variation in a symmetrical matrix, similar data can be extracted making only eight test runs and one confirmation run.

Eight calculations are made with the specified parameter levels given by the array (note, one other parameter could have been chosen as "G"). The response table is then tabulated from the array to give parameter sensitivity. Delta values are used to assess a parameter influence to the output (i.e. stress). General grouping can be assessed in "Rate the Performance" and helps to highlight the influential parameters. As can be seen in the evaluation of "color", some data noise is calculated, but when compared to the performance of the other parameters, it can supply useful information. In this case, color was the least influential, so it is assessed as "Not Important".

Combinations are then tabulated to produce the minimum stress or maximum stress if it were desired. In this example, level 2 for parameter "A" (Load Angle), level 1 for parameter "B" (Length L1), etc, are predicted to produce the minimum stress. This is the "Paper Champ". A confirmation run is then made to verify the prediction. Notice that from the test matrix, a spread of 17 KSI to 102 KSI was calculated. Using the "Paper Champ", the minimum stress was found as 10 KSI.

3.0 MODEL DESCRIPTION

The mass-elastic models for the rotor have been substantiated with a modal lab test in Reference 1. on page 131. The mass-elastic models for the housing have been calibrated with structural finite element models for definition of stiffness characteristics and weight audits for definition of mass terms including mass/inertia for the preburner housing.[2]

3.1 System Model

The rotor assembly and housing assembly rotordynamic model is constructed from simple geometric shapes as illustrated, for the rotor in Figure 8 on page 15. These "geometry codes" are reduced to a system of discretized masses connected by massless beams. The masses have inertia properties while the beams have both bending and shear flexibilities. The remainder of the assembly not represented by these codes are included as mass/inertia terms without any stiffness contributions.

The natural frequency modes from these models are generated and are connected using serial connections (boundary conditions) for later calculation of the system modes. A stick diagram is illustrated in Figure 7 with tabulated axial locations in Table 2 on page 14 to show the relative boundary condition 'connect points' with the rotor and housing models.

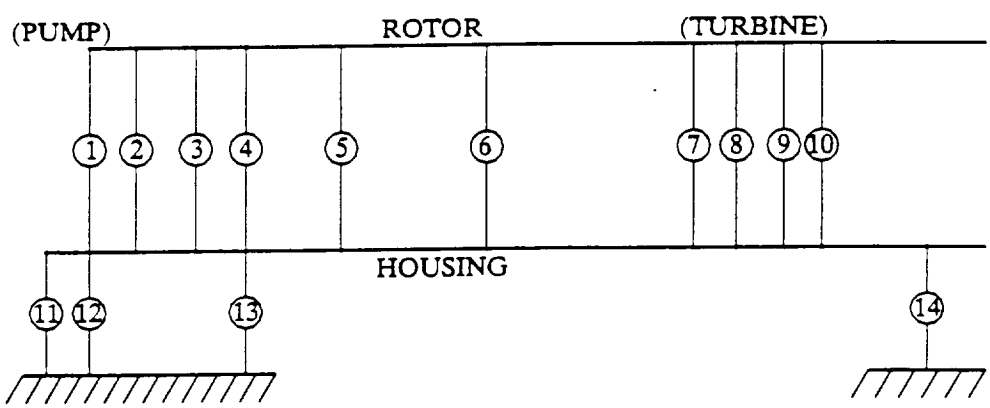

Figure 7. System Model Stick Diagram: Rotor and Housing models, including preburner housing mass/inertia with connecting boundary condition locations.

[2] Substantiation of the housing model with modal lab test is pending execution of the test.

Boundary Condition Connection Data				
Index	Boundary Condition	Axial Location	Station Number	
			Rotor	Housing
1	Preburner Impeller	1.596 in	5	04
2	Four Tooth Labyrinth Seal	2.330 in	7	07
3	Damper Seal	2.453 in	8	10
4	Ball Bearing	3.816 in	13	13
5	Main Stage Impeller	9.394 in	38	22
6	Primary H2 Labyrinth Seal, Secondary H2 Labyrinth Seal, Primary LO2 Labyrinth Seal	16.563 in	70	33
7	Roller Bearing	20.237 in	87	36
8	Turbine 2-3 Interstage Labyrinth	21.673 in	94	39
9	Turbine C.G.	22.299 in	96	42
10	Turbine 1-2 Interstage Labyrinth	22.897 in	99	44
11	Preburner Inlet Plumbing	0.0 in	N/A	01
12	Preburner Discharge Plumbing	1.3	N/A	02
13	Pump I/D Plumbing	9.578 in	N/A	23
14	Turbopump Mount	28.341 in	N/A	48

Table 2. System Model Boundary Condition Locations.

3.2 Rotor Model

The rotor model of Unit 1-1 design has been substantiated with laboratory modal analysis (Reference 1. on page 131). The model used in this report has been updated to represent the latest rotor design based on Unit 4-1 which includes the preburner impeller 'nut' spacer. This spacer extends the outer load path in the rotor stack for increased rotor stiffness as a result of ATD test development. There is essentially no change in rotor weight. Thus, the total rotor weight of Unit 1-1 and Unit 4-1 design are equal, but have different stiffness characteristics. Rotor weight of Unit 4-1 is itemized in Table 4 on page 16. The full rotor mass-normalized data for free-free modes of Unit 4-1 rotor design are included in Appendix C with mode shapes shown in Figure 9 on page 17 thru Figure 11 on page 19. A summary of the rotor free-free natural frequencies are included in Table 3.

Unit 4-1 Design Rotor Model, Free-Free Modes	
Mode	**Frequency**
1st Bending	490 Hz
2nd Bending	1040 Hz
3rd Bending	2000 Hz
Note: Total Rotor Weight = 106 lbm	

Table 3. **'Unit 4-1 Design' Rotor Model, Free-Free Modes:** Operating temperature material properties

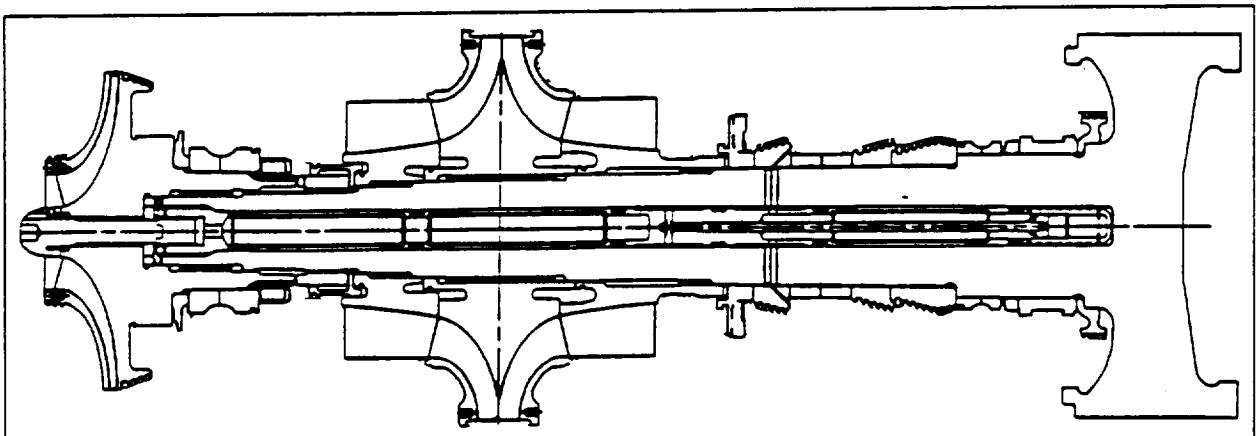

Figure 8. **'Unit 4-1 Design' Rotor Model:** Includes preburner impeller "nut" spacer

Part #	Part Description	Weight	Igyro
4750335	Main Stage Impeller	15.6500	20.1992
4750018	Pump Side Inducer	3.1500	12.3878
4750019	Turbine Side Inducer	3.1000	11.1599
4750020	Pump Side K/E Seal	0.3590	0.2241
4750338	Preburner Impeller	10.1000	10.0630
4750088	Spacer	0.0390	0.0000
4750101	1st Stage Turbine Blades	2.2000	23.5726
4750102	2nd Stage Turbine Blades	2.3263	25.5909
4750103	3rd Stage Turbine Blades	2.7000	30.2516
4750420	Tie Rod	0.2700	0.1525
4750421	Lock	0.0037	0.0000
4750110	Lock	0.0300	0.0000
4750428	Bumper Ball Bearing Inner Race	0.4870	0.4784
4750144	LOX K/E Seal	0.8470	0.8320
4750146	2nd H2 K/E Seal	0.7560	0.7143
4750147	Primary H2 K/E Seal	1.3050	1.1971
4750154	Spacer	0.4087	0.5090
4750646	Speed Pickup Nut	0.3340	0.2712
4750156	Washer	0.0220	0.0000
4750163	Converter	0.8310	0.9770
4750165	Roller Bearing Spring	0.1870	0.2317
4750167	Turbine Disk Seal	0.6990	1.2744
4750108	Roller Bearing Inner Race	0.9470	1.0956
4750173	Turbine Side Spacer	0.0560	0.0046
4750174	Bumper Ball Spacer	0.0340	0.0387
4750203	Turbine 1–2 Spacer	1.6070	14.5217
4750204	Turbine 2–3 Spacer	1.6000	14.5217
4750205	Retainer	0.6200	5.4440
4750206	Snap Ring	0.0840	0.0000
4750339	Shaft / Disk Assembly	51.1000	198.8835
ATD03141	Bumper Ball Sleeve	0.4413	0.3542
4750210	Retaining Nut	0.4510	0.1780
4750212	Bore Tube Assembly	1.0600	0.0000
4750198	Sleeve	0.7140	0.5567
4750426	1/2 Ball Bearing	0.5880	0.5736
4750430	1/2 Ball Bearing	0.7600	0.7261
ATD04710	Preburner Impeller Nut Spacer	0.1144	0.0520
TOTALS		105.9813	377.0374

Table 4. 'Unit 4-1 Rotor Design' Weight: Total = 106 lbm.

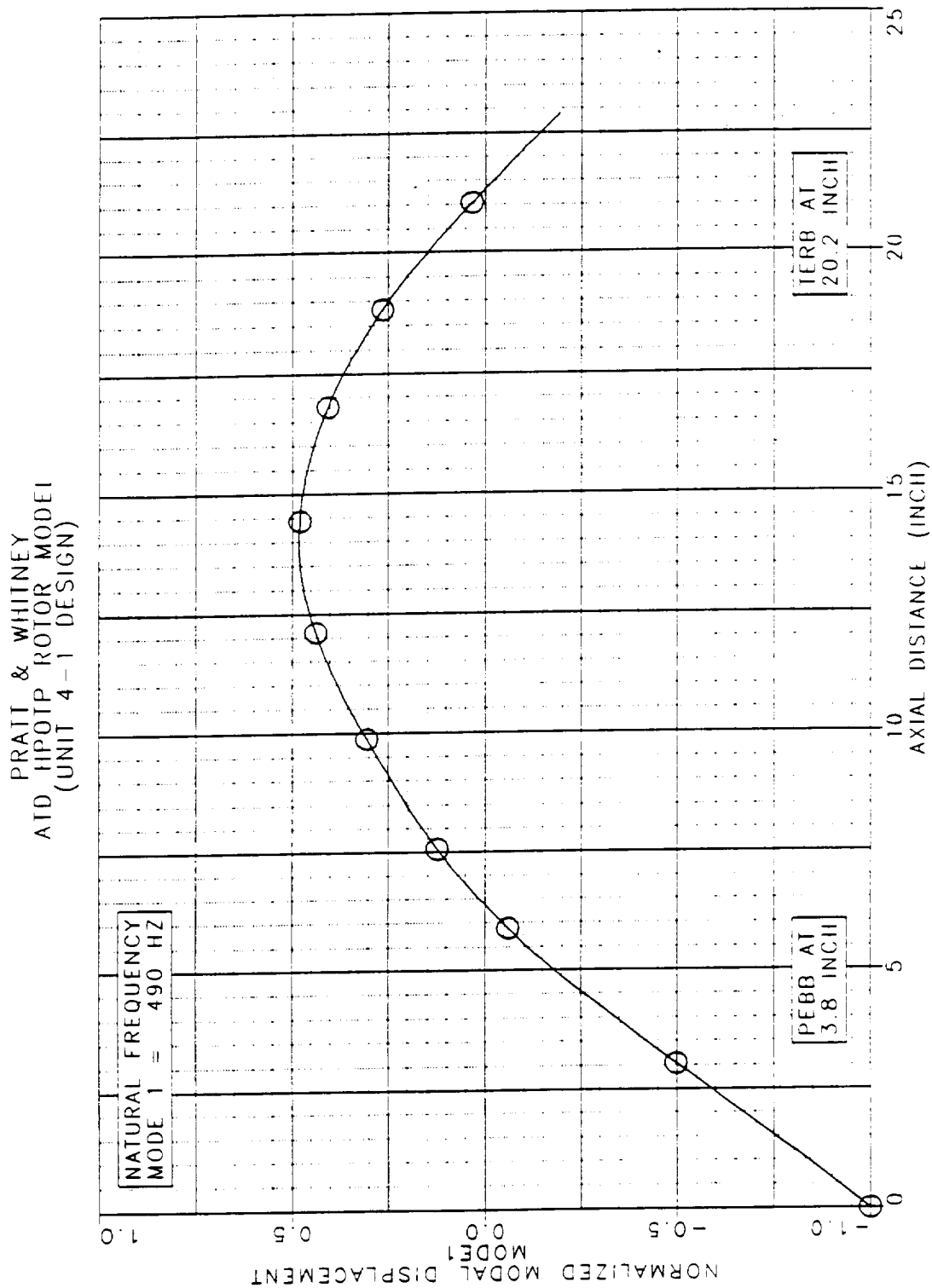

Figure 9. Rotor Free-Free Mode 1: 1st Lateral Bending Mode

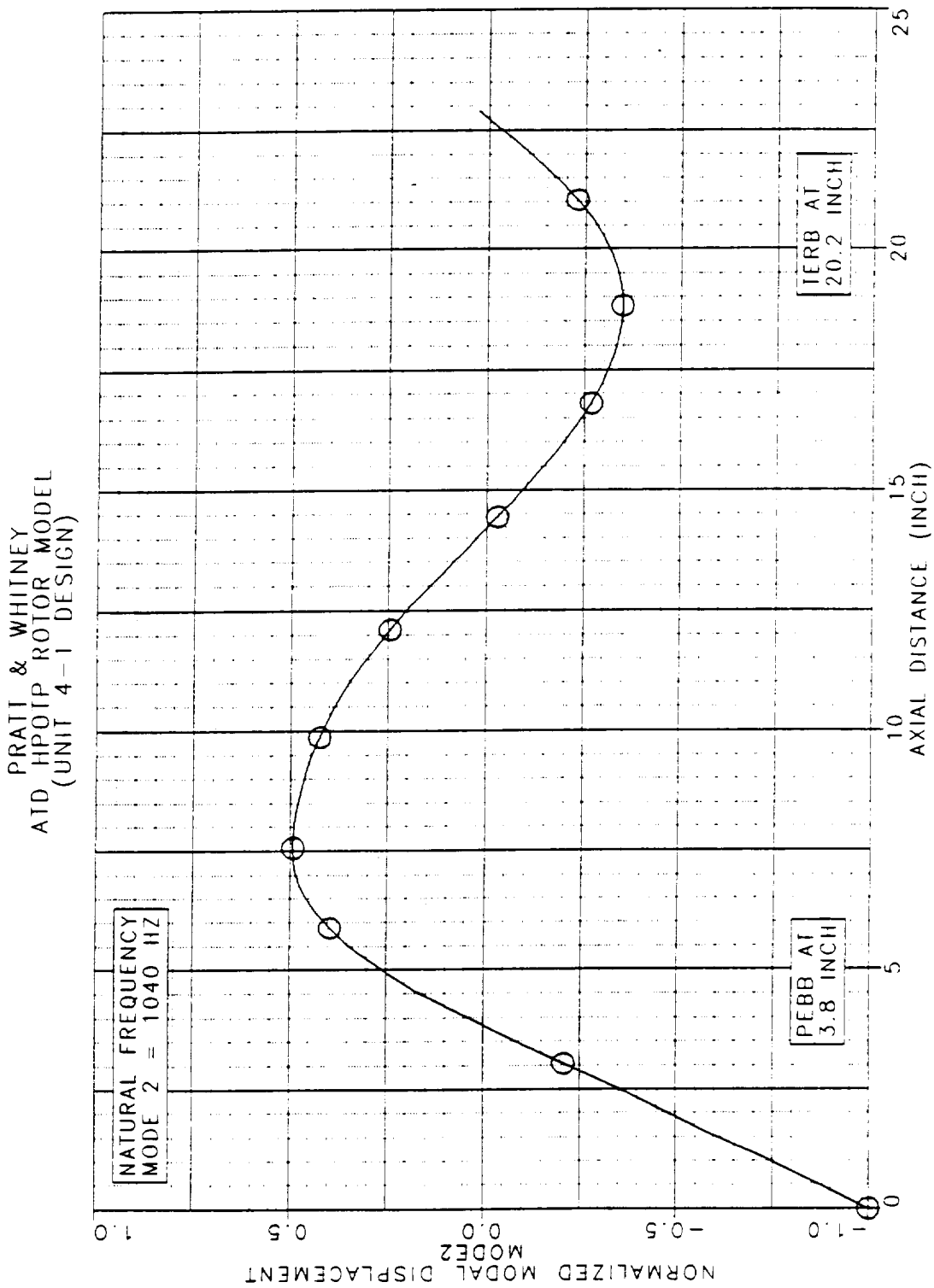

Figure 10. Rotor Free-Free Mode 2: 2nd Lateral Bending Mode

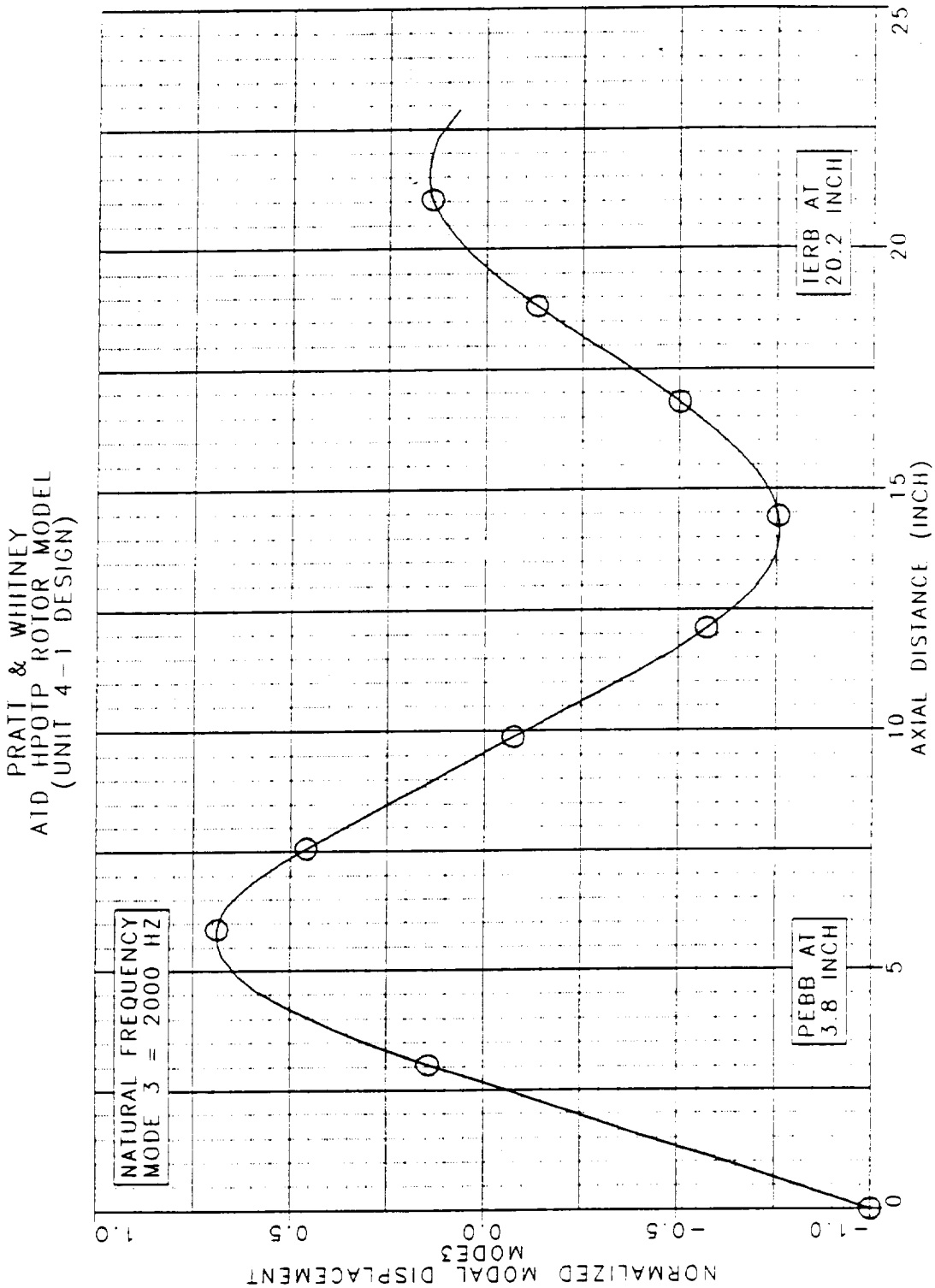

Figure 11. Rotor Free-Free Mode 3: 3rd Lateral Bending Mode

3.3 Housing Model

The mass-elastic models for the housing have been calibrated with structural finite element models for definition of stiffness characteristics. Weight audits of the housing and mass/inertia data of the preburner housing from Rocketdyne (Reference 6. on page 131) provided definition of mass terms. Housing weight of Unit 4-1 is itemized in Table 6 on page 24 thru Table 8 on page 26. Component modes are generated in two orthogonal planes X-Z and Y-Z as a result of the housing asymmetric mount. The mass-normalized data for lateral component housing modes are included in Appendix D with modes shapes shown in Figure 15 on page 27 thru Figure 18 on page 30. A summary of the housing mode frequencies are included in Table 5.

Component Housing Model Modes		
Mode	Frequency	
	X-Z Plane	Y-Z Plane
1	164 Hz	145 Hz
2	361 Hz	280 Hz
3	718 Hz	694 Hz
4	1197 Hz	1197 Hz
Note: Total Housing Model Weight = 893 lbm		

Table 5. **Housing Model Modes:** Operating temperature material properties

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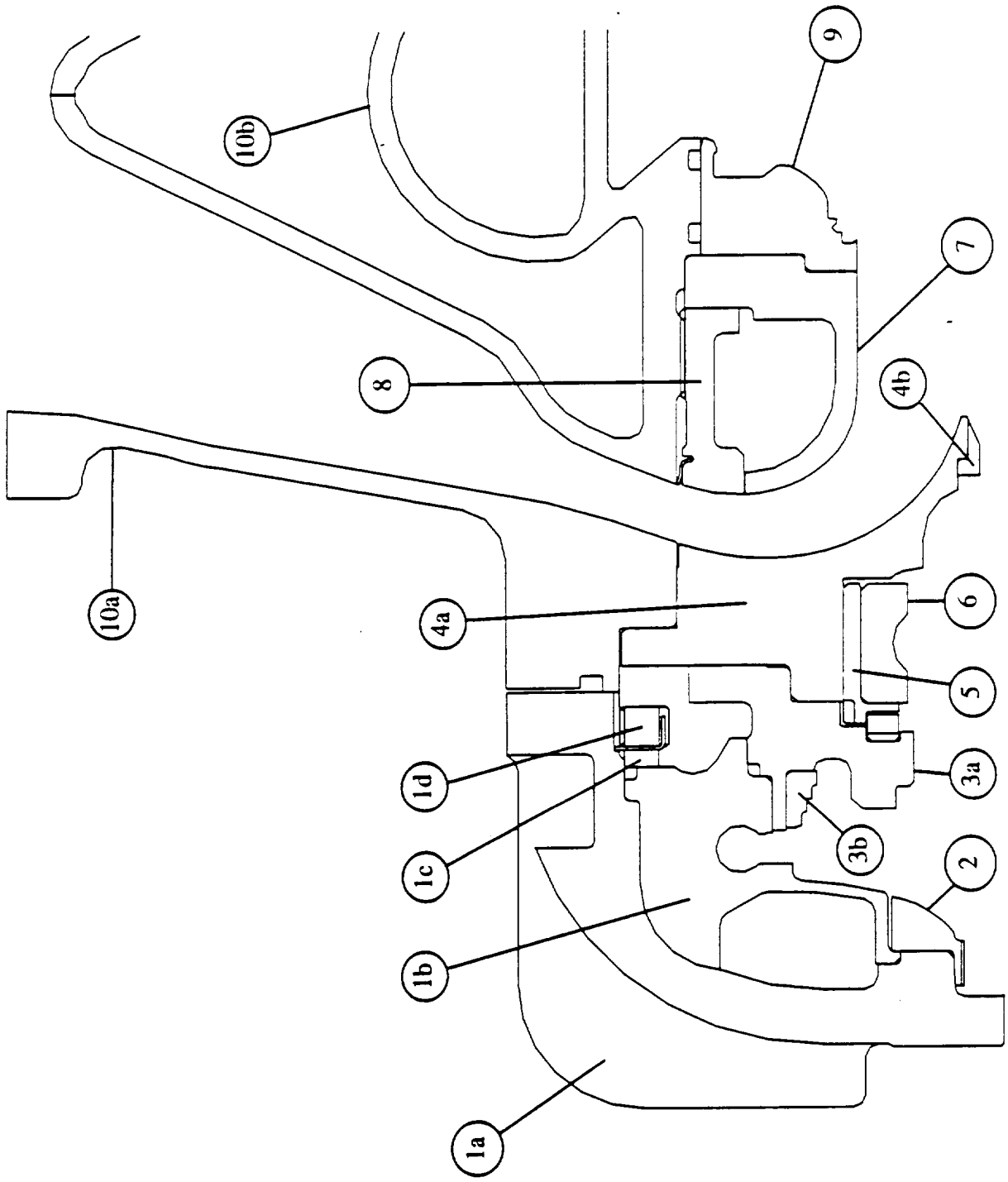

Figure 12. Housing Part Reference (Pump-End)

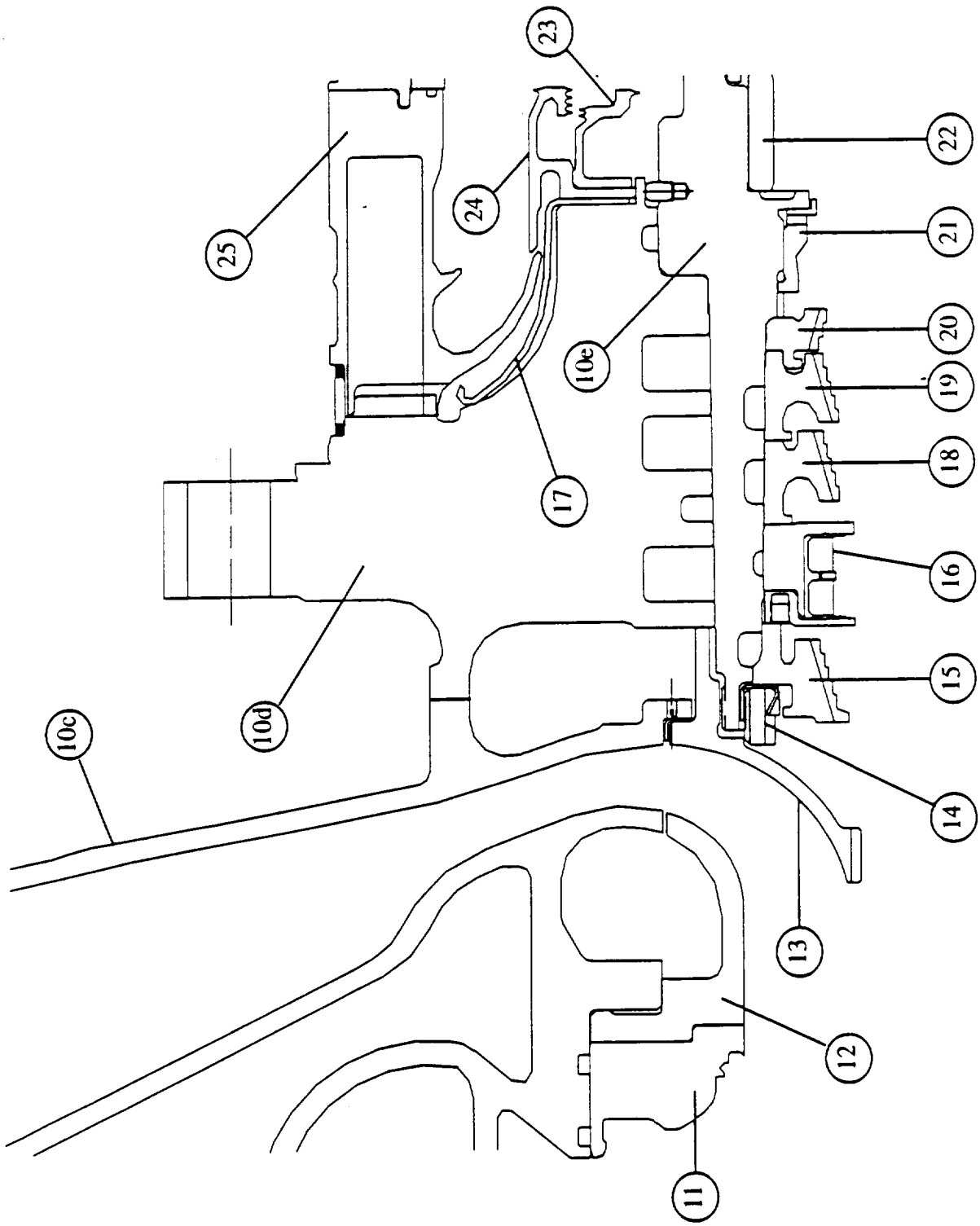

Figure 13. Housing Part Reference (Mid-Pump)

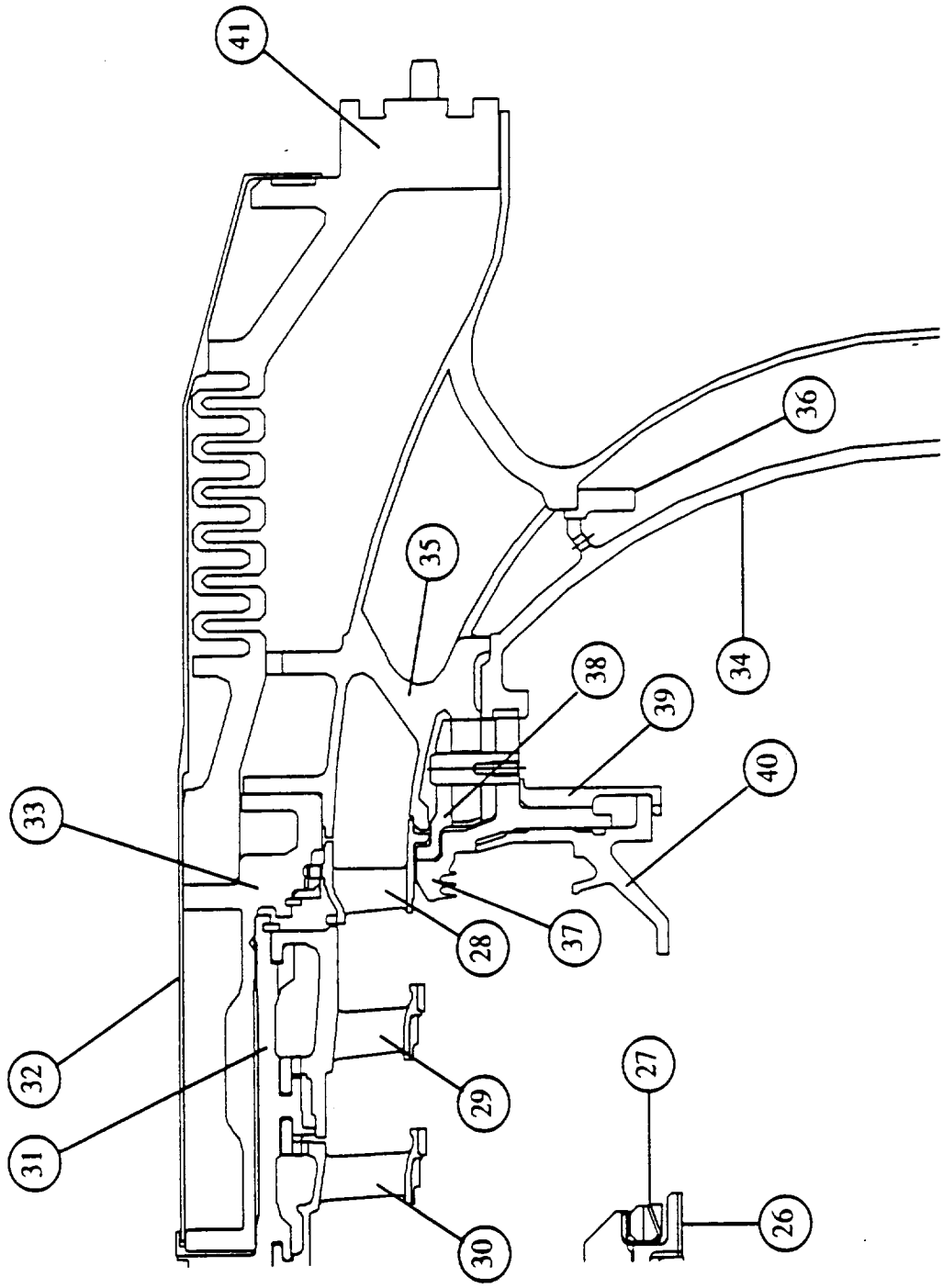

Figure 14. Housing Part Reference (Turbine-End)

Table 6. Housing Weights (part items 1-14)

Ref #	Part Number	Part Description	Weight	Ipolar
1a	4750098	Preburner Pump Housing – Outer	39.920	
1b	4750099	Preburner Pump Housing – Inner	13.050	
1c	4750138	Sealing Seat	0.450	
1d	4750139	Inverted Nut	1.618	
	4750644–01	Assembly Total	55.190	1066.550
2	4750642	Preburner Pump Impeller Sealing Ring – Shroud	0.639	2.400
3a	4750619–02	Preburner Damper Support	8.143	84.176
3b	4750340	Preburner Pump Impeller Sealing Ring – Back	0.862	0.868
	4750619–01	Assembly Total	9.553	95.072
4a	4750398–02	Ball Bearing Support	16.735	205.339
4b	4750342	Sealing Ring	0.279	0.584
	4750398–01	Assembly Total	17.014	205.923
5	4750647	Preburner Pump Bearing Housing	1.504	10.360
6	4750312	Ball Bearing Outer Race	2.012	9.382
7	4750397	Left Inducer Shroud	9.360	117.120
8	4750042	Main Stage Impeller Shroud Inverted Nut	5.600	90.350
9	4750334	Main Stage Impeller Shoud Seal – Left	15.920	188.510
10a	4750618–02	Main Stage Inlet Housing	70.600	
10b	4750618–03	Main Stage Outlet Housing	77.480	
10c	4750618–04	Main Stage Inlet Housing	57.000	
10d	4750347	Main Oxidizer Turbopump Intermediate Housing	116.445	
10e	4750617	Main Oxidizer Bearing & Seal Housing	20.326	
	4750618–01	Assembly Total	367.840	9751.690
11	4750334	Main Stage Impeller Seal – Right	15.920	188.510
12	4750032	Right Inducer Shroud	7.190	85.140
13	4750770	Main Oxidizer Pump Outlet Deflector	3.200	20.760
14	4750164	Inverted Nut	0.570	3.250

Table 7. Housing Weights (part items 15-41)

Ref #	Part Number	Part Description	Weight	Ipolar
15	4750120–01	Oxidizer Interpropellant Sealing Ring	1.698	7.220
16	4750689	Helium Interpropellant Seal Assembly	1.966	
17	4750003	Turnaround Duct Heat Shield	1.857	38.860
18	4750126–01	GH_2, Interpropellant Sealing Ring	1.580	6.450
19	4750129–01	LH_2, Left Interpropellant Sealing Ring	1.488	6.050
20	4750132–01	LH_2, Right Interpropellant Sealing Ring	0.828	3.500
21	4750425	Bumper Ball Bearing Outer Race	0.414	1.776
22	4750384	Roller Bearing Outer Race	1.241	7.018
23	4750181	Outlet Duct Seal	1.297	
24	4750002	Turbine Outlet Duct Seal	2.656	46.620
25	4750626	Turbine Outlet Duct	31.750	1048.540
26	4750168–01	Roller Bearing Sealing Ring	0.454	
27	4750171	Inverted Spanner Nut	0.537	3.206
28	4750141	1st Stage Turbine Vanes	2.107	52.950
29	4750282	2nd Stage Turbine Vanes	3.504	94.440
30	4750283	3rd Stage Turbine Vanes	2.925	79.060
31	4750160	Turbine Housing Assembly	14.110	513.970
32	4750289	Bellows Liner	6.670	244.010
33	4750418	Turbine Housing	8.642	331.360
34	4750387	Turbine Heat Shield	3.990	
35	4750096	Turbine Inlet Housing	13.010	
36	4750256	Turbine Heat Shield Support	0.640	
37	4750291	Turbine Inlet Seal	2.930	
38	4750255	Turbine Inlet Seal Loading Ring	2.823	
	4750284	Assembly Total	23.668	539.680
39	4750257	Turbine Inlet Seal Retaining Plate	0.899	9.826
40	4750258	Turbine Inlet Deflector	2.146	20.642
41	4750162	Bellows Assembly	30.410	888.540

Table 8. Housing Weights (miscellaneous parts)

Ref #	Part Number	Part Description	Weight	Ipolar
None	4750613	Outlet Duct Gasket	0.680	29.620
"	4750036	Plain Seal	0.440	31.790
"	4750435	Key Washer	0.069	1.340
"	4750507	Bolt–Instrumentation Adapter	1.820	57.780
"	4750642–01	Preburner Pump Impeller Sealing Ring	0.639	2.400
"	4750609	Bearing Washer	0.270	5.910
"	4750608	Washer	0.074	0.580
"	4750639	Key Washer	0.109	0.770
"	4750640	Key Washer	0.101	0.610
"	4750399	Key Washer	0.085	0.880
"	4750201	Turbine Bellows Positioning Ring	0.246	5.710
"	4750202	1st Stage Damper	0.170	3.440
"	2189339–18	Gasket	0.150	4.260
"	2189377–24	Spring Gasket	0.205	10.510
"	4750400–20	Cap Screw	0.150	2.050
"	4750400–24	Cap Screw	0.200	2.740
"	4750390–14	Machine Bolt	0.056	0.010
"	4750424	Instrumentation Boss Plug	0.350	0.090
"	4750690	Helium Interpropellant Seal Cover	0.558	2.160
"	4750197	Washer	0.067	0.220
"	4750310	Turbine Housing Flange	0.389	15.840
"	ATD03810	Sealing Washer	0.022	0.270
		Totals	661.209	15957.700

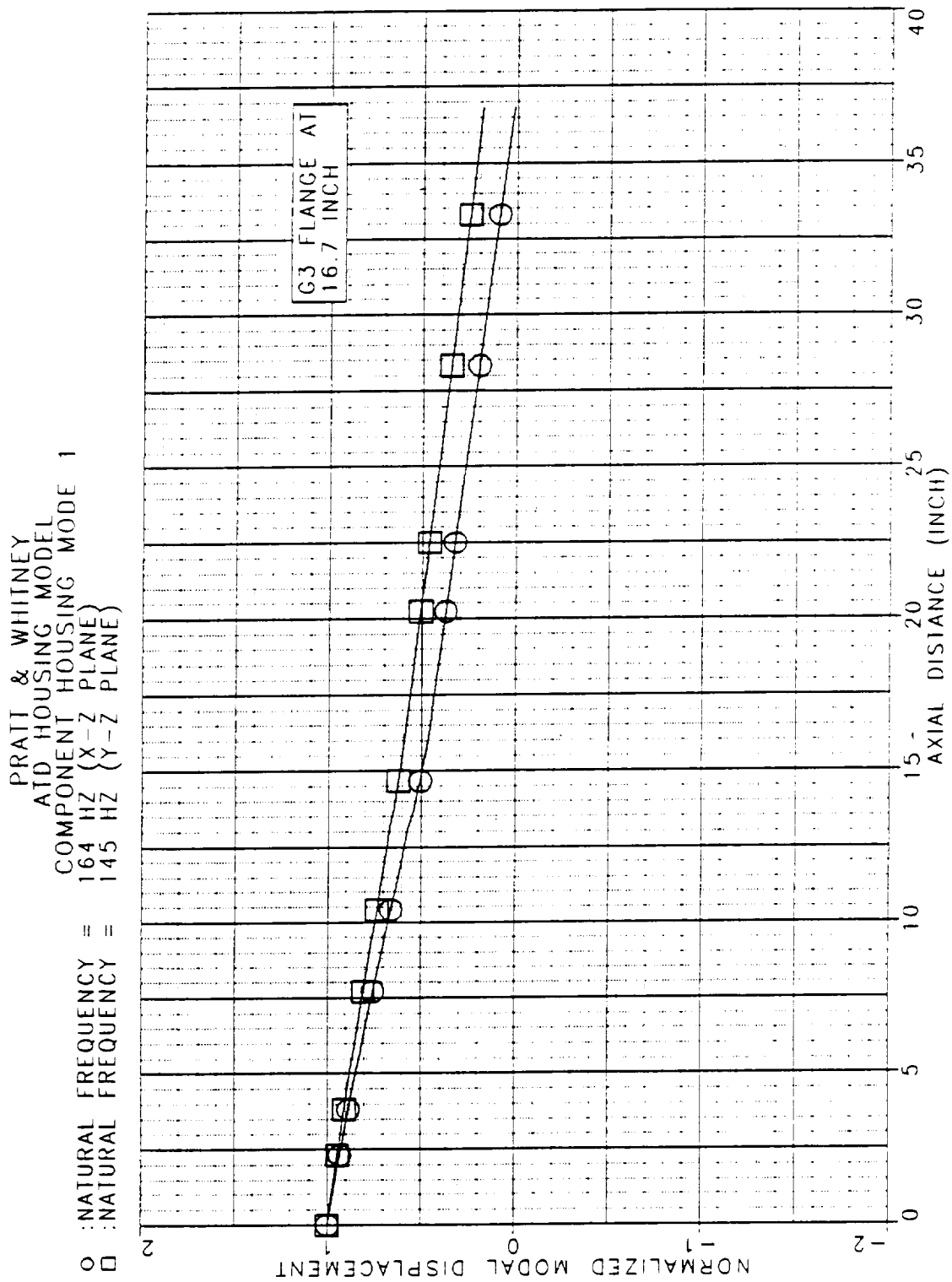

Figure 15. Component Housing Mode 1: Rigid Body (Pitch)

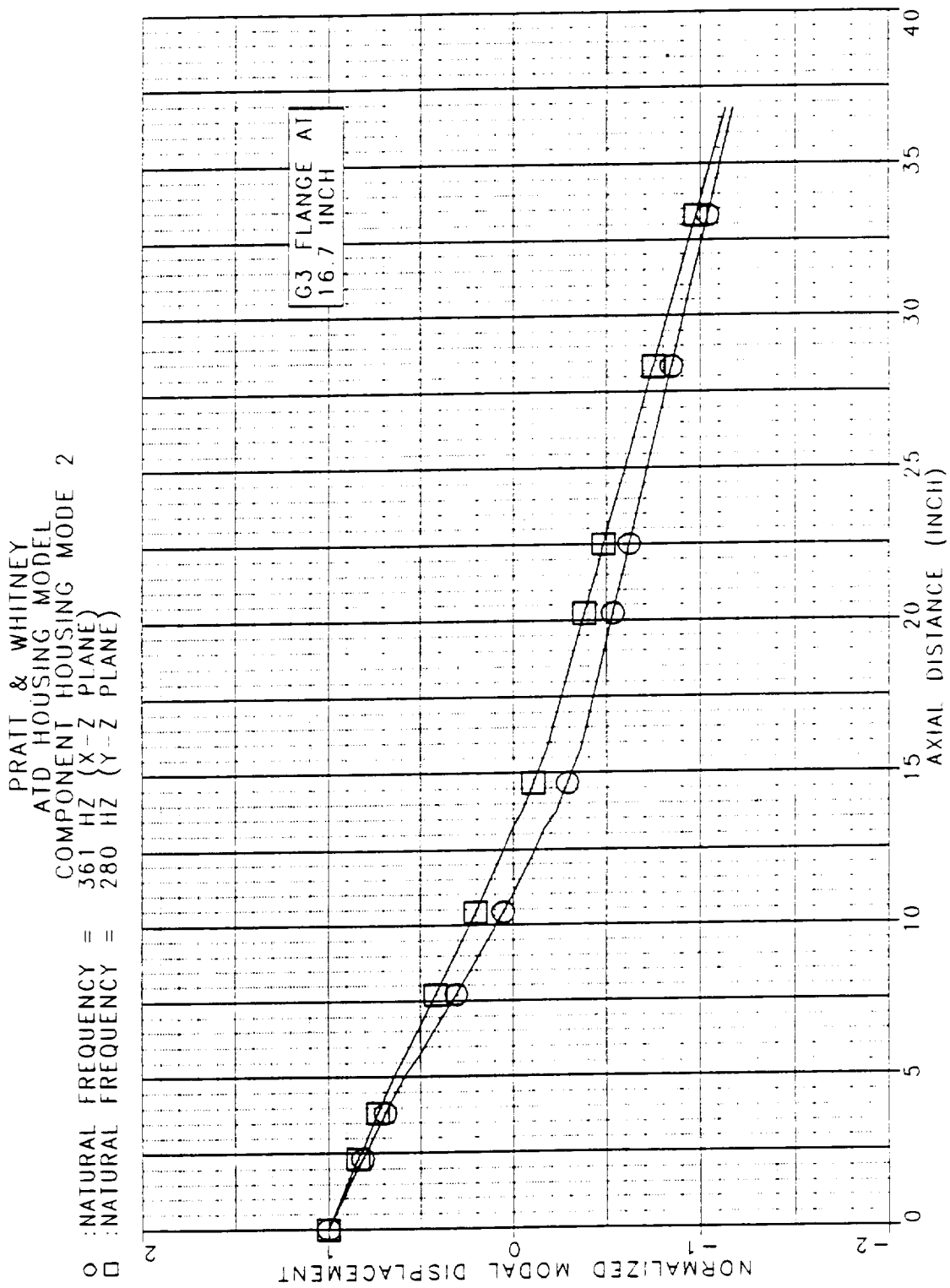

Figure 16. Component Housing Mode 2: Rigid Body (Bounce)

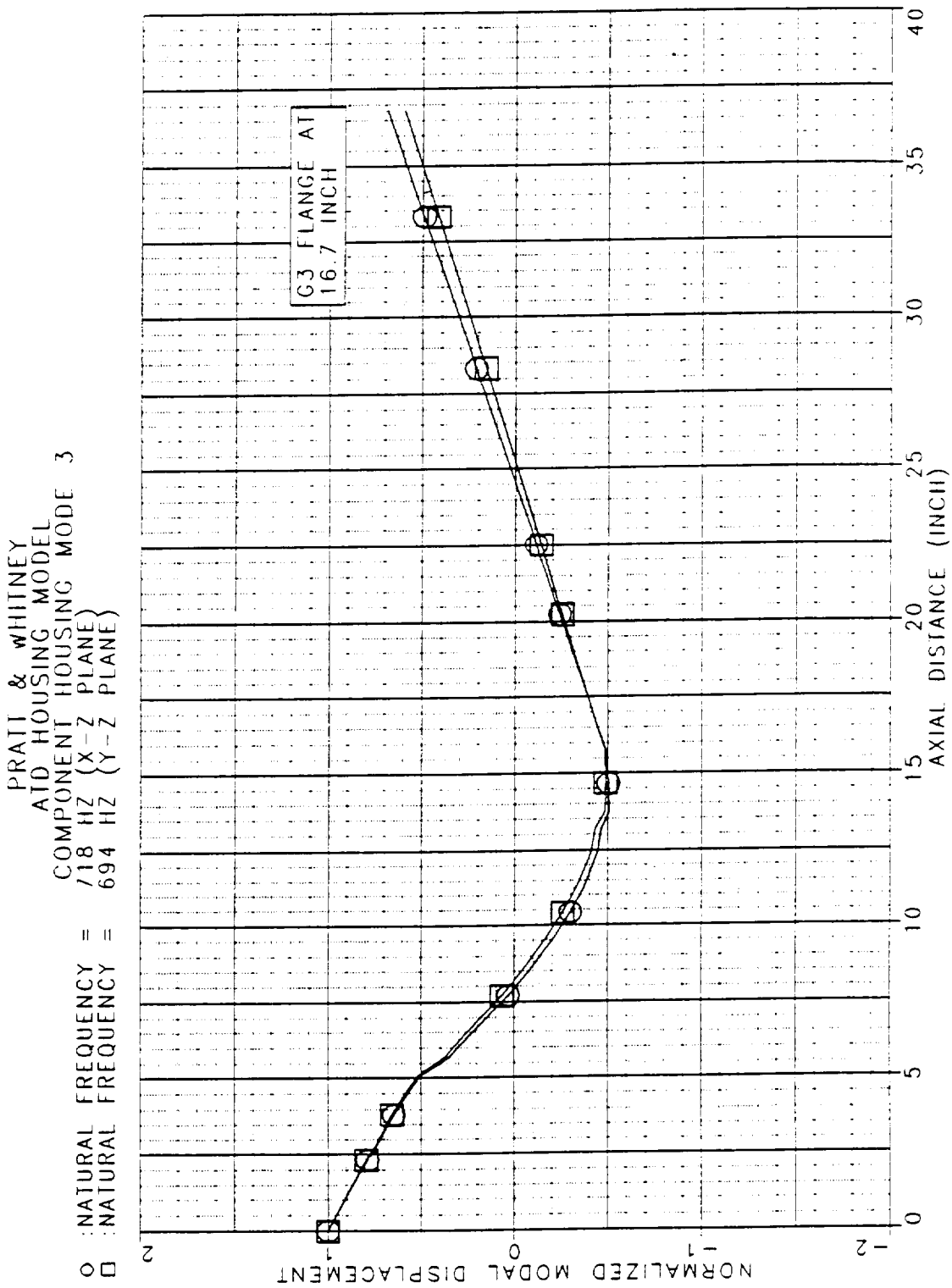

Figure 17. Component Housing Mode 3: 1st Lateral Bending

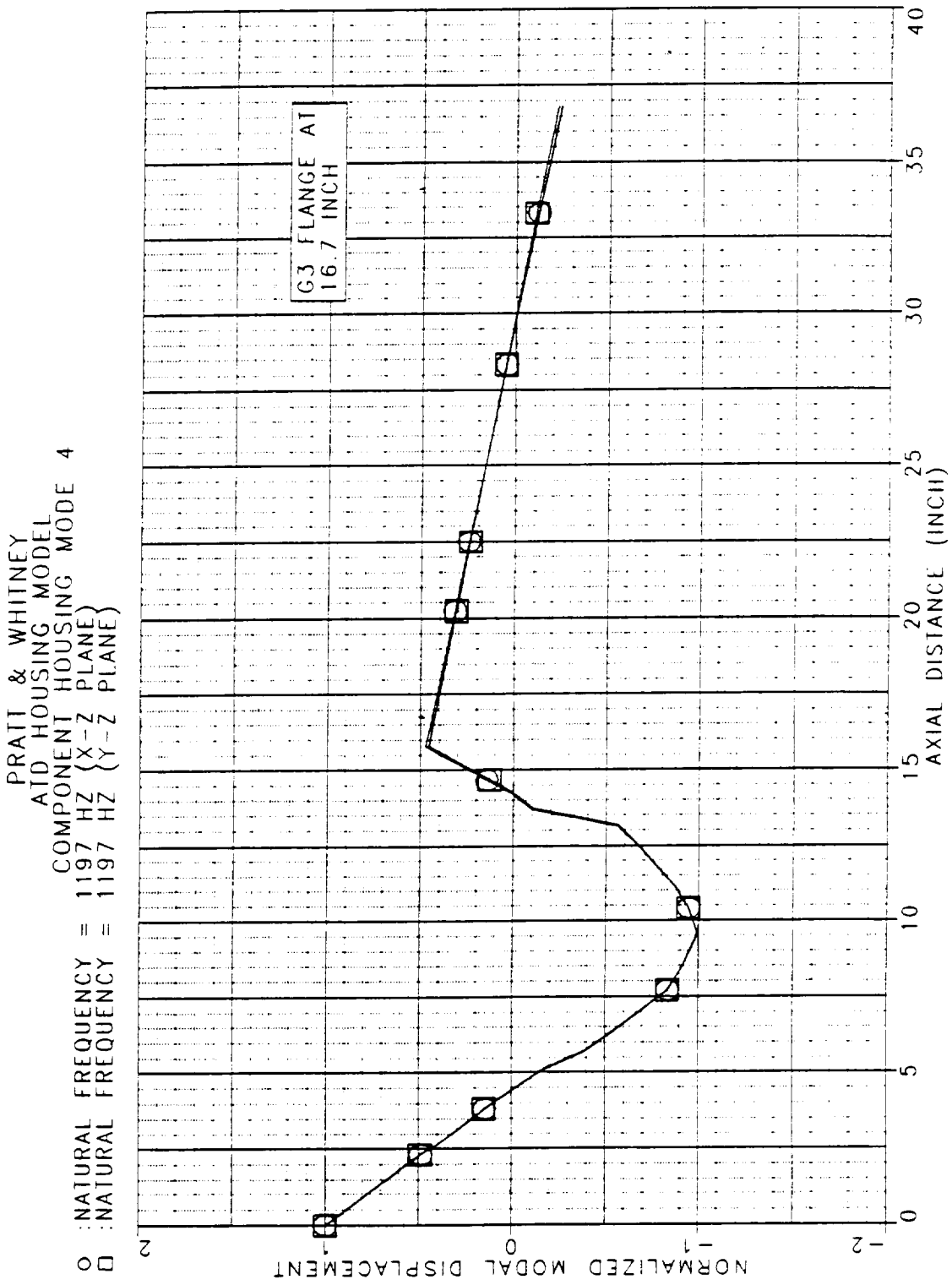

Figure 18. Component Housing Mode 4: 2nd Lateral Bending

4.0 BASELINE RESULTS

4.1 Boundary Conditions

The following BASELINE results are calculated as discussed in the METHODS section of 3.0. Nominal design values were used for inputs such as performance parameters, dimensional tolerances, etc. These rotor to housing boundary condition results are summarized for three power level settings and are used in the BASELINE ROTORDYNAMIC ANALYSES. Locations of the boundary conditions are illustrated in Figure 19 where applicable. Full documentation of the boundary conditions vs speed are included in the section 5.0.

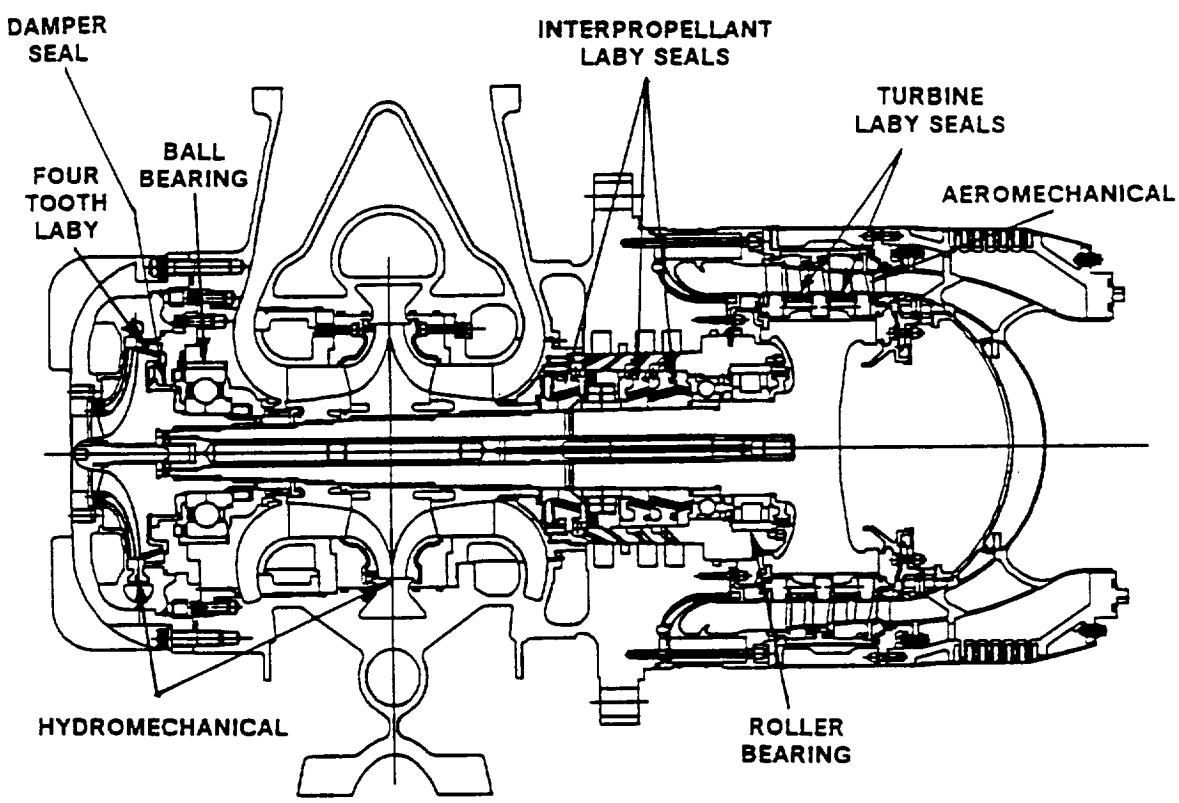

Figure 19. Boundary Condition Locations

4.1.1 Speed Profile

The speed profile used in this report is based on performance model PBM90A Configuration 0291.P. Dynamic coefficients are summarized for 65%, 90% and 109% RPL of this speed profile when plotting coefficients vs speed.

SPEED PROFILE						
POWER LEVEL	50%	65% (MPL)	90%	100% (RPL)	109% (FPL	115%
SPEED (RPM)	14,059	16,818	21,115	22,770	24,230	25,153
Note: RPL = 100% PL (470 Klbs vacuum thrust; 375 Klbs sea level).						

Table 9. Speed Profile Summary

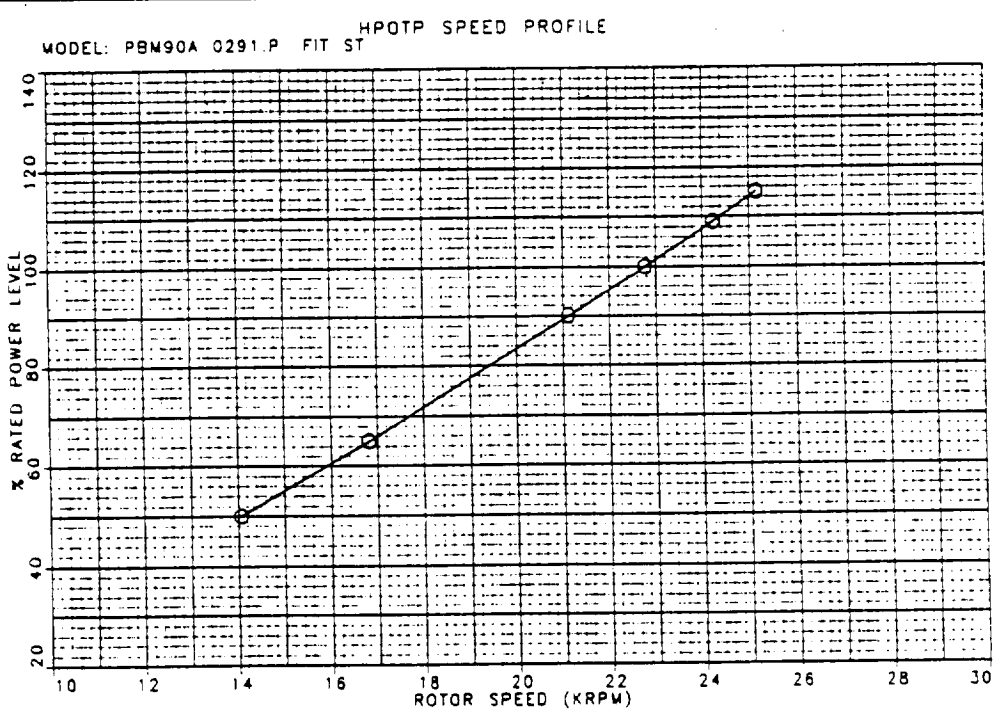

Figure 20. Speed Profile

4.1.2 Aeromechanical Force Coefficients

Cross Coupled Stiffness (K_{xy}) is calculated from the model illustrated in equation 1.0 of Section 2.1.1. for each of the three turbine stages. The results of each stage are summed as a single parameter and applied at the Turbine CG. Results are summarized below for 65%, 90% and 109% RPL.

STAGE	INPUT DATA					OUTPUT DATA		
	Blade Pitch Dia. (Inch)	Blade Height (Inch)	Stage Torque (ft-lb)			Cross Coupled Stiffness (lbf/in)		
			65% RPL	90% RPL	109% RPL	65% RPL	90% RPL	109% RPL
1	9.940	0.555	850	1400	1890	1825	3025	4100
2	10.050	0.665	850	1400	1890	1500	2500	3375
3	10.208	0.823	850	1400	1890	1200	2000	2700
Total	--	--	2725	4500	6075	4525	7525	10175
Note: Beta = 1.0								

Table 10. Aeromechanical Force Coefficients: Total parameter value is applied at turbine C.G.

4.1.3 Hydromechanical Force Coefficients

Direct and Cross Coupled stiffness, damping and inertia terms are calculated from the model illustrated in equation 2.0 of Section 2.1.2. for the preburner and main stage impeller. Results are summarized for 65%, 90% and 109% RPL.

Stage	Input Data				Output Data					
	Impeller Tip Radius (inch)	Impeller Exit Chord (inch)	Power Level	Fluid Density lbm/ft³	K_{YY} lb/in	K_{YY} lb/in	C_{YY} lb-s/in	C_{YY} lb-s/in	M_{YY} lb-s²/in	M_{YY} lb-s²/in
Preburner Impeller	3.190	0.150	65%	71.32	-4464	2694	3.0	7.7	0.003	0.0004
			90%	71.49	-7036	4247	3.8	9.7	0.003	0.0004
			109%	71.81	-9265	5592	4.3	11.1	0.003	0.0004
Main Impeller	3.850	0.830	65%	71.15	-35443	21332	24.0	61.0	0.020	0.003
			90%	71.22	-55710	33625	30.0	76.8	0.020	0.003
			109%	71.39	-73360	44278	34.5	88.1	0.020	0.003

Note: 1) Whirl Ratio = 0.50 2) Normalized Empirical Coefficients; Kxx = -2.80, Kxy = 1.69, Cxx = 3.33, Cxy = 8.53, Mxx = 5.50, Mxy = 0.74.

Table 11. Hydromechanical Force Coefficients

4.1.4 Damper Seal Coefficients

Direct and Cross Coupled stiffness, damping and inertia terms are calculated from Childs' analysis code (Reference 8. on page 131 and 9. on page 131). Results are summarized for 65%, 90% and 109% RPL.

Seal Length (inch)	Seal Dia. (inch)	Stator Holes			Hirs' Coeff	
		Dia. (in)	Depth (in)	No.	Rotor	Stator
0.656	3.810	0.052	0.015	935	M_r = -0.0980 N_r = +0.0191	M_s = -0.0433 N_s = +0.0312
Note: Inlet Loss Coefficient = 0.1						

Table 12. Damper Seal Detail:

Power Level	Input Data					Output Data				
	Delta Press (psi)	Clearance (in)		Viscosity (lbm/s-ft)	Density lbm/ft³	K_{xx} lb/in	K_{xy} lb/in	C_{xx} lb-s/in	C_{xy} lb-s/in	M_{xx} lb-s²/in
		Inlet	Exit							
65%	1500	0.0080	0.0055	0.87E-4	65.9	170E3	26E3	55	1.83	0.75
90%	2900	0.0075	0.0050	0.83E-4	65.3	363E3	50E3	83	2.46	0.81
109%	4400	0.0070	0.0045	0.81E-4	65.0	610E3	77E3	112	3.07	0.89
Note: Inlet Tangential Velocity Ratio = 0.3										

Table 13. Damper Seal Input/Output:

4.1.5 Labyrinth Seals

Baseline dynamic coefficient calculation are included for the gas labyrinth seals listed and illustrated below.

1. Interpropellant Seal Package
   a. GOX
   b. Secondary Hydrogen
   c. Primary Hydrogen
2. Turbine Interstage
   a. Stage 1-2
   b. Stage 2-3
3. Preburner Impeller 4-Tooth Seal

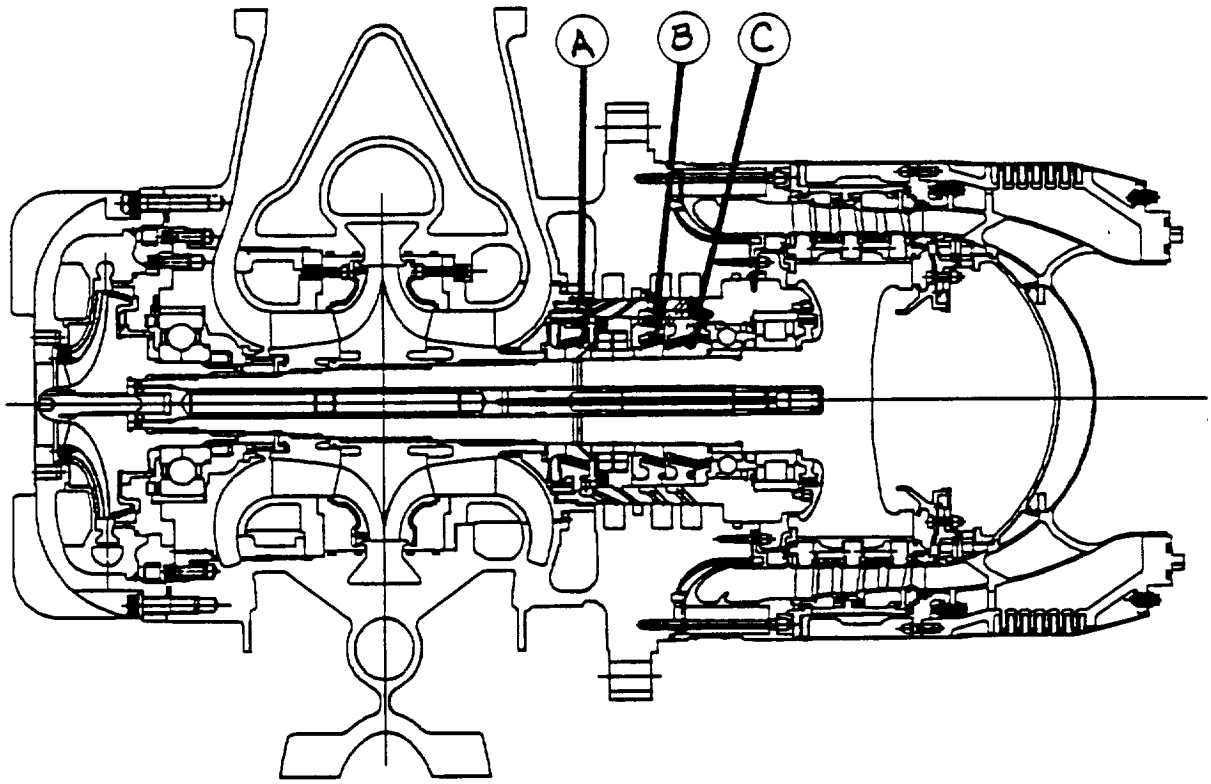

Figure 21. Interpropellant Labyrinth Seal Locations

4.1.5.1 *Interpropellant Seals*

Seal	Clearance (inch)	Radius (inch)	Tooth Height (inch)	Teeth Pitch (inch)	No. of Teeth	Hirs' Coeff	
						Rotor	Stator
A	0.004	1.710	0.140	0.140	5	$M_r = -0.2500$ $N_r = +0.0790$	$M_s = -0.2500$ $N_s = +0.0790$
B	0.004	1.680	0.140	0.140	5	$M_r = -0.2500$ $N_r = +0.0790$	$M_s = -0.2500$ $N_s = +0.0790$
C	0.004	1.710	0.140	0.140	8	$M_r = -0.2500$ $N_r = +0.0790$	$M_s = -0.2500$ $N_s = +0.0790$

Note: HEIGHT and PITCH dimensions are average values.

Table 14. Interpropellant Seal Detail

Seal	Power Level	Input Data						Output Data			
		Delta P (psi)	Fluid Temp (F)	Ratio of Spec Heats	C.C.	K.V.	G.C.	K_{xx} lb/in	K_{xy} lb/in	C_{xx} lb-s/in	C_{xy} lb-s/in
A	65%	302	147	1.380	0.994	9.89E-6	48	-4,528	1,687	0.9	0.312
	90%	444	134	1.380	0.994	6.42E-6	48	-11,166	4,493	2.4	0.609
	109%	538	129	1.380	0.994	5.44E-6	48	-17,518	8,313	4.3	0.825
B	65%	770	-165	1.340	1.000	6.45E-6	766	-119	3.6	0.03	0.007
	90%	118	-174	1.340	1.000	4.18E-6	766	-282	10.3	0.05	0.013
	109%	160	-174	1.340	1.000	3.54E-6	766	-440	17.9	0.07	0.018
C	65%	2499	-165	1.320	1.090	2.38E-5	766	-5,185	34	1.0	0.039
	90%	5138	-176	1.320	1.150	1.56E-5	766	-16,552	324	2.4	0.790
	109%	4866	-174	1.320	1.210	1.33E-5	766	-19,016	490	2.4	0.794

Note: C.C. is Compressibility Constant, K.V. is Kinematic Viscosity (lbm/s-ft), G.C. is Gas Constant. Tangential Velocity Ratio = 1.0

Table 15. Interpropellant Seal Input/Output:

4.1.5.2 *Turbine Interstage Seals*

Seal	Clearance (inch)	Radius (inch)	Tooth Height (inch)	Teeth Pitch (inch)	No. of Teeth	Hirs' Coeff	
						Rotor	Stator
1-2	0.023	4.540	0.130	0.120	4	$M_r = -0.2500$ $N_r = +0.0790$	$M_s = -0.1083$ $N_s = +0.2820$
2-3	0.016	4.540	0.130	0.120	4	$M_r = -0.2500$ $N_r = +0.0790$	$M_s = -0.1083$ $N_s = +0.2820$

Note: Height and Pitch dimensions are average values for two sets of two teeth.

Table 16. Turbine Interstage Seals Detail

Seal	Power Level	Input Data						Output Data			
		Delta P (psi)	Fluid Temp (F)	Ratio of Spec Heats	C.C.	K.V.	G.C.	K_{xx} lb/in	K_{xy} lb/in	C_{xx} lb-s/in	C_{xy} lb-s/in
1-2	65%	107	639	1.397	1.051	1.12E-5	547.6	156	1,683	1.3	-0.019
	90%	193	915	1.449	1.045	1.40E-5	488.0	328	3,220	2.1	-0.031
	109%	275	1127	1.414	1.055	1.60E-5	457.5	506	4,692	2.6	-0.041
2-3	65%	65	582	1.400	1.049	1.09E-5	553.5	179	1,848	1.6	-0.024
	90%	123	836	1.470	1.039	1.36E-5	494.0	381	3,530	2.4	-0.040
	109%	178	1034	1.430	1.049	1.55E-5	463.9	597	5,151	3.1	-0.053

Note: C.C. is Compressibility Constant, K.V. is Kinematic Viscosity (lbm/s-ft), G.C. is Gas Constant.
Tangential Velocity Ratio = 0.75

Table 17. Turbine Interstage Seals Input/Output

4.1.5.3 *Preburner Impeller 4-Tooth Labyrinth*

Gap (inch)	Radius (inch)	Tooth Height (inch)	Teeth Pitch (inch)	No. of Teeth	K.V.	Fluid Density lbm/ft³	Power Level	Delta P (psi)	Output Data		
									K_{xx} lb/in	K_{xy} lb/in	C_{xx} lb-s/in
0.007	3.065	0.100	0.140	4	0.90E-4	66.5	65%	1075	12,280	5,270	3.2
							90%	1600	17,430	10,660	4.3
							109%	1850	21,670	15,590	5.3

Note: Teeth dimensions are average values. K.V. is Kinematic Viscosity (lbm/s-ft).
Tangential Velocity Ratio = 0.75

Table 18. Preburner Impeller 4-Tooth Labyrinth Seal

4.1.6 Component Side Loads

These static side loads are from Reference 12. on page 132 with angular applied load and resultant bearing load orientation illustrated below (Figure 22).

Power Level	Component Side Load						Resultant Static Load			
	PBI		MSI		Turbine		Ball Bearing		Roller Bearing	
	Load (lbf)	Phase (deg)	Load (lbf)	Phase (deg)	Load (lbf)	Phase (deg)	Load (lbf)	Phase (deg)	Load (lbf)	Phase (deg)
65%	62	159	290	291	200	270	130	91	325	97
90%	75	142	475	293	260	270	215	105	450	99
109%	125	125	670	296	300	270	275	114	565	100

Note: PBI is Preburner Impeller, MSI is Main Stage Impeller.

Table 19. Component Side Loads

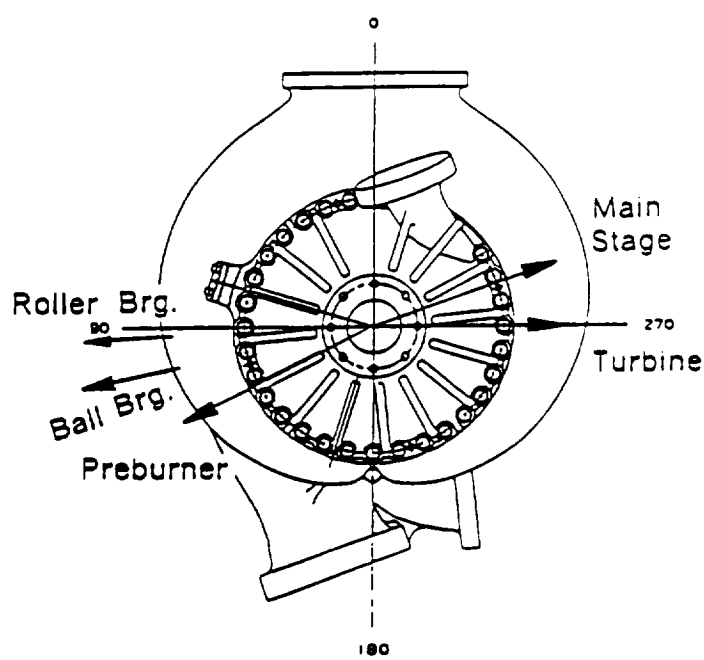

Figure 22. Side Load Phase Orientation

4.1.7 Bearing Radial Dynamic Stiffness

Nominal values for the baseline rotordynamic analyses have been chosen as 0.75E6 lb/in for the pump end ball bearing (PEBB) and 3.5E6 lb/in for the turbine end roller bearing (TERB). These values were chosen during the preliminary analyses and based on past experience with similar design bearings, such as the HPFTP ball bearing rig and P&W early turbopump testing of the XLR129. However, A.B. Jones bearing load-deflection analyses and stiffness evaluations are provided in the SENSITIVITY SECTION for examination, as discussed in the METHODS SECTION. Generally, the ball bearing calculations give higher stiffness values than those chosen for the analyses but are within the range of the parametric values of the sensitivity analyses. Whereas, the roller bearing calculations give much higher values than experienced in past roller bearing design applications. The range of roller bearing and ball bearing stiffness values for the sensitivity analyses are presented in the SENSITIVITY SECTION.

Pump End Ball Bearing Dynamic Radial Stiffness = 0.75E6 lb/in

Turbine End Roller Bearing Dynamic Radial Stiffness = 3.50E6 lb/in

4.1.8 Bearing Deadbands

Bearing deadband is defined as the operating clearance between the bearing outer race carrier O.D and the housing bearing support I.D. for the PEBB, and the bearing outer race O.D. and housing bearing support I.D. for the TERB.[3] The deadband values presented here and in the parametric analyses are intended to represent a wide range potential values, since at the time of this analysis, these fits were still in development. Therefore, the actual deadbands of certification design are anticipated to be within the range of fits considered, but will certainly have less range (i.e. tolerances are generally within +/- 0.0005 in.).

Bearing Radial Deadband (Dia.)	
PEBB	0.0025 in
TERB	0.0015 in

Table 20. Nominal Bearing Deadbands

[3] Deadband for the turbine end ball bearing is significantly greater than the TERB and does not transmit radial load between the bearing and housing. Hence, TEBB radial boundary conditions are not considered in the rotordynamic analyses.

4.2 Rotordynamic Analyses

The following BASELINE results are calculated as discussed in the METHODS section of 3.0. Nominal design values were used for the Boundary Conditions outlined in the Study Plan (Appendix A) and documented in section 4.1. These BASELINE analyses include Critical Speed, Stability and Forced Response (linear and nonlinear). Some of the results are summarized for the two turbopump planes derived from the asymmetric mount housing stiffness characteristics. The orientation of the coordinate system for this report is illustrated in Figure 23.

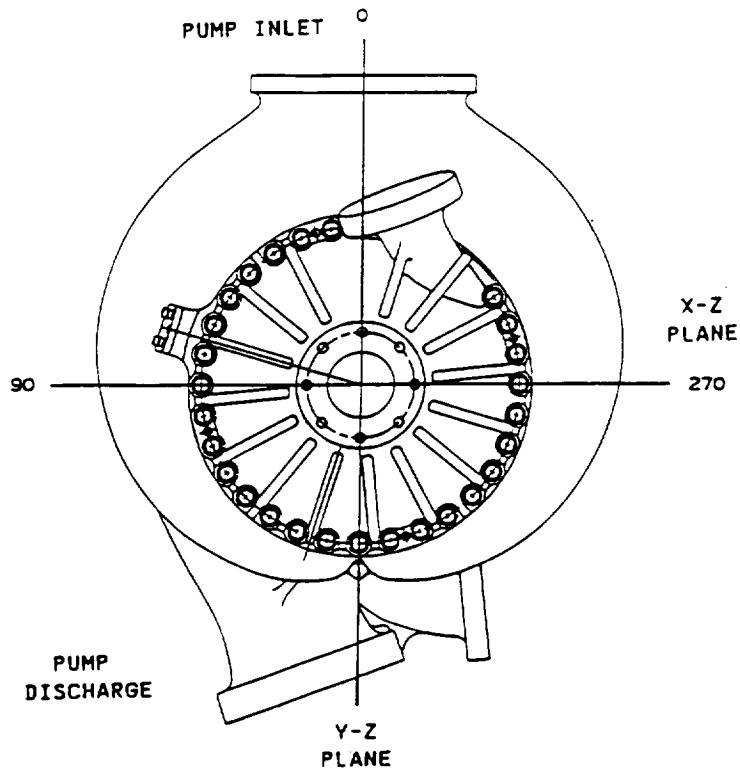

Figure 23. Pump Coordinate Orientation:

4.2.1 Critical Speed

Critical speeds are summarized in Table 21 with normalized system mode shapes in Figure 24 on page 45 and Figure 25 on page 46 for baseline input parameters. These modes represent the lateral housing and rotor resonances in the X-Z and Y-Z planes as a result of the housing mount asymmetry. For more detailed information, a complete set of forward and backward whirl modes are illustrated in the whirl frequency map in Figure 26 on page 47 and Figure 27 on page 48 for the X-Z and Y-Z planes respectively. Mode shapes for selected speeds from these maps are included in Appendix E (Figure 82 on page 178 thru Figure 153 on page 213).

Subcritical operation is predicted with all rotor modes above the maximum operating speed range.

Mode	Description	Critical Speed	
		X-Z Plane	Y-Z Plane
1	Housing Bounce	9,000 RPM (150 Hz)	7,000 RPM (115 Hz)
2	Housing Pitch	20,000 RPM (335 Hz)	16,500 RPM (275Hz)
3	Rotor Pump Bounce	29,000 RPM (480 Hz)	31,000 RPM (515 Hz)
4	Rotor Turbine Bounce	37,000 RPM (615 Hz)	37,000 RPM (615 Hz)
5	Housing 1st Bending	> 40,000 RPM (> 665 Hz)	> 40,000 RPM (> 665 Hz)
6	Rotor 1st Bending	> 40,000 RPM (> 665 Hz)	> 40,000 RPM (> 665 Hz)

Table 21. Nominal Critical Speed Results

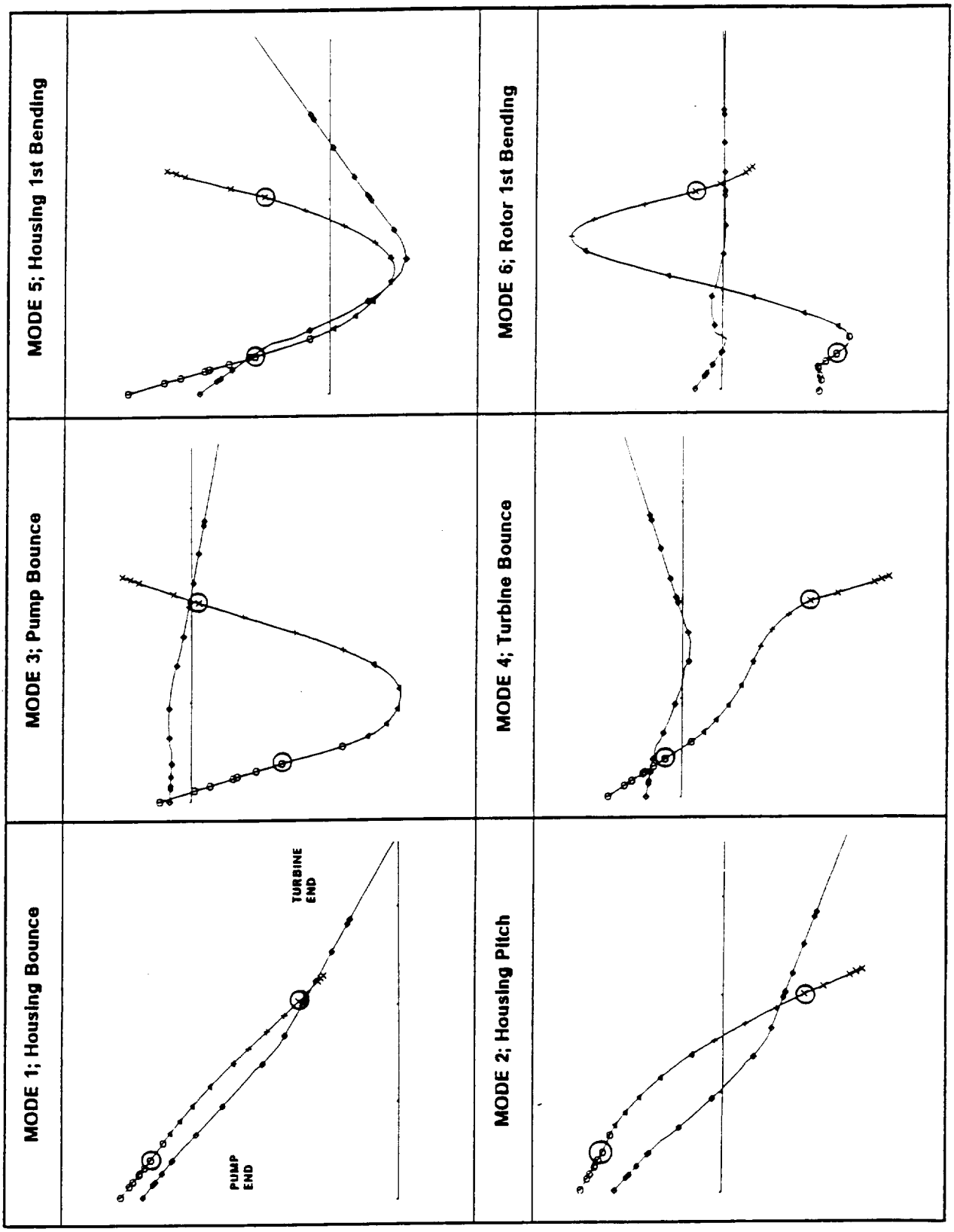

Figure 24. Critical Speed Mode Shapes (X-Z Plane)

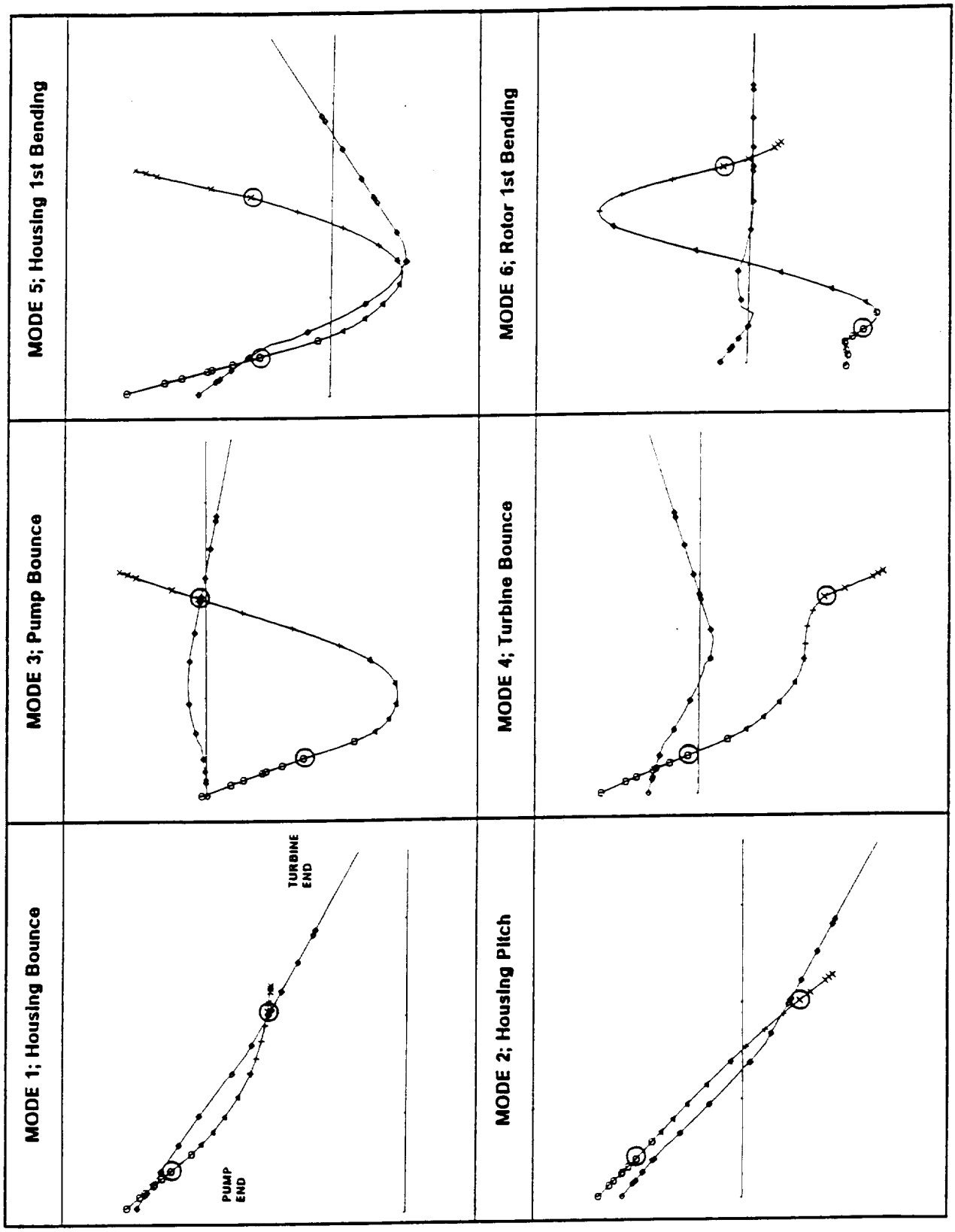

Figure 25. Critical Speed Mode Shapes (Y-Z Plane)

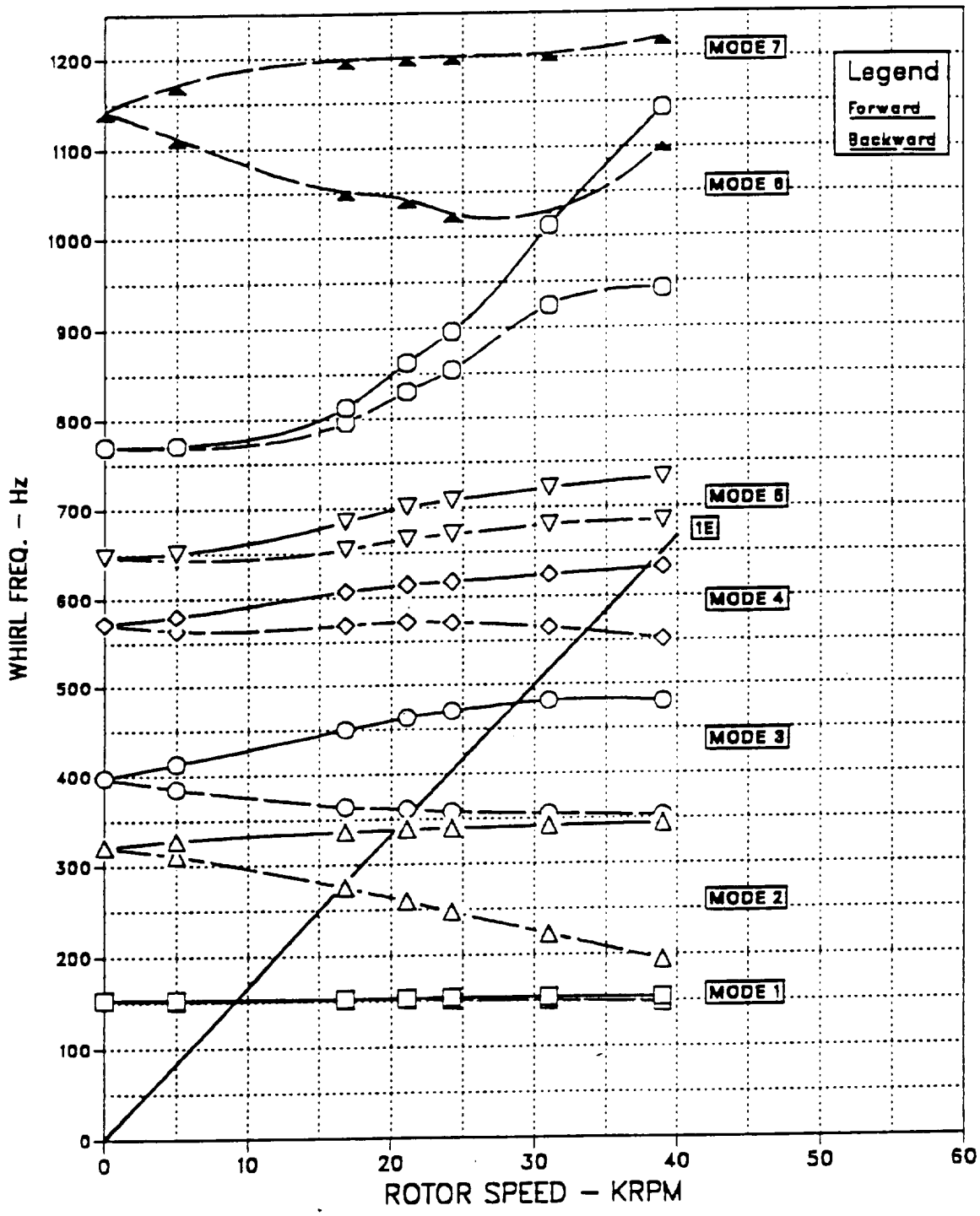

Figure 26. Whirl Frequency Map (X-Z Plane)

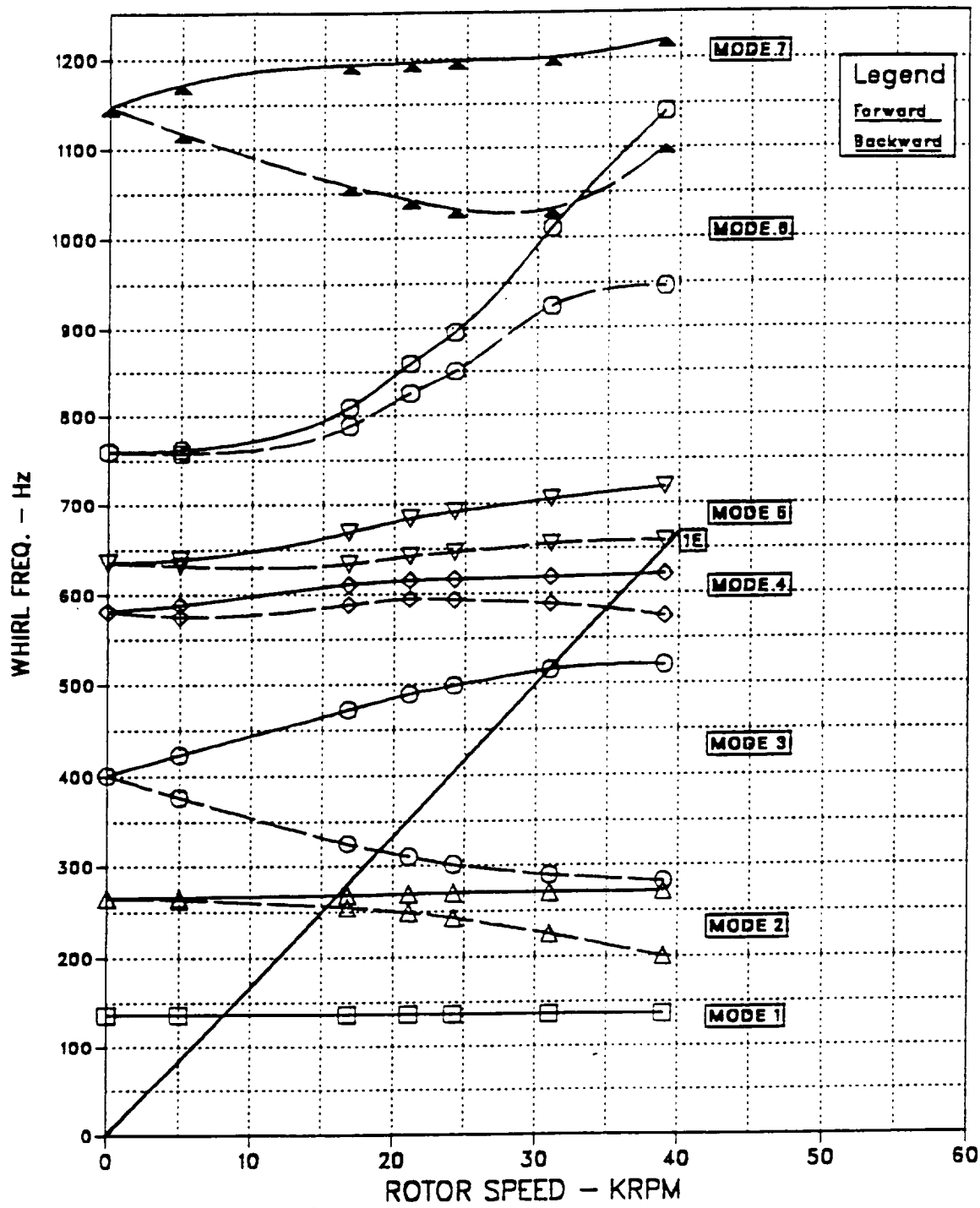

Figure 27. Whirl Frequency Map (Y-Z Plane)

4.2.2 Stability

Stability results for 109% RPL and onset speed of instability (OSI) are summarized in Table 22 on page 49. Maps of LOG-DEC vs speed are illustrated in Figure 28 on page 50. Stable operation is predicted with Onset Speed of Stability (OSI) beyond the maximum speed search of 39,000 RPM.

Mode		Stability	
No.	Description	LOG-DEC @ 109% RPL	OSI
1	Housing Bounce	0.18	> 40,000 RPM
2	Housing Pitch	0.20	> 40,000 RPM
3	Rotor Pump Bounce	0.24	> 40,000 RPM
4	Rotor Turbine Bounce	0.24	> 40,000 RPM
5	Housing 1st Bending	0.17	> 40,000 RPM
6	Rotor 1st Bending	1.64	> 40,000 RPM

Table 22. Nominal Stability Results

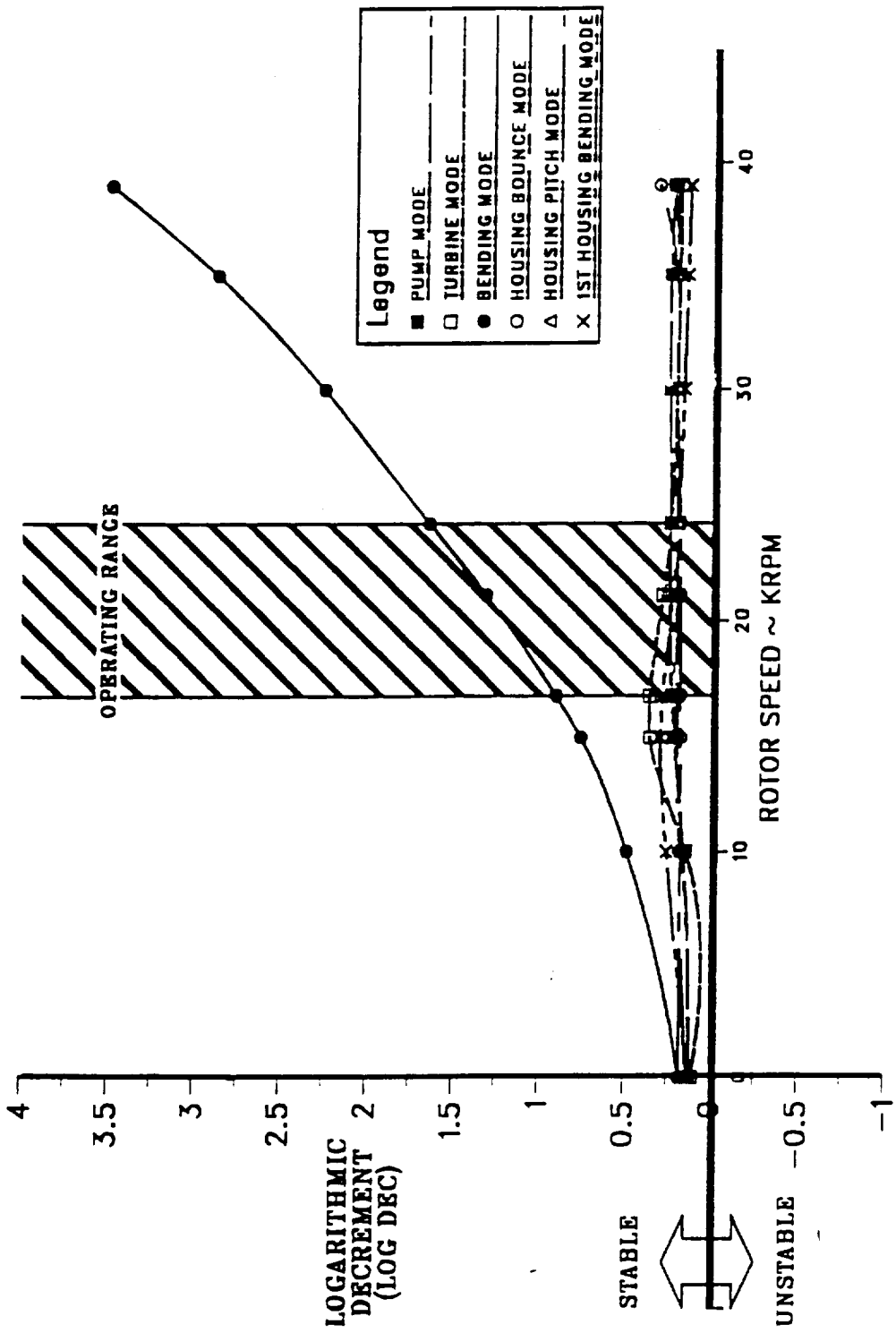

Figure 28. Stability Map: LOG-DEC vs Speed

4.2.3 Forced Response

The BASELINE boundary conditions documented in section 4.1 have been used for the BASELINE FORCED RESPONSE ANALYSES of this section. All the boundary conditions are used as discussed in the METHODS section of 2.2. The analyses include a linear analysis for initial review and correlation of modal characteristics with the Critical Speed Analysis of section 4.2.1, and a linear speed transient analysis for correlating model accuracy of the nonlinear analysis. The nonlinear inputs are then added for calculation of complex time transient conditions in addition to Steady State Time Transient Analysis. Results are summarized for 109% RPL in Table 25 on page 89 from the response plots. An outline of this analysis is presented below.

1. Linear Forced Response
    - a. Bearing Loads
    - b. Rotor-to-Housing Deflections
    - c. Housing Accelerations
2. Transient Forced Response
    - a. Linear Speed Transient (no deadband or side load)
        - 1) Bearing Loads
        - 2) Rotor-to-Housing Deflections
        - 3) Housing Accelerations
    - b. Nonlinear Speed Transient
        - 1) Speed Set "A" (10-27 KRPM)
            - a) Bearing Loads
            - b) Rotor-to-Housing Deflections
            - c) Housing Accelerations
        - 2) Speed Set "B" (27-39 KRPM)
            - a) Bearing Loads
            - b) Rotor-to-Housing Deflections
            - c) Housing Accelerations
    - c. Nonlinear Time Transient (S.S. Speed)
        - 1) Bearing Loads
        - 2) Rotor-to-Housing Deflections

3) Housing Accelerations

4) Whirl Orbit Deflection

5) Spectrum Analysis (FFT's)

4.2.3.1 Linear Analysis

Linear analysis results are valid only at the rotational speed analyzed. To simulate a speed transient, multiple speed points are analyzed and the results are plotted versus speed (spline fitted). Roughly 100 speed points were analyzed in this analysis. Plots for the linear forced response analysis are illustrated in Figure 29 on page 54 for correlation to the transient model. These results are used only for comparison of frequency and amplitude correlation of system modes. These results show modal responses at the Pump Flange Acceleration plot. Modes 1-4 have peak response at speeds that agree with critical speed results. The asymmetry of the housing modes can also be seen at speeds of 17-21 KRPM (Mode 2). These results show good correlation of resonant frequencies for use in the transient analyses.

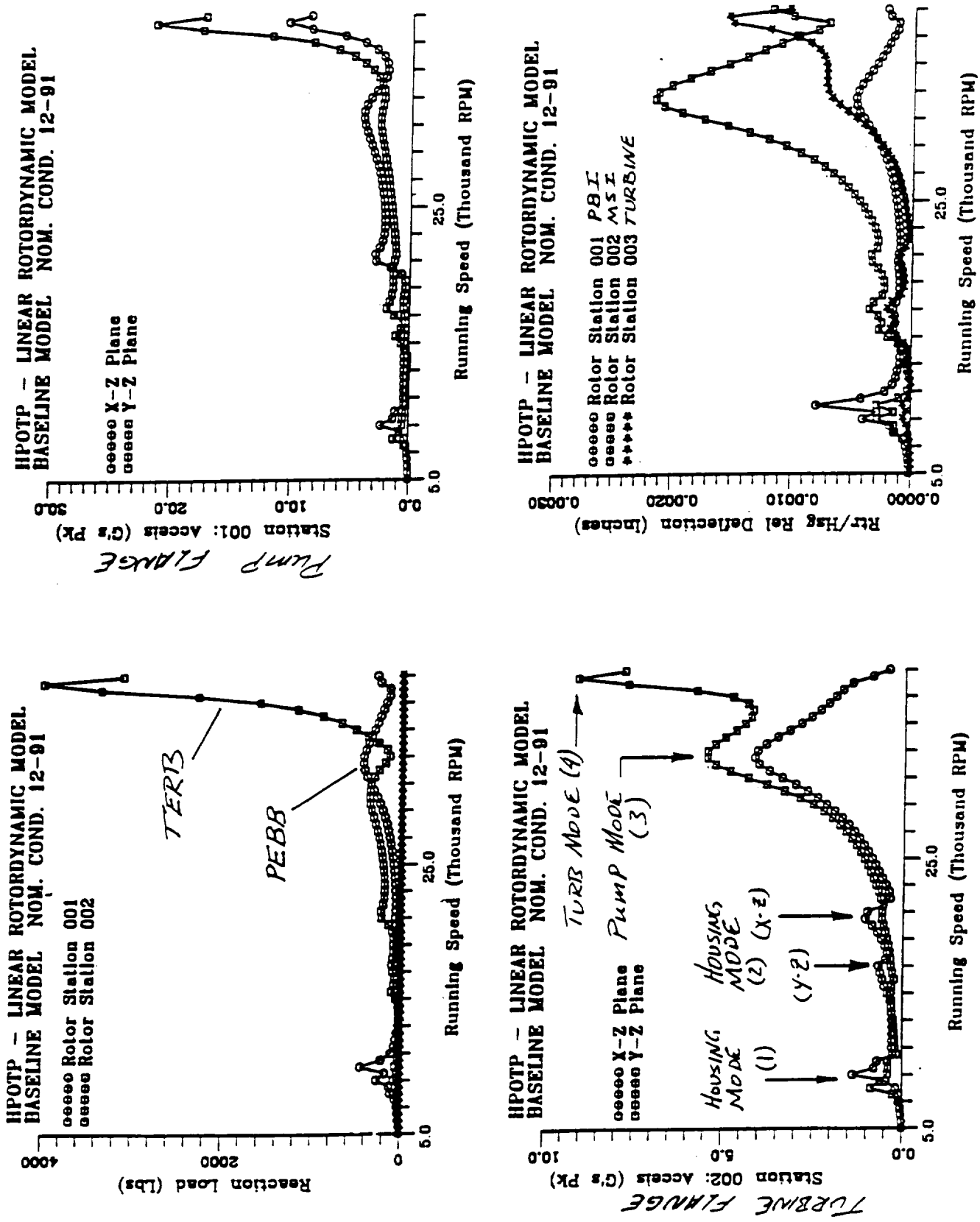

Figure 29. Linear Forced Response Plots

4.2.3.2 Transient Analysis

The following analyses include speed and time transient linear and nonlinear forced response. The linear case (no side loads or bearing deadband) is presented for correlation to the prior linear stability model of section 4.2.3.1.

Linear Speed Transient Analysis: Plots for speed transient linear forced response analysis (no side load or bearing deadband) are illustrated in Figure 30 on page 57 and show good correlation to the linear model results of Figure 29 on page 54. A summary of pump flange peak response can be seen at the speeds and amplitudes as illustrated in Figure 30 on page 57 for modes 1-4, for two speed sets, 10-27 KRPM and 27-39 KRPM. Additional plots are included in Appendix F.

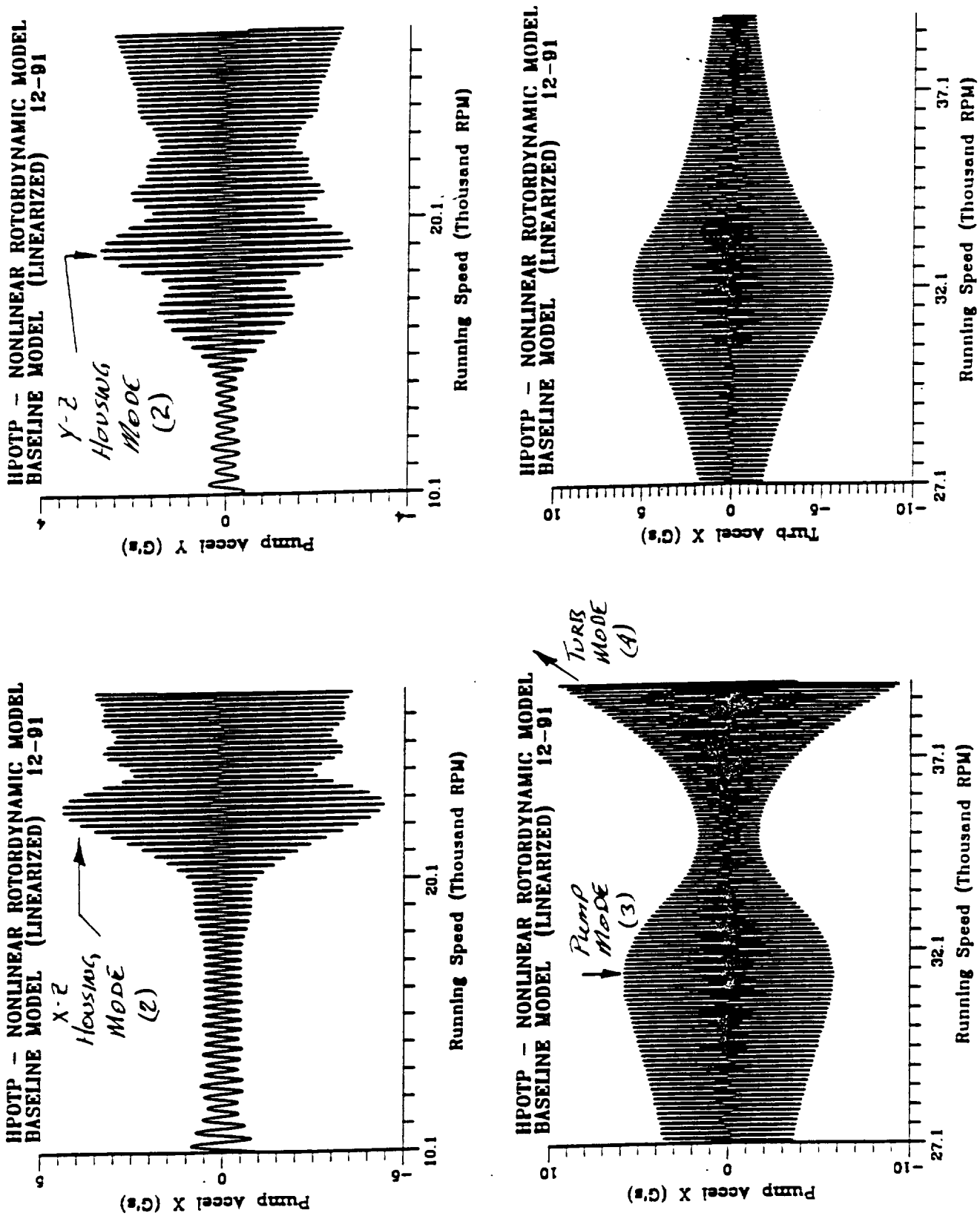

Figure 30. Linear Speed Transient Forced Response Plots

Nonlinear Speed Transient Analysis Plots for speed transient nonlinear forced response analysis are illustrated in Figure 31 on page 59 thru Figure 44 on page 72. These data include bearing deadbands and static side load as the nonlinear inputs. Generally, amplitudes vary little from the linear analysis as a result of the subcritical operation. A reduction of the first rotor mode (Pump Bounce) can be seen in the response, from approximately 31,500 RPM to 30,000 RPM. Likewise, the 2nd rotor mode (Turbine Bounce) is reduced from approximately 39,000 RPM to 35,500 RPM.

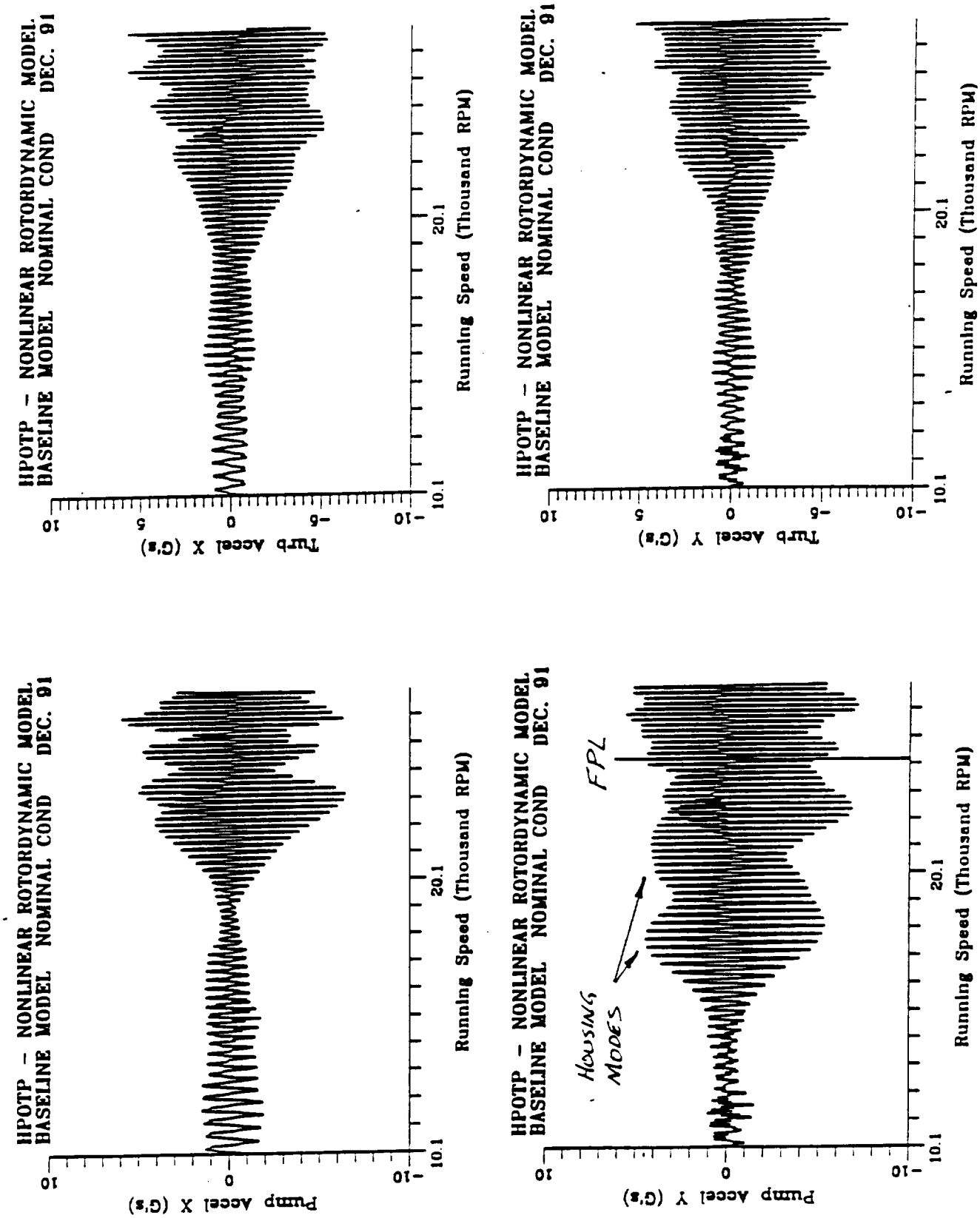

Figure 31. Speed Transient Nonlinear Forced Response Plots: Speed set "A", 10-27 KRPM

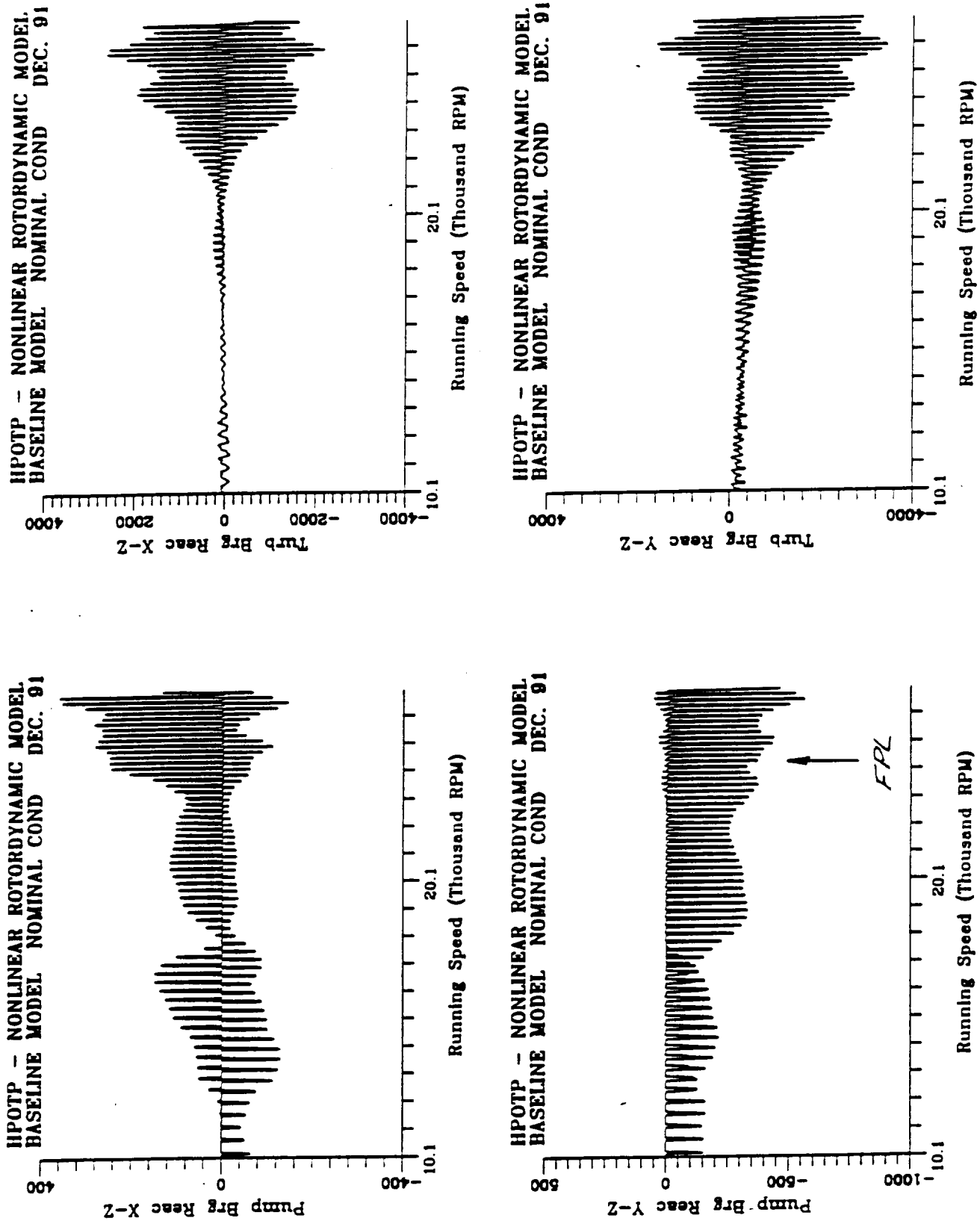

Figure 32. Speed Transient Nonlinear Forced Response Plots: Speed set "A", 10-27 KRPM

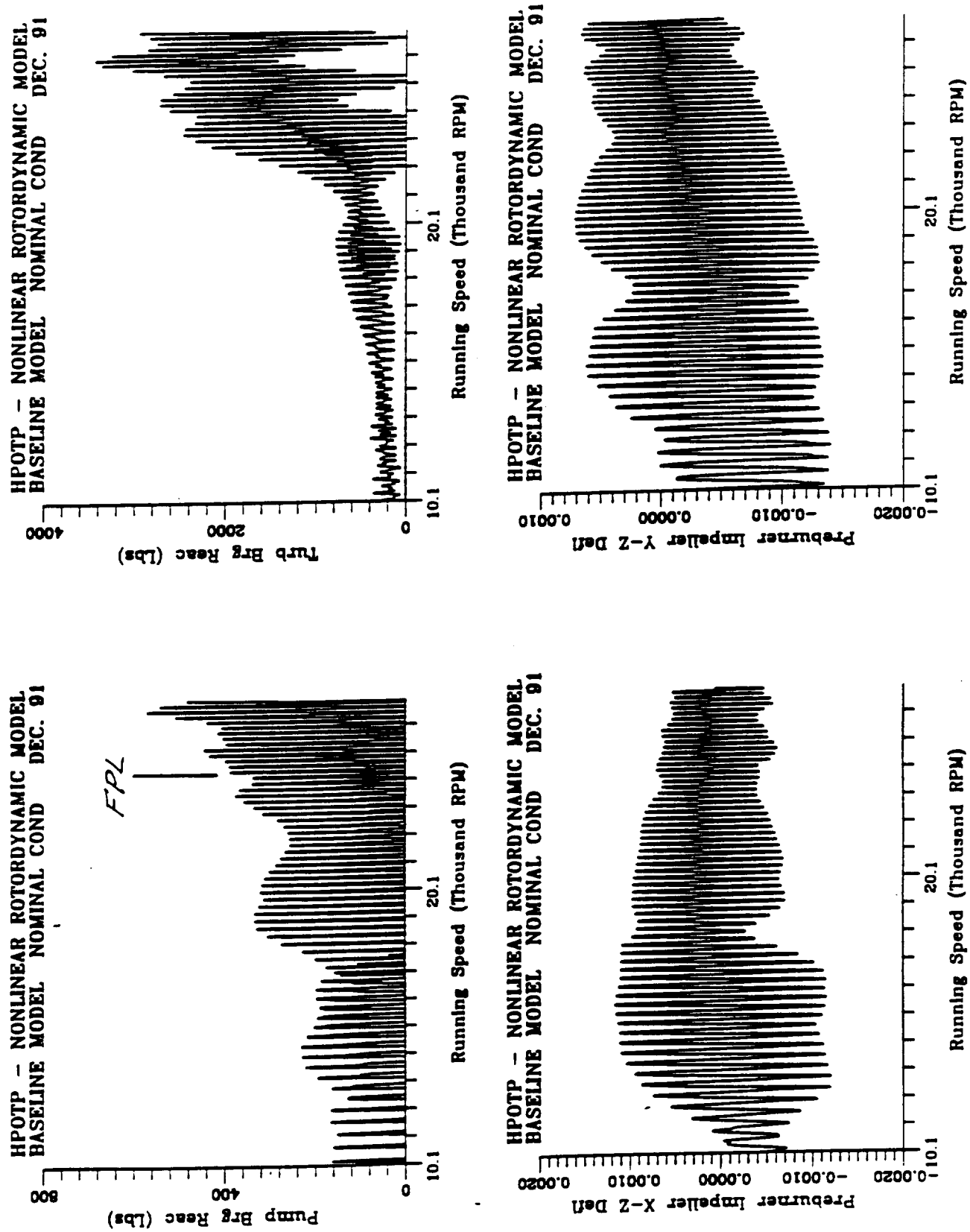

Figure 33. Speed Transient Nonlinear Forced Response Plots: Speed set "A", 10-27 KRPM

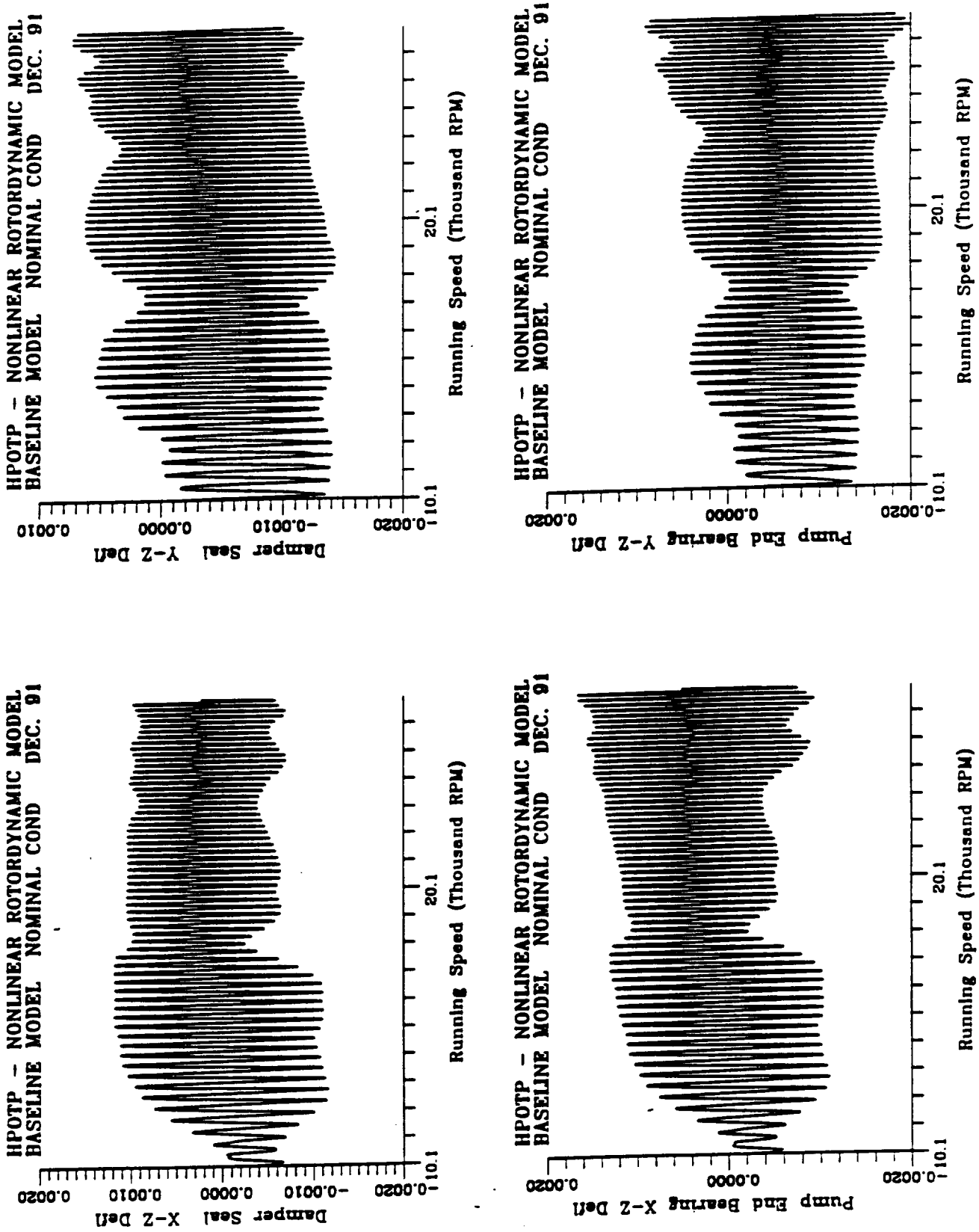

Figure 34. Speed Transient Nonlinear Forced Response Plots: Speed set "A", 10-27 KRPM

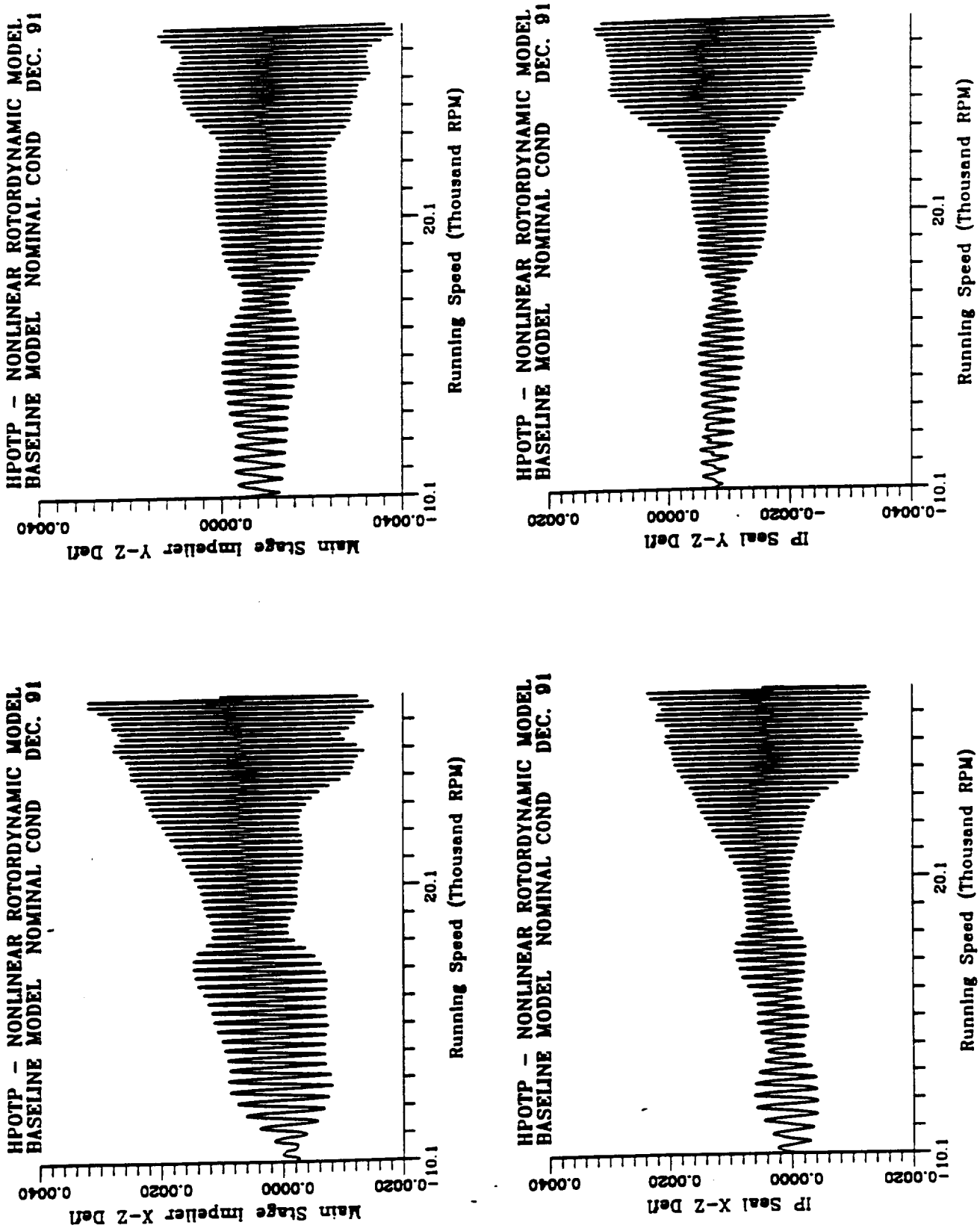

Figure 35. Speed Transient Nonlinear Forced Response Plots: Speed set "A", 10-27 KRPM

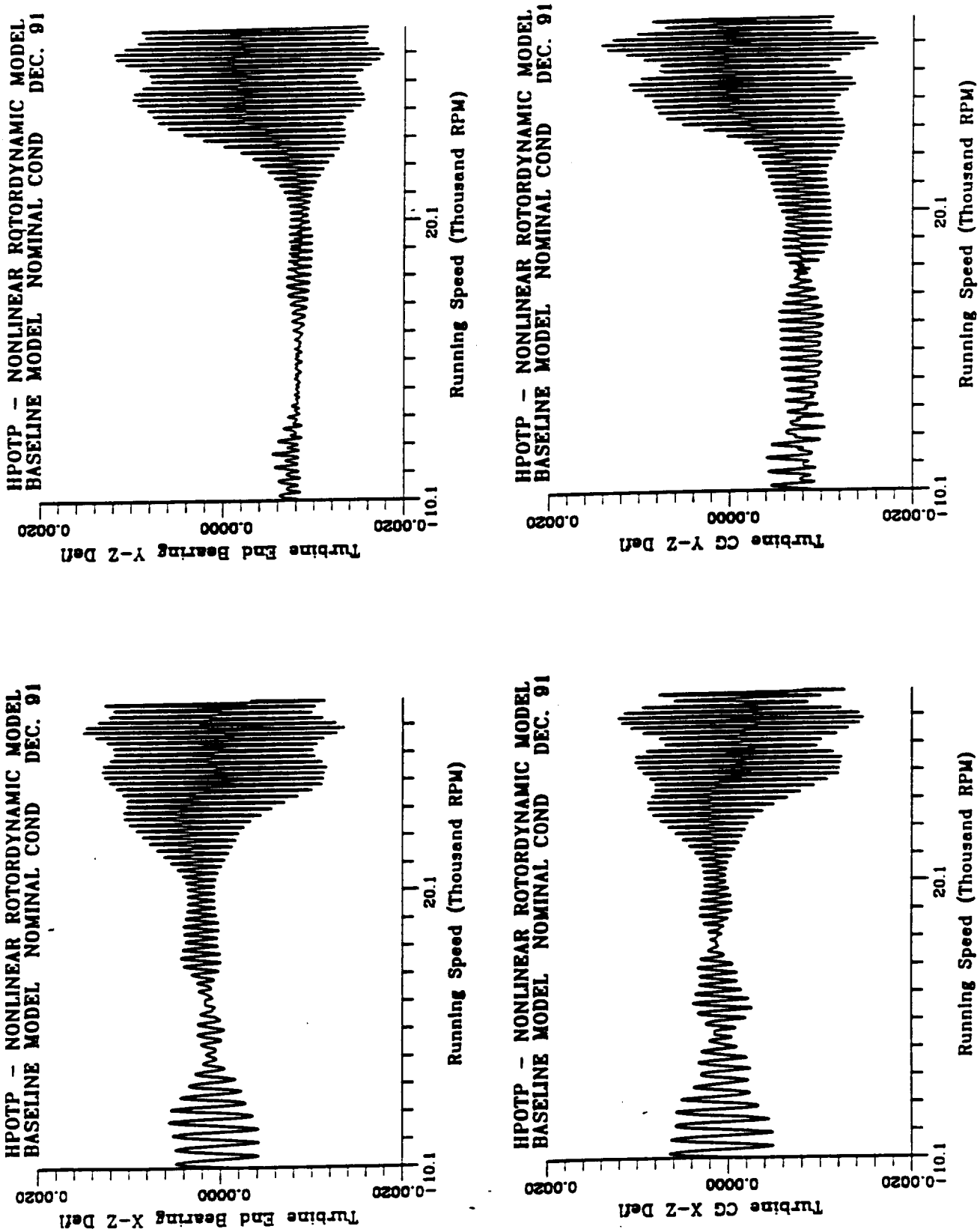

Figure 36. Speed Transient Nonlinear Forced Response Plots: Speed set "A", 10-27 KRPM

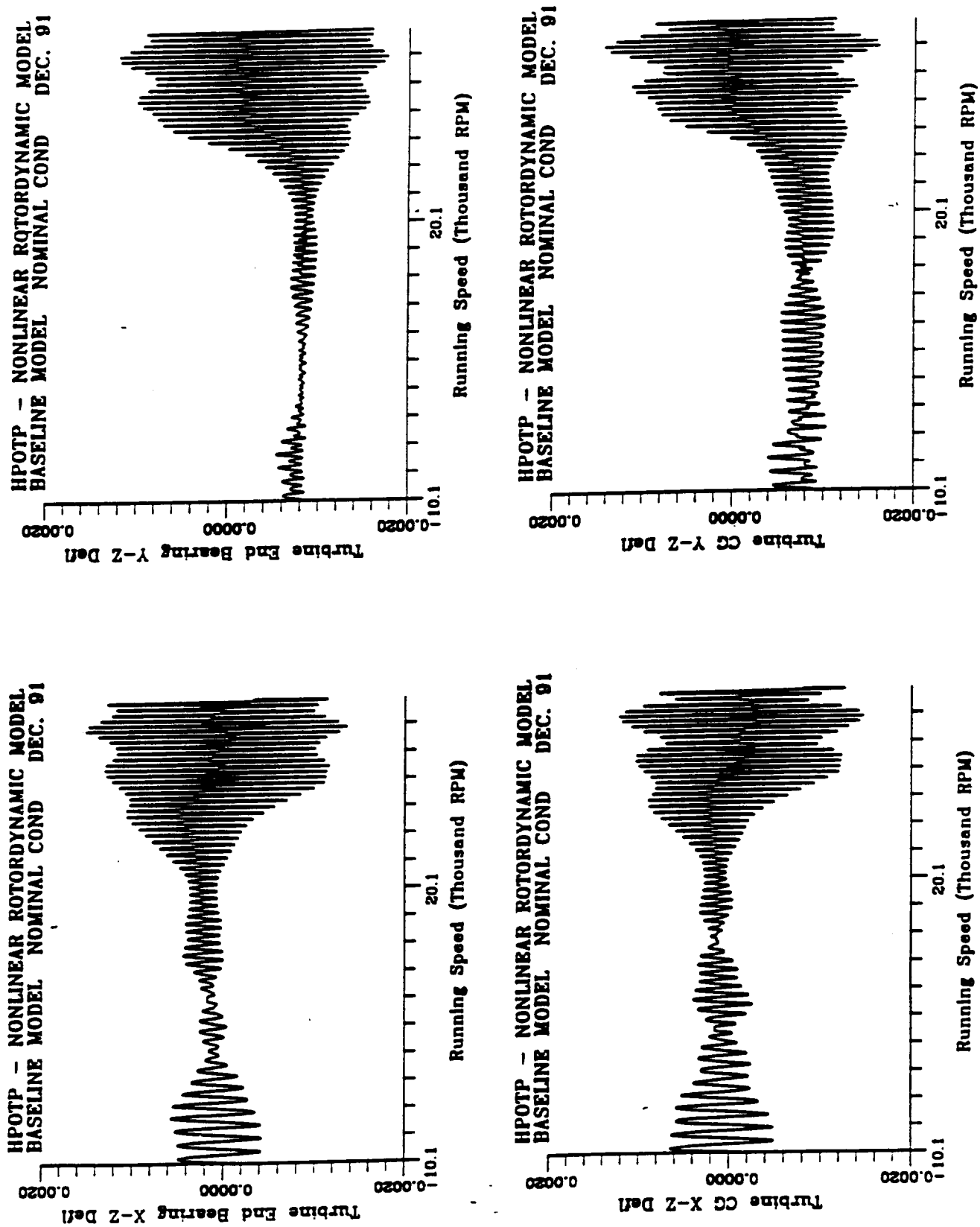

Figure 37. Speed Transient Nonlinear Forced Response Plots: Speed set "A", 10-27 KRPM

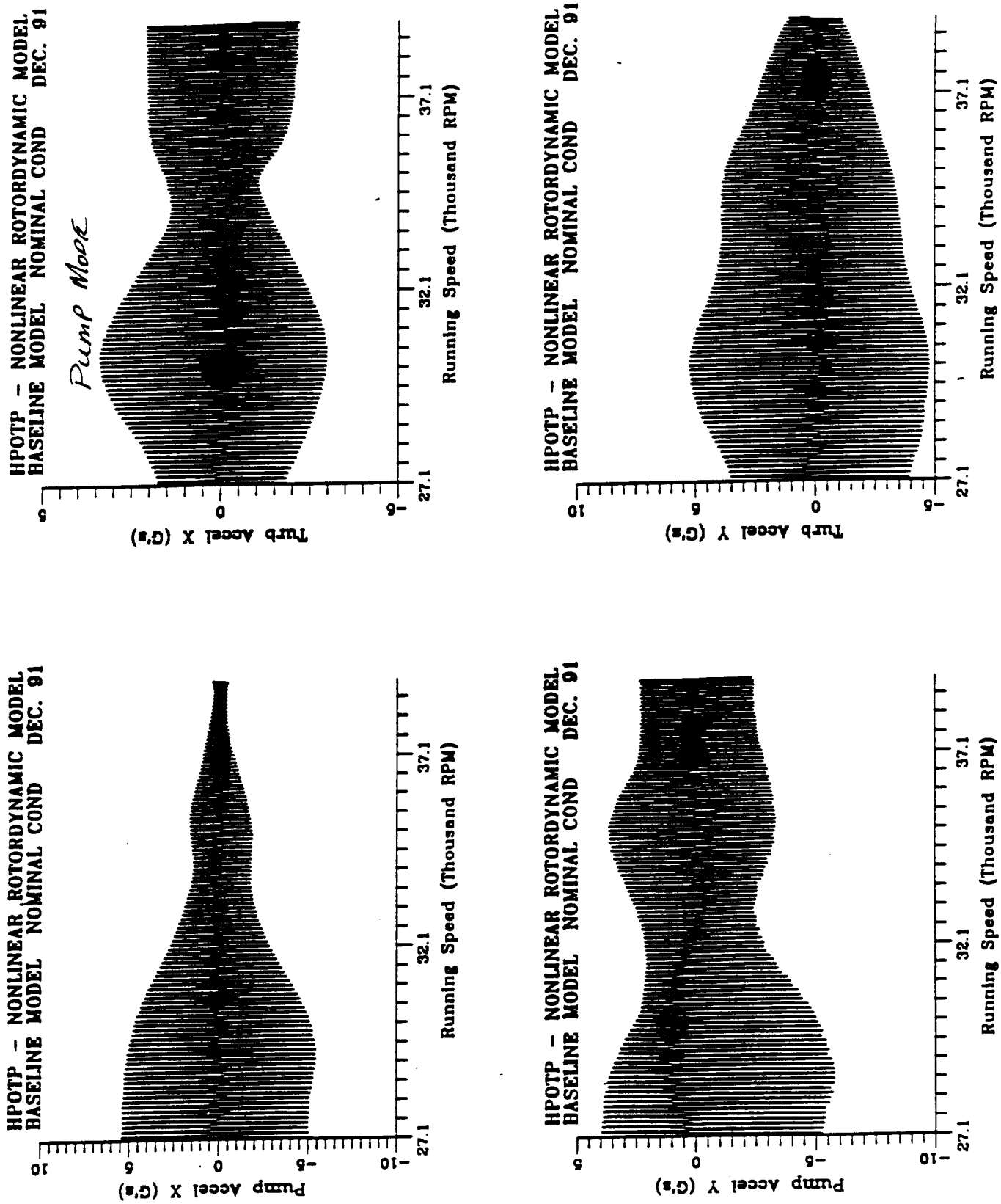

Figure 38. Speed Transient Nonlinear Forced Response Plots: Speed set "B", 27-39 KRPM

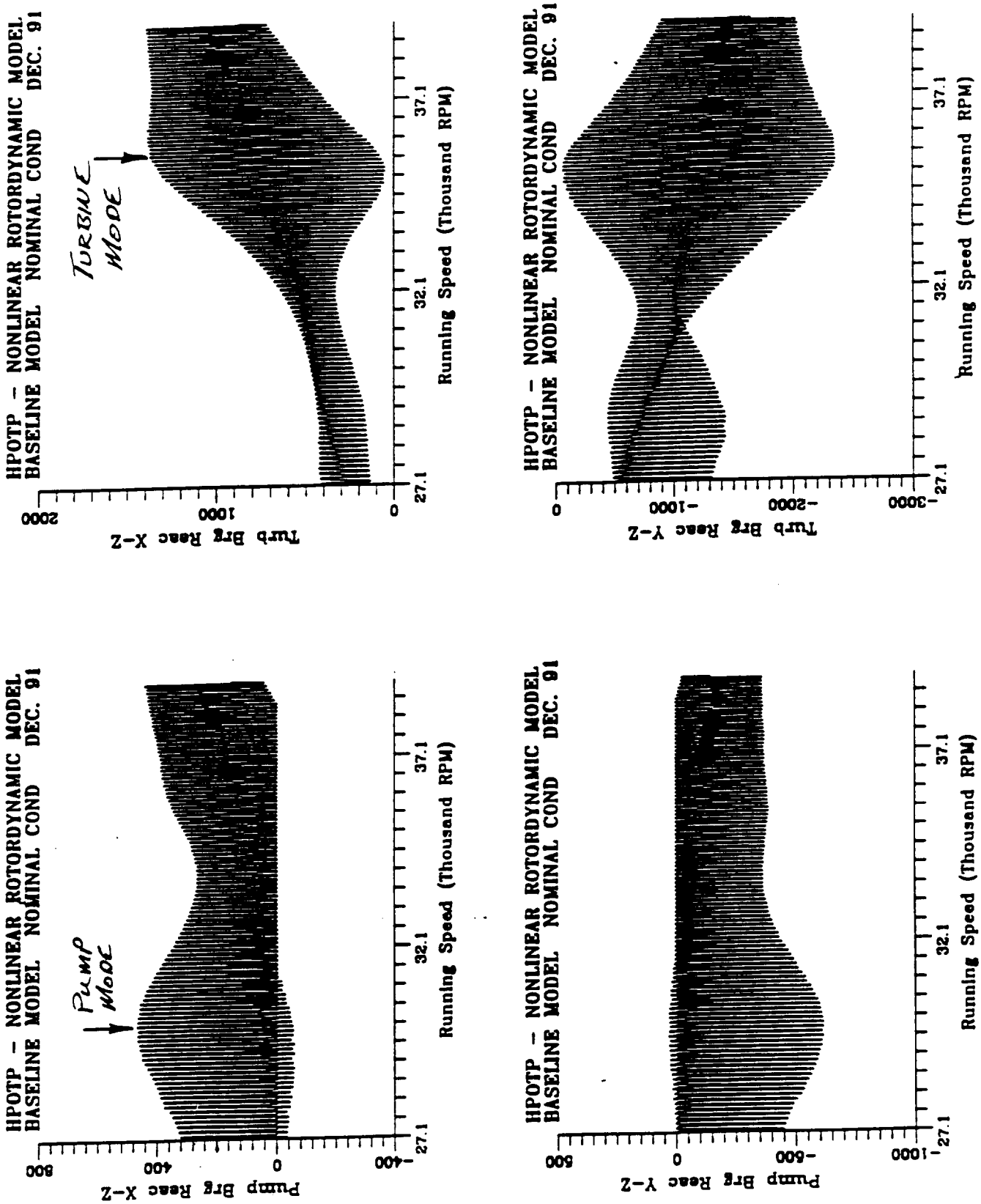

Figure 39. Speed Transient Nonlinear Forced Response Plots: Speed set "B", 27-39 KRPM

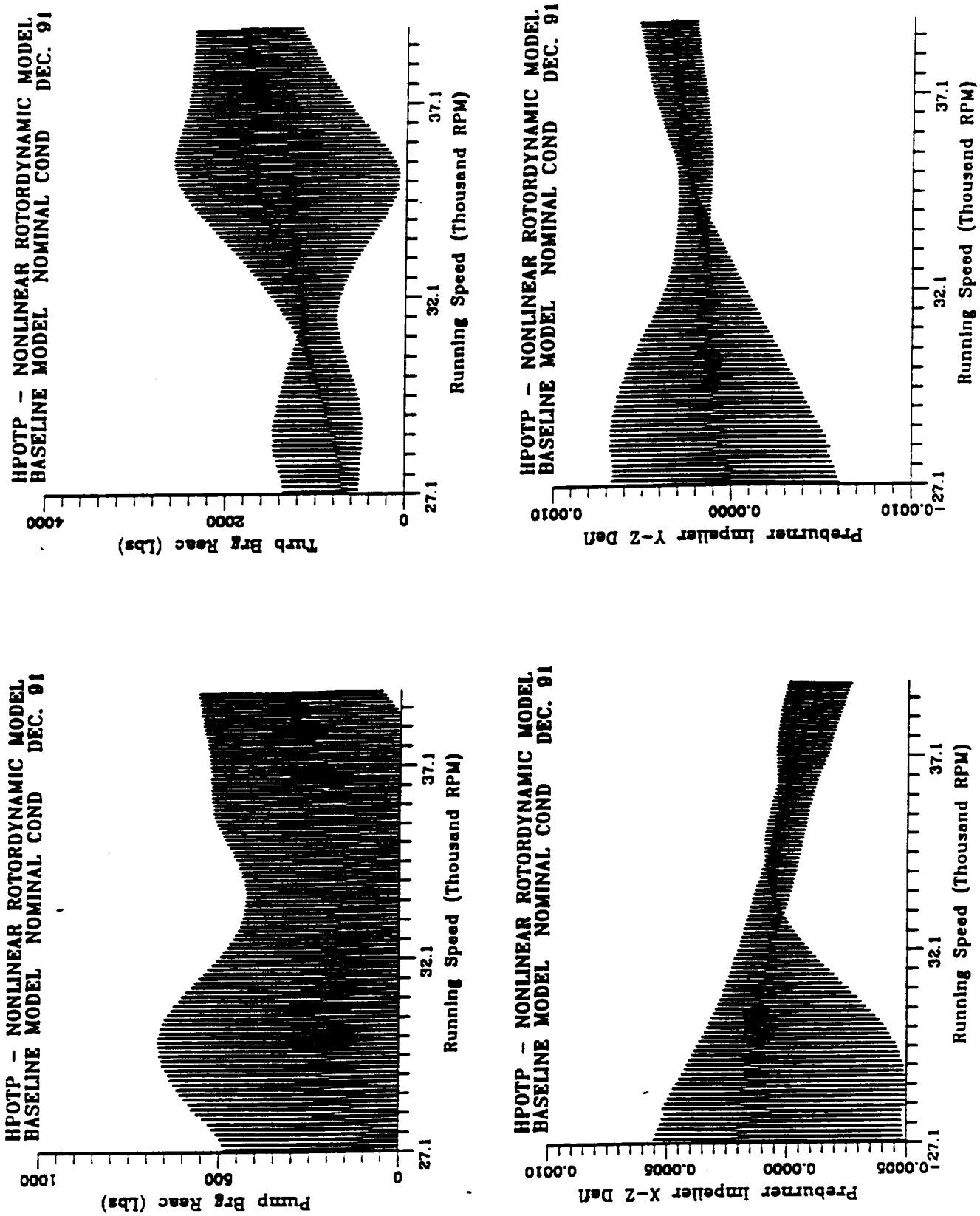

Figure 40. Speed Transient Nonlinear Forced Response Plots: Speed set "B", 27-39 KRPM

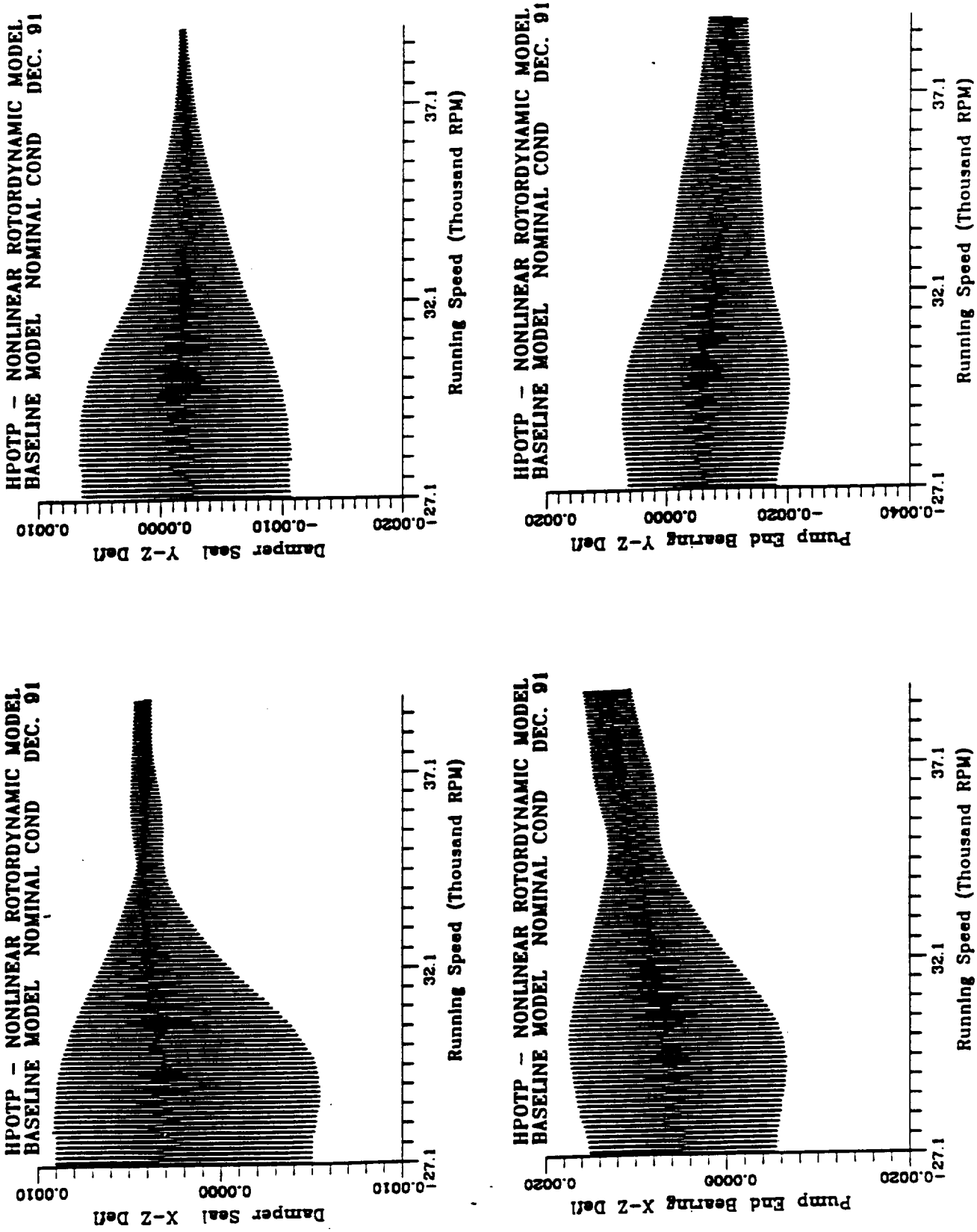

Figure 41. Speed Transient Nonlinear Forced Response Plots: Speed set "B", 27-39 KRPM

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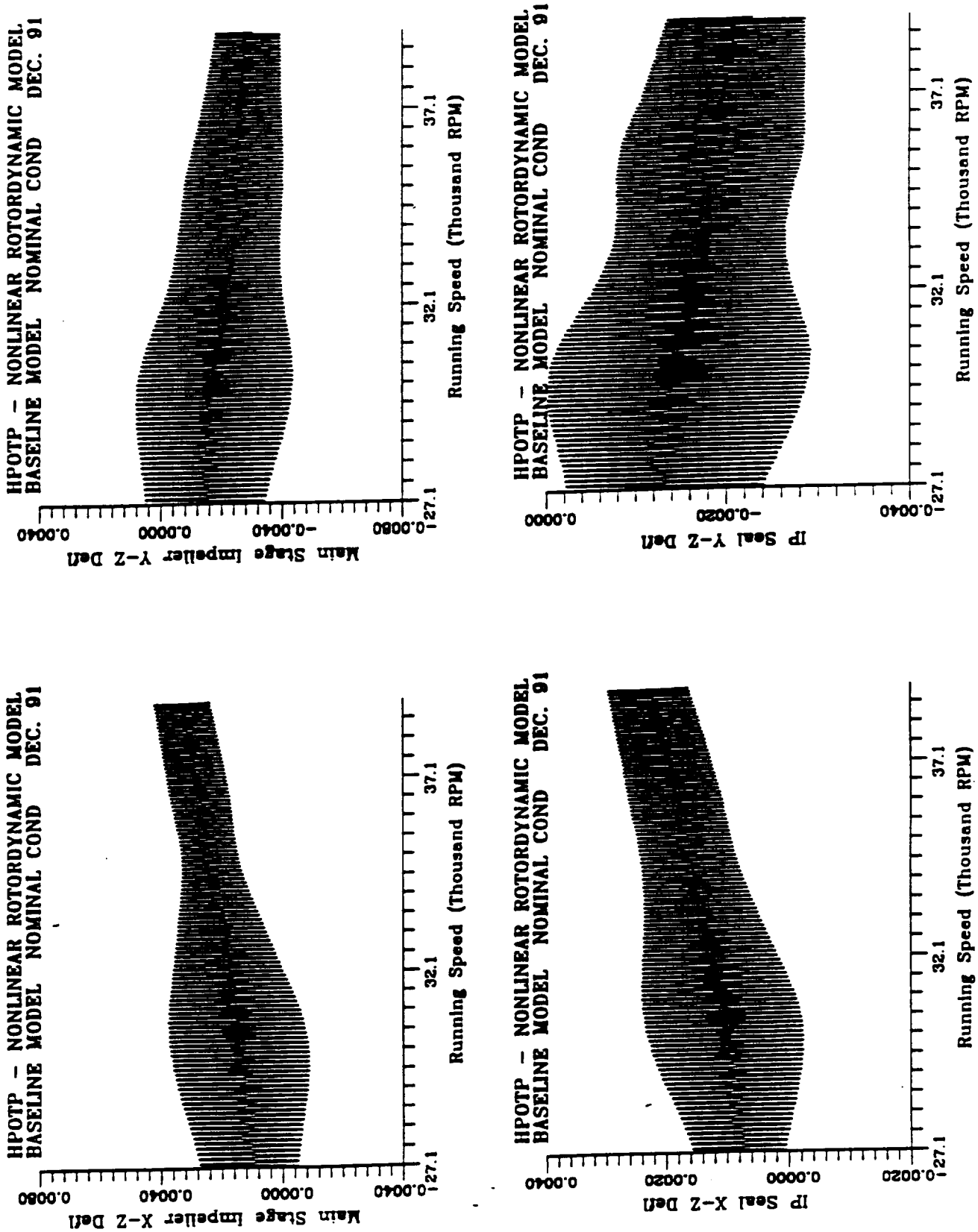


Figure 42. Speed Transient Nonlinear Forced Response Plots: Speed set "B", 27-39 KRPM

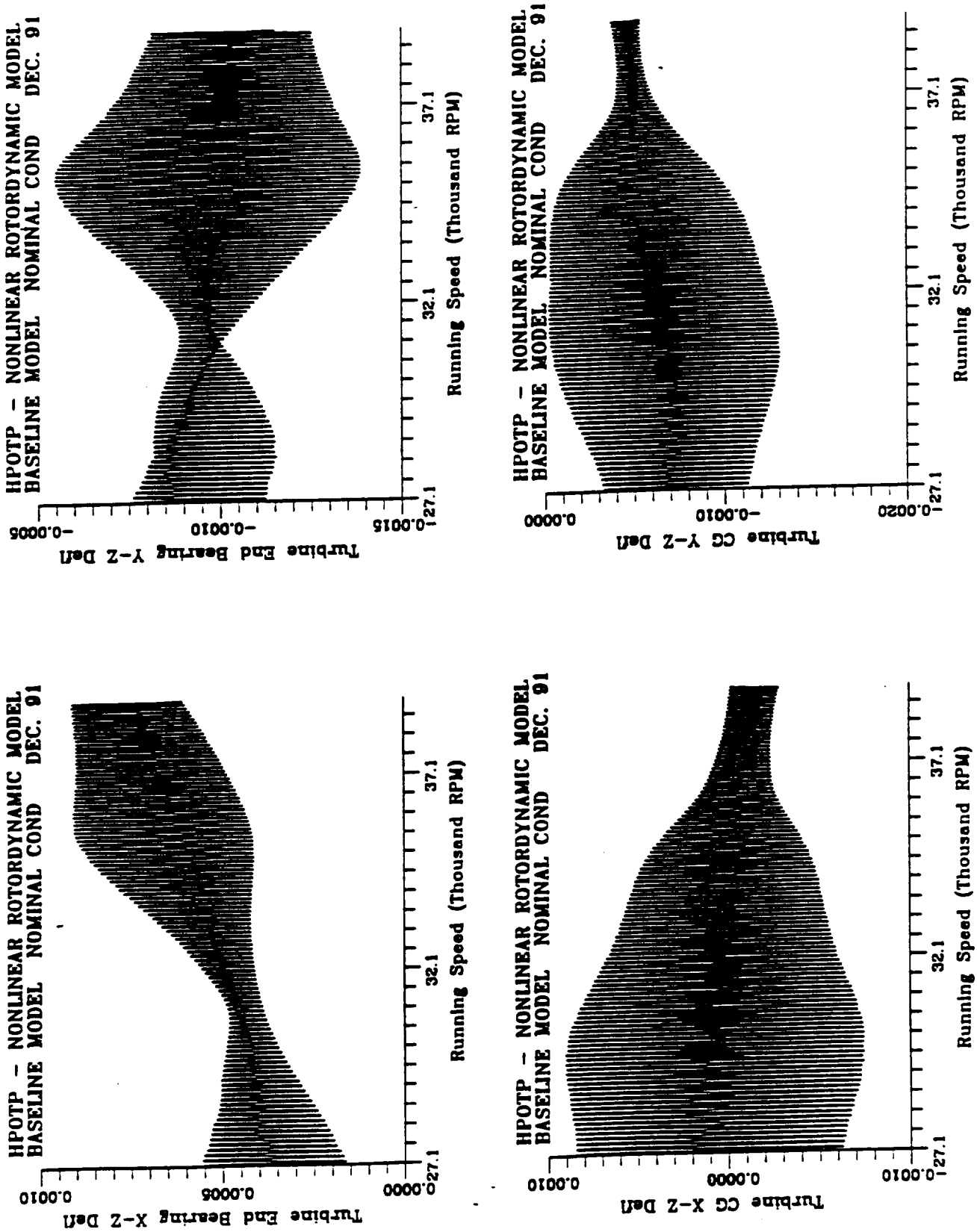


Figure 43. Speed Transient Nonlinear Forced Response Plots: Speed set "B", 27-39 KRPM

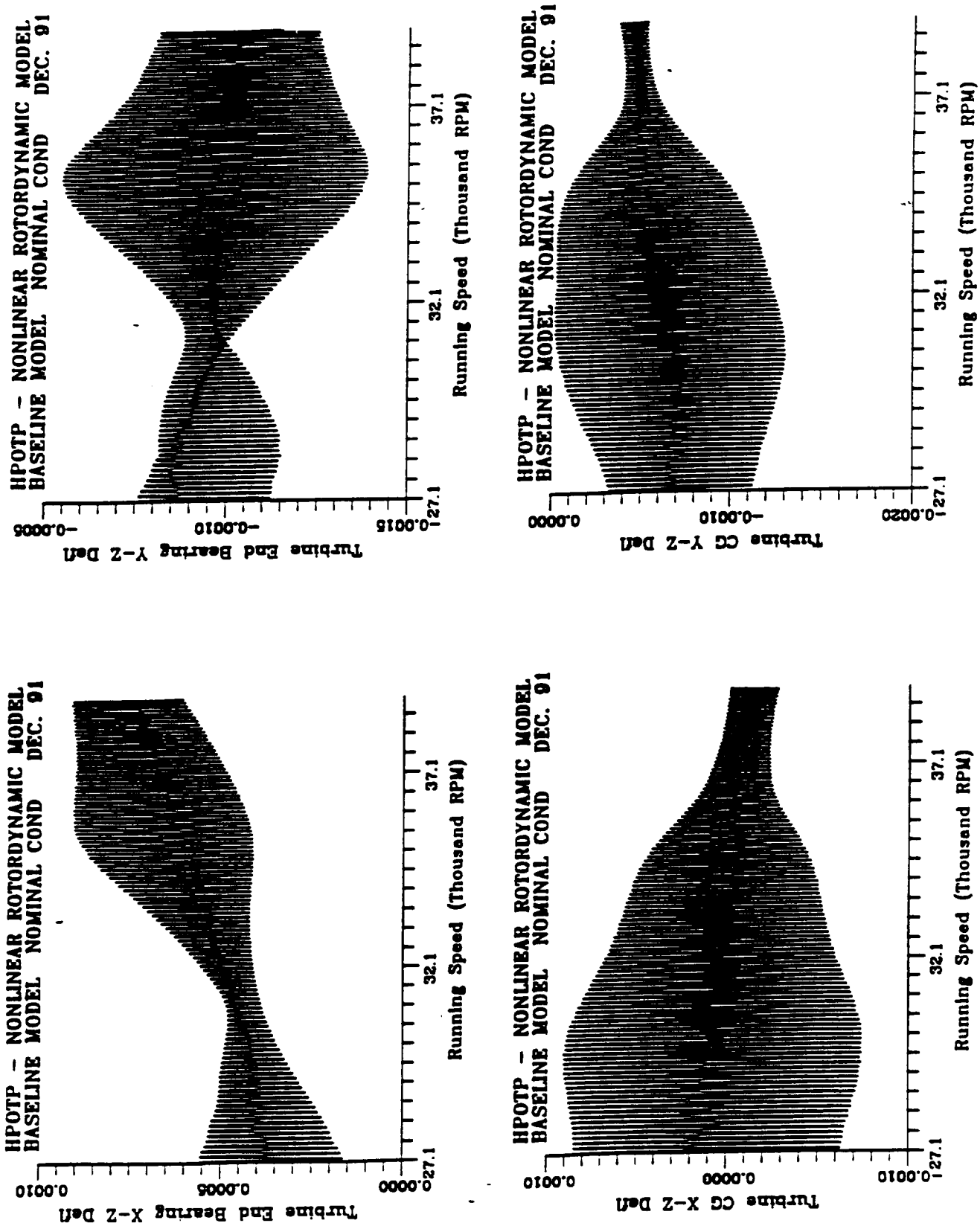


Figure 44. Speed Transient Nonlinear Forced Response Plots: Speed set "B", 27-39 KRPM

Steady State Time Transient Analysis: Plots for steady state time transient forced response analysis are made for calculation of whirl orbits and FFT's and are included in Appendix G.

Rotor internal loads (shear and moment) have been calculated at 109% RPL for documentation of shaft dynamic loads and are illustrated in Figure 45 on page 74 with shear and moment diagrams vs axial length.

Plots of steady state time transient response are included in Figure 46 on page 75 thru Figure 52 on page 81 for 109% RPL.

Plots of whirl orbits are illustrated in Figure 53 on page 82 thru Figure 54 on page 83.

Plots of FFT's are illustrated in Figure 55 on page 84 thru Figure 57 on page 86.

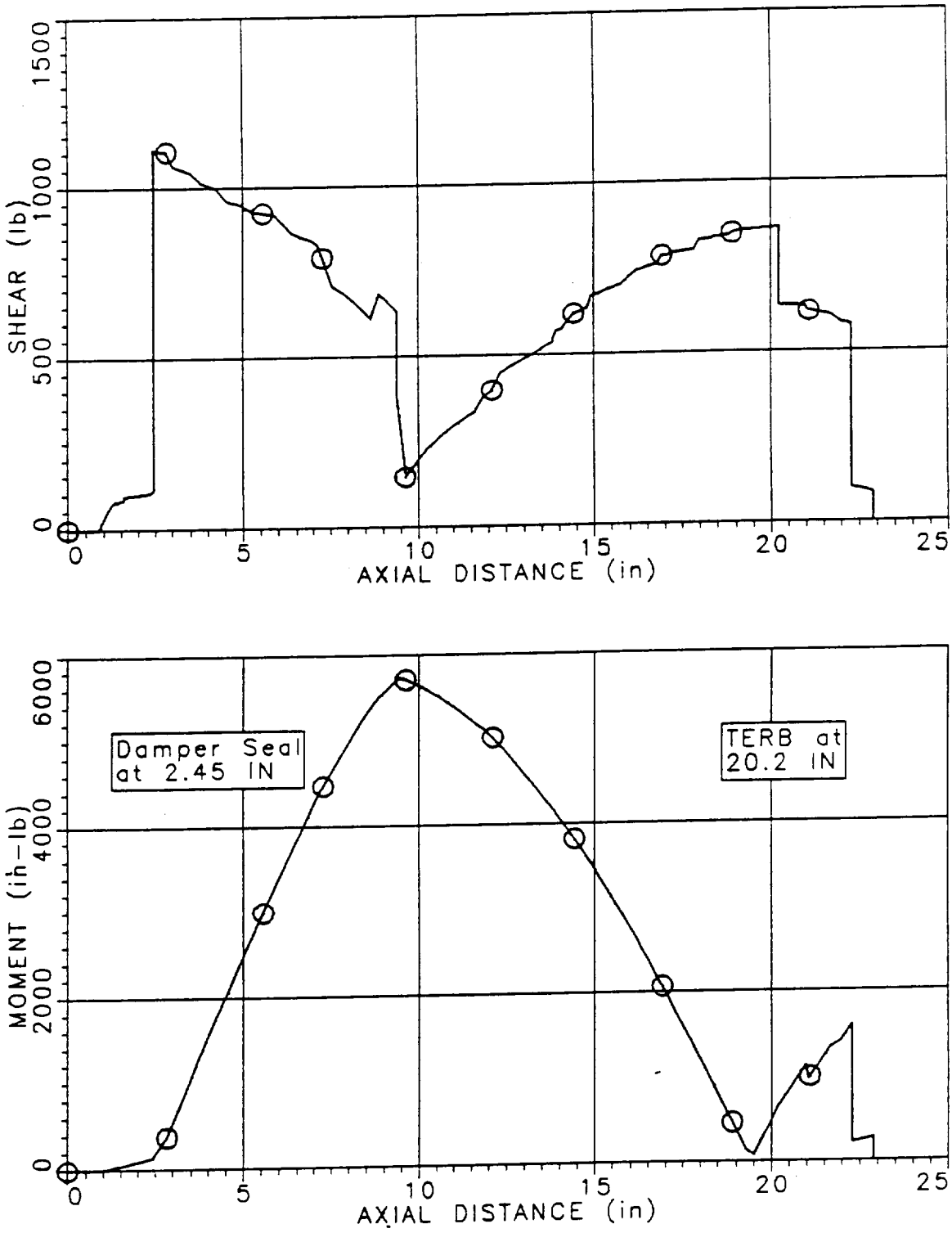


Figure 45. Rotor Internal Dynamic Loads; Shear and Moment: Nominal, 109% RPL

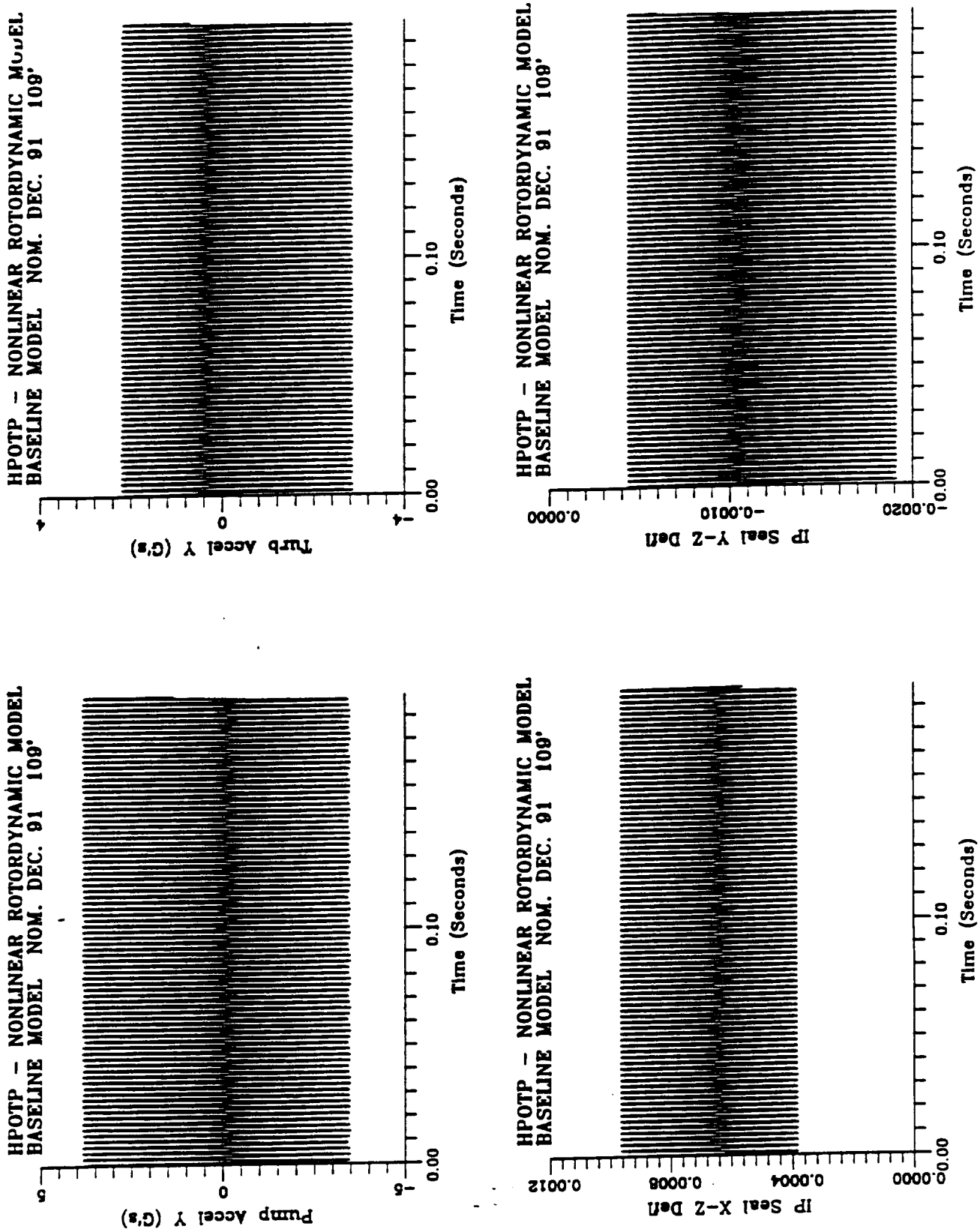


Figure 46. Steady State Time Transient Plots @ 109% RPL

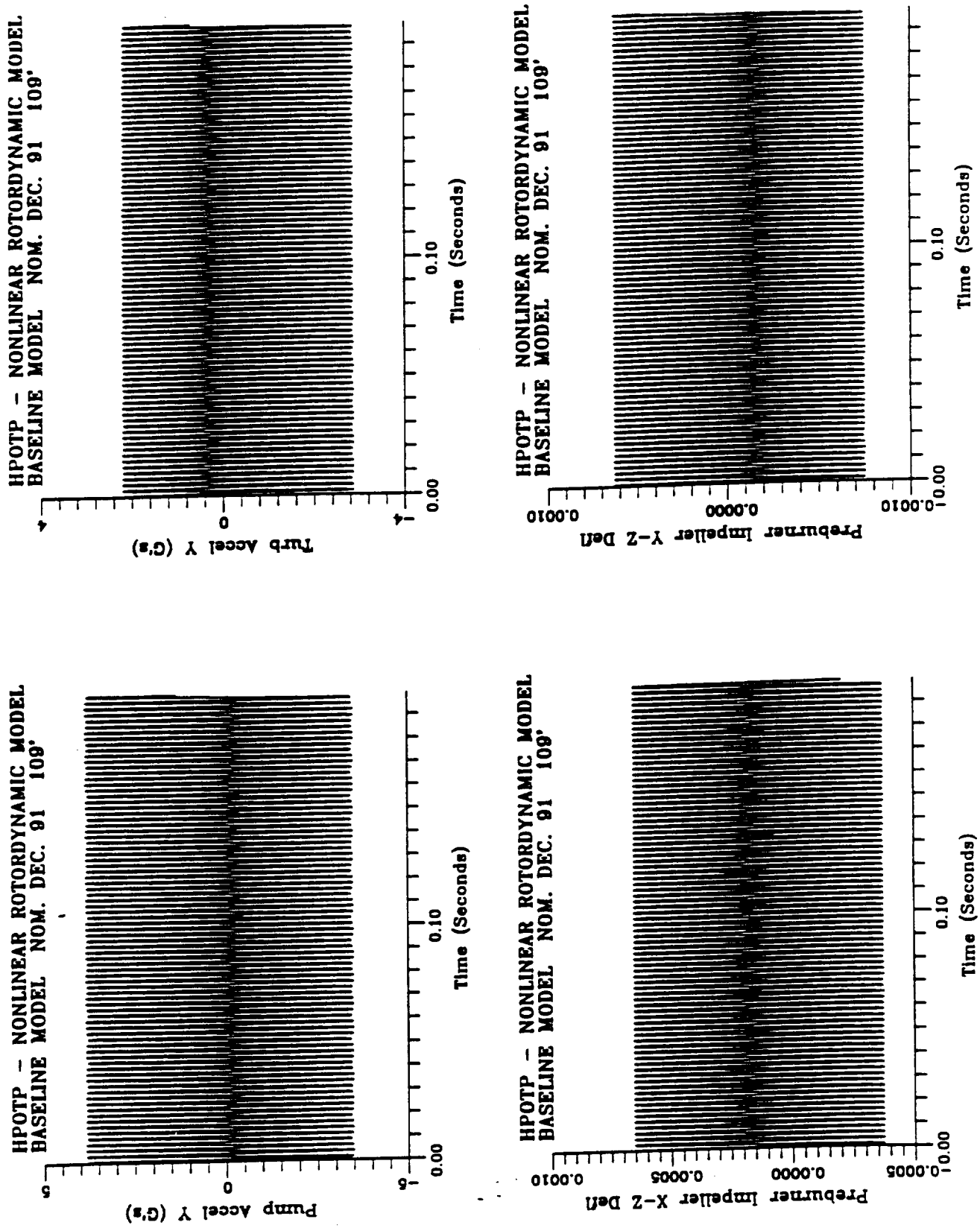


Figure 47. Steady State Time Transient Plots @ 109% RPL

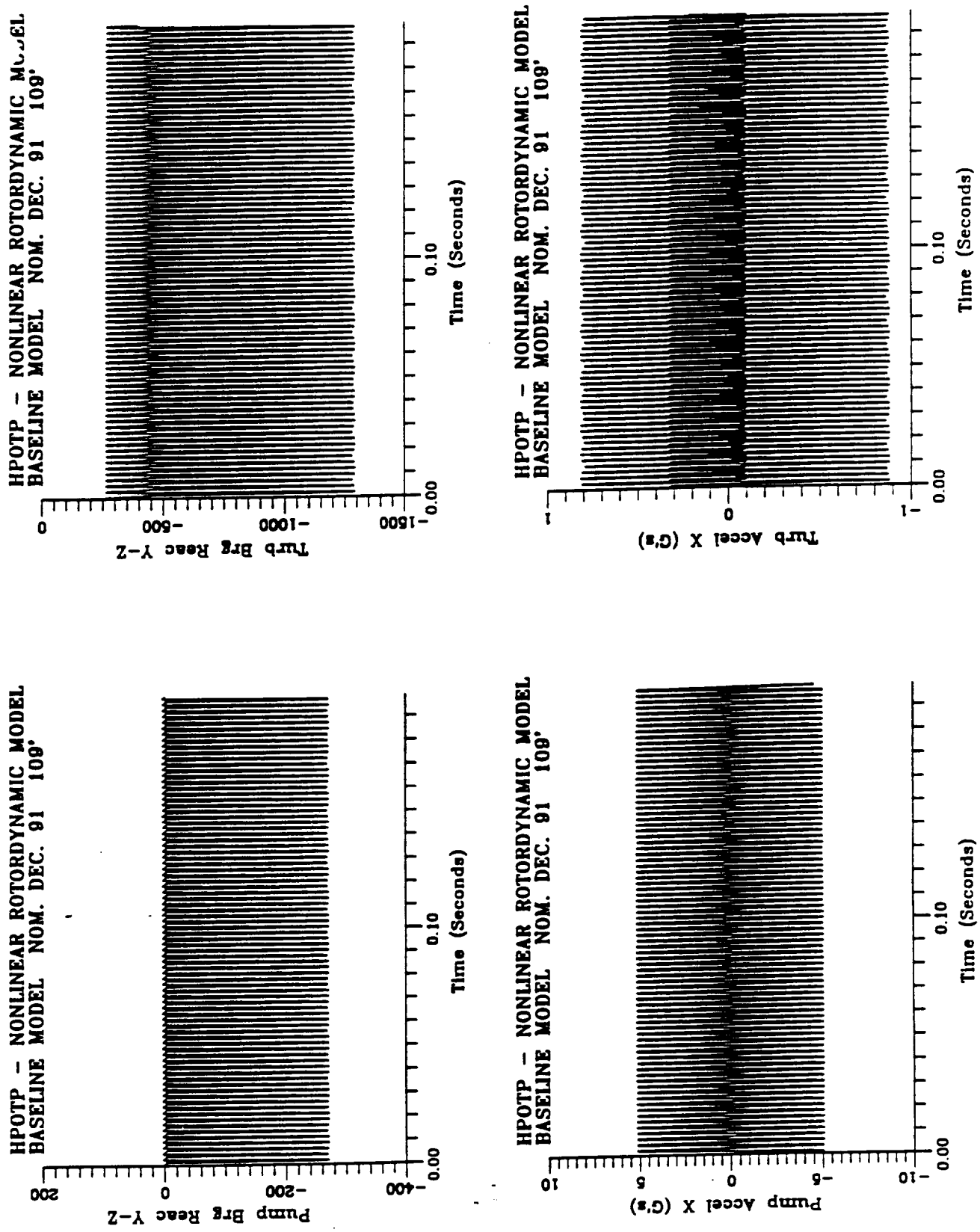


Figure 48. Steady State Time Transient Plots @ 109% RPL

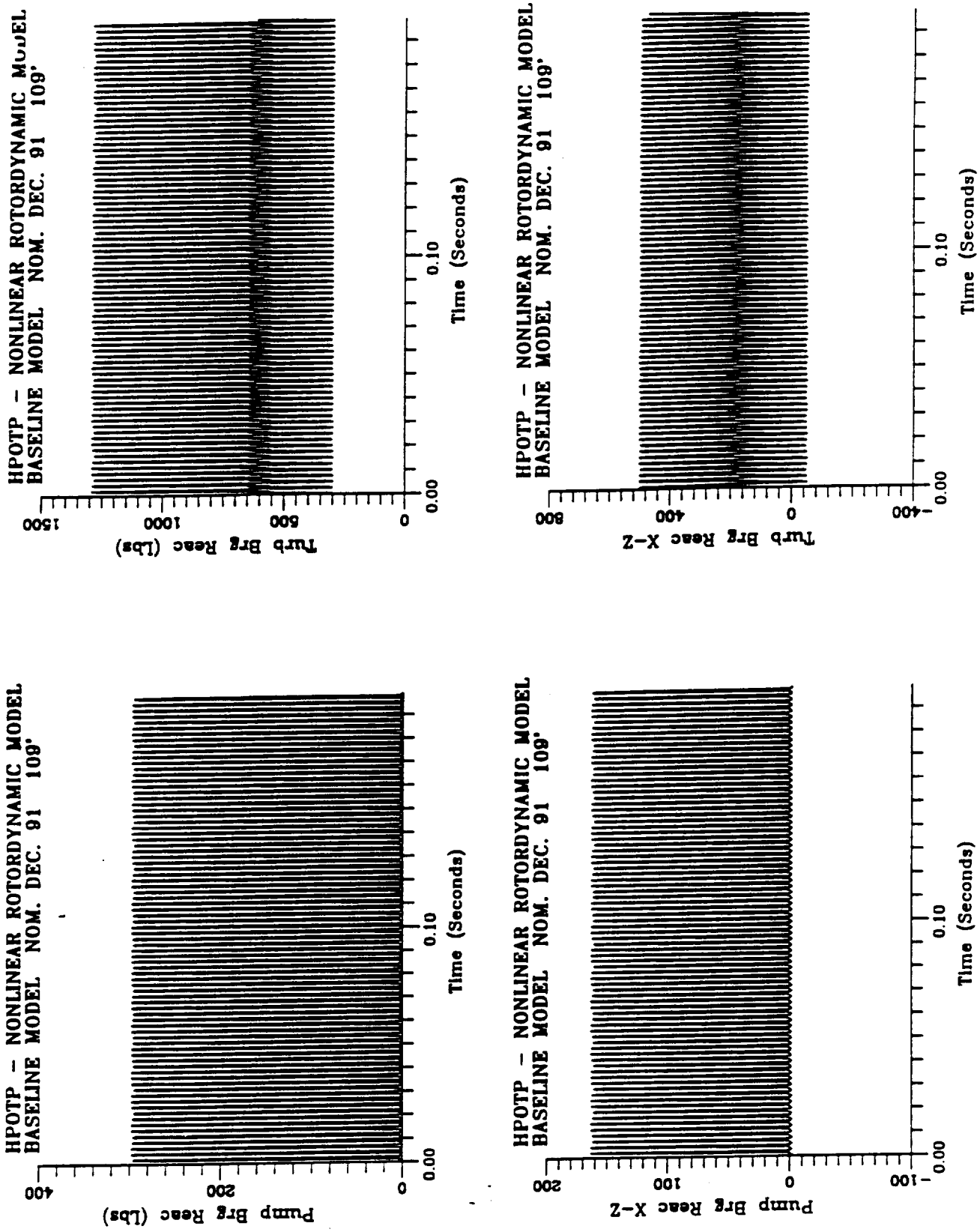


Figure 49. Steady State Time Transient Plots @ 109% RPL

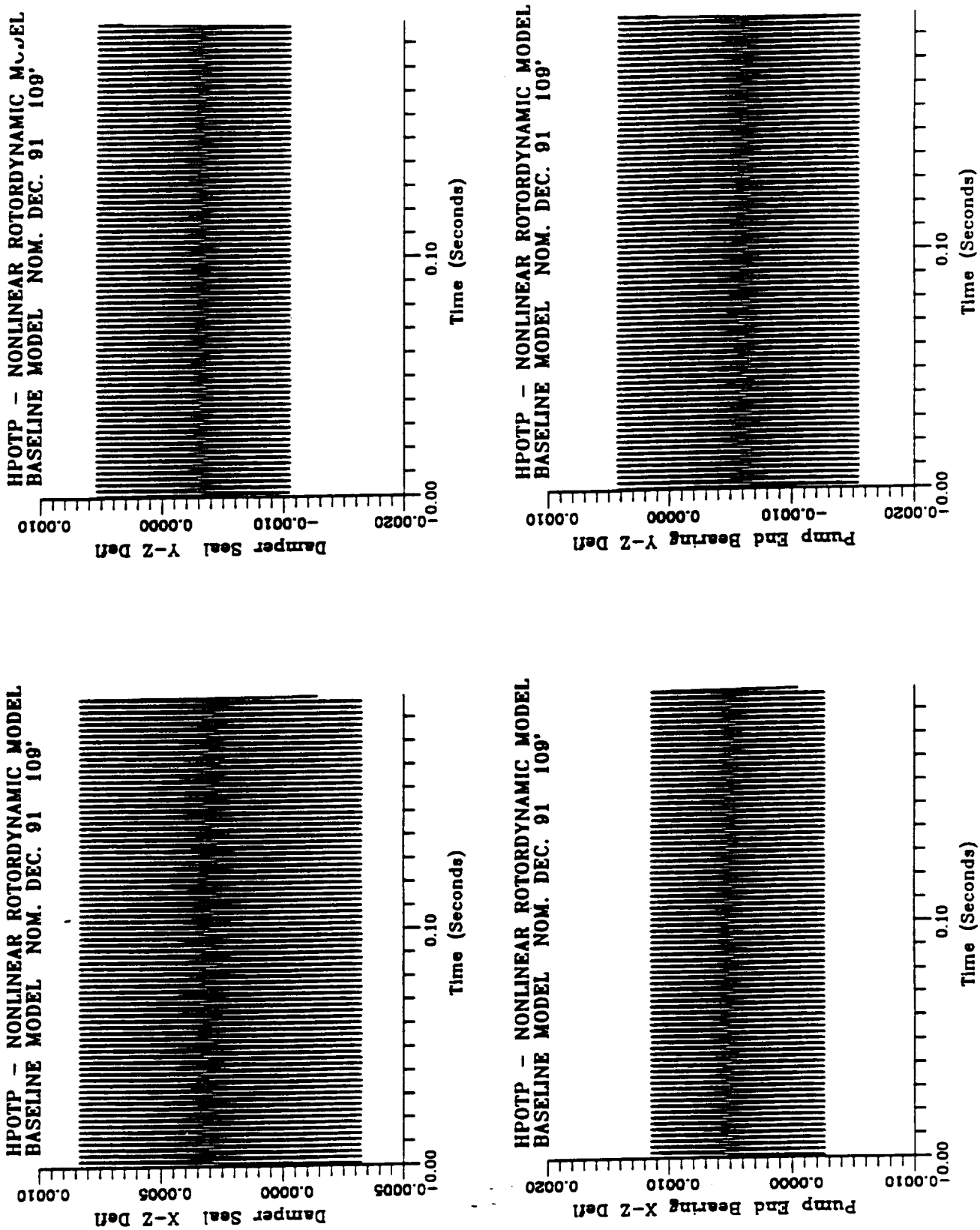


Figure 50. Steady State Time Transient Plots @ 109% RPL

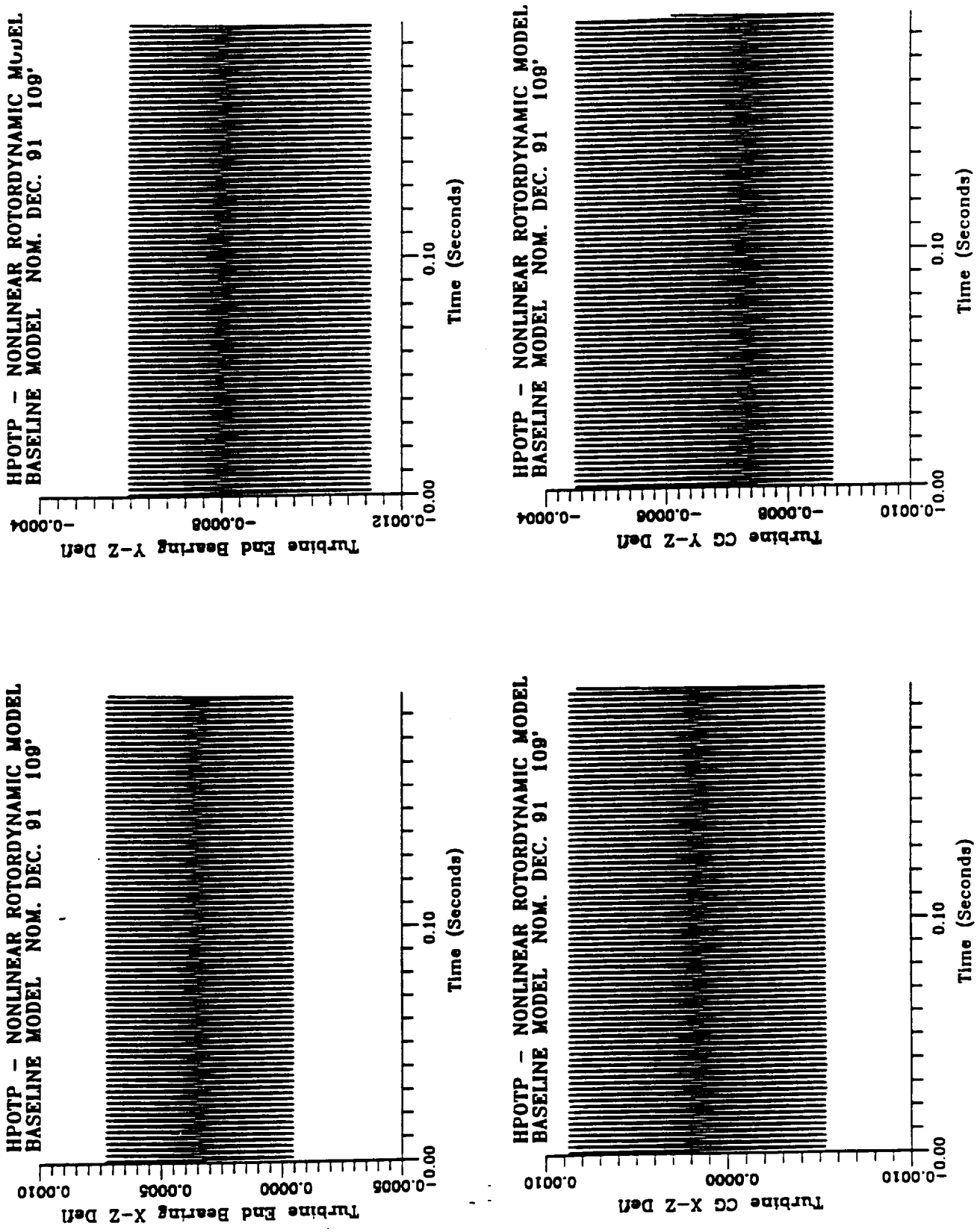
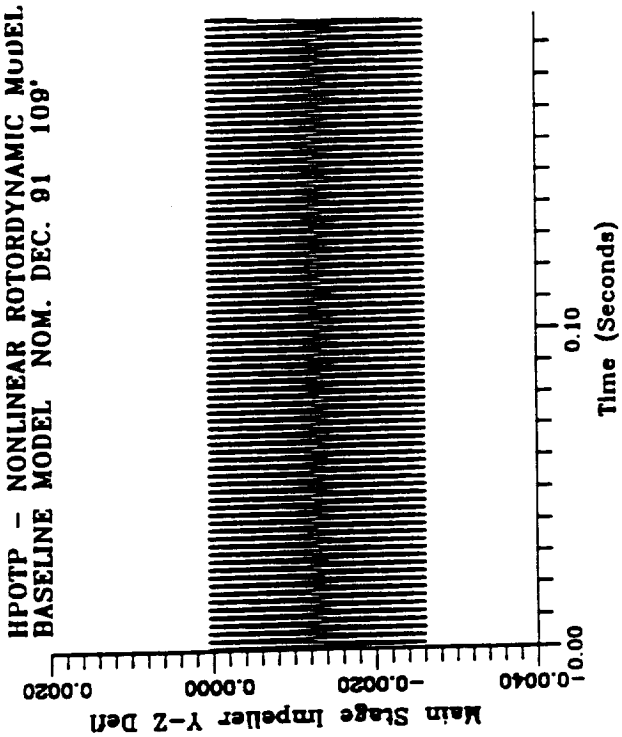


Figure 51. Steady State Time Transient Plots @ 109% RPL



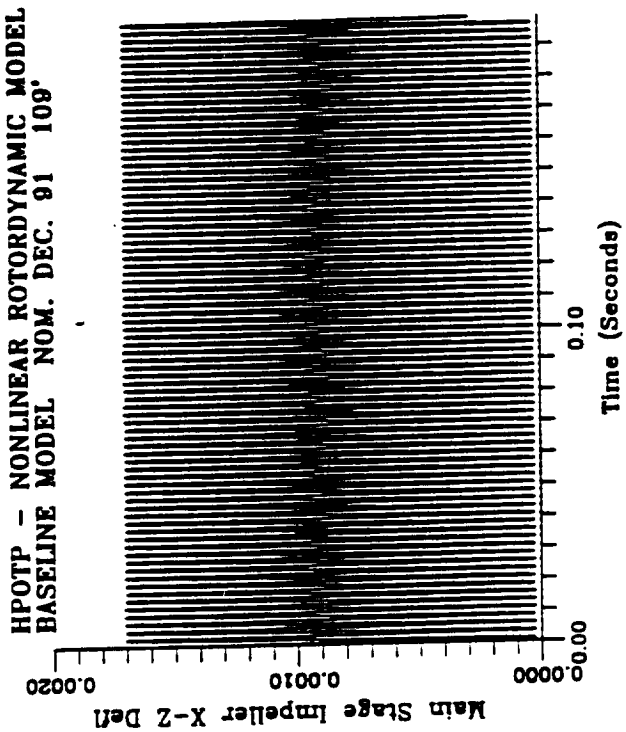


Figure 52. Steady State Time Transient Plots @ 109% RPL

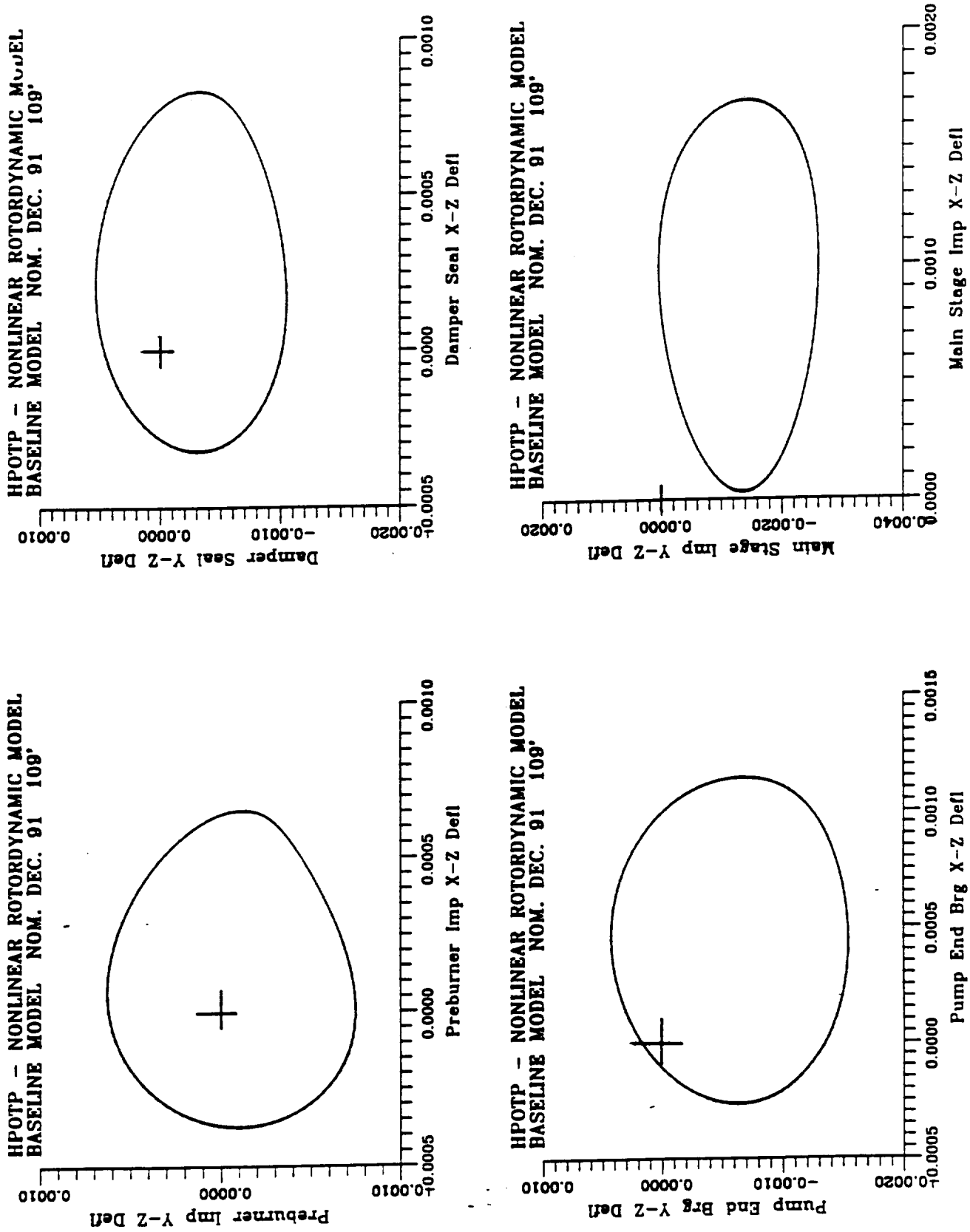
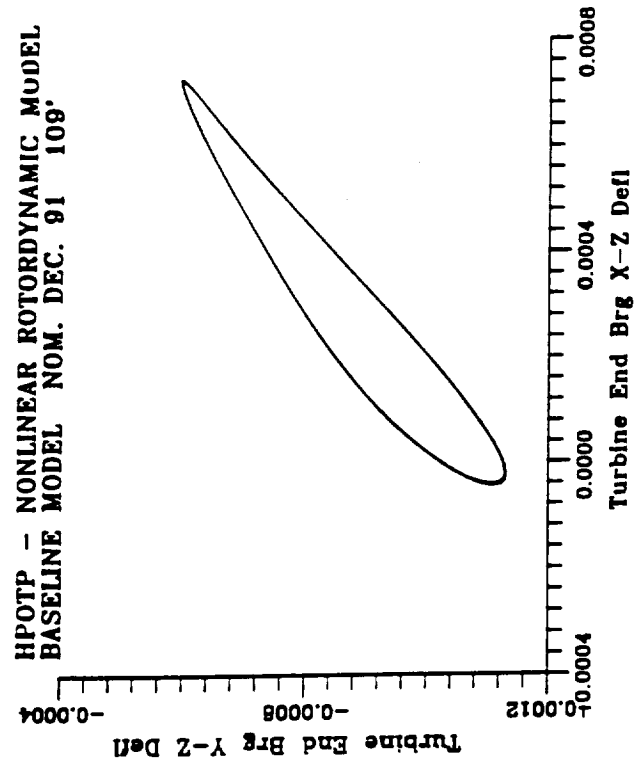
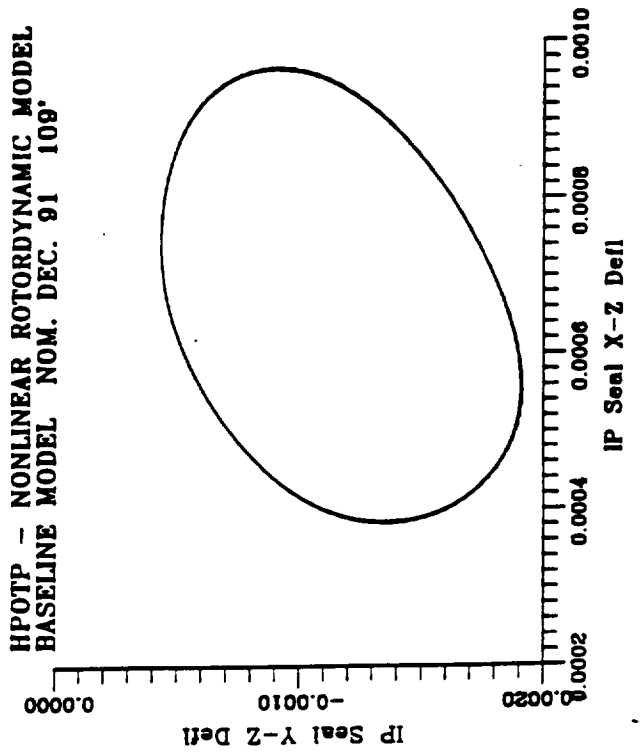


Figure 53. Whirl Orbit Plots @ 109% RPL





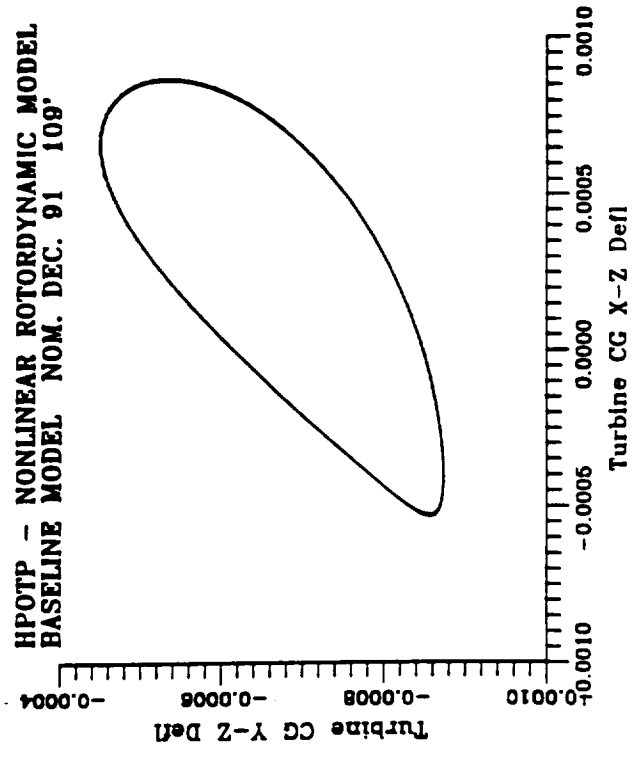


Figure 54. Whirl Orbit Plots @ 109% RPL

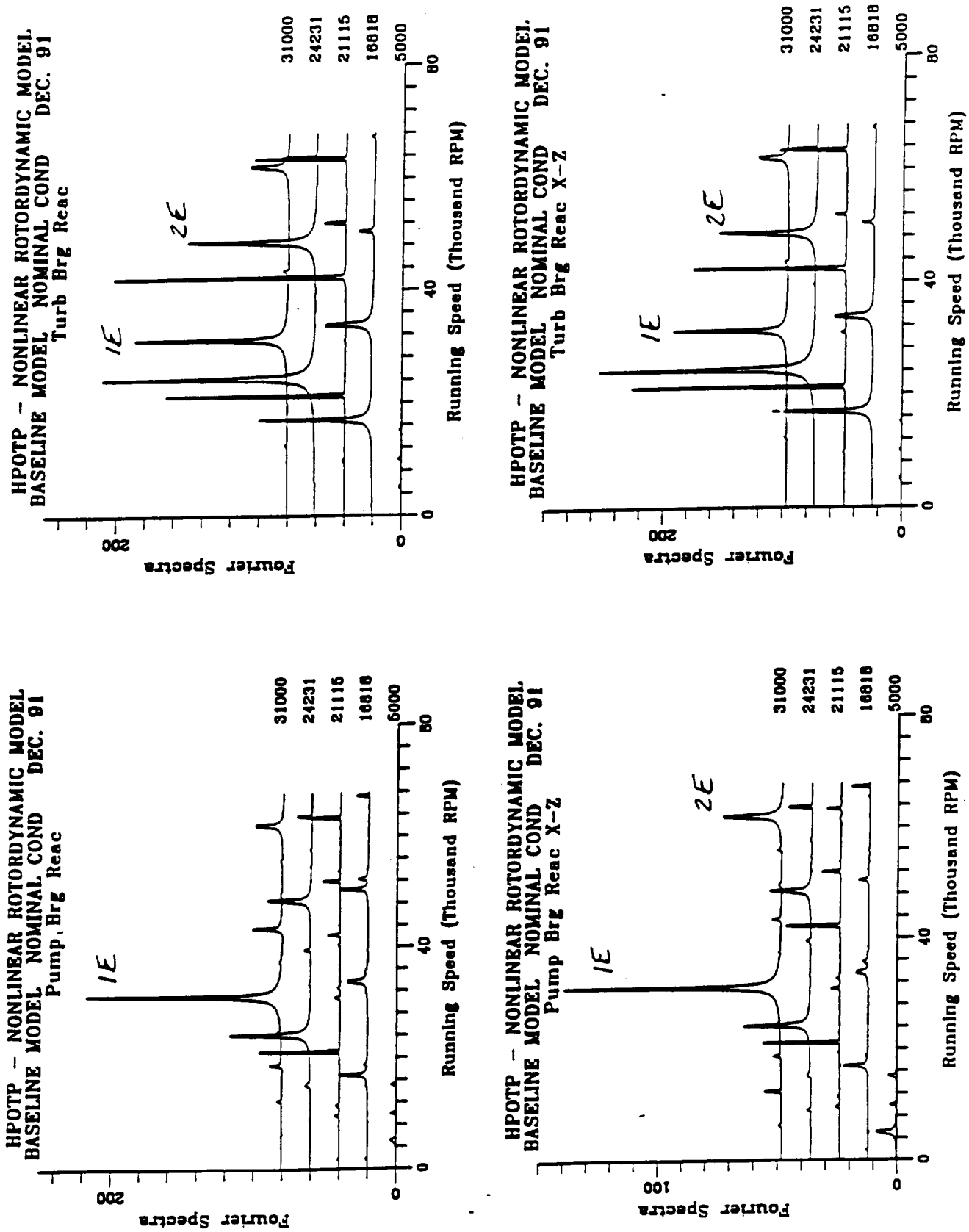


Figure 55. Nonlinear Forced Response FFT's

C-2.

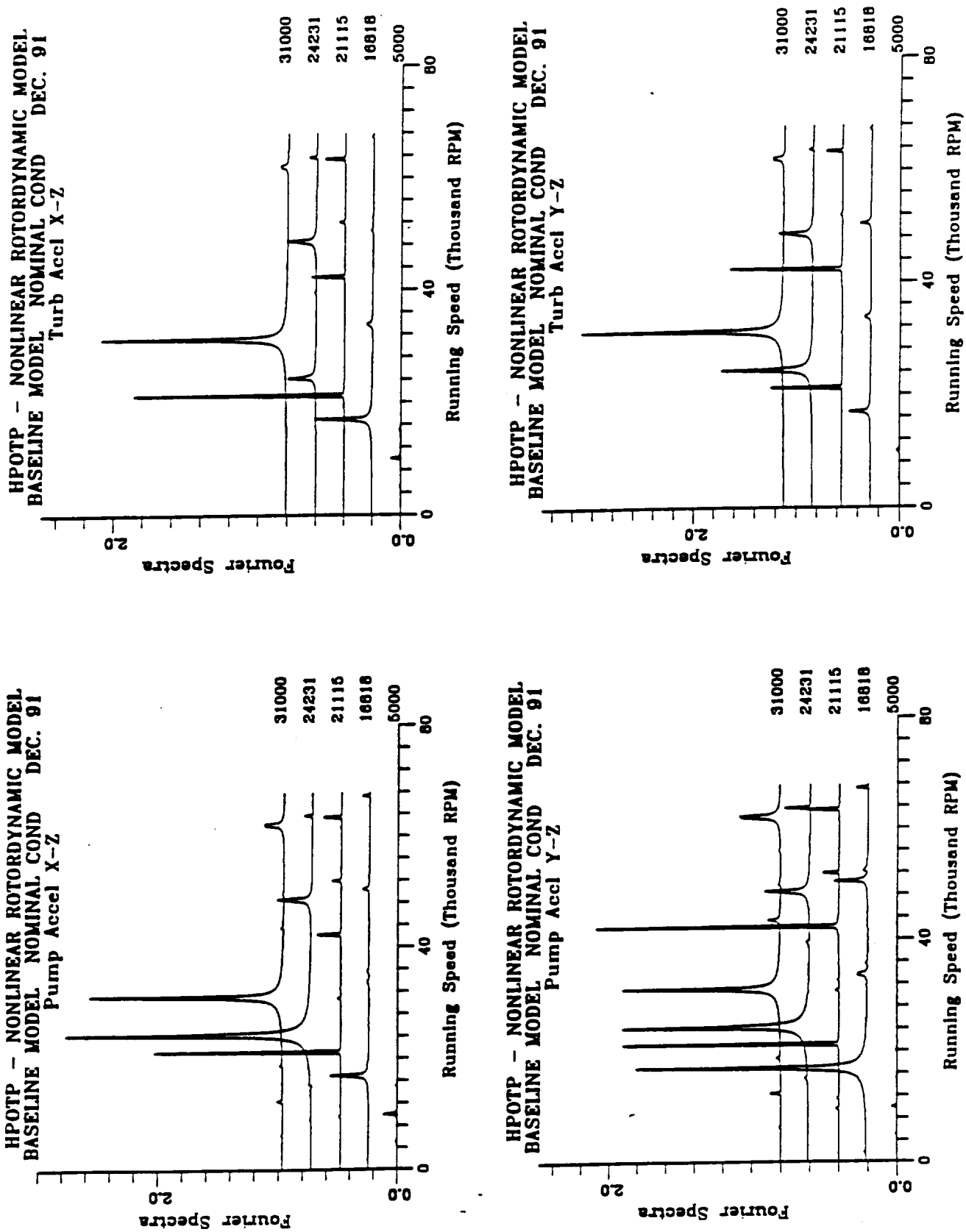


Figure 56. Nonlinear Forced Response FFT's

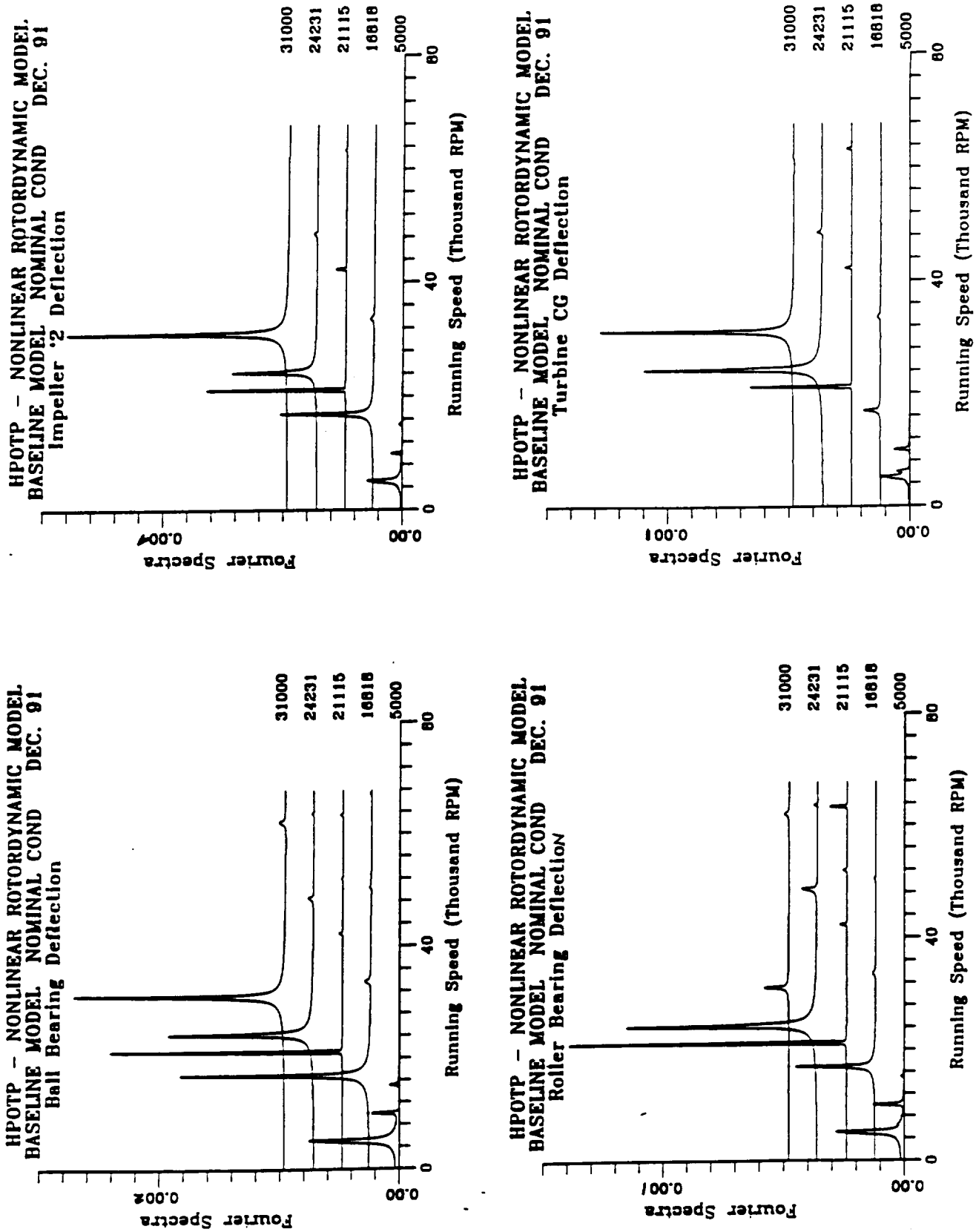


Figure 57. Nonlinear Forced Response FFT's

4.2.4 Summary

Linear and nonlinear rotordynamic analyses of the baseline input parameters show low, stable dynamic response for accelerations, rotor deflections and loads. All fundamental rotor bending modes are tuned out of the operating range, with approximately a 2X margin. The first bending mode is predicted at 900 Hz (1E is equal to 420 Hz at 115% RPL). The two rigid body modes, Pump Bounce and Turbine Bounce, occur at approximately 500 Hz and 615 Hz respectively and provide 20% speed margin for subcritical operation. Two sets of low energy rigid body housing modes are predicted at 115/150 Hz and 275/335 Hz with the turbopump housing mount stiffness providing the asymmetric resonance. Housing bending modes are predicted well above the operating speed range with the 1st bending mode occurring at approximately 665 Hz.

Critical Speed Results - Nominal			
Mode	Description	Critical Speed	
		X-Z Plane	Y-Z Plane
1	Housing Bounce	9,000 RPM (150 Hz)	7,000 RPM (115 Hz)
2	Housing Pitch	20,000 RPM (335 Hz)	16,500 RPM (275Hz)
3	Rotor Pump Bounce	29,000 RPM (480 Hz)	31,000 RPM (515 Hz)
4	Rotor Turbine Bounce	37,000 RPM (615 Hz)	37,000 RPM (615 Hz)
5	Housing 1st Bending	> 40,000 RPM (> 665 Hz)	> 40,000 RPM (> 665 Hz)
6	Rotor 1st Bending	> 40,000 RPM (> 665 Hz)	> 40,000 RPM (> 665 Hz)

Table 23. Critical Speed Summary

Stable operation is predicted with Onset Speed of Instability (OSI) above 40,000 RPM for all modes. The rotor modes have LOG-DEC values of 0.24 or greater at 109% RPL.

Stability Results - Nominal			
Mode		LOG-DEC @ 109% RPL	OSI
No.	Description		
1	Housing Bounce	0.18	> 40,000 RPM
2	Housing Pitch	0.20	> 40,000 RPM
3	Rotor Pump Bounce	0.24	> 40,000 RPM
4	Rotor Turbine Bounce	0.24	> 40,000 RPM
5	Housing 1st Bending	0.17	> 40,000 RPM
6	Rotor 1st Bending	1.64	> 40,000 RPM

Table 24. Stability Summary

Forced response results are summarized below for FPL nominal conditions. These conditions are representative of nominal conditions for all input parameters such as clearances, pressures, loads, etc. Both, linear and nonlinear response show subcritical stable operation. Accelerations, deflections and loads are all within design tolerances.

Nonlinear Forced Response Results - Nominal		
Station	**Power Level**	**S.S. Nonlinear Forced Response**
Pump Flange Housing Response	65% RPL	4 G's
	109% RPL	5 G's
Turbine Flange Housing Response	65% RPL	1 G's
	109% RPL	2.8 G's
PBI Deflection	65% RPL	1.2 mils
	109% RPL	0.7 mils
MSI Deflection	65% RPL	1.5 mils
	109% RPL	2.6 mils
Damper Seal Defl	65% RPL	1.3 mils
	109% RPL	1.0 mils
IP Seal Deflection	65% RPL	1.1 mils
	109% RPL	1.9 mils
Turbine CG Deflection	65% RPL	0.9 mils
	109% RPL	0.9 mils
PEBB Load	65% RPL	190 lbf
	109% RPL	300 lbf
TERB Load	65% RPL	620 lbf
	109% RPL	1300 lbf
Note: Bearing loads are peak composite; Static and Dynamic.		

Table 25. Steady State Nonlinear Forced Response Summary

5.0 SENSITIVITY RESULTS

5.1 Boundary Conditions

The following Sensitivity results are calculated as discussed in the METHODS section of 3.0 for use in the ROTORDYNAMIC SENSITIVITY ANALYSES. Selected input parameters were used for variation, based on MSFC/P&W discussion, and are documented in Appendix A. The majority of the input variation values reflect the operating tolerances to represent expected actual conditions where applicable, such as seal clearances and pressures. Other boundary conditions were varied by a fix percentage for sensitivity variation only, such as aeromechanical forces (Beta), static side loads, etc.

Those boundary conditions that have multiple input parameter variations (damper seal, turbine interstage labyrinth seals, etc) and were analyzed with Taguchi Methods, have outputs presented in congruent sets (i.e. Min/Nom/Max stiffness, damping and inertia terms are a result of a single set of input parameters respectively). A single output parameter is used to label Min/Nom/Max properties. In the case of the damper seal, direct damping was chosen. Thus, the summary tables may list maximum values for direct damping (Cxx) but have minimum values for other parameters (Kxx, Kxy, etc.). This is intended to represent actual trends in hardware configuration. For example, if a given clearance were to produce maximum direct damping and minimum direct stiffness, this set of output parameters are used of a quoted "maximum damper seal configuration" in the rotordynamic analyses. It would represent damper seal parameters for a single clearance (i.e. MAXIMUM damping and MAXIMUM stiffness would not be predicted for a maximum clearance value).

5.1.1 Aeromechanical Force Coefficients

Cross Coupled Stiffness (K_{xy}) is calculated from the model illustrated in equation 1.0 of Section 2.1.1. for each of the three turbine stages. The results of each stage are summed as a single parameter and applied at the Turbine CG. These results have been varied by the nondimensional value of BETA (see METHODS SECTION). The values used for BETA are 0.6/1.0/1.5 for Min/Nom/Max conditions. These values reflect the empirical range of P&W and Rocketdyne experience. Results summarized below are the total turbine force coefficient for 65%, 90% and 109% RPL. Plots of Aeromechanical Force Coefficients vs Speed are provided in Figure 58 on page 93.

Level	Beta	Rated Power Level	Kxy (lb/in)
Min	0.6	65%	2,725
		90%	4,500
		109%	6,075
Nom	1.0	65%	4,525
		90%	7,525
		109%	10,175
Max	1.5	65%	6,825
		90%	11,250
		109%	15,200

Table 26. Aeromechanical Force Coefficient Sensitivity

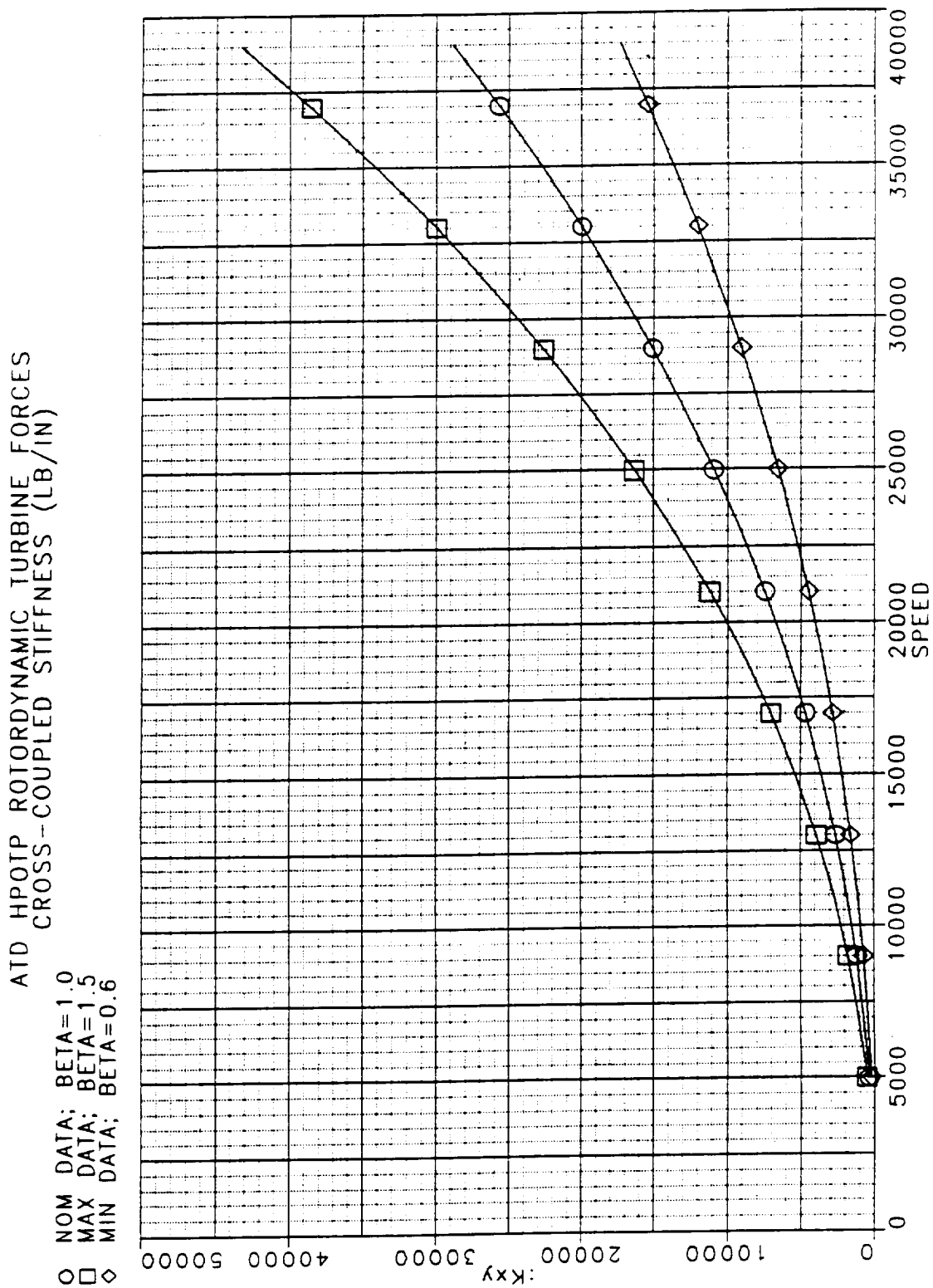


Figure 58. Aeromechanical Force Coefficients vs Speed

5.1.2 Hydromechanical Force Coefficients

Stiffness, damping and inertia terms are calculated from the model illustrated in equation 2.0 of Section 2.1.2. for the preburner and main stage impeller. The results of each impeller have been varied by +/- 25% but holding the cross coupled stiffness constant so that the whirl ratio (Kxy/Cxx) would vary in the parametric evaluation of Hydromechanical coefficients. Results summarized below are for 65%, 90% and 109% RPL. Ptops of Hydromechanical Force Coefficients vs Speed are provided in Figure 59 on page 95 for the Preburner Stage Impeller (PBI) and Figure 60 on page 96 for the Main Stage Impeller (MSI).

Level	Whirl Ratio	Rated Power Level	Dynamic Coefficients					
			K_{xx} lb/in	K_{xy} lb/in	C_{xx} lb-s/in	C_{xy} lb-s/in	M_{xx} lb-s²/in	M_{xy} lb-s²/in
Min (-25%)	0.25	65%	-3,348	2,694	3.70	5.8	0.002	0.0003
		90%	-5,277	4,247	4.70	7.3	0.002	0.0003
		.109%	-6,949	5,592	5.40	8.3	0.002	0.0003
Nom	0.50	65%	-4,464	2,694	3.00	7.7	0.003	0.0004
		90%	-7,036	4,247	3.80	9.7	0.003	0.0004
		109%	-9,265	5,592	4.30	11.1	0.003	0.0004
Max (+25%)	0.75	65%	-5,580	2,694	2.30	9.6	0.004	0.0005
		90%	-8,795	4,247	2.80	12.1	0.004	0.0005
		109%	-11,582	5,592	3.30	13.9	0.004	0.0005

Table 27. PBI Hydromechanical Force Coefficient Sensitivity

Level	Whirl Ratio	Rated Power Level	Dynamic Coefficients					
			K_{xx} lb/in	K_{xy} lb/in	C_{xx} lb-s/in	C_{xy} lb-s/in	M_{xx} lb-s²/in	M_{xy} lb-s²/in
Min (-25%)	0.25	65%	-26,507	21,332	29.50	45.9	0.020	0.002
		90%	-41,782	33,625	37.10	57.6	0.020	0.002
		109%	-55,020	44,278	42.50	66.1	0.020	0.002
Nom	0.50	65%	-35,343	21,332	23.90	61.1	0.020	0.002
		90%	-55,710	33,625	30.00	76.8	0.020	0.002
		109%	-73,360	44,278	34.40	88.1	0.020	0.002
Max (+25%)	0.75	65%	-44,178	21,332	17.90	76.4	0.030	0.004
		90%	-69,637	33,625	22.50	95.9	0.030	0.004
		109%	-91,699	44,278	25.84	110.1	0.030	0.004

Table 28. MSI Hydromechanical Force Coefficient Sensitivity

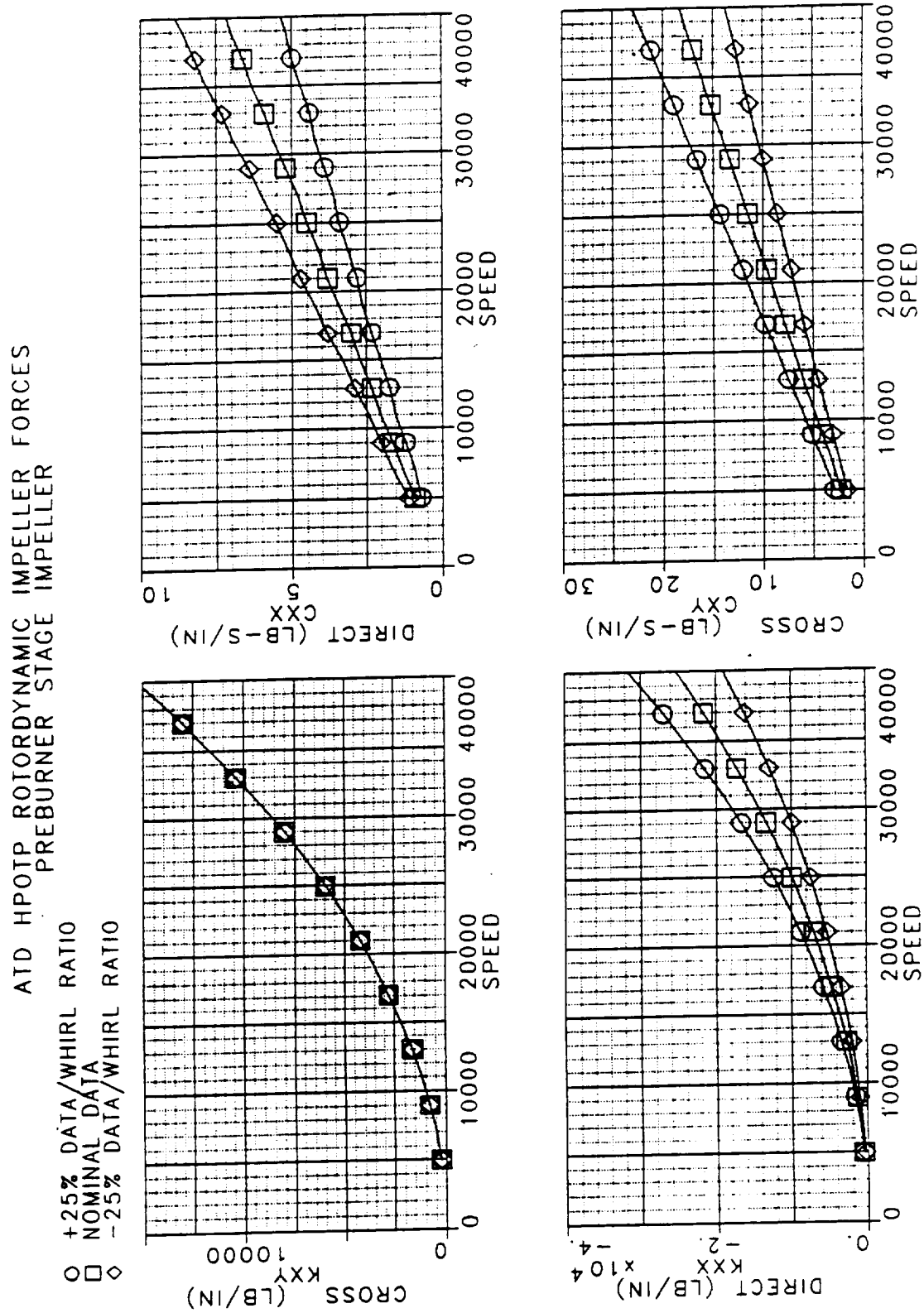


Figure 59. Hydromechanical Force Coefficients vs Speed: Preburner Stage Impeller

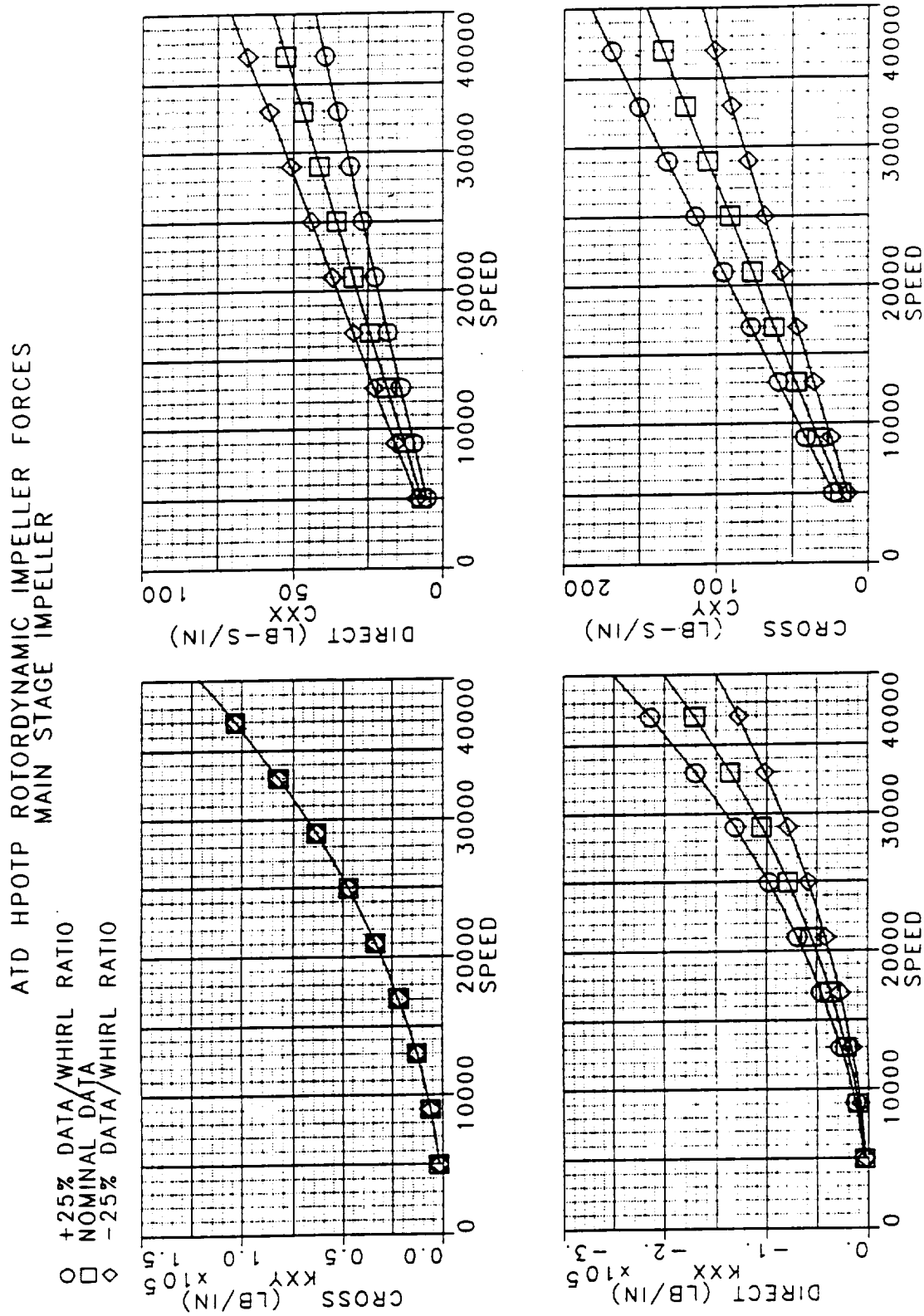


Figure 60. Hydromechanical Force Coefficients vs Speed: Main Stage Impeller

5.1.3 Damper Seal Coefficients

PARAMETRIC ANALYSIS of the preburner impeller damper seal include variations in pressure, clearance, clearance taper, and inlet tangential velocity ratio, as outlined in the study plan of Appendix A. Taguchi statistical methods were used to calculate input parameter sensitivities and establish a response table for use in identifying the combination of input that would yield minimum and maximum outputs.

The input variations are tabulated below and were used in a Taguchi L9 array. The output from the array are included in Appendix G. From the array, the sensitivities results can be found and are presented in Figure 61 on page 98 The combination of input parameter levels are then calculated from the array and used for confirmation runs with the damper seal analysis. The results from this "Paper Champ" are the MINIMUM and MAXIMUM damper seal output conditions. These results are tabulated in Table 30 on page 98 and plotted vs speed in Figure 62 on page 99

Rated Power Level	Level	Average Clearance (inch)	Clearance Taper (rad)	Delta Pressure (psi)	TVR
65%	1	0.0058	0.0023	1,300	0.1
	2	0.0068	0.0038	1,500	0.3
	3	0.0078	0.0053	1,700	0.5
90%	1	0.0053	0.0023	2,700	0.1
	2	0.0063	0.0038	2,900	0.3
	3	0.0073	0.0053	3,100	0.5
109%	1	0.0048	0.0023	4,200	0.1
	2	0.0058	0.0038	4,400	0.3
	3	0.0068	0.0053	4,600	0.5
Note: TVR = Inlet Tangential Velocity Ratio.					

Table 29. Damper Seal Input Variation Levels:

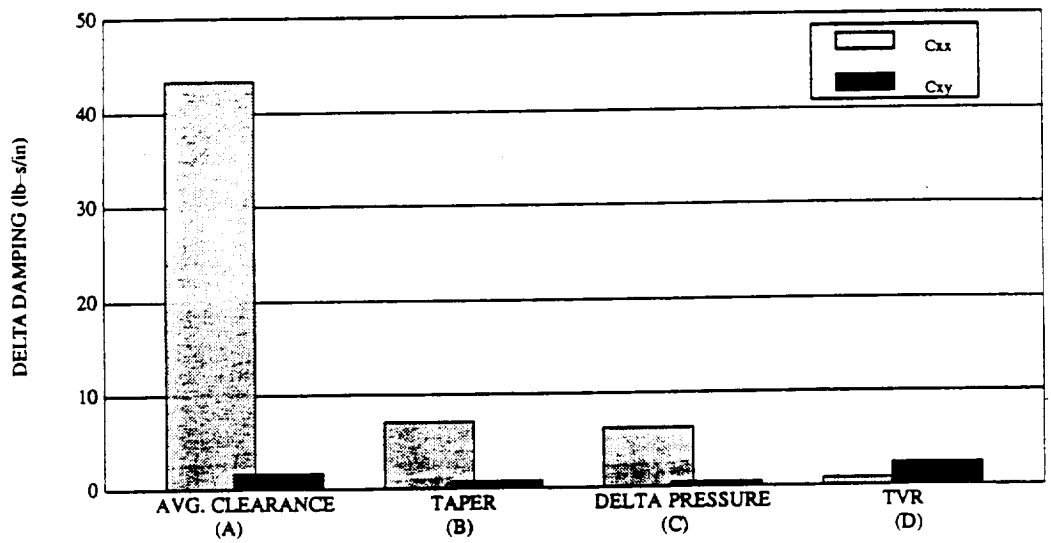


Figure 61. Damper Seal Coefficient Sensitivity

Level	Rated Power Level	Input Data				Output Data				
		TVR	Delta Press (psi)	Clearance (in)		K_{xx} lb/in	K_{xy} lb/in	C_{xx} lb-s/in	C_{xy} lb-s/in	M_{xx} lb-s²/in
				Inlet	Exit					
Min	65%	0.1	1300	0.0085	0.0070	111E3	7E3	43	1.10	0.63
	90%	0.1	2700	0.0080	0.0065	250E3	14E3	67	1.43	0.67
	109%	0.1	4200	0.0075	0.0060	419E3	22E3	90	1.75	0.72
Nom	65%	0.3	1500	0.0080	0.0055	170E3	26E3	55	1.83	0.75
	90%	0.3	2900	0.0075	0.0050	363E3	50E3	83	2.46	0.81
	109%	0.3	4400	0.0070	0.0045	610E3	77E3	112	3.07	0.89
Max	65%	0.5	1700	0.0075	0.0040	280E3	54E3	72	3.38	0.97
	90%	0.5	3100	0.0070	0.0035	580E3	99E3	107	4.75	1.09
	109%	0.5	4600	0.0085	0.0050	988E3	153E3	146	6.20	1.25

Note: Level is based on Direct Damping (Cxx).

Table 30. Damper Seal Coefficient Sensitivity:

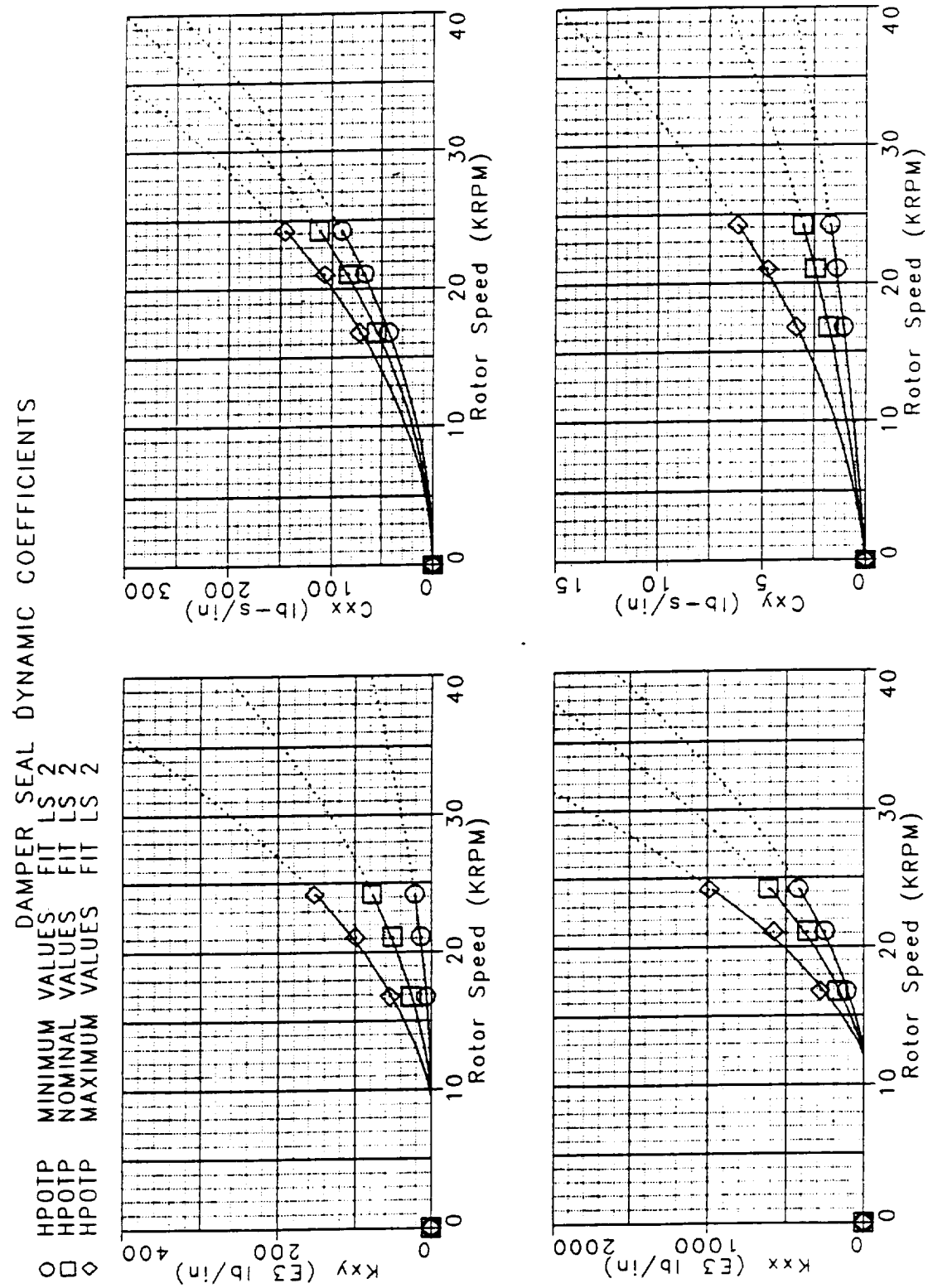


Figure 62. Damper Seal Coefficients vs Speed

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5.1.4 Turbine Interstage Seals

PARAMETRIC ANALYSIS of the turbine 1-2 and 2-3 interstage labyrinth seals include variations in pressure, clearance, gas temperature, and inlet tangential velocity ratio, as outlined in the study plan of Appendix A. Taguchi statistical methods were used to calculate input parameter sensitivities and establish a response table for use in identifying the combination of inputs that would yield minimum and maximum outputs.

The outputs are presented in similar arrangement as the damper seal parametric analysis.

The input variations are tabulated below and were used in a Taguchi L9 array. The output from the array are included in Appendix H. From the array, the sensitivities results can be found and are presented in Figure 63 on page 101 and Figure 64 on page 102. The combination of input parameter levels are then calculated from the array and used for confirmation runs with the damper seal analysis. The results from this "Paper Champ" are the MINIMUM and MAXIMUM damper seal output conditions. These results are tabulated in Table 32 on page 101 and Table 33 on page 102 and plotted vs speed in Figure 65 on page 103 and Figure 66 on page 104

Seal	Rated Power Level	Level	Average Clearance (inch)	Fluid Temp (F)	Delta Pressure (psi)	TVR
1-2	65%	1	0.0190	575	95	0.5
		2	0.0230	639	107	0.75
		3	0.0270	703	119	1.00
	90%	1	0.0190	823	187	0.5
		2	0.0230	915	193	0.75
		3	0.0270	1,007	201	1.00
	109%	1	0.0190	1,014	245	0.5
		2	0.0230	1,127	275	0.75
		3	0.0270	1,240	307	1.00
2-3	65%	1	0.0120	523	58	0.5
		2	0.0160	582	65	0.75
		3	0.0200	640	72	1.00
	90%	1	0.0120	750	111	0.5
		2	0.0160	834	123	0.75
		3	0.0200	917	136	1.00
	109%	1	0.0120	930	160	0.5
		2	0.0160	1,034	178	0.75
		3	0.0200	1,138	197	1.00

Note: TVR = Inlet Tangential Velocity Ratio.

Table 31. Turbine Interstage Seal Input Variation Levels

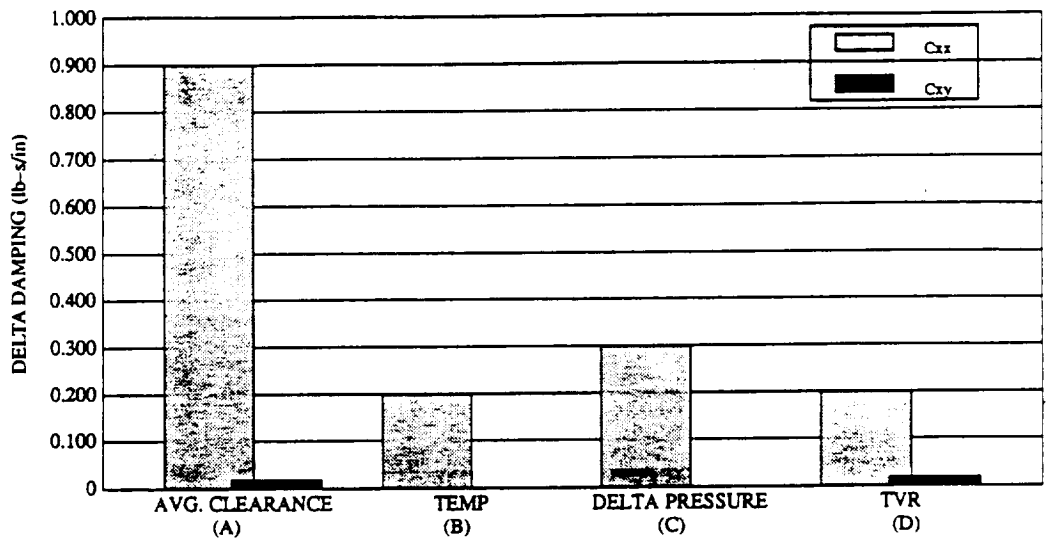

Figure 63. 1-2 Turbine Interstage Seal Coefficient Sensitivity

Level	Rated Power Level	Input Data				Output Data			
		Average Clearance (inch)	Fluid Temp (F)	Delta Pressure (psi)	TVR	K_{xx} lb/in	K_{xy} lb/in	C_{xx} lb-s/in	C_{xy} lb-s/in
Min	65%	0.0190	575	95	0.50	75	894	1.10	-0.011
	90%	0.0190	823	187	0.50	175	1,802	1.77	-0.019
	109%	0.0190	1,014	245	0.50	264	2,537	2.18	-0.024
Nom	65%	0.0230	639	107	0.75	156	1,683	1.34	-0.019
	90%	0.0230	915	193	0.75	328	3,220	2.06	-0.031
	109%	0.0230	1,127	275	0.75	506	4,692	2.63	-0.041
Max	65%	0.0270	703	119	1.00	269	2,781	1.69	-0.029
	90%	0.0270	1,007	201	1.00	528	5,081	2.51	-0.046
	109%	0.0270	1,240	307	1.00	851	7,710	3.32	-0.065

Note: Level is based on Direct Damping (Cxx).

Table 32. Turbine Interstage Seal Coefficient Sensitivity:

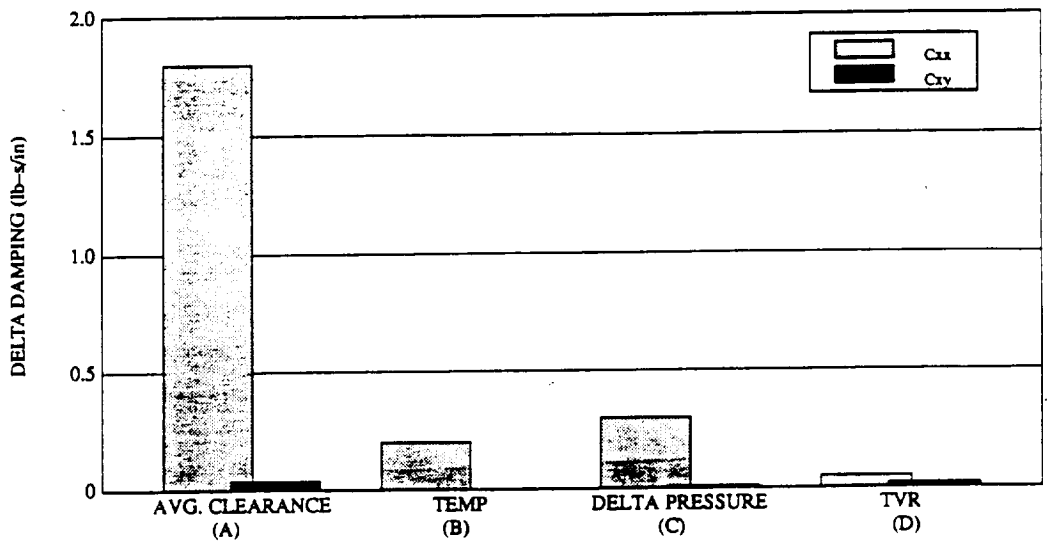

Figure 64. 2-3 Turbine Interstage Seal Coefficient Sensitivity

Level	Rated Power Level	Input Data				Output Data			
		Average Clearance (inch)	Fluid Temp (F)	Delta Pressure (psi)	TVR	K_{xx} lb/in	K_{xy} lb/in	C_{xx} lb-s/in	C_{xy} lb-s/in
Min	65%	0.0120	523	58	0.50	86	955	1.19	-0.013
	90%	0.0120	834	111	0.50	191	1,858	1.85	-0.022
	109%	0.0120	930	160	0.50	304	2,714	2.36	-0.029
Nom	65%	0.0160	582	65	0.75	179	1,848	1.57	-0.024
	90%	0.0160	836	836	0.75	381	3,530	2.40	-0.040
	109%	0.0160	1,034	1,034	0.75	597	5,151	3.05	-0.053
Max	65%	0.0200	640	72	1.00	321	3,237	2.19	-0.042
	90%	0.0200	917	136	1.00	686	6,178	3.35	-0.070
	109%	0.0200	1,138	197	1.00	1,075	8,991	4.26	-0.095

Note: Level is based on Direct Damping (Cxx).

Table 33. Turbine Interstage Seal Coefficient Sensitivity:

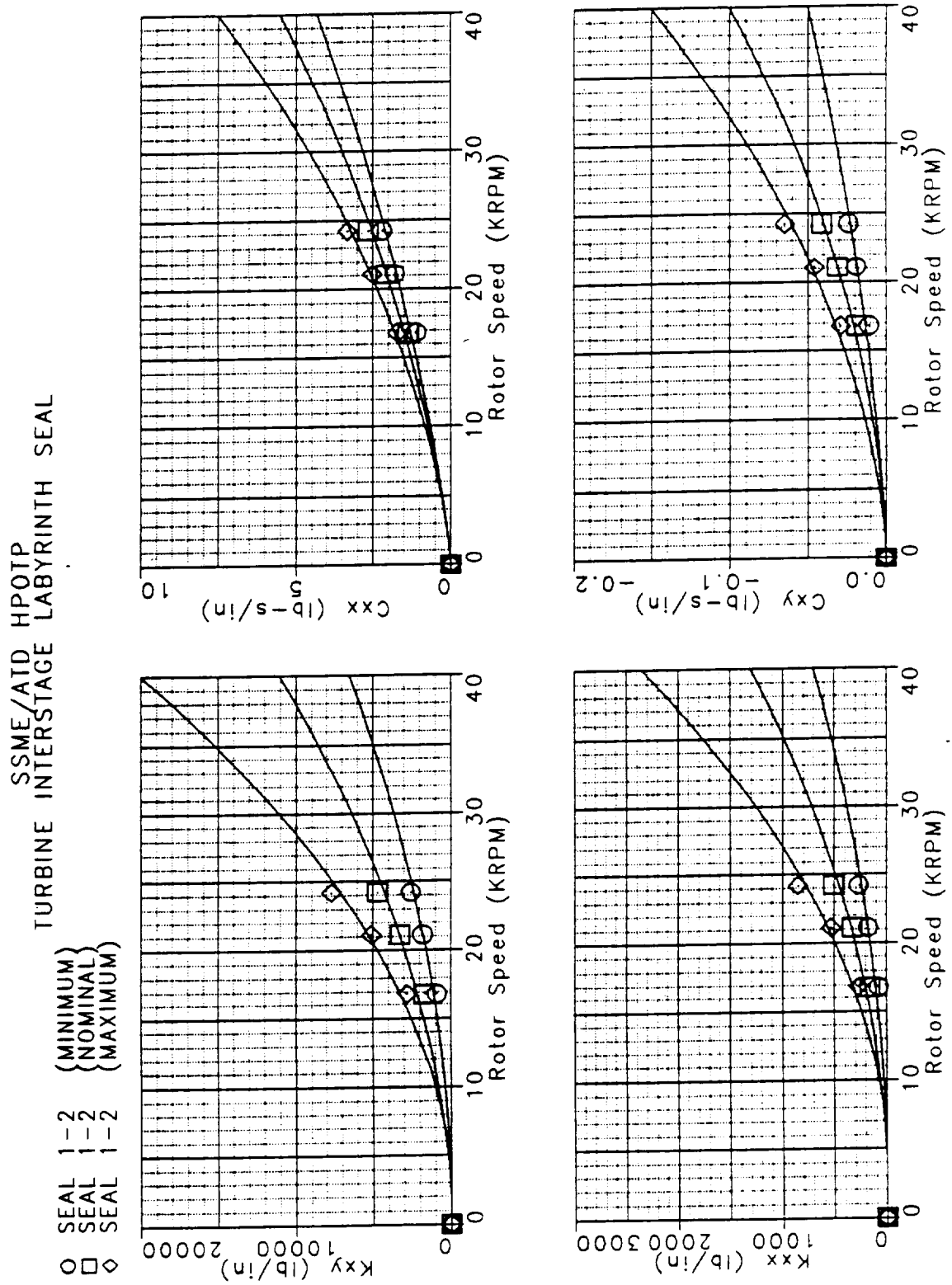

Figure 65. 1-2 Turbine Interstage Seal Coefficients vs Speed

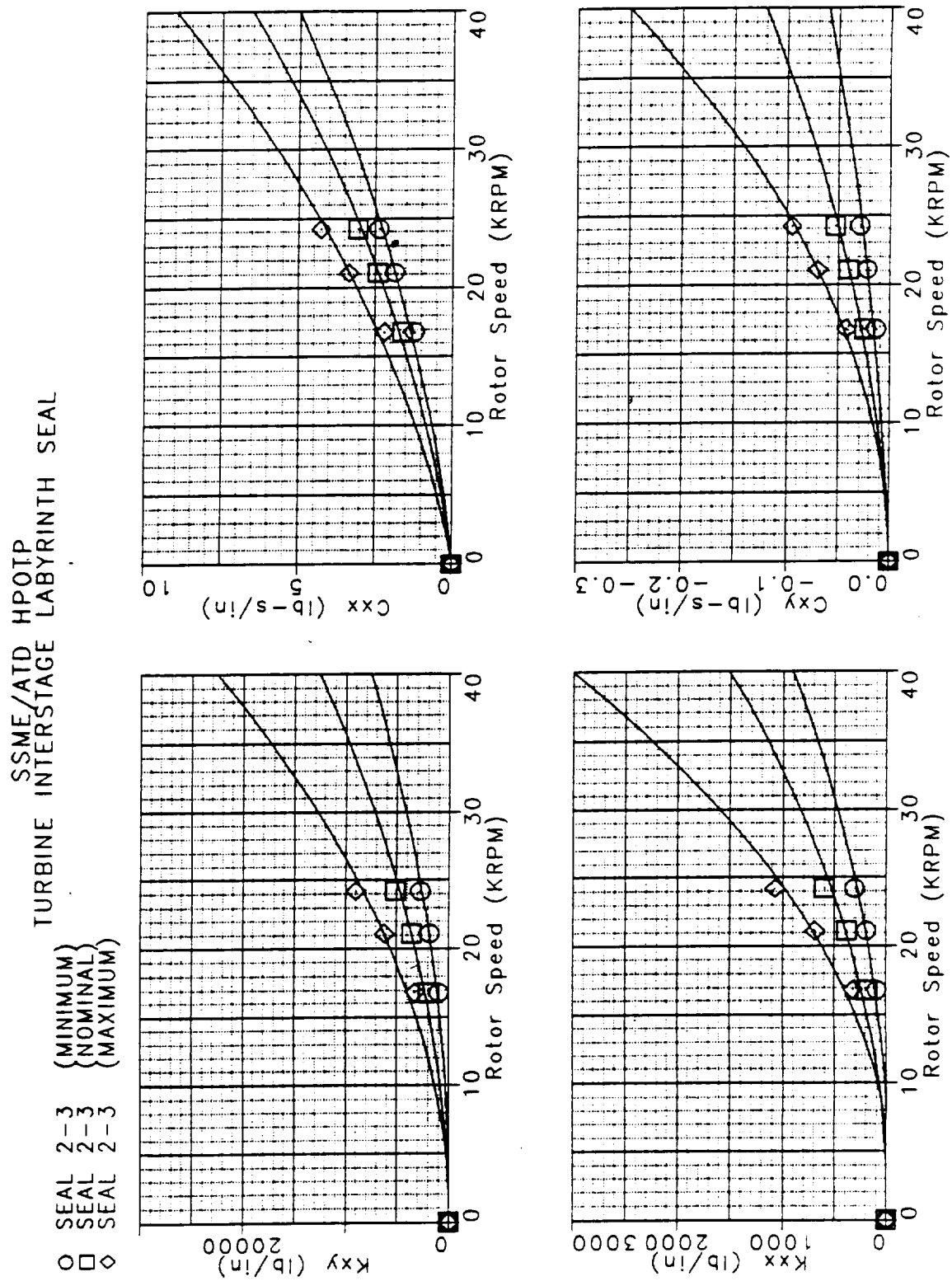

Figure 66. 2-3 Turbine Interstage Seal Coefficients vs Speed

5.1.5 Component Side Loads

Static side loads have been calibrated to main stage impeller and turbine flow rigs (Reference 12. on page 132). These loads are used in the nonlinear forced response analysis and are applied at each component stage (preburner impeller, main impeller and turbine) center of gravity (C.G.). Phase of each component is also provided from the Hydromechanical and Aeromechanical Component Design Groups. Loads, phase, and resultant bearing reaction loads are tabulated in Table 34. Variations were made in each component load of +/- 25% of the baseline values.

Level	Rated Power Level	Component Side Load (lb)			Resultant Bearing Load (lb)	
		PBI	MSI	Turbine	Ball Bearing	Roller Bearing
Min	65%	47	218	150	98	242
	90%	56	356	195	161	339
	109%	94	503	225	204	423
Nom	65%	62	290	200	130	322
	90%	75	475	260	215	452
	109%	125	670	300	272	564
Max	65%	78	363	250	163	403
	90%	94	594	325	269	565
	109%	156	838	375	340	705

Note: PBI is Preburner Impeller, MSI is Main Stage Impeller.

Table 34. Component Side Loads - Sensitivity

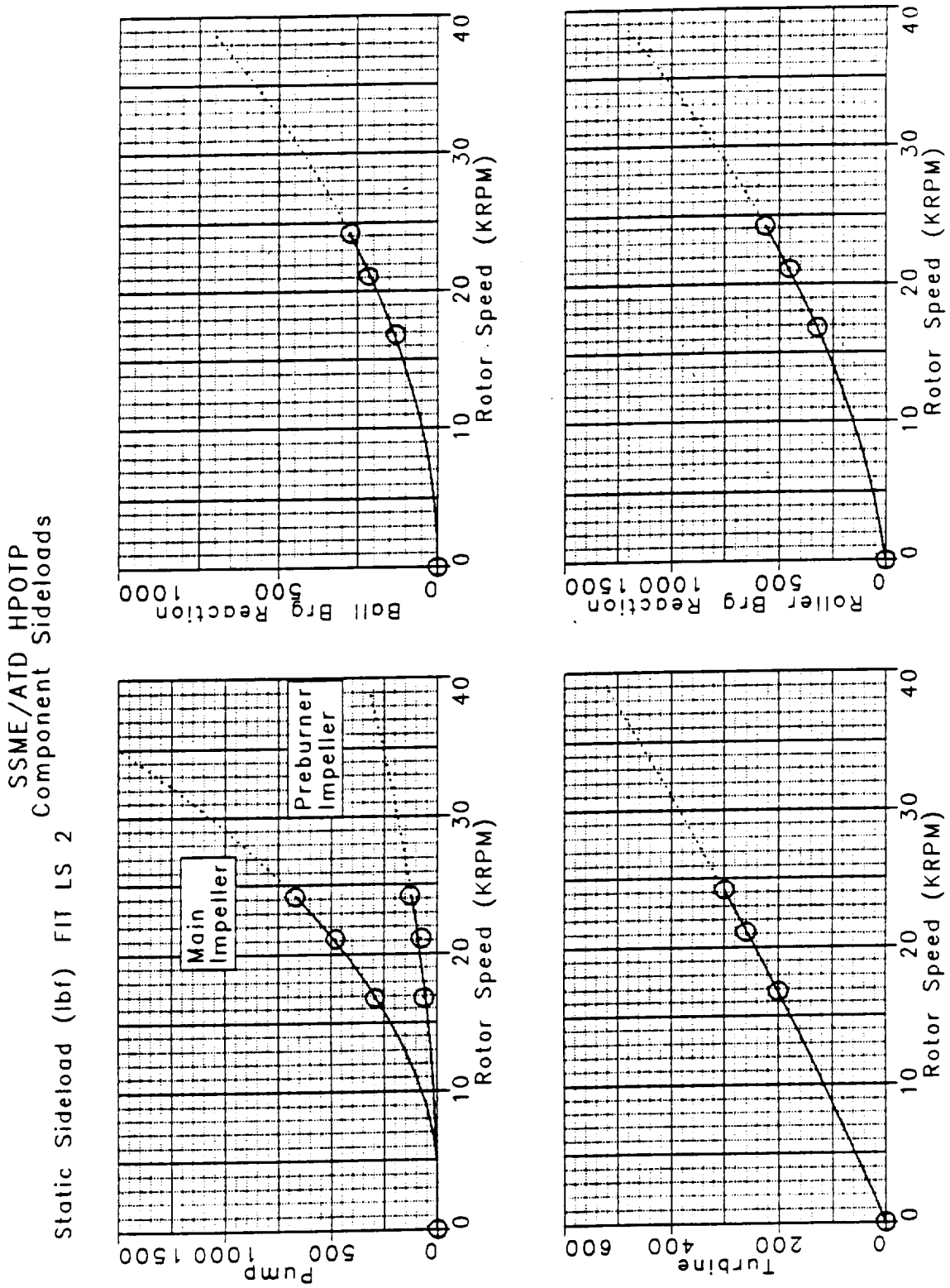

Figure 67. Component Side Load vs Speed

5.1.6 Bearing Radial Dynamic Stiffness

Dynamic radial bearing springrates used in the sensitivity analyses are include in the table below. These are values chosen for purposes of study and are not intended to represent actual operational ranges. However, bearing load deflection analyses, as presented in the METHODS section are included in Figure 68 on page 108 thru Figure 69 on page 109 for ball bearing and roller bearing stiffness. Analyses represent radial stiffness vs axial load for a set of axial preloads. Internal Radial Clearance (IRC) is varied for operational minimum and maximum values. Generally, the PEBB calculations are representative of actual values (predicted actual range is 0.82-1.10E6 lb/in) based on ATD bearing rig experience (11. on page 131). However, the roller bearing, as can be seen in Figure 69 on page 109, does not correlate. Thus, typical roller bearing values were used based on empirical data (see METHODS SECTION).

Bearing Radial Dynamic Springrate		
Level	**PEBB (lb/in)**	**TERB (lb/in)**
Min	0.50E6	2.50E6
Nom	0.75E6	3.50E6
Max	1.00E6	4.50E6
Note: Turbine-End bumper bearing transmits no radial rotor loads as a result of the outer race radial clearance.		

Table 35. Bearing Springrates - Sensitivity

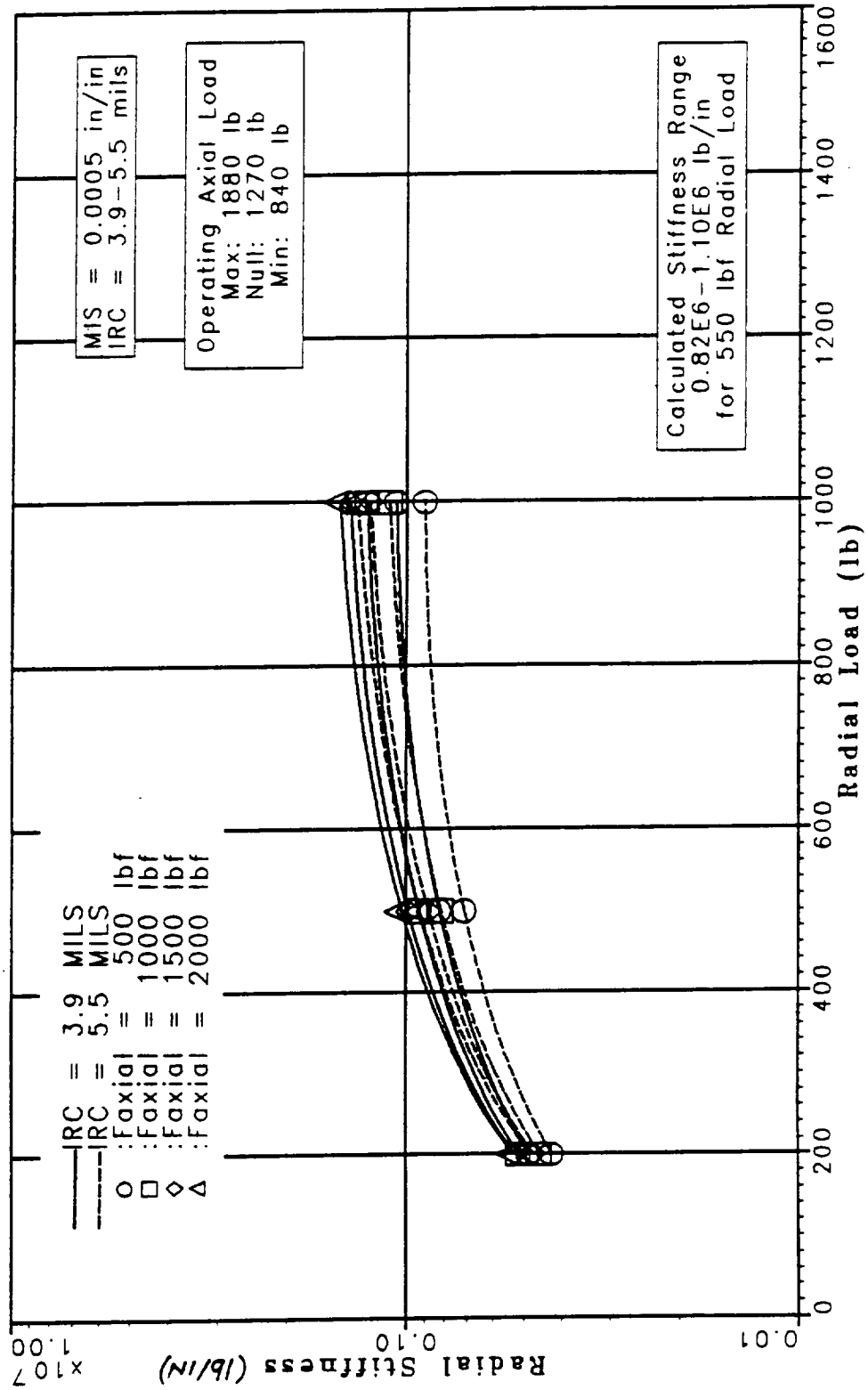

Figure 68. Ball Bearing Radial Stiffness Plot:

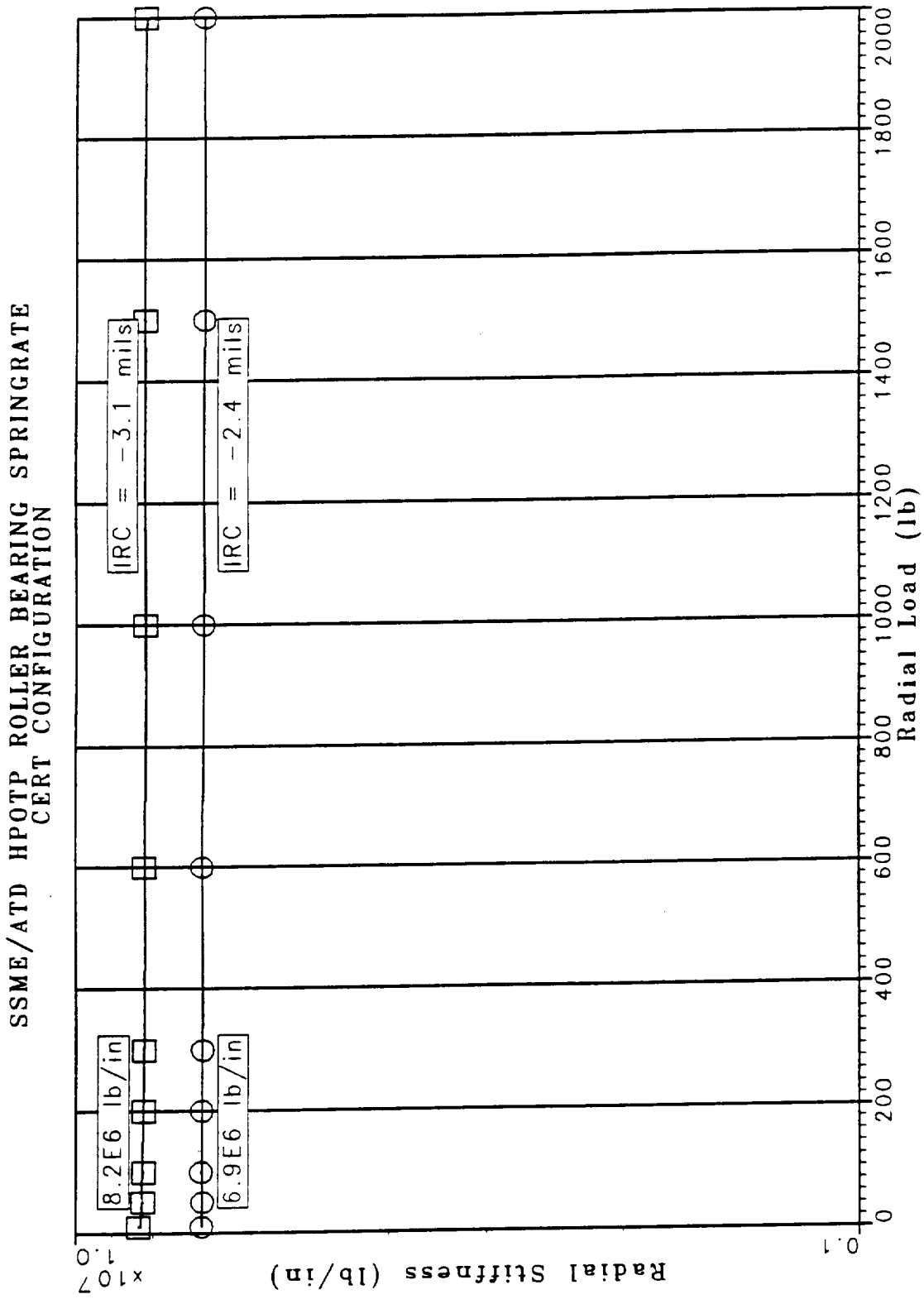

Figure 69. Ball Bearing Radial Stiffness Plot:

5.1.7 Bearing Deadband

Bearing deadband clearances used in the sensitivity analyses are presented in the table below. These are values chosen for purposes of study and are not intended to represent actual operational ranges. Actual clearances were being developed during the time of this analysis, but are expected to be within these ranges, with the exception of smaller tolerances (operational tolerances are expected to be approximately +/- 0.0005 in).

Bearing Deadbands (Dia.)		
Level	**PEBB (inch)**	**TERB (inch)**
Min	0.0010	0.0010
Nom	0.0025	0.0015
Max	0.0040	0.0020
Note: Deadbands are diametral dimensions.		

Table 36. Bearing Deadbands

5.1.8 Structural Damping

Structural Damping	
Level	**Critical Damping (%)**
Min	0.5
Nom	3.0
Max	6.0

Table 37. Structural Damping

5.1.9 Rotor Imbalance

The rotor imbalance distribution discussed in Section 2.1.8 has been used in the Sensitivity Analysis with phase change between the turbine and pump subassembly sections. Forced Response analyses were preformed using the Taguchi Methods for In-Phase and Out-of-Phase rotor imbalance with no alterations in the imbalance magnitudes.

5.2 Rotordynamic Analyses

Predicting the rotordynamic behavior of the HPOTP is best described through sensitivity studies on the variable rotordynamic component parameters. Each parameter has a different affect on how the turbopump responds during its operation. Likewise, each different combination of the levels of these parameters will change the behavior of the turbopump in a different way. Obviously, the number of different combinations of rotordynamic parameter levels for a turbopump can be enormous. For example, if there are nine parameters and each could be in one of two different states at any time, the number of independent combinations of these parameters and states is 2^9 or 512. Making 512 different analytical runs for a rotordynamic sensitivity study would be very time consuming. Therefore, implementing a statistical method for a study of this sort would prove cost-effective as will ensure robustness.

In the case of the HPOTP, linear and nonlinear rotordynamic parameter sensitivity studies were completed using 'Design of Experiments Methods' or Taguchi design optimization technique. This statistical method is based on an orthogonal (balanced) array compiled and customized with an assignment of variables by Dr. Taguchi. A simple example of the Taguchi design optimization method is shown in Appendix B.

The sensitivity studies for both linear and nonlinear rotordynamic analyses on the HPOTP are summarized in the following two subsections. Plots of each parametric nonlinear forced response analysis from which the summaries were taken, are included in Appendix I.

5.2.1 Linear Analysis Sensitivity Study

Critical speeds of the HPOTP are largely dependent on the pump end and turbine end rotor supports. The pump end support is a split contribution from the PEBB and damper seal direct stiffness, and the turbine end support is dependent on the TERB direct stiffness. Further, the rotor supports are major contributors to the principal rotor Pump Bounce Mode and Turbine Bounce Mode. Sensitivity plots (Figure 70 on page 112 thru Figure 73 on page 115) of the first six (6) system modes are presented for variations in pump end and turbine end support stiffness. These results are intended as a guide to parameter sensitivity for the nonlinear analyses.

The critical speed plots show the Pump Bounce Mode is sensitive to pump end rotor support stiffness and Turbine Bounce Mode sensitivity to turbine end rotor support stiffness. Likewise, the Pump Bounce Mode is not sensitivity to turbine end rotor support stiffness and the Turbine Bounce Mode is not sensitive to pump end rotor support stiffness. The only other system mode sensitivity to rotor support stiffness can be seen in the Housing Bending Mode at approximately 45 KRPM, to both pump end and turbine end rotor support stiffness.

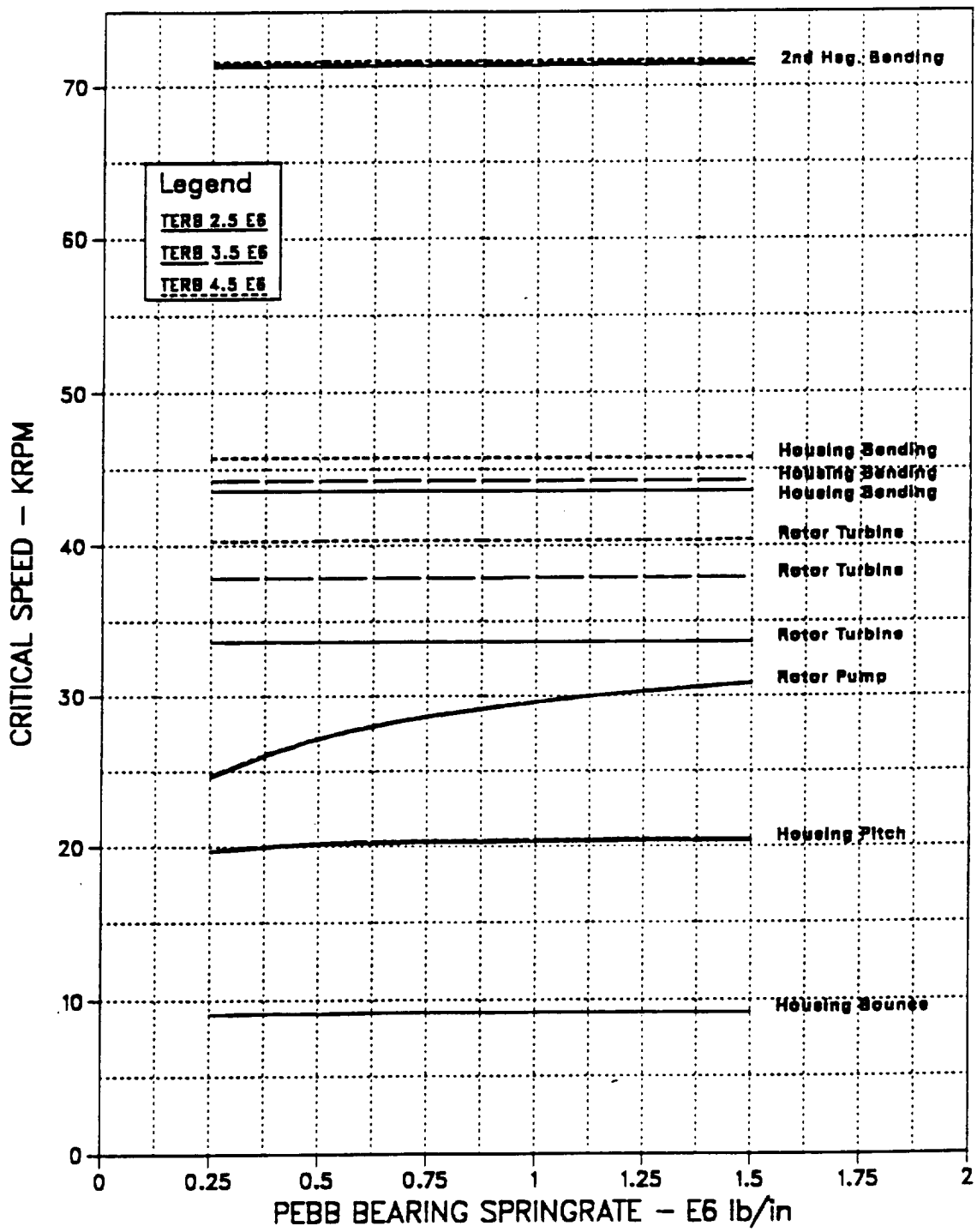

Figure 70. Critical Speed Sensitivity Map: PEBB Springrate (X-Z Plane)

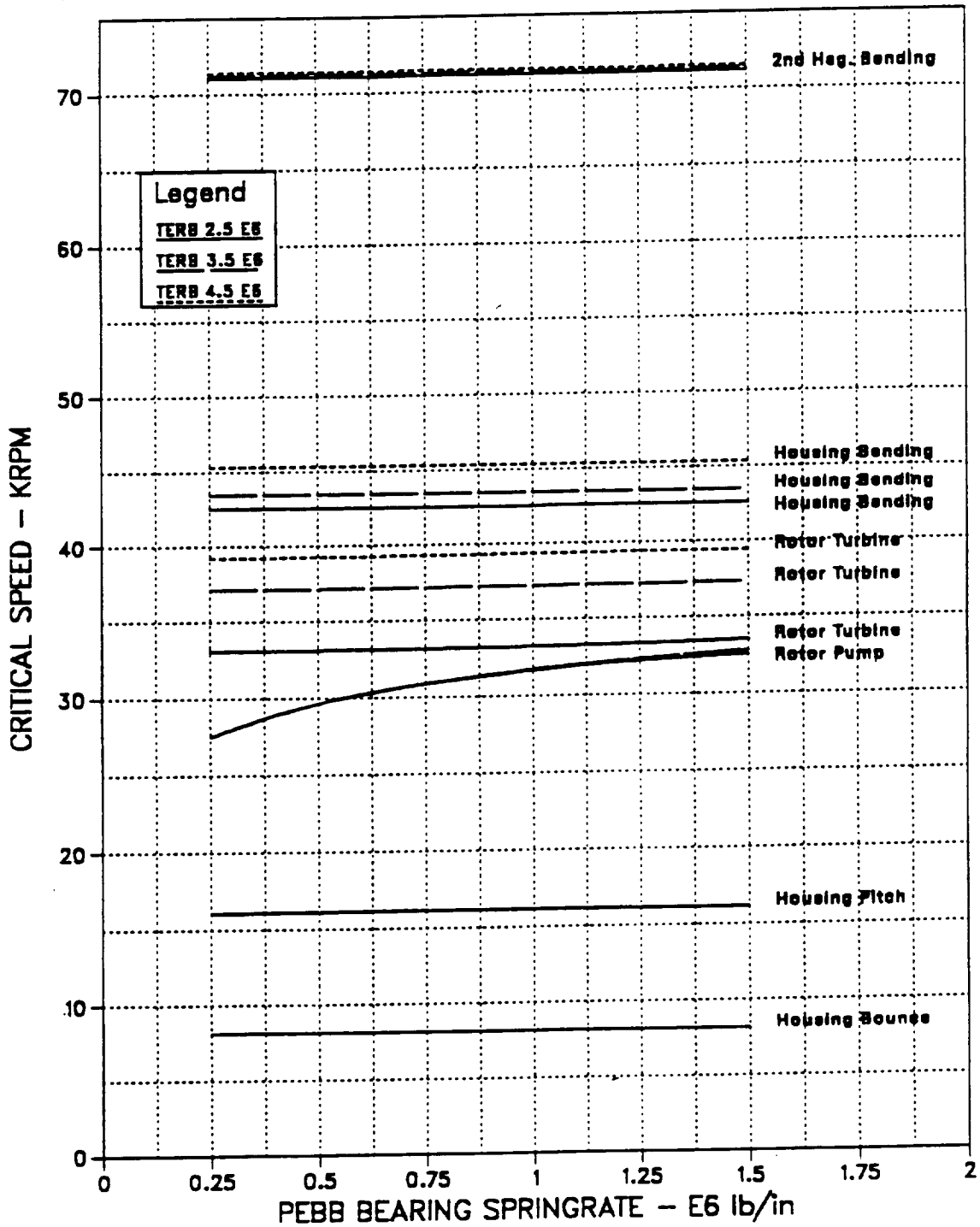

Figure 71. Critical Speed Sensitivity Map: PEBB Springrate (Y-Z Plane)

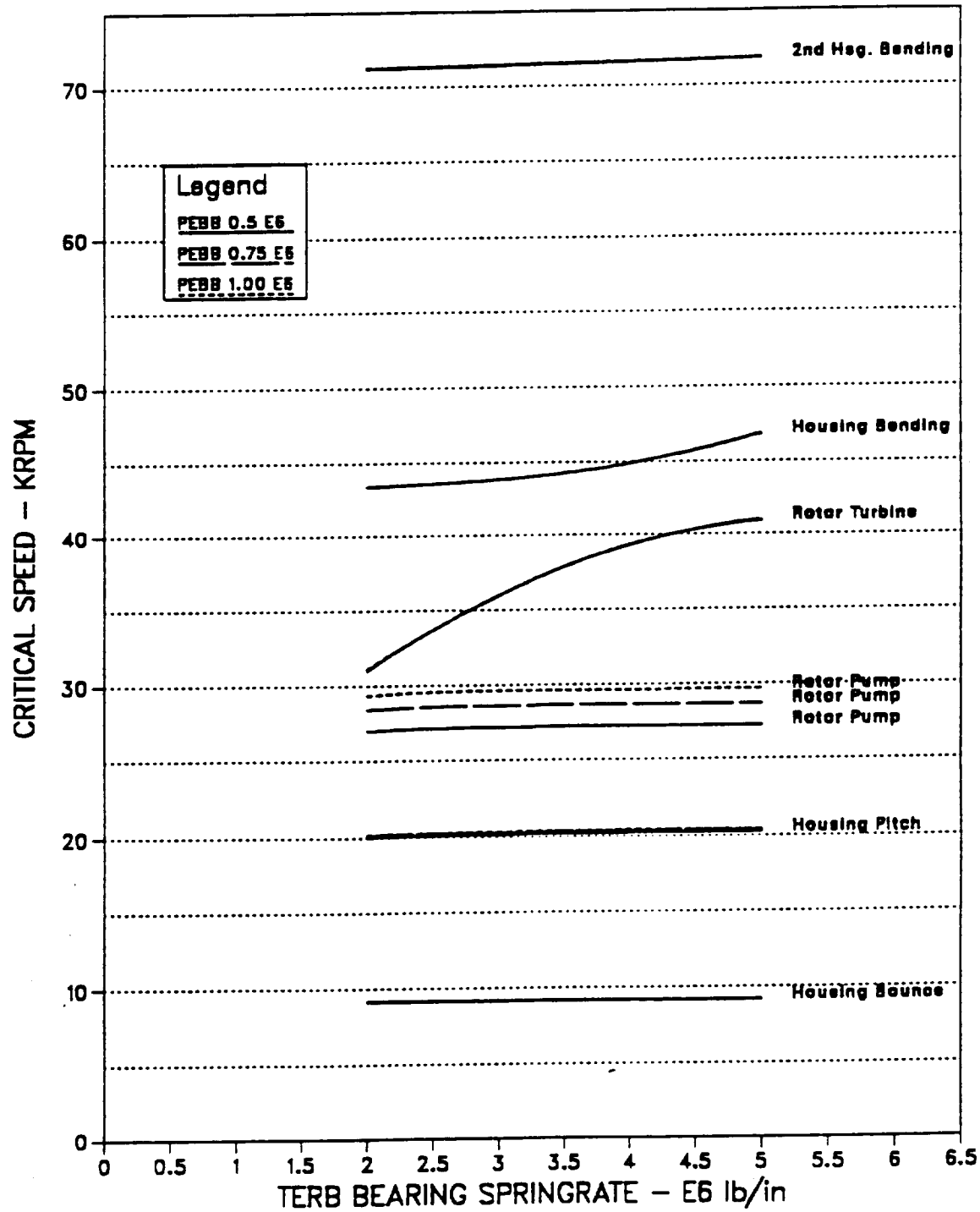

Figure 72. Critical Speed Sensitivity Map: TERB Springrate (X-Z Plane)

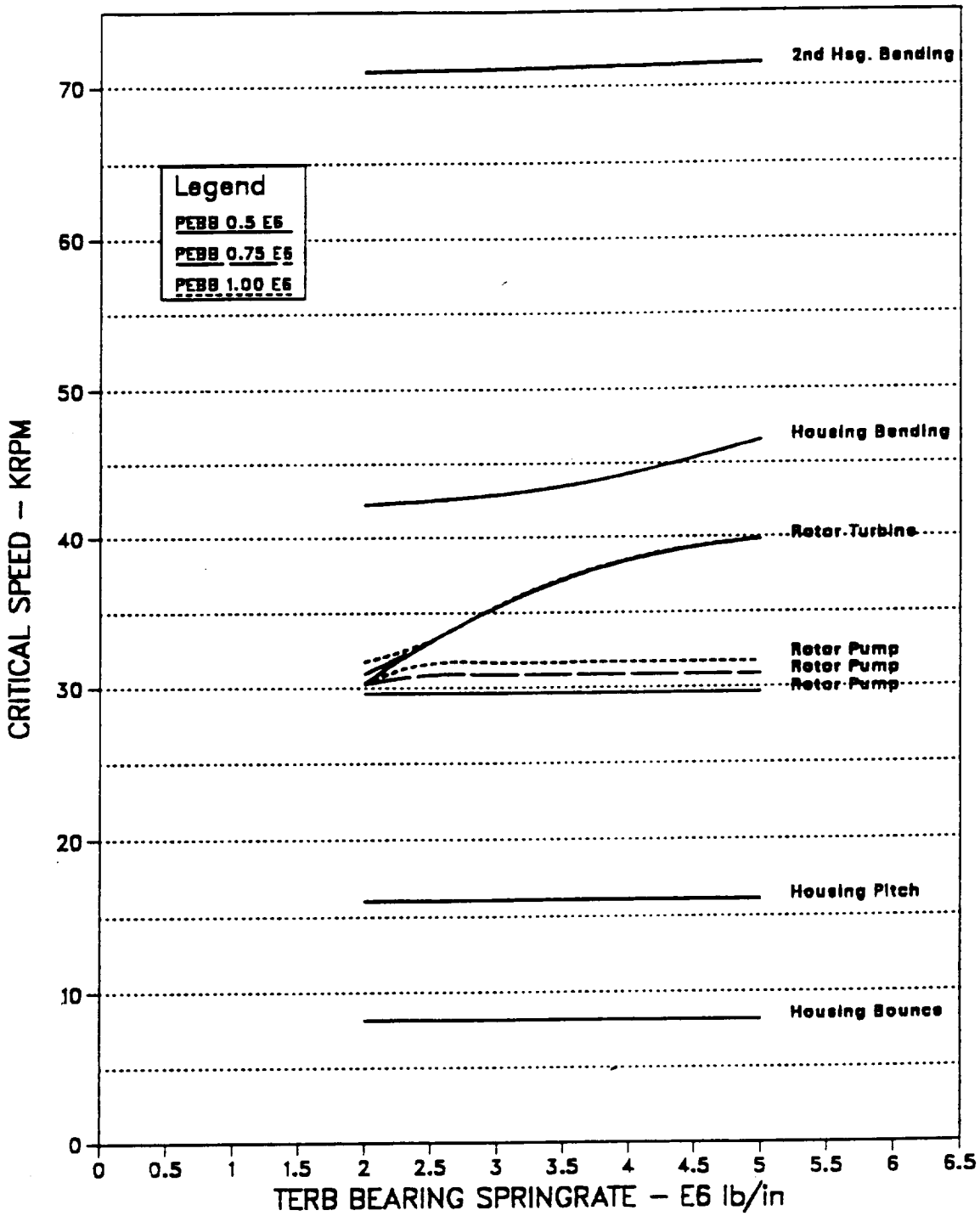

Figure 73. Critical Speed Sensitivity Map: TERB Springrate (Y-Z Plane)

In the linear stability sensitivity study, the statistical Taguchi approach was implemented for seven parameters each having two levels. The parameters studied were damper seal forces, turbine seal forces, turbine blade forces, impeller forces, ball bearing springrate, roller bearing springrate and structural damping. The two levels for each of these parameters are contained in Table 38 on page 117. An orthogonal array L_8 was used to define eight test cases for this study (Appendix G). The parameter sensitivity Figure 74 shows which parameters affect the logarithmic decrement of the rotor modes the greatest. For instance, the stability of the rotor pump mode is most sensitive to the impeller forces and least sensitive to the turbine labyrinth seal forces. Likewise, the stability of the 1st rotor bending mode is most sensitive to the damper seal forces and least sensitive to the structural housing damping. Figure 74 is a plot of the differences between the output averages for each parameter level, taken from the Taguchi response table (Appendix H).

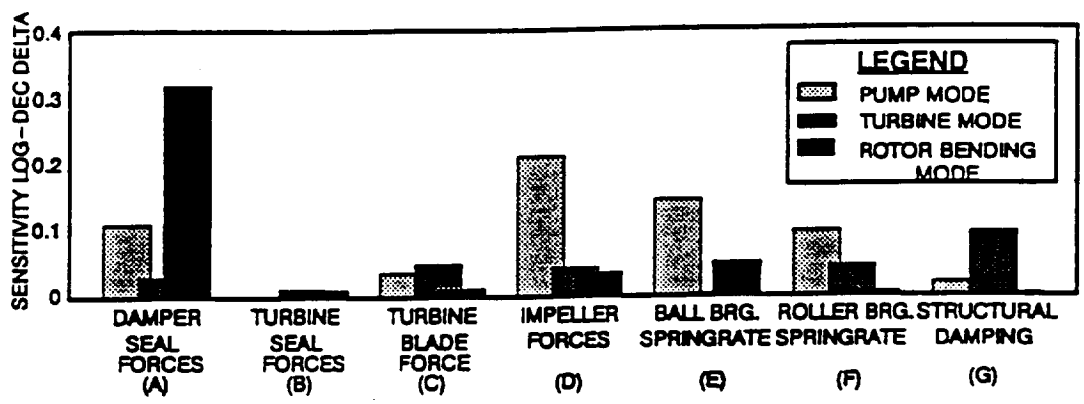

Figure 74. Stability Analysis Parameter Sensitivity Results

Contained in Table 39 on page 117 are the minimum and maximum stability parameter level combinations for each mode. These combinations were established through the paper champ experiment and the LOG-DEC values were taken at 109% (24,230 RPM). The table shows that the minimum predicted stability condition for the pump mode has a LOG-DEC value of 0.027 and an OSI of 29 KRPM. This was the only combination of parameter levels to give an OSI below 39 KRPM for any of the three rotor modes. In addition, both the turbine mode and 1st rotor bending mode demonstrated stable characteristics for their minimum stability combinations.

Stability Analysis Parameter Values at 109% RPL								
Parameter	Level	K_{xx} lb/in	K_{xy} lb/in	C_{xx} lb-s/in	C_{xy} lb-s/in	M_{xx} lb-s²/in	M_{xy} lb-s²/in	Zeta
A) Damper Seal	1	4.19E6	2.2E4	9.0E1	1.75	7.2E-1	-	-
	2	9.88E6	1.53E5	1.46E2	6.2	1.25	-	-
B) Turbine Laby Seals	1	5.68E2	5.251E3	4.54	-5.3E-2	-	-	-
	2	1.926E3	1.67E3	7.58	-1.6E-1	-	-	-
C) Turbine Blade Forces	1	-	6.075E3	-	-	-	-	-
	2	-	1.52E4	-	-	-	-	-
D) Impeller *Forces*[1]	1	-5.5E4	4.428E4	4.25E1	6.61E1	2.0E-2	2.0E-3	-
	2	-9.17E4	4.428E4	2.58E1	1.101E1	3.0E-2	4.0E-3	-
E) Ball Bearing	1	5.0E5	-	-	-	-	-	-
	2	1.0E6	-	-	-	-	-	-
F) Roller Bearing	1	2.5E6	-	-	-	-	-	-
	2	4.5E6	-	-	-	-	-	-
G) Structural Damping	1	-	-	-	-	-	-	5.0E-3
	2	-	-	-	-	-	-	6.0E-2

Note: 1) Parameter values listed for main stage impeller only. However, both main stage and preburner impellers were changed together.

Table 38. Stability Analysis Parameter Levels

Stability Combinations at 109% RPL									
Mode	State	Combination							Log-dec (OSI)
Pump Mode	Min	A2	B2	C2	D2	E2	F1	G1	0.027 (29 KRPM)
	Max	A1	B1	C1	D1	E1	F2	G2	0.515 (>39 KRPM)
Turbine Mode	Min	A2	B1	C2	D2	E1	F2	G1	0.107 (>39 KRPM)
	Max	A1	B2	C2	D1	E1	F2	G2	0.285 (>39 KRPM)
1st Rotor Bending Mode	Min	A1	B2	C2	D2	E2	F1	G1	1.440 (>39 KRPM)
	Max	A2	B1	C1	D1	E1	F2	G2	1.900 (>39 KRPM)

Table 39. Stability Analysis Paper Champs

To summarize, based on the linear analytical study of seven rotordynamic parameters for the HPOTP, Figure 74 on page 116 shows which of these seven parameters has the biggest affect on the rotor stability (e.g. increasing the stability of the pump mode can be accomplished largely with the decrease in impeller forces). Also, the minimum stability condition of the parameters still demonstrates stable rotordynamic behavior.

5.2.2 Nonlinear Analysis Sensitivity Study

In the nonlinear forced response sensitivity study, nine parameters were varied using two levels. The nine parameters were damper seal forces, turbine labyrinth seal forces, impeller forces, ball bearing springrate, roller bearing springrate, structural damping, ball bearing deadband, roller bearing deadband and static side loads. The two levels for each of these parameters can be found in Table 40 on page 119. An orthogonal array L_{12} was used from the Taguchi statistical design optimization technique (Appendix H). This array established twelve test cases for the sensitivity study. The results are shown in Figure 75 for two separate cases, turbine imbalance in-phase with the pump imbalance and turbine imbalance 180 degrees out-of-phase with the pump imbalance. It can be seen from this figure that for an in-phase turbine imbalance the pump housing response at 109% RPL (24,230 RPM) is most sensitive to impeller forces and structural damping where as it is least sensitive to ball bearing deadband. For an out-of-phase turbine imbalance case the static side loads are the most sensitive parameter and the roller bearing springrate is least sensitive. Figure 75 is a plot of the differences between the output averages for each parameter level, taken from the Taguchi response table (Appendix H).

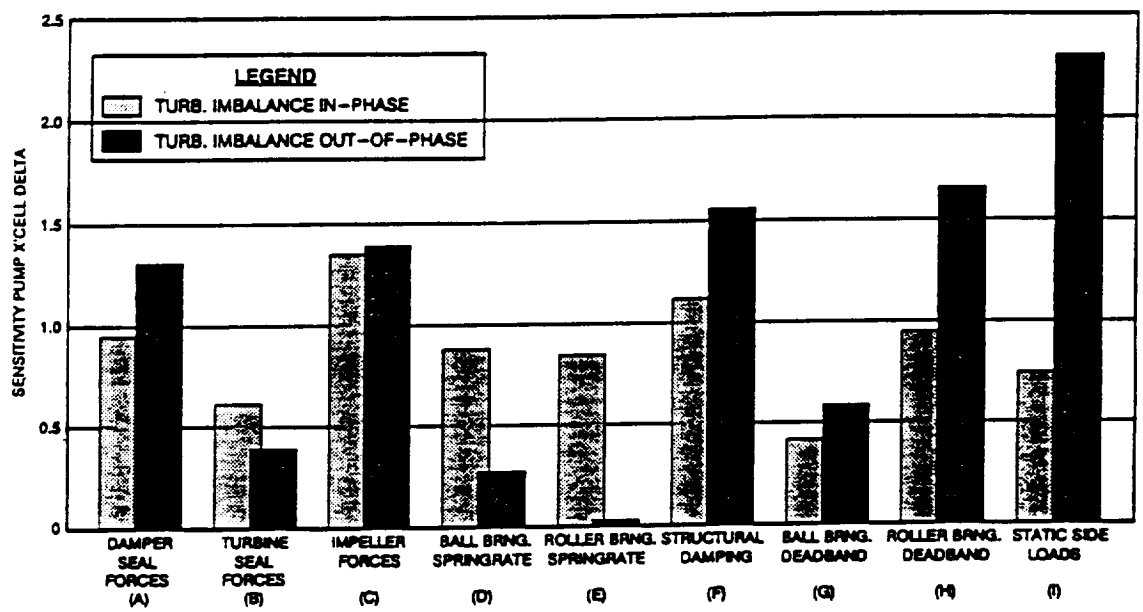

Figure 75. Nonlinear Analysis Pump HSG Response Sensitivity Results

Nonlinear Analysis Parameter Values at 109% RPL							
Parameter	**Level**	K_{xx} lb/in	K_{xy} lb/in	C_{xx} lb-s/in	**Zeta**	**Clearance**	**Side Load**
A) Damper Seal	1	4.19E6	2.2E4	9.0E1	-	-	-
	2	9.88E6	1.53E5	1.46E2	-	-	-
B) Turbine Laby Seals	1	5.68E2	5.251E3	4.54	-	-	-
	2	1.926E3	1.67E3	7.58	-	-	-
C) Impeller *Forces*[1]	1	-5.5E4	4.428E4	4.25E1	-	-	-
	2	-9.17E4	4.428E4	2.58E1	-	-	-
D) Ball Bearing	1	5.0E5	-	-	-	-	-
	2	1.0E6	-	-	-	-	-
E) Roller Bearing	1	2.5E6	-	-	-	-	-
	2	4.5E6	-	-	-	-	-
F) Structural Damping	1	-	-	-	5.0E-3	-	-
	2	-	-	-	6.0E-2	-	-
G) Ball Bearing deadband	1	-	-	-	-	5.0E-4	-
	2	-	-	-	-	2.0E-3	-
H) Roller Bearing Deadband	1	-	-	-	-	5.0E-4	-
	2	-	-	-	-	1.0E-3	-
I) Static Side *Loads*[2]	1	-	-	-	-	-	2.203E2
	2	-	-	-	-	-	3.671E2

Note: 1) Parameter values listed for main stage impeller only. However, both main stage and preburner impellers were changed together. 2) Main stage impeller (X-Dir.) side load listed only. However, turbine and preburner impeller side loads were changed accordingly.

Table 40. Nonlinear Analysis Parameter Levels

Pump Hsg. Response Conditions at 109 %RPL											
Turbine Imbalance	**State**	**Combination**									**Gs Peak**
In-Phase With Pump	Min	A1	B1	C1	D2	E1	F2	G2	H1	I2	2.4
	Max	A2	B2	C2	D1	E2	F1	G1	H2	I1	9.0
Out-of-Phase With Pump	Min	A1	B2	C2	D2	E1	F2	G2	H1	I2	3.0
	Max	A2	B1	C2	D2	E2	F1	G2	H2	I1	11.5

Table 41. Nonlinear Analysis Paper Champs

Table 41 shows the minimum and maximum pump housing response combinations of parameter levels. For an in-phase turbine imbalance the pump housing response at 109% RPL (24,230 RPM) could be as low as 2.4 G's and as high as 9.0 G's peak. Likewise, for an out-of-phase turbine imbalance, the pump housing response could be as low as 3.0 G's and as high as 11.5 G's. These minimum and maximum pump housing responses represent the best and worst case response of the pump housing at 109% RPL.

In summary, Figure 75 on page 118 can be used as a guide to the sensitivity of each nine rotordynamic parameters as they affect the pump housing response of the HPOTP (e.g. the pump housing response is most sensitive to the amount of structural damping in the housing, for an in-phase turbine imbalance, and least sensitive to the pump end ball bearing deadband at 109% RPL). Also, the best and worst case pump housing response is shown in Table 41 on page 119. Parameter sensitivity graphs for pump end bearing load, turbine end bearing load, preburner impeller deflection, main stage impeller deflection and turbine CG deflection are shown in the following figures.

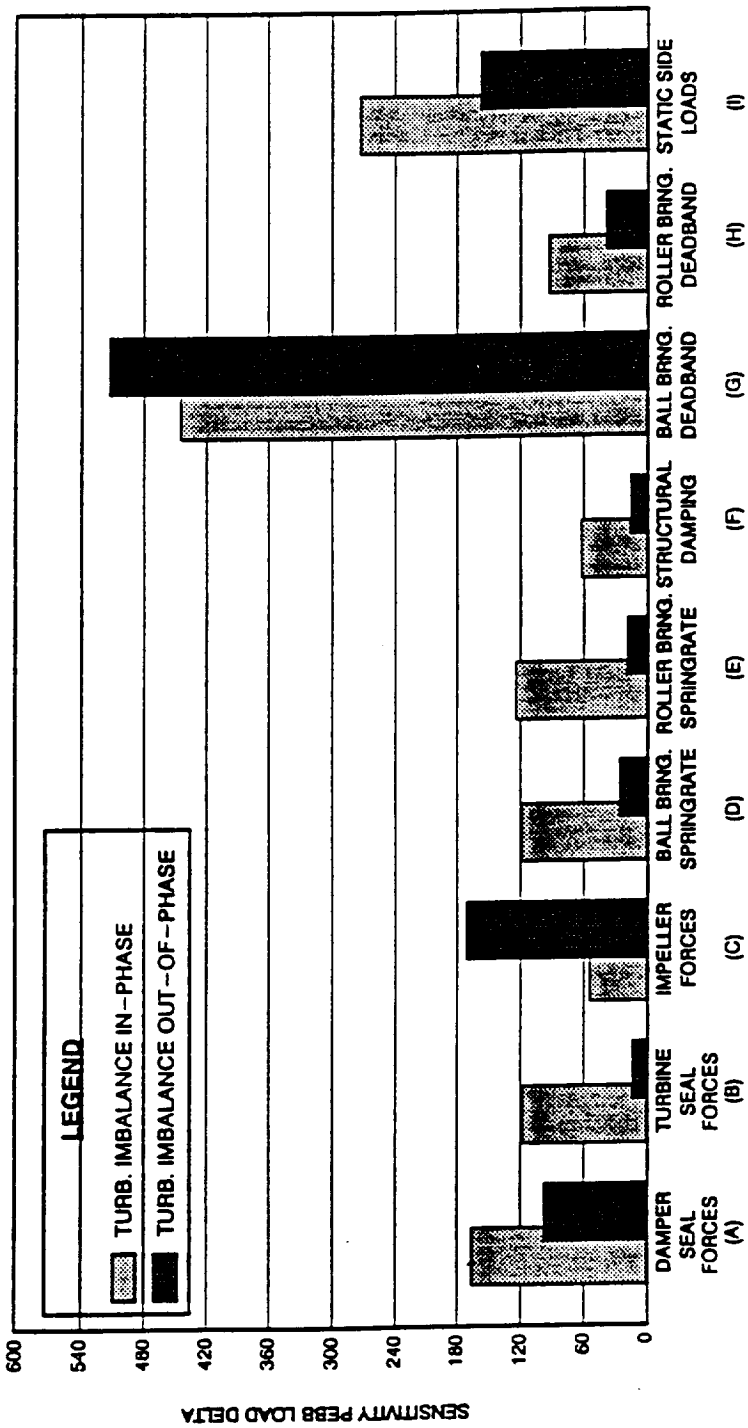

Figure 76. Nonlinear Analysis PEBB Load Sensitivity Results

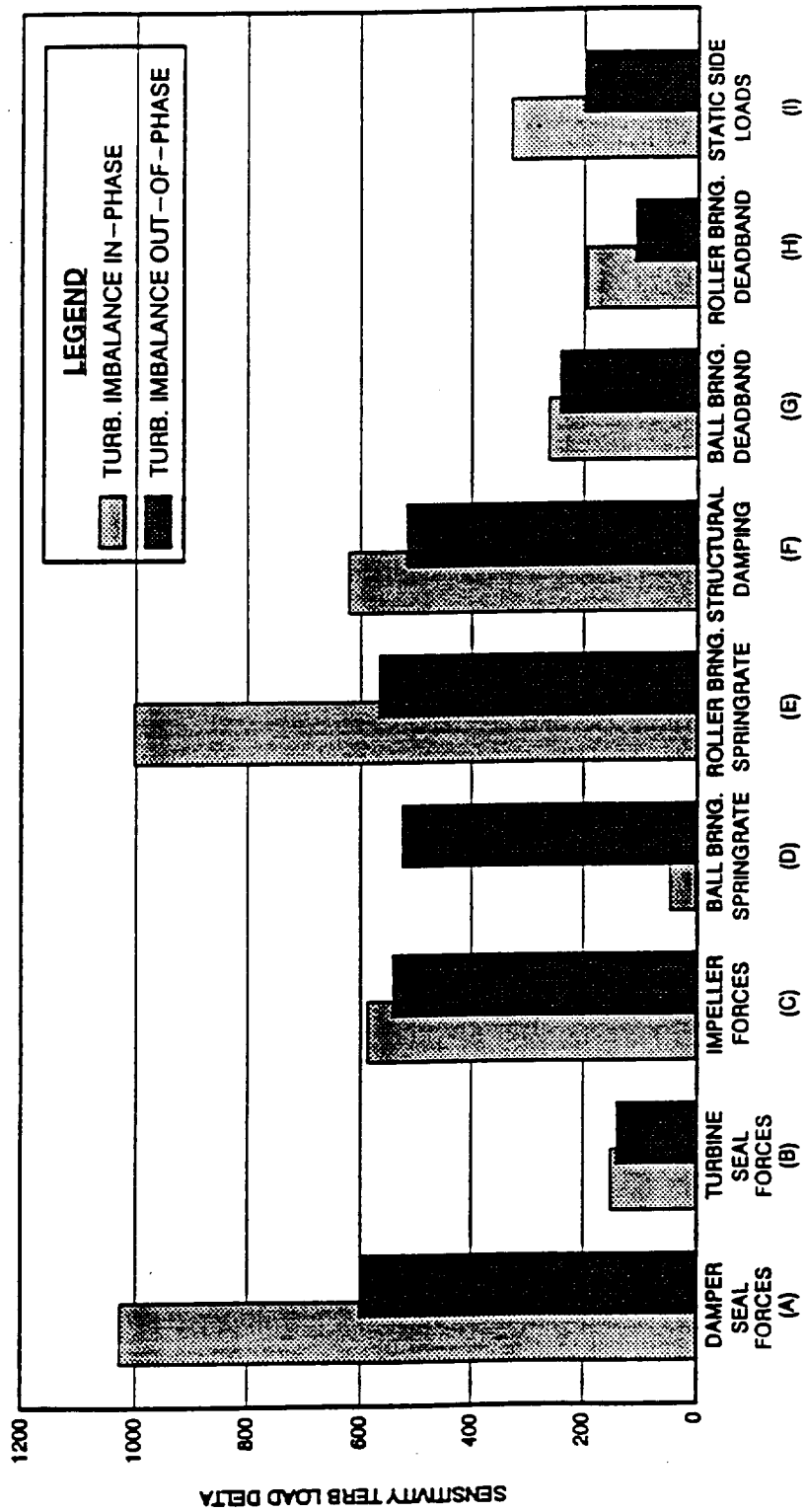

Figure 77. Nonlinear Analysis TERB Load Sensitivity Results

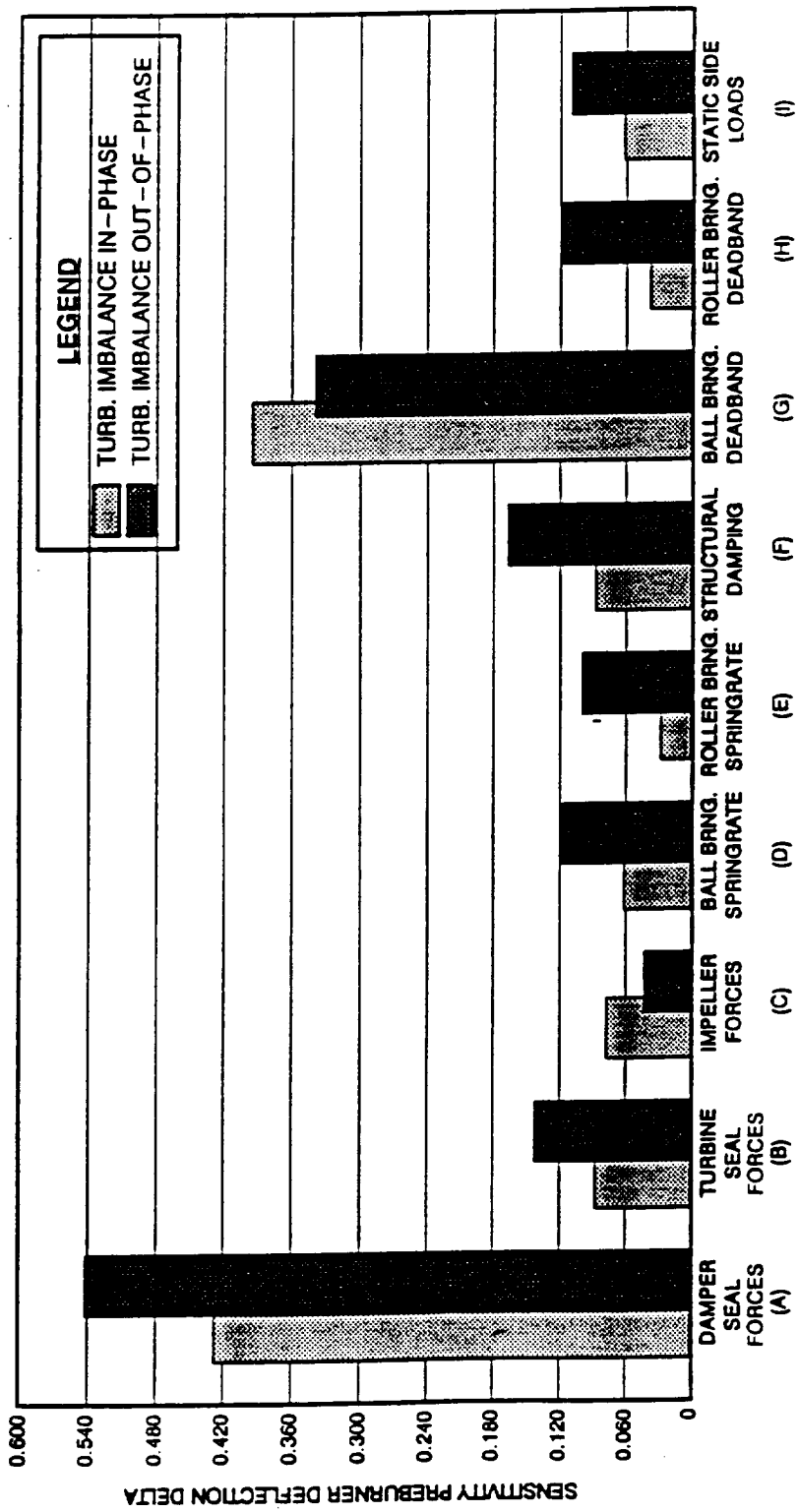

Figure 78. Nonlinear Analysis Preburner Impeller Deflection Sensitivity Results

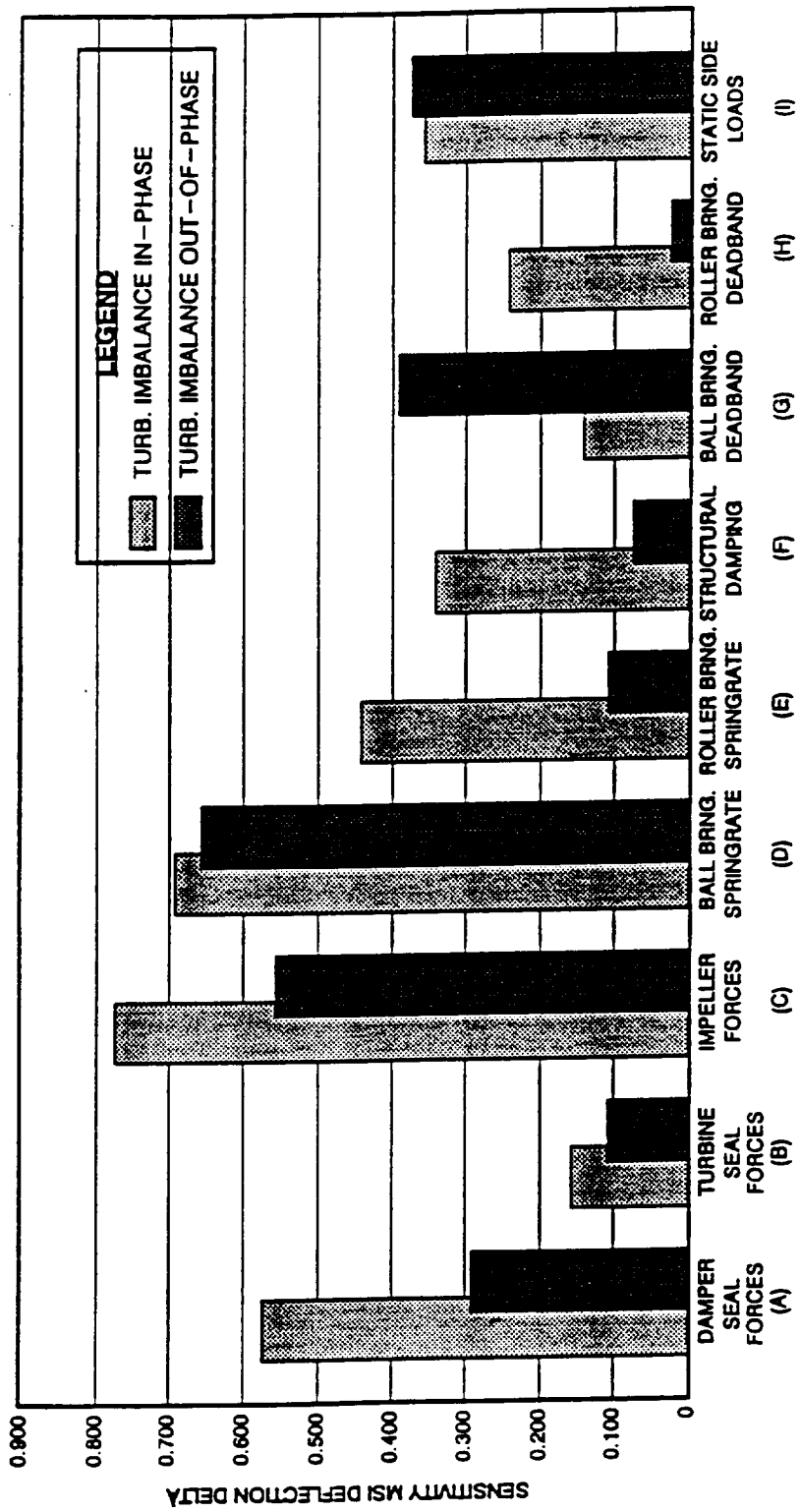

Figure 79. Nonlinear Analysis Main Stage Impeller Deflection Sensitivity Results

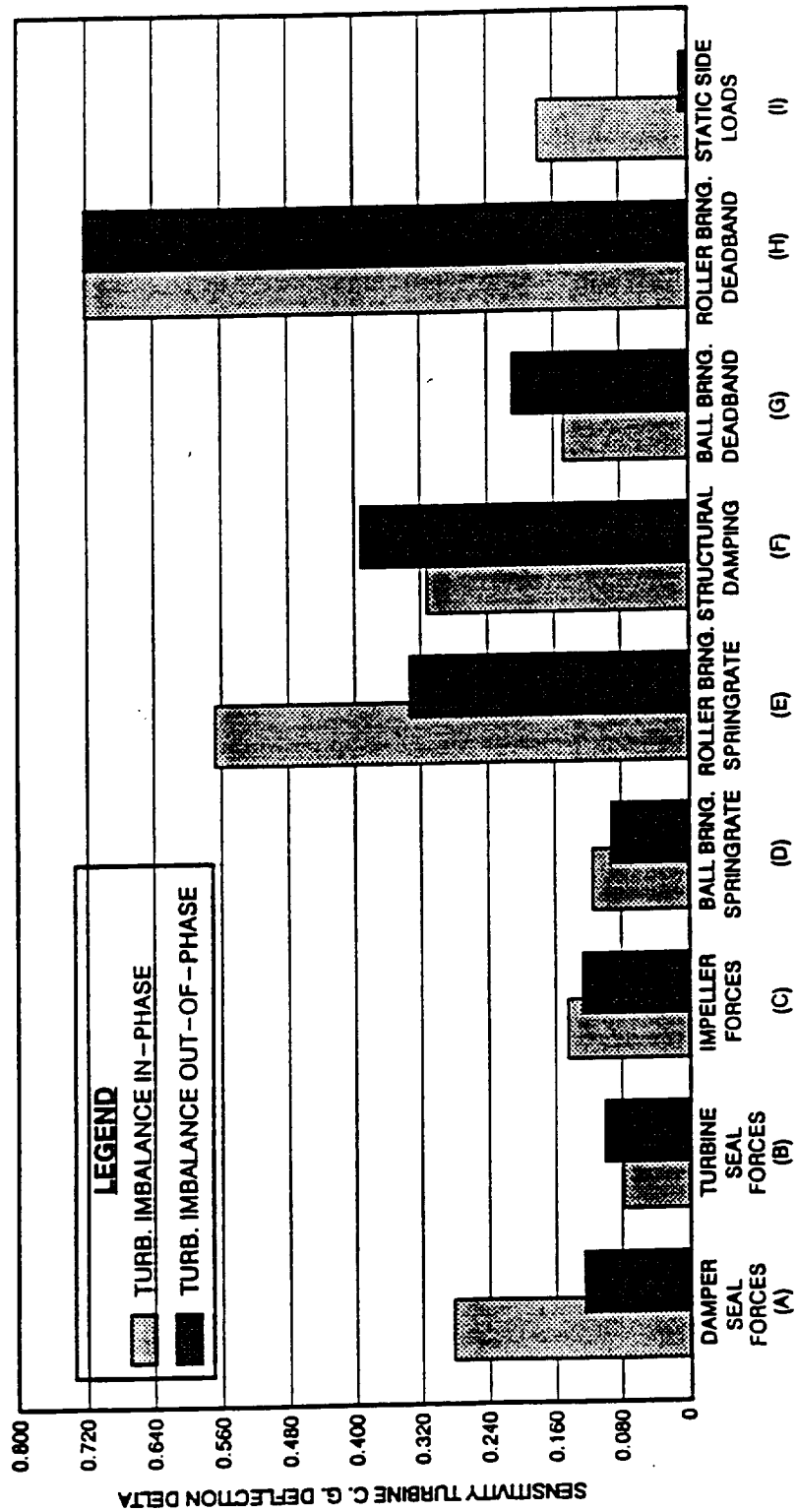

Figure 80. Nonlinear Analysis Turbine CG Deflection Sensitivity Results

5.2.3 Summary

The critical speed sensitivity analyses show the Pump Bounce Mode is sensitive to pump end rotor support stiffness and Turbine Bounce Mode sensitivity to turbine end rotor support stiffness. Likewise, the Pump Bounce Mode is not sensitivity to turbine end rotor support stiffness and the Turbine Bounce Mode is not sensitive to pump end rotor support stiffness. The only other system mode sensitive to rotor support stiffness can be seen in the Housing Bending Mode at approximately 45 KRPM, to both pump end and turbine end rotor support stiffness. Variation in the Housing 1st Bending Mode is small, approximately 42,500 to 45,000 RPM.

A nonlinear critical speed assessment is presented in the following section.

Critical Speed Sensitivity to Bearing Radial Stiffness				
Bearing Springrate Variation		Principal Rotor Mode	Critical Speed Range	
PEBB	TERB		X-Z Plane	Y-Z Plane
0.5E6-1.0E6 (lb/in)	3.5E6 (lb/in)	Pump Bounce	28.5-29.5 (KRPM)	29.5-32.0 (KRPM)
		Turbine Bounce	No Change	No Change
0.75E6 (lb/in)	2.5E6-4.5E6 (lb/in)	Pump Bounce	No Change	No Change
		Turbine Bounce	33.5-40.5 (KRPM)	33.0-39.0 (KRPM)

Table 42. Critical Speed Sensitivity Summary

Based on the analytical stability sensitivity study of seven rotordynamic parameters for the HPOTP, the main stage impeller hydromechanical forces have the biggest affect on the rotor stability (e.g. increasing the stability of the pump mode can be accomplished largely with the decrease in impeller forces). However, with all input parameter variations of the sensitivity analysis (damper seal, turbine seal, aeromechanical, hydromechanical forces, and PEBB springrate, TERB springrate and structural damping) stable operation is predicted when considering these parameters as "worst case" as shown in the MINIMUM CASE of Table 43.

Stability Sensitivity (LOG-DEC @ FPL)		
Mode	**Minimum**	**Maximum**
Pump Mode	0.027	0.515
Turbine Bounce	0.107	0.285
1st Rotor Bending	1.440	1.900

Table 43. Stability Sensitivity Summary

Based on the analytical nonlinear forced response sensitivity study of nine rotordynamic parameters (damper seal, turbine seal, aeromechanical, hydromechanical forces, and PEBB springrate and deadband, TERB springrate and deadband, structural damping, and static side loads) for the HPOTP, the static side loads and TERB deadband have the biggest affect on Pump Flange Accelerations at FPL. Other less sensitive parameters include, damper seal forces, impeller forces, and structural damping.

Other measurements for sensitivity assessment include PEBB and TERB load, and preburner, main stage and turbine deflections. These results show the PEBB load to be most sensitive to PEBB deadband, the TERB load to be most sensitive to damper seal forces and TERB stiffness, the PBI deflection to be most sensitive to damper seal forces and PEBB deadband, MSI deflection to most sensitive to MSI forces and PEBB deadband, and the turbine deflections to most sensitive to TERB stiffness and deadband.

The nonlinear peak response assessment of critical speed location is illustrated in Figure 81 on page 129 for consideration of deadband effects. Results show subcritical operation is maintained with worst case conditions PEBB and TERB deadbands. The Pump Mode critical speed range is 28,500 to 31,250 RPM for a PEBB deadband range of 1.0 to 4.0 mil (Dia.).

Minimum and maximum conditions are summarized below for the Pump Flange Response with resulting station responses. The spread of 2.4 to 11.5 G's is a result of the parameter variations considered. Test results are expected to be reduced in range and amplitude.

Nonlinear Forced Response Sensitivity (FPL)						
Output Parameter	Load (lbs)		Acceleration (Gs)		Deflection (mils)	
	Level 1	Level 2	Level 1	Level 2	Level 1	Level 2
Pump Housing X-Cel	-	-	2.4	11.5	-	-
Turbine Housing X-Cel	-	-	1.5	7.0	-	-
Pump End Bearing	0	130	-	-	1.6	2.0
Turbine End Bearing	1250	2400	-	-	1.0	1.6
Preburner Impeller	-	-	-	-	0.6	1.2
Damper seal	-	-	-	-	1.4	1.3
Main Stage Impeller	-	-	-	-	2.6	3.4
I.P. Seal Package	-	-	-	-	1.7	2.5
Turbine C.G.	-	-	-	-	0.7	2.1
Note: 'Level' is based on Min/Max Pump Flange Acceleration Conditions.						

Table 44. Nonlinear Forced Response Sensitivity Summary

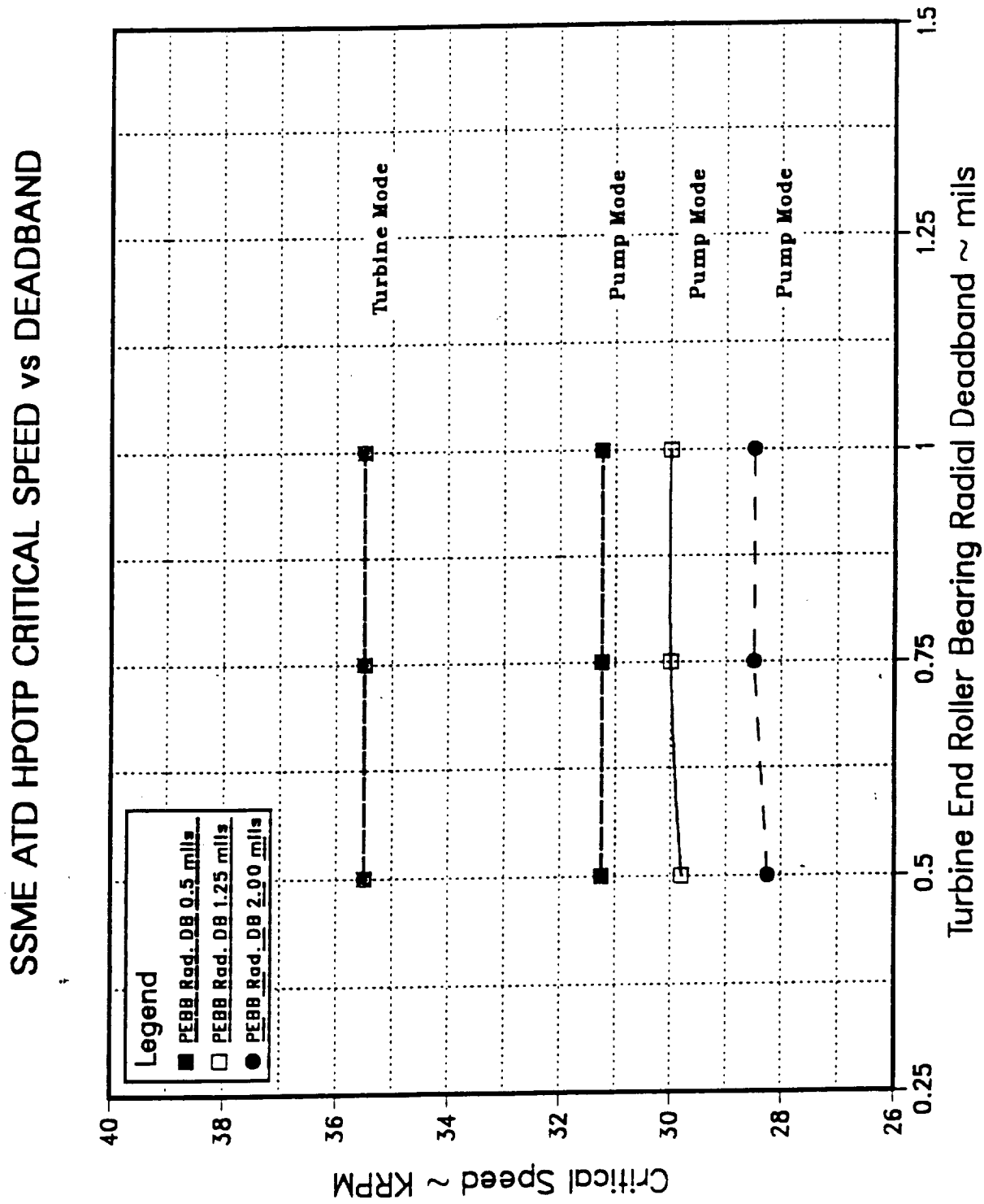

Figure 81. Nonlinear Critical Speed Results: Based on forced response with bearing deadbands and static sideloads.

6.0 CONCLUSIONS

The analyses presented in this report include both detailed parametric sensitivity studies, in combination with a thorough baseline analysis.

The following conclusions are supported from the results of these analyses:

1. The ATD HPOTP has 2X critical speed margin relative to the fundamental rotor bending mode (i.e., satisfy 20% DVS criteria).
2. Subcritical operation is predicted for baseline conditions and nonlinear tolerances, including bearing deadband. The first rotor mode is predicted to occur at 30,000 RPM (124% of FPL).
3. The ATD HPOTP has adequate rotordynamic stability margin from both linear and nonlinear studies (OSI exceeds 40K RPM with 0.24 LOG-DEC value at 109% RPL).
4. Acceptable housing accelerations and bearing loads are predicted.
5. All DVS rotordynamic criteria are satisfied.

7.0 REFERENCES

1. FR-20730-19, SSME Alternate Turbopump Development Program (HPOTP),"Rotor Dynamics Analysis Verification Report; Rotor Assembly Modal Test", Pratt & Whitney; September 1990.

2. Specification No, DVS-29, SSME Alternate Turbopump Development Program,"Design Verification Specification for High-Pressure Oxidizer Turbopump", Revision 3, April 21, 1989, Pratt & Whitney.

3. Childs, D.W.,"The Space Shuttle Main Engine High-Pressure Fuel Turbopump Rotordynamic Instability Problem," ASME Transaction, December 1976.

4. Alford, J., "Protecting Turbomachinery from Self-Excited Rotor Whirl," ASME Transaction, Journal of Engineering for Power, October 1965, pp. 333-334.

5. Jery, B., Acosta, A.J., Bremmem, C.E., Caughey, T.K., "Hydrodynamic Impeller Stiffness, Damping and Inertia in the Rotordynamics of Centrifugal Pumps," NASA Conference Publication 2338, Proceedings of a Workshop on Rotordynamics Instability Problems in High Performance Turbomachinery, Texas A&M University, College Station, Tx, May 1984, pp 137-160.

6. W.T. McFarlen (Rocketdyne Division) to D.E. Guisinger (Pratt & Whitney),"SSME ATD Interface Inertia and Stiffness Characteristics", August 3, 1988. (88RC09590)

7. W.T. McFarlen (Rocketdyne Division) to D.E. Guisinger (Pratt & Whitney),"Interface Springrates". September 29, 1988. (88RC11999)

8. Childs, D.W., Kim Chang-Ho,"Analysis and Testing for Rotordynamic Coefficients of Turbulent Annular Seals with Different, Directionally-Homogeneous Surface-Roughness Treatment for Rotor and Stator Elements," ASME Transaction, Journal of Tribology, Vol. 107, July 1985.

9. Childs, D.W., Kim Chang-Ho,"Test Results for Round-Hole-Pattern Damper Seals: Optimum Configurations and Dimensions for Maximum Net Damping," ASME Transaction, -- date --.

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11. FR-20730-18, SSME Alternate Turbopump Development Program, "Pump Ball Bearing Design Verification Substantiation (DVS)", Pratt & Whitney; May 1991.

12. FR-20713-20 & FR-20727-18, SSME Alternate Turbopump Development Program, "Interim Verification Complete Report; HPOTP & HPFTP Ball Bearing Radial Side Load Analysis", Pratt & Whitney; September 1991.

Appendix A. Study Plan

PW SSME/ATD

ROTORDYNAMICS
Parametric Study Plan

PCDR RID'S DR-04 & DR-08

D. Hudson
03/12/91

SSME/ATD ROTORDYNAMICS

PCDR RIDS DR-04 & DR-08

PREBOARD RECOMMENDATIONS

1. Scope of effort will be worked out between MSFC & PW.

   Analytical studies have been outlined to include: type of analyses, detail of responses that will be monitored and inputs that will be varied for sensitivity assessments.

2. Effort will cover RIDS DR-04, 10, 11, 20, 22 & 23.

   All RIDS incorporated into DR-04 to include linear analyses for the ATD HPOTP & HPFTP.

3. Effort will cover RIDS DR-08 & DR-09.

   DR-09 is incorporated into DR-08 to include non-linear analyses for the ATD HPOTP & HPFTP.

SCOPE OF EFFORT

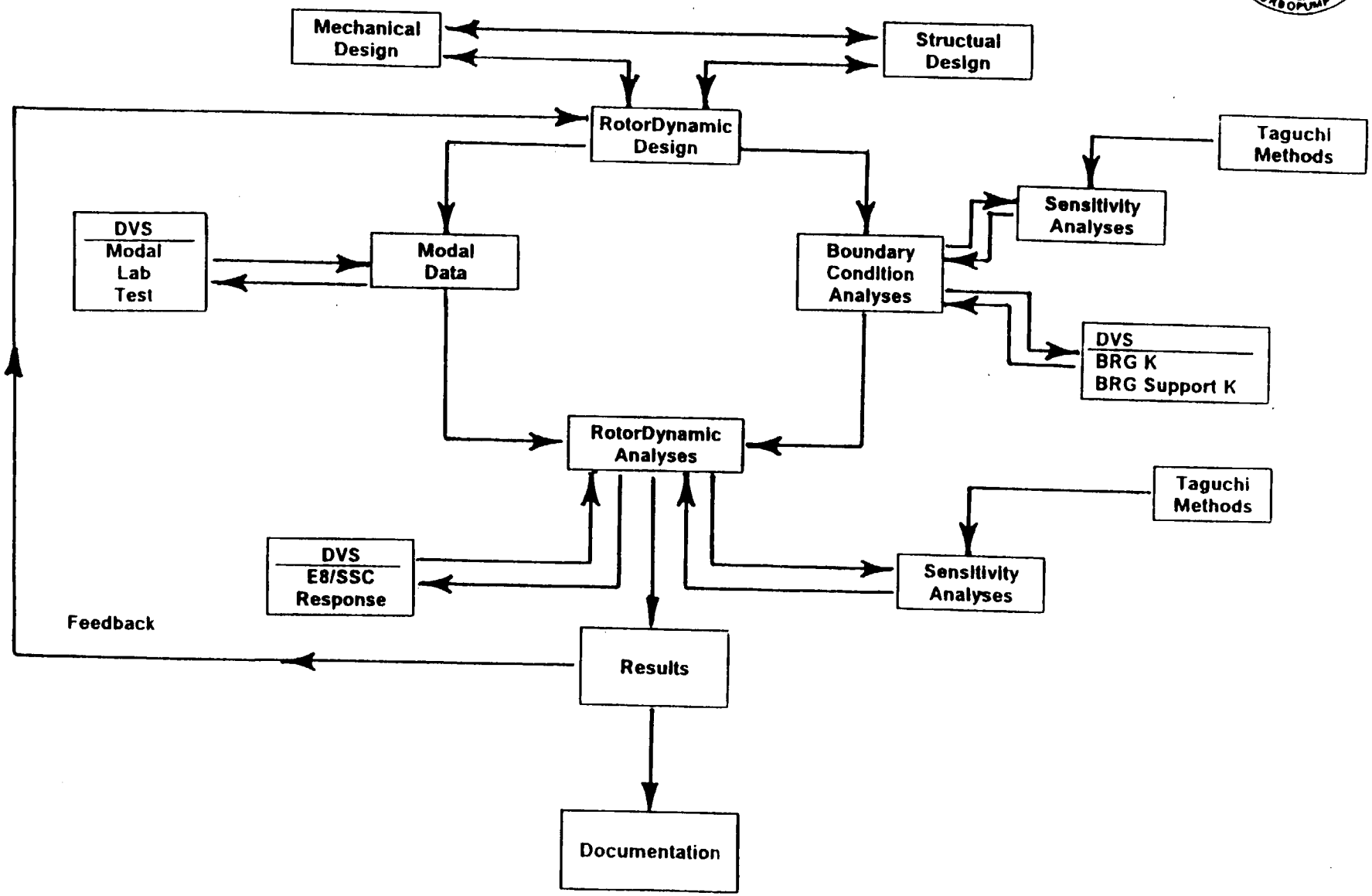
Establish parametric studies for current hardware configuration with variations on operating tolerances and conditions.

135

D. Hudson
3/8/91

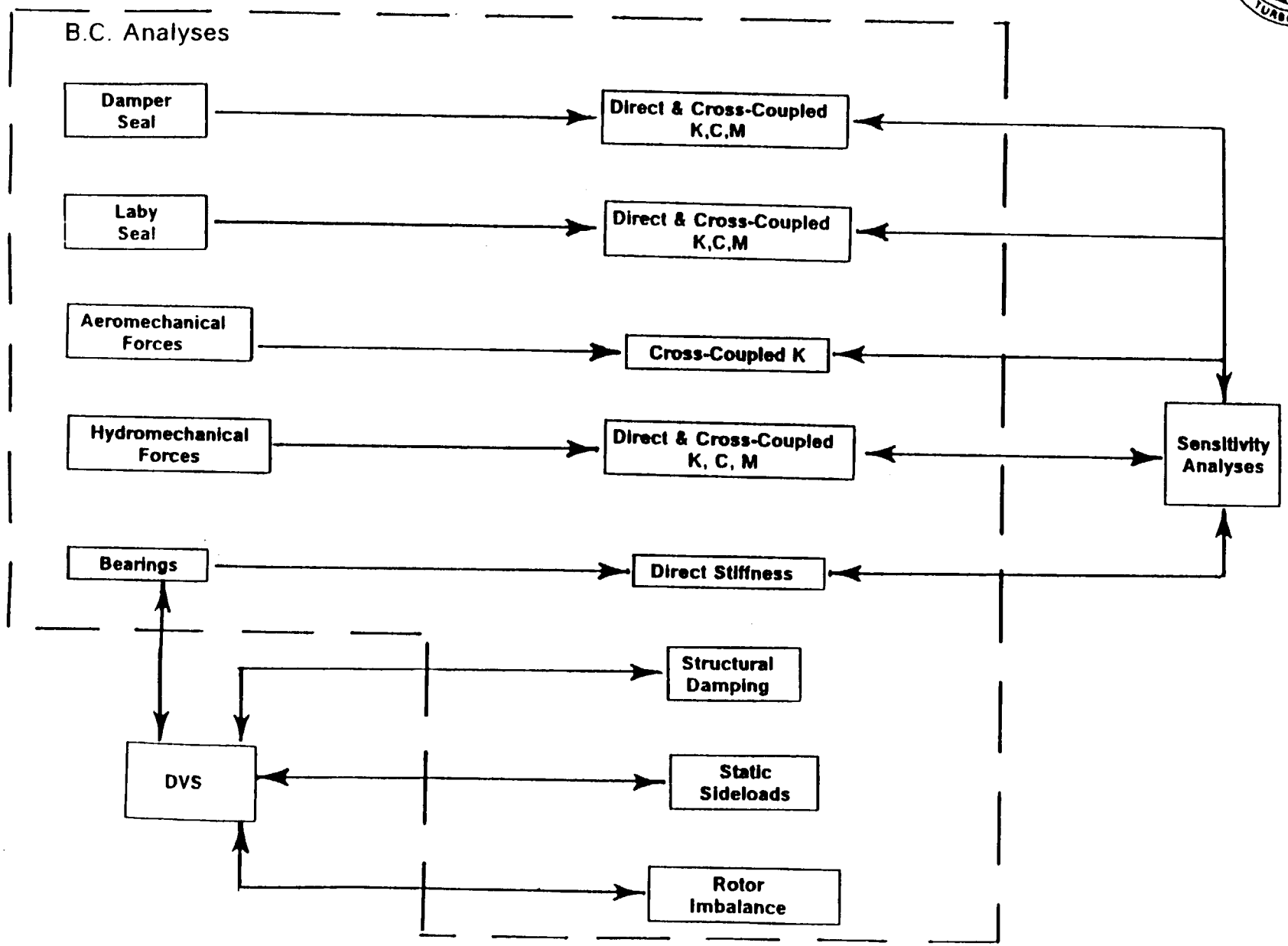
SSME/ATD ROTORDYNAMICS

Analyses Flow Chart



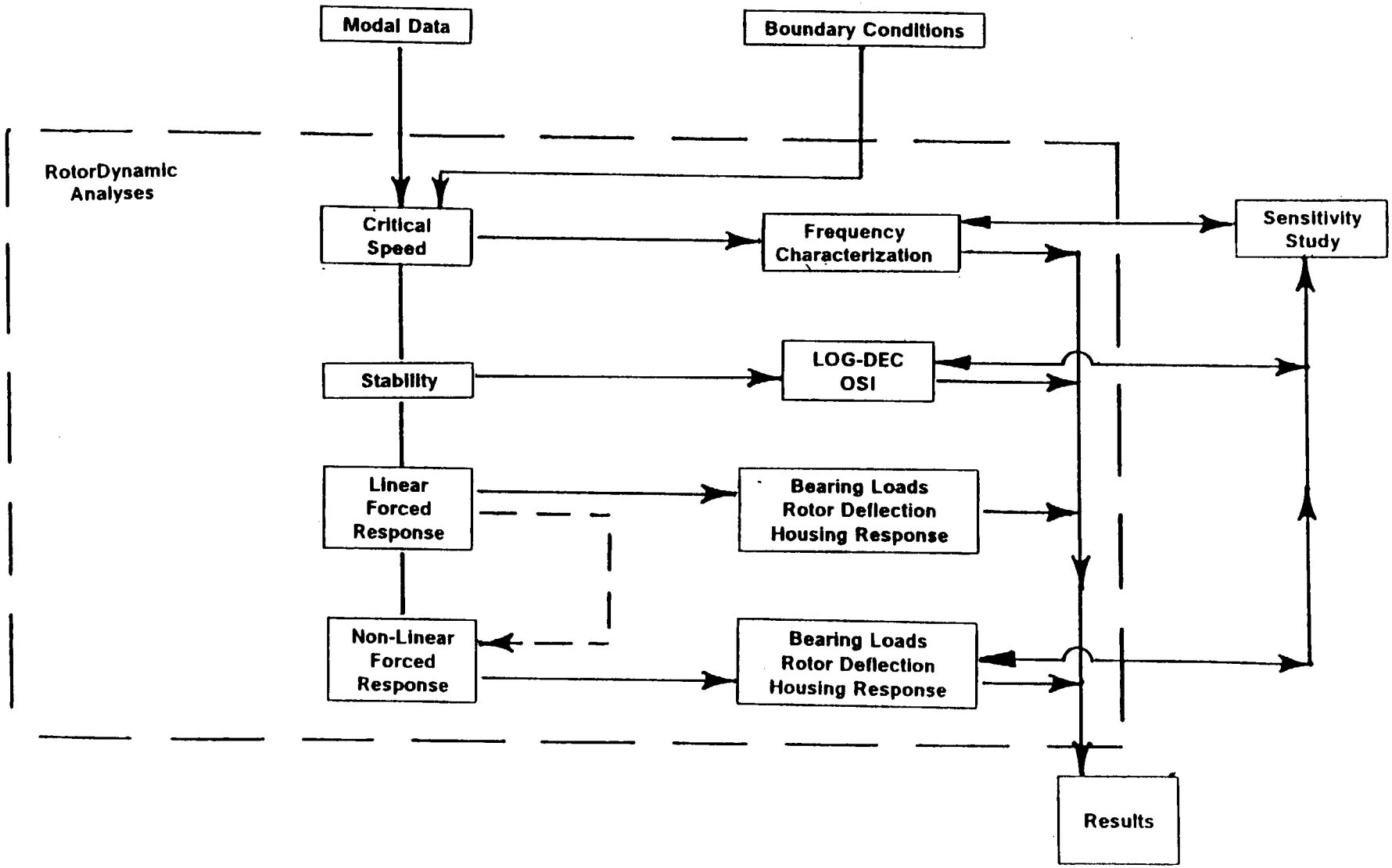
SSME/ATD ROTORDYNAMICS

Boundary Conditions Analyses Flow Chart



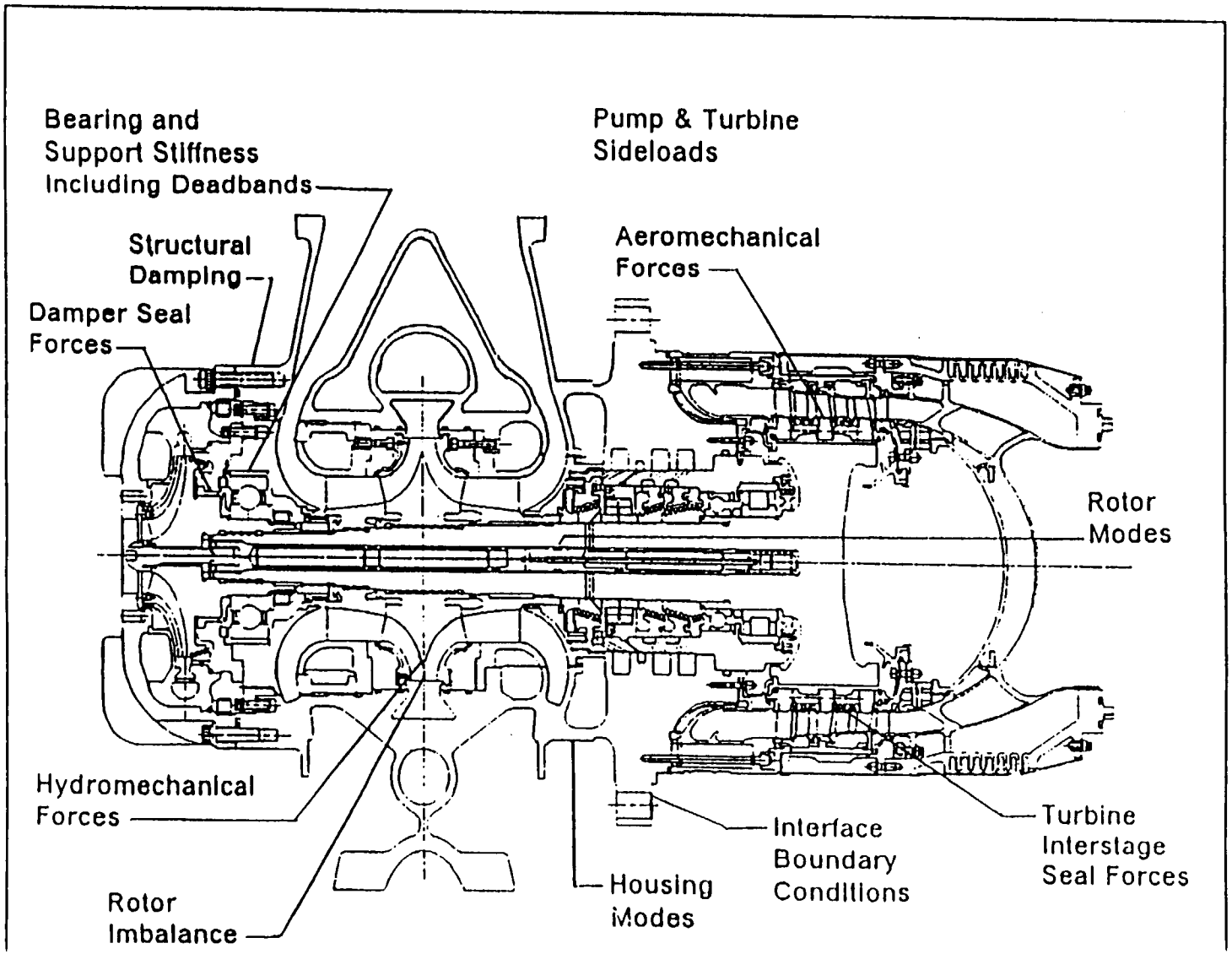
SSME/ATD ROTORDYNAMICS

RotorDynamic Analyses Flow Chart



ATD HPOTP PRECURSOR CDR

ROTORDYNAMICS - PARAMETER INPUTS



SSME/ATD ROTORDYNAMICS

Boundary Conditions

- Use min, nom, max values from these calculations where applicable in rotordynamic analysis

Analysis	Input	Output
Damper Seal	PRESSURE, Length, CLEARANCE, TAPER Radius, Viscosity, Density Seal Roughness, Inlet Loss, TANGENTIAL VELOCITY RATIO	Direct & Cross Coupled Siffness Direct & Cross-Coupled Damping Direct & Cross-Coupled Mass
Labyrinth Seal	Seal Geometry, CLEARANCE, TOOTH TIP WIDTH, PRESSURE, TANGENTIAL VELOCITY RATIO, Gas Properties, Seal Roughness	Direct & Cross-Coupled Stiffness Direct & Cross-Coupled Damping Direct & Cross-Coupled Mass
Aeromechanical Force	Turbine Torque, Blade Diameter, Blade Height, BETA	Cross-coupled Stiffness
Hydromechanical Force	DELTA PRESSURE, Fluid Density, Fluid Exit Width, CLEARANCE, Fluid Exit Radius, EMPIRICAL COEFFICIENT K & k	Direct & Cross-Coupled Stiffness Direct & Cross Coupled Damping Direct & Cross-Coupled Mass
Bearing	No. Elements, Element dia., Pitch Dia., Ball/Roller Geometry, I.R. Curvature, O.R. Curvature, IRC, AXIAL LOAD, RADIAL LOAD, MISALIGNMENT	Direct Stiffness

Note: Highlighted input variables will be used in statistical matrix of coefficient sensitivity calculations

SSME/ATD HPOTP ROTOR MIC PARAMETRIC STUDY
BOUNDARY COND1..ON ANALYSES

Analysis	No. Factors Input	No. Factors Output	No. of Sets	Full Matrix	One-At-A-Time	Selected Factors Input	Selected Factors Output	Selected Factors O.A.A.T	Selected Factors Statistical
Damper Seal	10	6	3x3	(177K) 3x3E10	(63) 3(1+2(10))	4	6	(27) 3(1+2(4))	(27) 3xL9(3:4)
Turbine Interstage Labyrinth Seal									
- Stage 1-2	13	6	3x3	(4.8M) 3x3E13	(81) 3(1+2(13))	4	6	(27) 3(1+2(4))	(27) 3xL9(3:4)
- Stage 2-3	13	6	3x3	(4.8M) 3x3E13	(81) 3(1+2(13))	4	6	(27) 3(1+2(4))	(27) 3xL9(3:4)
Aeromechanical									
- Turb 1st Stage	4	1	3x3	(243) 3x3E4	(27) 3(1+2(4))	1	1	(9) 3(1+2(1))	(9) See Note 4
- Turb 2nd Stage	4	1	3x3	(243) 3x3E4	(27) 3(1+2(4))	1	1	(9) 3(1+2(1))	(9) See Note 4
- Turb 3rd Stage	4	1	3x3	(243) 3x3E4	(27) 3(1+2(4))	1	1	(9) 3(1+2(1))	(9) See Note 4
Hydromechanical									
- Preburner Imp	6	6	3x3	(2.2K) 3x3E6	(39) 3(1+2(6))	4	6	(27) 3(1+2(4))	(27) 3xL9(3:4)
- Main Stage Imp	6	6	3x3	(2.2K) 3x3E6	(39) 3(1+2(6))	4	6	(27) 3(1+2(4))	(27) 3xL9(3:4)
Bearing Springrate									
- Ball Bearing	10	1	3x3	(177K) 3x3E10	(63) 3(1+2(10))	4	1	(27) 3(1+2(4))	(27) 3xL9(3:4)
- Roller Bearing	10	1	3x3	(177K) 3x3E10	(63) 3(1+2(10))	4	1	(27) 3(1+2(4))	(27) 3xL9(3:4)
Totals	(80)	(34)		(10.2M)	(510)	(31)	(35)	(216)	(216)

NOTES: 1) Number in ( ) equals total number of runs.
2) 'No. of sets' = Number of analyses to define MIN, NOM, & MAX levels vs speed.
3) Statistical Matrix (Ln(X**P)); n = total number of runs
X = number of levels (i.e. low, med, high)
P = number of factors (inputs)
4) Same as O.A.A.T for one selected input factor.

HPOTP; Other Boundary Conditions
Establish MIN, NOM & MAX for Rotordynamic Analyses
o Structural Damping
o Bearing Deadband Clearance
o Static Sideloads
o Rotor Imbalance (See Rotordynamic Analyses)

SSME/ATD ROTORDYNAMICS

Rotordynamic Analyses (HPOTP)

- Use min, nom, max values from Boundary Conditions Analyses

Analysis	Input	Output
Critical Speed	Free-Free Rotor/Hsg Modes, Boundary Conditions - (Kxx): - Damper Seal - Eight Misc. Laby Seals - Turbine Laby Seals - Impellers - BALL BEARING - ROLLER BEARING	Frequency Characterization 2 Rigid Body Modes 4 Bending Modes _____ 6 Modes Total
Stability	Free-Free Rotor/Hsg Modes, Boundary Conditions (Kxx,Kxy,Cxx,Cxy, Mxx,Mxy) - DAMPER SEAL - Eight Misc. Laby Seals - TURBINE LABY SEALS - TURBINE - IMPELLERS - BALL BEARING (Kxx) - ROLLER BEARING (Kxx) - STRUCTURAL DAMPING	- LOG-DEC - Onset Speed of Instability (6 Modes)

Note: Highlighted input variables will be used in statistical matrix for sensitivity studies.

SSME/ATD ROTORDYNAMICS

Rotordynamic Analyses (HPOTP)

- Use min, nom, max values from Boundary Conditions Analyses

Analysis	Input	Output
Non-linear Forced Response	Free-free Rotor/Hsg Modes Boundary Conditions - (Kxx, Kxy, Cxx) - DAMPER SEAL - Eight Misc. Laby Seals - TURBINE LABY SEAL - IMPELLERS - BALL BEARING (Kxx) - ROLLER BEARING (Kxx) - STRUCTURAL DAMPING (Cxx) - BALL BEARING DEADBAND - ROLLER BEARING DEADBAND - STATIC SIDELOADS - Rotor Imbalance (in & out of phase)	- Bearing Loads - Rotor Deflection Preburner Impeller Main Stage Impeller Damper Seal Ball Bearing IP Seals Roller Bearing Turbine CG - Housing Response Pump Flange Turbine Flange

Note: Highlighted input variables will be used in statistical matrix for sensitivity studies.

SSME/ATD HPOTP ROTORDYNAMIC PARAMETRIC STUDY
ROTORDYNAMIC ANALYSES

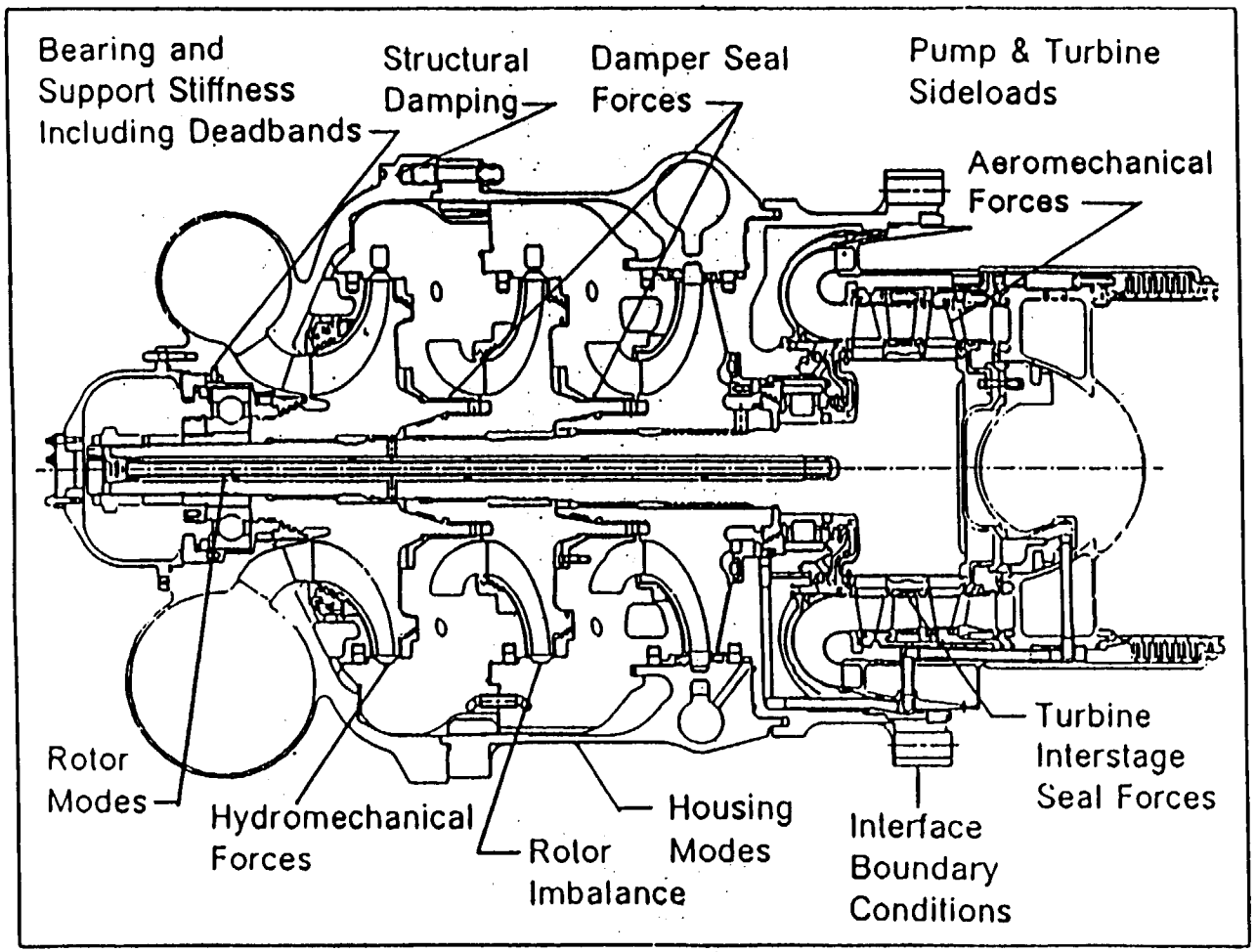
Engine Level Analysis	No. Factors Input	No. Factors Output	No. of Sets	Full Matrix	One-At-A-Time	Selected Factors Input	Selected Factors Output	O.A.A.T	Statistical
Critical Speed	15	6	7x3	(100M) 7x3E15	(217) 7(1+2(15))	2	6	(35) 7(1+2(2))	(28) see outline
Stability	15	12	4x3	(57M) 4x3E15	(124) 4(1+2(15))	7	12	(60) 4(1+2(7))	(32) 4xL8(2:7)
Linear Forced Response	14	11	2x3	(9.5M) 2x3E14	(58) 2(1+2(14))	2	11	(10) 2(1+2(2))	(10) see outline
Non-Linear Forced Response	17	11	2x3	(258M) 2x3E17	(70) 2(1+2(17))	10	11	(42) 2(1+2(10))	(12) 2xL12(2:10)
Totals	(61)	(40)		(424M)	(469)	(21)	(40)	(147)	(82)

E-8 Level Analysis	Nominal (4) Predictions
Critical Speed	7
Stability	4
Linear Forced Response	2
Non-Linear Forced Response	2
Total	12

NOTES: 1) Number in ( ) equals total number of runs.
2) 'No. of sets' = Number of analyses to define MIN, NOM, & MAX levels vs speed.
3) Statistical Matrix (Ln(X**P)); n = total number of runs
X = number of levels (i.e. low, med, high)
P = number of factors (inputs)
4) Nominal prediction of E-8 test stand configuration will be compared to engine level parametric studies.

ATD HPFTP PRECURSOR CDR

ROTORDYNAMICS - PARAMETER INPUTS



SSME/ATD ROTORDYNAMICS

Boundary Conditions

- Use min, nom, max values from these calculations where applicable in rotordynamic analysis

Analysis	Input	Output
Damper Seal	PRESSURE, Length, CLEARANCE, TAPER Radius, Viscosity, Density Seal Roughness, Inlet Loss, TANGENTIAL VELOCITY RATIO	Direct & Cross Coupled Siffness Direct & Cross-Coupled Damping Direct & Cross-Coupled Mass
Labyrinth Seal	Seal Geometry, CLEARANCE, TOOTH TIP WIDTH, PRESSURE, TANGENTIAL VELOCITY RATIO, Gas Properties, Seal Roughness	Direct & Cross-Coupled Stiffness Direct & Cross-Coupled Damping Direct & Cross-Coupled Mass
Aeromechanical Force	Turbine Torque, Blade Diameter, Blade Height, BETA	Cross-coupled Stiffness
Hydromechanical Force	DELTA PRESSURE, Fluid Density, Fluid Exit Width, CLEARANCE, Fluid Exit Radius, EMPIRICAL COEFFICIENT K & k	Direct & Cross-Coupled Stiffness Direct & Cross Coupled Damping Direct & Cross-Coupled Mass
Bearing	No. Elements, Element dia., Pitch Dia., Ball/Roller Geometry, I.R. Curvature, O.R. Curvature, IRC, AXIAL LOAD, RADIAL LOAD, MISALIGNMENT	Direct Stiffness

Note: Highlighted input variables will be used in statistical matrix of coefficient sensitivity calculations

SSME/ATD HPFTP ROTORD IC PARAMETRIC STUDY
BOUNDARY CONDITION ANALYSES

Analysis	No. Factors Input	No. Factors Output	No. of Sets	Full Matrix	One-At-A-Time	Selected Factors Input	Selected Factors Output	O.A.A.T	Statistical
Damper Seal									
- Stage 1-2	10	6	3x3	(177K) 3x3E10	(63) 3(1+2(10))	4	6	(27) 3(1+2(4))	(27) 3xL9(3:4)
- Stage 2-3	10	6	3x3	(177K) 3x3E10	(63) 3(1+2(10))	4	6	(27) 3(1+2(4))	(27) 3xL9(3:4)
Turbine Interstage Labyrinth Seal	13	6	3x3	(4.8M) 3x3E13	(81) 3(1+2(13))	4	6	(27) 3(1+2(4))	(27) 3xL9(3:4)
Aeromechanical									
- Turb 1st Stage	4	1	3x3	(243) 3x3E4	(27) 3(1+2(4))	1	1	(9) 3(1+2(1))	(9) See Note 4
- Turb 2nd Stage	4	1	3x3	(243) 3x3E4	(27) 3(1+2(4))	1	1	(9) 3(1+2(1))	(9) See Note 4
Hydromechanical									
- 1st Stage Imp	6	6	3x3	(2.2K) 3x3E6	(39) 3(1+2(6))	4	6	(27) 3(1+2(4))	(27) 3xL9(3:4)
- 2nd Stage Imp	6	6	3x3	(2.2K) 3x3E6	(39) 3(1+2(6))	4	6	(27) 3(1+2(4))	(27) 3xL9(3:4)
- 3rd Stage Imp	6	6	3x3	(2.2K) 3x3E6	(39) 3(1+2(6))	4	6	(27) 3(1+2(4))	(27) 3xL9(3:4)
Bearing Springrate									
- Ball Bearing	10	1	3x3	(177K) 3x3E10	(63) 3(1+2(10))	4	1	(27) 3(1+2(4))	(27) 3xL9(3:4)
- Roller Bearing	10	1	3x3	(177K) 3x3E10	(63) 3(1+2(10))	4	1	(27) 3(1+2(4))	(27) 3xL9(3:4)
Totals	(79)	(40)		(12M)	(504)	(34)	(40)	(234)	(234)

NOTES: 1) Number in ( ) equals total number of runs.
2) 'No. of sets' = Number of analyses to define MIN, NOM, & MAX levels vs speed.
3) Statistical Matrix (Ln(X**P)); n = total number of runs
X = number of levels (i.e. low, med, high)
P = number of factors (inputs)
4) Same as O.A.A.T for one selected input factor.

HPFTP; Other Boundary Conditions
Establish MIN, NOM & MAX for Rotordynamic Analyses
o Structural Damping
o Bearing Deadband Clearance
o Static Sideloads
o Rotor Imbalance (See Rotordynamic Analyses)

SSME/ATD ROTORDYNAMICS

Rotordynamic Analyses (HPFTP)

- Use min, nom, max values from Boundary Conditions Analyses

Analysis	Input	Output
Critical Speed	Free-Free Rotor/Hsg Modes, Boundary Conditions - (Kxx); - Damper Seal - Six Misc. Laby Seals - Turbine Laby Seal - Impellers - BALL BEARING - ROLLER BEARING	Frequency Characterization 2 Rigid Body Modes 4 Bending Modes _____ 6 Modes Total
Stability	Free-Free Rotor/Hsg Modes, Boundary Conditions (Kxx,Kxy,Cxx,Cxy, Mxx,Mxy) - DAMPER SEAL - Six Misc. Laby Seals - TURBINE LABY SEAL - TURBINE - IMPELLERS - BALL BEARING (Kxx) - ROLLER BEARING (Kxx) - STRUCTURAL DAMPING	- LOG-DEC - Onset Speed of Instability (6 Modes)

Note: Highlighted input variables will be used in statistical matrix for sensitivity studies.

SSME/ATD ROTORDYNAMICS

Rotordynamic Analyses (HPFTP)

- Use min, nom, max values from Boundary Conditions Analyses

Analysis	Input	Output
Non-linear Forced Response	Free-free Rotor/Hsg Modes Boundary Conditions - (Kxx, Kxy, Cxx) - DAMPER SEAL - Six Misc. Laby Seals - TURBINE LABY SEAL - IMPELLERS - BALL BEARING (Kxx) - ROLLER BEARING (Kxx) - STRUCTURAL DAMPING (Cxx) - BALL BEARING DEADBAND - ROLLER BEARING DEADBAND - STATIC SIDELOADS - Rotor Imbalance (in & out of phase)	- Bearing Loads - Rotor Deflection 1st Stage Impeller 2nd Stage Impeller 3rd Stage Impeller 1-2 Damper Seal 2-3 Damper Seal Ball Bearing Roller Bearing Turbine CG - Housing Response Pump Flange Turbine Flange

Note: Highlighted input variables will be used in statistical matrix for sensitivity studies.

SSME/ATD HPFTP ROTORDYNAMIC PARAMETRIC STUDY
ROTORDYNAMIC ANALYSES

Engine Level Analysis	No. Factors		No. of Sets	Full Matrix	One-At-A-Time	Selected Factors			
	Input	Output				Input	Output	O.A.A.T	Statistical
Critical Speed	15	6	7x3	(100M) 7x3E15	(217) 7(1+2(15))	2	6	(35) 7(1+2(2))	(28) see outline
Stability	15	12	4x3	(57M) 4x3E15	(124) 4(1+2(15))	7	12	(60) 4(1+2(7))	(32) 4xL8(2:7)
Linear Forced Response	9	12	2x3	(39K) 2x3E9	(38) 2(1+2(9))	2	12	(10) 2(1+2(2))	(10) see outline
Non-Linear Forced Response	12	12	2x3	(1M) 2x3E12	(50) 2(1+2(12))	9	12	(38) 2(1+2(9))	(12) 2xL12(2:9)
Totals	(51)	(42)		(158M)	(429)	(20)	(42)	(143)	(82)

E-8 Level Analysis	Nominal (4) Predictions
Critical Speed	7
Stability	4
Linear Forced Response	2
Non-Linear Forced Response	2
Total	12

NOTES: 1) Number in ( ) equals total number of runs.
2) 'No. of sets' = Number of analyses to define MIN, NOM, & MAX levels vs speed.
3) Statistical Matrix (Ln(X**P)); n = total number of runs
X = number of levels (i.e. low, med, high)
P = number of factors (inputs)
4) Nominal prediction of E-8 test stand configuration will be compared to engine level parametric studies.

Appendix B. 'Design of Experiments' Example (Taguchi)

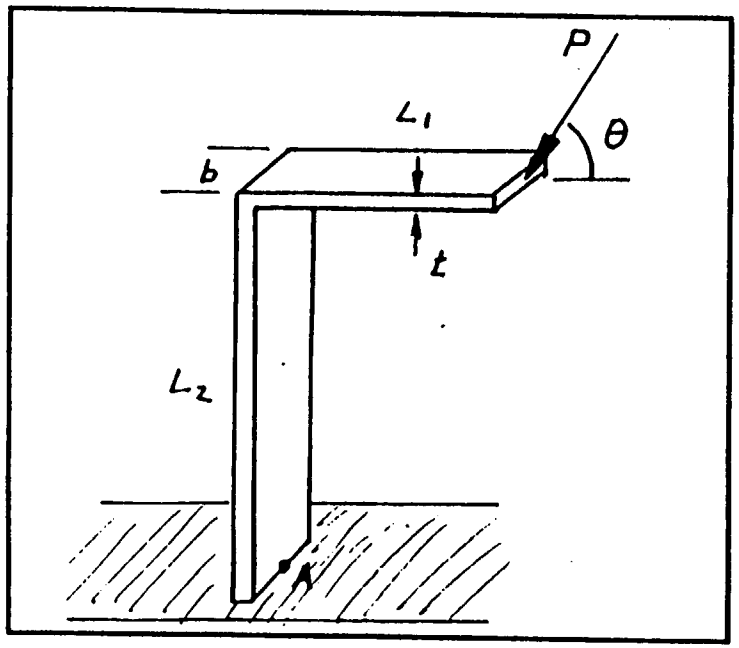
DESIGN OF EXPERIMENTS USING ORTHOGONAL ARRAY METHODS

(TAGUCHI METHODS)

D. HUDSON
August 1989

152

SAMPLE PROBLEM
DESIGN OPTIMATION



QUALITY FACTOR = STRESS at "A"

FACTORS	LEVELS 1	LEVELS 2
A) Load Angle	30	45
B) Length (L1)	5	3
C) Length (L2)	10	14
D) Width (b)	1.0	1.5
E) Thickness (t)	0.25	0.375
F) Color	Black	White

USE AN L8 ARRAY

Number	A 1	B 2	C 3	D 4	E 5	F 6	G 7	Results
1	1	1	1	1	1	1	1	y_1
2	1	1	1	2	2	2	2	y_2
3	1	2	2	1	1	2	2	y_3
4	1	2	2	2	2	1	1	y_4
5	2	1	2	1	2	1	2	y_5
6	2	1	2	2	1	2	1	y_6
7	2	2	1	1	2	2	1	y_7
8	2	2	1	2	1	1	2	y_8

FULL FACTORIAL EXPERIMENT EQUALS

$2^7 = 128$

L8 REDUCES THIS TO 8 RUNS

SET-UP/RESULTS

L8 ORTHOGONAL ARRAY

TEST	A	B	C	D	E	F	G	A	B	C	D	E	F	G	Q
1	1	1	1	1	1	1	1	30	5	10	1.0	0.25	B	--	59
2	1	1	1	2	2	2	2	30	5	10	1.5	0.375	W	--	17
3	1	2	2	1	1	2	2	30	3	14	1.0	0.25	W	--	102
4	1	2	2	2	2	1	1	30	3	14	1.5	0.375	B	--	30
5	2	1	2	1	2	1	2	45	5	14	1.0	0.375	B	--	27
6	2	1	2	2	1	2	1	45	5	14	1.5	0.25	W	--	40
7	2	2	1	1	2	2	1	45	3	10	1.0	0.375	W	--	21
8	2	2	1	2	1	1	2	45	3	10	1.5	0.25	B	--	31

CALCULATE RESPONSE TABLE

Ex; For B1; (59 + 17 + 27 + 40)/4 = 36
For B2; (102 + 30 + 21 + 31)/4 = 46

	STRESS	DELTA		STRESS	DELTA
A1 A2	52 29	23	E1 E2	58 24	34
B1 B2	36 46	10	F1 F2	37 45	8
C1 C2	32 50	18	G1 G2	-- --	--
D1 D2	52 30	22			

o RATE THE PERFORMANCE

Very Important :	E D A
Important :	C B
Not Important :	F

o PAPER CHAMP

A2 , B1 , C1 , D2 , E2 , F1

NOTE THIS COMBINATION WAS NOT RUN IN THE L8 ARRAY

o MAKE A CONFIRMATION RUN WITH PAPER CHAMP

STRESS = 10 KSI

OPTIMUM DESIGN HAS BEEN FOUND WITH A TOTAL OF 9 RUNS

Appendix C. Rotor Model Mass Normalized Data

SSME-ATD HPOTP; UNIT 4-1 FREE-FREE, ZERO SPEED, FULL ROTOR 105.9 LBM
FILE: HPOTPR1 M636

Number of stations: **

Station Data

STA. No.	AXIAL Location	WEIGHT (lb)	DIAMETRAL (lb-in**2)	MASS (lb-sec**2/in)	DIAMETRAL (in-lb-sec**2)	POLAR (in-lb-sec**2)
1	0.0	0.9954187E-02	0.1049298E-02	0.2570960E-04	0.2715575E-05	0.5431149E-05
2	0.880	0.4262741E-01	0.4888631E-02	0.1103194E-03	0.1265174E-04	0.2530348E-04
3	1.112	0.1649895E+01	0.3377545E+01	0.4267842E-02	0.8741058E-02	0.1748212E-01
4	1.292	0.6122888E+00	0.8144340E+00	0.1584599E-02	0.2107749E-02	0.4215498E-02
5	1.596	0.4376364E+00	0.2089814E+00	0.1132600E-02	0.5408421E-03	0.1081684E-02
6	1.596	0.5840434E+00	0.2738307E+00	0.1511500E-02	0.7086718E-03	0.1417344E-02
7	2.330	0.6550940E+00	0.3154919E+00	0.1695378E-02	0.8164905E-03	0.1632981E-02
8	2.453	0.4826498E+01	0.4383862E+01	0.1249143E-01	0.1134548E-01	0.2269088E-01
9	2.453	0.2801743E+00	0.1416649E+00	0.7250889E-03	0.3666277E-03	0.7332554E-03
10	2.840	0.3779619E+00	0.1901726E+00	0.9781623E-03	0.4921651E-03	0.9843302E-03
11	3.041	0.7103665E+00	0.6459628E+00	0.1838423E-02	0.1671747E-02	0.3343493E-02
12	3.494	0.9356773E+00	0.7255342E+00	0.2421526E-02	0.1877677E-02	0.3755354E-02
13	3.816	0.1474555E+00	0.6346518E-01	0.3816136E-03	0.1642474E-03	0.3284947E-03
14	3.816	0.4489876E+00	0.8165109E-01	0.1161976E-02	0.2113124E-03	0.4226246E-03
15	4.226	0.1099376E+01	0.8495734E+00	0.2845176E-02	0.2198689E-02	0.4397377E-02
16	4.592	0.2012951E+00	0.5314059E-01	0.5209500E-03	0.1375274E-03	0.2750547E-03
17	4.894	0.5000624E+00	0.2970921E+00	0.1294157E-02	0.7688720E-03	0.1537744E-02
18	5.285	0.8998752E-01	0.1711169E-01	0.2328870E-03	0.4428491E-04	0.8856982E-04
19	5.352	0.5541173E-01	0.1055688E-01	0.1434051E-03	0.2729956E-04	0.5458872E-04
20	5.566	0.1122605E+00	0.2252802E-01	0.2905293E-03	0.5830234E-04	0.1166047E-03
21	5.876	0.6130691E+00	0.2869495E+00	0.1586618E-02	0.5355836E-03	0.1071167E-02
22	6.184	0.4741644E+00	0.2479163E+00	0.1227134E-02	0.6416054E-03	0.1283211E-02
23	6.384	0.9009804E-01	0.2491498E-01	0.2331523E-03	0.6447977E-04	0.1289595E-03
24	6.489	0.9254724E-01	0.3207149E-01	0.2395115E-03	0.8380076E-04	0.1660015E-03
25	6.602	0.4768898E-01	0.1651927E-01	0.1234187E-03	0.4275174E-04	0.8550347E-04
26	6.602	0.8424538E-01	0.2776348E-01	0.2180264E-03	0.7185167E-04	0.1437033E-03
27	6.790	0.1870106E+00	0.7276887E-01	0.4839818E-03	0.1883253E-03	0.3766504E-03
28	6.978	0.2138821E+00	0.9947598E-01	0.5514547E-03	0.2574429E-03	0.5148859E-03
29	7.164	0.7302722E+00	0.1068447E+02	0.1889939E-02	0.2765132E-01	0.5530265E-01
30	7.285	0.1602796E+01	0.8241274E+00	0.4148021E-02	0.2132835E-02	0.4265670E-02
31	7.567	0.4192479E+00	0.2768118E+00	0.1085010E-02	0.7163866E-03	0.1432773E-02
32	7.889	0.4947739E+00	0.3777637E+00	0.1280471E-02	0.9776494E-03	0.1955299E-02
33	8.190	0.4725075E+00	0.4159786E+00	0.1222846E-02	0.1076549E-02	0.2153099E-02
34	8.431	0.4942283E+00	0.5000952E+00	0.1279059E-02	0.1294237E-02	0.2588475E-02
35	8.672	0.5645910E+00	0.6267636E+00	0.1461157E-02	0.1622059E-02	0.3244118E-02
36	8.913	0.6112440E+00	0.7177056E+00	0.1581895E-02	0.1857416E-02	0.3714833E-02
37	9.153	0.6438751E+00	0.7859288E+00	0.1666344E-02	0.2028802E-02	0.4057601E-02
38	9.394	0.1191115E+02	0.1457378E+02	0.3082591E-01	0.3771683E-01	0.7543361E-01
39	9.394	0.3274334E+00	0.4033827E+00	0.8473958E-03	0.1043951E-02	0.2087903E-02
40	9.635	0.6438751E+00	0.7859288E+00	0.1666344E-02	0.2028802E-02	0.4057601E-02
41	9.876	0.6112440E+00	0.7177056E+00	0.1581895E-02	0.1857416E-02	0.3714833E-02
42	10.116	0.5645910E+00	0.6267636E+00	0.1461157E-02	0.1622059E-02	0.3244118E-02
43	10.357	0.4942283E+00	0.5000952E+00	0.1279059E-02	0.1294237E-02	0.2588475E-02
44	10.598	0.3617090E+00	0.3331112E+00	0.9678599E-03	0.8628892E-03	0.1724178E-02
45	10.800	0.3176532E+00	0.2384805E+00	0.8228838E-03	0.6171856E-03	0.1234371E-02
46	11.023	0.2926052E+00	0.2052395E+00	0.7572600E-03	0.5311582E-03	0.1062316E-02
47	11.218	0.2678860E+00	0.1788473E+00	0.6932668E-03	0.4628554E-03	0.9257109E-03
48	11.417	0.2785249E+00	0.1818453E+00	0.7208202E-03	0.4706141E-03	0.9412281E-03
49	11.625	0.8503922E+00	0.1806635E+02	0.2200808E-02	0.2812205E-01	0.5624486E-01
50	11.862	0.4185112E+00	0.2815941E+00	0.1083104E-02	0.7287632E-03	0.1457526E-02
51	12.108	0.1108575E+01	-0.1155196E+01	0.2848281E-02	-0.2989639E-02	-0.5979277E-02
52	12.365	0.4376428E+00	0.2692271E+00	0.1132616E-02	0.6967576E-03	0.1393515E-02
53	12.635	0.4168051E+00	0.2174515E+00	0.1078680E-02	0.5627428E-03	0.1125526E-02
54	12.966	0.4438232E+00	0.2114398E+00	0.1148611E-02	0.5472944E-03	0.1094489E-02
55	13.333	0.3949695E+00	0.1893534E+00	0.1022177E-02	0.4900449E-03	0.9800899E-03
56	13.579	0.3590330E+00	0.1764339E+00	0.9291745E-03	0.4566895E-03	0.9132191E-03
57	13.844	0.1989679E+00	0.9937775E-01	0.5149275E-03	0.2571887E-03	0.5143774E-03
58	13.844	0.6187795E+00	0.2406579E-01	0.1580693E-02	0.6228207E-04	0.1245641E-03
59	13.942	0.1334949E+00	0.5824745E-01	0.3454837E-03	0.1508488E-03	0.2688800E-03
60	14.097	0.1091748E+01	0.1075183E+01	0.2825436E-02	0.2782565E-02	0.5565129E-02
61	14.435	0.2885920E+00	0.1091424E+00	0.7468737E-03	0.2824597E-03	0.5649193E-03
62	14.639	0.2048667E+00	0.7762831E-01	0.5301953E-03	0.2009015E-03	0.4018028E-03
63	14.819	0.1800593E+01	0.8898374E+00	0.2589526E-02	0.2302892E-02	0.4605781E-02
64	14.929	0.1819193E+00	0.6978258E-01	0.4708057E-03	0.1805963E-03	0.3611925E-03
65	15.155	0.2292465E+00	0.8671365E-01	0.5932681E-03	0.2295902E-03	0.4591804E-03
66	15.348	0.5292044E+00	0.1263322E+00	0.8519783E-03	0.3269466E-03	0.6538952E-03
67	15.742	0.1146677E+01	0.7590539E+00	0.2967591E-02	0.1912614E-02	0.3825228E-02
68	16.150	0.3345993E+00	0.1292314E+00	0.8659405E-03	0.3344498E-03	0.6688996E-03
69	16.375	0.2304816E+00	0.9855587E-01	0.5964044E-03	0.2543558E-03	0.4687116E-03
70	16.543	0.2453812E+00	0.9573575E-01	0.6350444E-03	0.2477632E-03	0.4955265E-03
71	16.818	0.9534809E+00	0.7909773E+00	0.2467601E-02	0.2047043E-02	0.4094083E-02
72	16.922	0.1866974E+00	0.7382101E-01	0.4831713E-03	0.1910482E-03	0.3820963E-03
73	17.150	0.1296303E+00	0.5167532E-01	0.3354822E-03	0.1337502E-03	0.2676402E-03
74	17.150	0.1021307E+00	0.4072368E-01	0.2643133E-03	0.1053926E-03	0.2107851E-03
75	17.338	0.3887511E+00	0.1536590E+00	0.1006085E-02	0.3976682E-03	0.7953364E-03
76	17.841	0.1683069E+01	0.1346099E+01	0.4355770E-02	0.3483694E-02	0.6967384E-02
77	18.884	0.2871067E+00	0.1154386E+00	0.7430247E-03	0.2987541E-03	0.5975082E-03
78	18.341	0.2335889E+00	0.9504888E-01	0.6045261E-03	0.2459638E-03	0.4919268E-03
79	18.405	0.8831453E-01	0.3639983E-01	0.2285573E-03	0.9420248E-04	0.1884050E-03
80	18.490	0.2460955E+00	0.1014308E+00	0.6368926E-03	0.2625819E-03	0.5250038E-03
81	18.820	0.6848559E+00	0.4545888E+00	0.1772402E-02	0.1176472E-02	0.2352944E-02
82	18.901	0.6592093E+00	0.5411736E+00	0.1654269E-02	0.1408553E-02	0.2801106E-02
83	19.077	0.2242242E+00	0.8792698E-01	0.5802903E-03	0.2275544E-03	0.4551087E-03
84	19.305	0.3363912E+00	0.1807738E+00	0.8705778E-03	0.4678418E-03	0.9356021E-03
85	19.531	0.6552236E+00	0.4803162E+00	0.1695713E-02	0.1243855E-02	0.2486109E-02
86	19.884	0.5714774E+00	0.3838672E+00	0.1478979E-02	0.7843354E-03	0.1568671E-02
87	20.237	0.1484258E+01	0.1247686E+01	0.3841196E-02	0.3227448E-02	0.6454892E-02
88	20.237	0.3837988E+00	0.1589857E+00	0.9932476E-03	0.4114537E-03	0.8229073E-03
89	20.607	0.5995814E+00	0.3179712E+00	0.1551712E-02	0.8229071E-03	0.1645814E-02
90	20.977	0.3054680E+01	0.3844441E+02	0.7905487E-02	0.7879508E-01	0.1575902E+00
91	21.838	0.1897803E+00	0.7162988E-01	0.2841104E-03	0.1853776E-03	0.3707551E-03
92	21.884	0.1057871E+01	0.1508165E+01	0.2735491E-02	0.3903120E-02	0.7806238E-02
93	21.378	0.6863618E+00	0.3958788E+00	0.1569260E-02	0.1024531E-02	0.2049062E-02
94	21.673	0.2231686E+01	0.1492944E+02	0.5775377E-02	0.3863727E-01	0.7727450E-01
95	21.986	0.6428518E+00	0.4194505E+00	0.1663696E-02	0.1085535E-02	0.2171069E-02
96	22.299	0.3429875E+02	0.2164438E+03	0.8876491E-01	0.5601549E+00	0.1120309E+01
97	22.299	0.3875494E+00	0.2806711E+00	0.7959355E-03	0.5193358E-03	0.1038670E-02
98	22.598	0.6150982E+00	0.4813417E+00	0.1591869E-02	0.1038669E-02	0.2077338E-02
99	22.897	0.4747548E+01	0.4373903E+02	0.1228661E-01	0.1131963E+00	0.2263925E+00

ORIGINAL PAGE IS
OF POOR QUALITY

NATURAL FREQUENCY = 490 HZ

DIAMETRAL INERTIA NORMALIZED: FACTOR = 0.5057935E+01

Station	INPUT Displacement	INPUT Slope	DIAMETRAL NORMALIZED Displacement	DIAMETRAL NORMALIZED Slope
1	-0.1000000E+01	0.1634000E+00	-0.5057935E+01	0.8264665E+00
2	-0.8563000E+00	0.1633000E+00	-0.4331109E+01	0.8259606E+00
3	-0.8183000E+00	0.1633000E+00	-0.4138907E+01	0.8259606E+00
4	-0.7884000E+00	0.1630000E+00	-0.3987676E+01	0.8244433E+00
5	-0.7381000E+00	0.1627000E+00	-0.3733261E+01	0.8229259E+00
6	-0.7381000E+00	0.1627000E+00	-0.3733261E+01	0.8229259E+00
7	-0.6174000E+00	0.1621000E+00	-0.3122768E+01	0.8198913E+00
8	-0.5971000E+00	0.1620000E+00	-0.3020092E+01	0.8193854E+00
9	-0.5971000E+00	0.1620000E+00	-0.3020092E+01	0.8193854E+00
10	-0.5326000E+00	0.1612000E+00	-0.2693855E+01	0.8153390E+00
11	-0.4986000E+00	0.1604000E+00	-0.2521886E+01	0.8112926E+00
12	-0.4223000E+00	0.1576000E+00	-0.2135965E+01	0.7971384E+00
13	-0.3689000E+00	0.1551000E+00	-0.1865871E+01	0.7844856E+00
14	-0.3689000E+00	0.1551000E+00	-0.1865871E+01	0.7844856E+00
15	-0.3023000E+00	0.1513000E+00	-0.1529813E+01	0.7652656E+00
16	-0.2438000E+00	0.1444000E+00	-0.1233124E+01	0.7303658E+00
17	-0.1975000E+00	0.1390000E+00	-0.9989420E+00	0.7030529E+00
18	-0.1402000E+00	0.1312000E+00	-0.7091225E+00	0.6636011E+00
19	-0.1306000E+00	0.1297000E+00	-0.6605662E+00	0.6560141E+00
20	-0.1008000E+00	0.1248000E+00	-0.5098397E+00	0.6312304E+00
21	-0.6010000E-01	0.1185000E+00	-0.3039618E+00	0.5993652E+00
22	-0.2156000E-01	0.1116000E+00	-0.1090490E+00	0.5644654E+00
23	0.2218000E-02	0.1069000E+00	0.1121850E-01	0.5406931E+00
24	0.1445000E-01	0.1040000E+00	0.7308710E-01	0.5260251E+00
25	0.2731000E-01	0.1008000E+00	0.1381322E+00	0.5098397E+00
26	0.2731000E-01	0.1008000E+00	0.1381322E+00	0.5098397E+00
27	0.4767000E-01	0.9543002E-01	0.2411117E+00	0.4826788E+00
28	0.6606002E-01	0.9192997E-01	0.3381734E+00	0.4649758E+00
29	0.8516002E-01	0.8897001E-01	0.4307558E+00	0.4500045E+00
30	0.9682000E-01	0.8702999E-01	0.4897092E+00	0.4401920E+00
31	0.1229000E+00	0.8511999E-01	0.6216202E+00	0.4204155E+00
32	0.1511000E+00	0.7985997E-01	0.7642538E+00	0.4039265E+00
33	0.1764000E+00	0.7734001E-01	0.8922197E+00	0.3911807E+00
34	0.1960000E+00	0.7569999E-01	0.9913551E+00	0.3828856E+00
35	0.2158000E+00	0.7445002E-01	0.1087456E+01	0.3765635E+00
36	0.2337000E+00	0.7334000E-01	0.1182038E+01	0.3709489E+00
37	0.2529000E+00	0.7233000E-01	0.1274599E+01	0.3658404E+00
38	0.2700000E+00	0.7134002E-01	0.1365642E+01	0.3608332E+00
39	0.2700000E+00	0.7134002E-01	0.1365642E+01	0.3608332E+00
40	0.2875000E+00	0.7031000E-01	0.1454156E+01	0.3556234E+00
41	0.3046000E+00	0.6919998E-01	0.1540647E+01	0.3500090E+00
42	0.3215000E+00	0.6794000E-01	0.1626125E+01	0.3436360E+00
43	0.3381000E+00	0.6645000E-01	0.1710088E+01	0.3360997E+00
44	0.3543000E+00	0.6437999E-01	0.1792026E+01	0.3256298E+00
45	0.3675000E+00	0.6199000E-01	0.1858798E+01	0.3138862E+00
46	0.3814000E+00	0.5869000E-01	0.1929096E+01	0.2968501E+00
47	0.3929000E+00	0.5548000E-01	0.1987262E+01	0.2806142E+00
48	0.4040000E+00	0.5211000E-01	0.2043406E+01	0.2635689E+00
49	0.4149000E+00	0.4854000E-01	0.2098536E+01	0.2455121E+00
50	0.4263000E+00	0.4524000E-01	0.2156197E+01	0.2288209E+00
51	0.4373000E+00	0.4202000E-01	0.2211835E+01	0.2125364E+00
52	0.4479000E+00	0.3854000E-01	0.2265449E+01	0.1949328E+00
53	0.4579000E+00	0.3571000E-01	0.2316028E+01	0.1805830E+00
54	0.4679000E+00	0.2506000E-01	0.2366607E+01	0.1267516E+00
55	0.4756000E+00	0.1568000E-01	0.2405553E+01	0.7938839E-01
56	0.4788000E+00	0.9512998E-02	0.2421739E+01	0.4811612E-01
57	0.4806000E+00	0.4021000E-02	0.2430843E+01	0.2033795E-01
58	0.4806000E+00	0.4021000E-02	0.2430843E+01	0.2033795E-01
59	0.4809000E+00	0.2195000E-02	0.2432341E+01	0.1110217E-01
60	0.4810000E+00	-0.6040001E-05	0.2432866E+01	-0.3463674E-02
61	0.4795000E+00	-0.6903001E-02	0.2425280E+01	-0.3531956E-01
62	0.4776000E+00	-0.1076000E-01	0.2415669E+01	-0.5442338E-01
63	0.4752000E+00	-0.1430000E-01	0.2403538E+01	-0.7232845E-01
64	0.4734000E+00	-0.1645000E-01	0.2394425E+01	-0.8328302E-01
65	0.4690000E+00	-0.2059000E-01	0.2372170E+01	-0.1041428E+00
66	0.4644000E+00	-0.2411000E-01	0.2348985E+01	-0.1219468E+00
67	0.4522000E+00	-0.3209000E-01	0.2287198E+01	-0.1623091E+00
68	0.4376000E+00	-0.3946000E-01	0.2213352E+01	-0.1995861E+00
69	0.4279000E+00	-0.4343000E-01	0.2164289E+01	-0.2196661E+00
70	0.4191000E+00	-0.4672000E-01	0.2119780E+01	-0.2363067E+00
71	0.4060000E+00	-0.5144000E-01	0.2053521E+01	-0.2601801E+00
72	0.4004000E+00	-0.5334000E-01	0.2025196E+01	-0.2697902E+00
73	0.3872000E+00	-0.5723000E-01	0.1958432E+01	-0.2894655E+00
74	0.3872000E+00	-0.5723000E-01	0.1958432E+01	-0.2894655E+00
75	0.3763000E+00	-0.6026000E-01	0.1903300E+01	-0.3047912E+00
76	0.3418000E+00	-0.6928003E-01	0.1728802E+01	-0.3504139E+00
77	0.3298000E+00	-0.7289998E-01	0.1668106E+01	-0.3646770E+00
78	0.3036000E+00	-0.7745999E-01	0.1535508E+01	-0.3917875E+00
79	0.2984000E+00	-0.7845998E-01	0.1509287E+01	-0.3968454E+00
80	0.2914000E+00	-0.8003998E-01	0.1473802E+01	-0.4048370E+00
81	0.2632000E+00	-0.8502001E-01	0.1331248E+01	-0.4380256E+00
82	0.2560000E+00	-0.8622003E-01	0.1294838E+01	-0.4360952E+00
83	0.2400000E+00	-0.8873999E-01	0.1213904E+01	-0.4488410E+00
84	0.2185000E+00	-0.9270000E-01	0.1105159E+01	-0.4688705E+00
85	0.1964000E+00	-0.9573001E-01	0.9933785E+00	-0.4841961E+00
86	0.1606000E+00	-0.1003000E+00	0.8123043E+00	-0.5071109E+00
87	0.1233000E+00	-0.1048000E+00	0.6236434E+00	-0.5300714E+00
88	0.1233000E+00	-0.1048000E+00	0.6236434E+00	-0.5300714E+00
89	0.8232999E-01	-0.1092000E+00	0.4164197E+00	-0.5523264E+00
90	0.3976000E-01	-0.1135000E+00	0.2011034E+00	-0.5740756E+00
91	0.3353000E-01	-0.1139000E+00	0.1695925E+00	-0.5760987E+00
92	0.2728000E-01	-0.1142000E+00	0.1379804E+00	-0.5776161E+00
93	-0.7534999E-02	-0.1161000E+00	-0.3811155E-01	-0.5872263E+00
94	-0.4298000E-01	-0.1180000E+00	-0.2169853E+00	-0.5968361E+00
95	-0.8096999E-01	-0.1197000E+00	-0.4095489E+00	-0.6054348E+00
96	-0.1196000E+00	-0.1214000E+00	-0.6049298E+00	-0.6140332E+00
97	-0.1196000E+00	-0.1214000E+00	-0.6049298E+00	-0.6140332E+00
98	-0.1561000E+00	-0.1217000E+00	-0.7895434E+00	-0.6155586E+00
99	-0.1927000E+00	-0.1220000E+00	-0.9746642E+00	-0.6170679E+00

NORMALIZING CHECK (DIAMETRAL ONLY): 0.9999990E+00

ORIGINAL PAGE IS
OF POOR QUALITY

NATURAL FREQUENCY = 1040 HZ DETER

DIAMETRAL INERTIA NORMALIZED: FACTOR = 0.4789545E+01

Station	INPUT Displacement	INPUT Slope	DIAMETRAL NORMALIZED Displacement	DIAMETRAL NORMALIZED Slope
1	-0.1000000E+01	0.2566000E+00	-0.4789545E+01	0.1228946E+01
2	-0.7742000E+00	0.2565000E+00	-0.3707911E+01	0.1228466E+01
3	-0.7144000E+00	0.2564000E+00	-0.3421508E+01	0.1227987E+01
4	-0.6661000E+00	0.2543000E+00	-0.3190182E+01	0.1217930E+01
5	-0.5863000E+00	0.2529000E+00	-0.2807992E+01	0.1211225E+01
6	-0.5863000E+00	0.2529000E+00	-0.2807992E+01	0.1211225E+01
7	-0.5960000E+00	0.2500000E+00	-0.1896580E+01	0.1197336E+01
8	-0.5640000E+00	0.2493000E+00	-0.1743321E+01	0.1193983E+01
9	-0.5640000E+00	0.2493000E+00	-0.1743321E+01	0.1193983E+01
10	-0.2616000E+00	0.2459000E+00	-0.1252892E+01	0.1177699E+01
11	-0.2075000E+00	0.2426000E+00	-0.9937889E+00	0.1161895E+01
12	-0.8702999E-01	0.2314000E+00	-0.4168166E+00	0.1108254E+01
13	-0.4896000E-02	0.2219000E+00	-0.2344863E-01	0.1062755E+01
14	-0.4896000E-02	0.2219000E+00	-0.2344863E-01	0.1062755E+01
15	0.9415001E-01	0.2079000E+00	0.4509168E+00	0.9957047E+00
16	0.1775000E+00	0.1834000E+00	0.8501067E+00	0.8783657E+00
17	0.2393000E+00	0.1650000E+00	0.1146090E+01	0.7902420E+00
18	0.3102000E+00	0.1389000E+00	0.1485654E+01	0.6652399E+00
19	0.3214000E+00	0.1339000E+00	0.1539295E+01	0.6412932E+00
20	0.3548000E+00	0.1178000E+00	0.1699259E+01	0.5641848E+00
21	0.3957000E+00	0.9750003E-01	0.1895144E+01	0.4669612E+00
22	0.4296000E+00	0.7595003E-01	0.2057582E+01	0.3637508E+00
23	0.4477000E+00	0.6134000E-01	0.2144189E+01	0.2937784E+00
24	0.4562000E+00	0.5255000E-01	0.2184898E+01	0.2516808E+00
25	0.4663000E+00	0.4276000E-01	0.2223692E+01	0.2047924E+00
26	0.4663000E+00	0.4276000E-01	0.2223692E+01	0.2047924E+00
27	0.4750000E+00	0.2661000E-01	0.2274939E+01	0.1274444E+00
28	0.4824000E+00	0.1620000E-01	0.2310379E+01	0.7758737E-01
29	0.4876000E+00	0.7484000E-02	0.2335284E+01	0.3584345E-01
30	0.4899000E+00	0.1945000E-02	0.2346299E+01	0.9315275E-02
31	0.4920000E+00	-0.9016000E-02	0.2356357E+01	-0.4318073E-01
32	0.4901000E+00	-0.1798000E-01	0.2347258E+01	-0.8572924E-01
33	0.4857000E+00	-0.2459000E-01	0.2326184E+01	-0.1177700E+00
34	0.4804000E+00	-0.2886000E-01	0.2300801E+01	-0.1382204E+00
35	0.4740000E+00	-0.3201000E-01	0.2270149E+01	-0.1533069E+00
36	0.4646000E+00	-0.3475000E-01	0.2254700E+01	-0.1664297E+00
37	0.4584000E+00	-0.3720000E-01	0.2195436E+01	-0.1781636E+00
38	0.4495000E+00	-0.3952000E-01	0.2152810E+01	-0.1892748E+00
39	0.4495000E+00	-0.3952000E-01	0.2152810E+01	-0.1892748E+00
40	0.4374000E+00	-0.4176000E-01	0.2094859E+01	-0.2000050E+00
41	0.4244000E+00	-0.4403000E-01	0.2032598E+01	-0.2108748E+00
42	0.4106000E+00	-0.4646000E-01	0.1966504E+01	-0.2225129E+00
43	0.3958000E+00	-0.4915000E-01	0.1895622E+01	-0.2353965E+00
44	0.3795000E+00	-0.5263000E-01	0.1817555E+01	-0.2520652E+00
45	0.3643000E+00	-0.5653000E-01	0.1744758E+01	-0.2707416E+00
46	0.3462000E+00	-0.6124000E-01	0.1658071E+01	-0.2932994E+00
47	0.3291000E+00	-0.6563002E-01	0.1576173E+01	-0.3143247E+00
48	0.3108000E+00	-0.6989002E-01	0.1488528E+01	-0.3347274E+00
49	0.2908000E+00	-0.7406998E-01	0.1392741E+01	-0.3547466E+00
50	0.2678000E+00	-0.7735997E-01	0.1282586E+01	-0.3705035E+00
51	0.2434000E+00	-0.8020997E-01	0.1165726E+01	-0.3841532E+00
52	0.2170000E+00	-0.8288002E-01	0.1039288E+01	-0.3969409E+00
53	0.1877000E+00	-0.8598000E-01	0.8989599E+00	-0.4117878E+00
54	0.1485000E+00	-0.9025002E-01	0.7112178E+00	-0.4322584E+00
55	0.1039000E+00	-0.9329998E-01	0.4976150E+00	-0.4468458E+00
56	0.7358998E-01	-0.9438002E-01	0.3524477E+00	-0.4520184E+00
57	0.4181000E-01	-0.9467000E-01	0.2002425E+00	-0.4534072E+00
58	0.4181000E-01	-0.9467000E-01	0.2002425E+00	-0.4534072E+00
59	0.3019000E-01	-0.9468998E-01	0.1445903E+00	-0.4531198E+00
60	0.1186000E-01	-0.9453001E-01	0.5680164E-01	-0.4517789E+00
61	-0.2804000E-01	-0.9292001E-01	-0.1342932E+00	-0.4458259E+00
62	-0.5177000E-01	-0.9157002E-01	-0.2479444E+00	-0.4385684E+00
63	-0.7266998E-01	-0.8996999E-01	-0.3480416E+00	-0.4308973E+00
64	-0.8525997E-01	-0.8862999E-01	-0.4083394E+00	-0.4254375E+00
65	-0.1104000E+00	-0.8658002E-01	-0.5287437E+00	-0.4133205E+00
66	-0.1314000E+00	-0.8376998E-01	-0.6293198E+00	-0.4012033E+00
67	-0.1749000E+00	-0.7681000E-01	-0.8376564E+00	-0.3678696E+00
68	-0.2125000E+00	-0.6884003E-01	-0.1017735E+01	-0.3296986E+00
69	-0.2525000E+00	-0.6391001E-01	-0.1113525E+01	-0.3060870E+00
70	-0.2483000E+00	-0.5946000E-01	-0.1189194E+01	-0.2847744E+00
71	-0.2686000E+00	-0.5253000E-01	-0.1286417E+01	-0.2515842E+00
72	-0.2762000E+00	-0.4954000E-01	-0.1322817E+01	-0.2372641E+00
73	-0.2916000E+00	-0.4307000E-01	-0.1396572E+01	-0.2062771E+00
74	-0.2916000E+00	-0.4307000E-01	-0.1396572E+01	-0.2062771E+00
75	-0.3026000E+00	-0.3769000E-01	-0.1449255E+01	-0.1805103E+00
76	-0.3285000E+00	-0.1990000E-01	-0.1573299E+01	-0.9530795E-01
77	-0.3344000E+00	-0.1378000E-01	-0.1601557E+01	-0.6599712E-01
78	-0.3432000E+00	-0.1363000E-02	-0.1643703E+01	-0.6527875E-02
79	-0.3444000E+00	0.1066000E-02	-0.1649449E+01	0.5105440E-02
80	-0.3458000E+00	0.4997998E-02	-0.1656155E+01	0.2393714E-01
81	-0.3479000E+00	0.1682000E-01	-0.1666212E+01	0.8658395E-01
82	-0.3477000E+00	0.2131000E-01	-0.1665255E+01	0.1020609E+00
83	-0.3461000E+00	0.2843000E-01	-0.1657592E+01	0.1361610E+00
84	-0.3425000E+00	0.4014000E-01	-0.1640358E+01	0.1922443E+00
85	-0.3357000E+00	0.4957000E-01	-0.1607782E+01	0.2374078E+00
86	-0.3206000E+00	0.6480002E-01	-0.1535463E+01	0.3103496E+00
87	-0.2998000E+00	0.8065999E-01	-0.1435845E+01	0.3863084E+00
88	-0.2998000E+00	0.8065999E-01	-0.1435845E+01	0.3863084E+00
89	-0.2712000E+00	0.9786999E-01	-0.1298870E+01	0.4687331E+00
90	-0.2360000E+00	0.1156000E+00	-0.1130285E+01	0.5536482E+00
91	-0.2302000E+00	0.1172000E+00	-0.1102507E+01	0.5613112E+00
92	-0.2243000E+00	0.1187000E+00	-0.1074249E+01	0.5684955E+00
93	-0.1900000E+00	0.1275000E+00	-0.9099755E+00	0.6096837E+00
94	-0.1530000E+00	0.1360000E+00	-0.7327697E+00	0.6513507E+00
95	-0.1188000E+00	0.1450000E+00	-0.5306595E+00	0.6944548E+00
96	-0.6573999E-01	0.1541000E+00	-0.3148515E+00	0.7380380E+00
97	-0.6573999E-01	0.1541000E+00	-0.3148515E+00	0.7380380E+00
98	-0.1933000E-01	0.1556000E+00	-0.9257799E-01	0.7452221E+00
99	0.2754000E-01	0.1571000E+00	0.1318985E+00	0.7524061E+00

NORMALIZING CHECK (DIAMETRAL ONLY): 0.9999990E+00

ORIGINAL PAGE IS
OF POOR QUALITY

NATURAL FREQUENCY = 2000 HZ

DIAMETRAL INERTIA NORMALIZED: FACTOR = 0.4987884E+01

Station	INPUT Displacement	INPUT Slope	DIAMETRAL NORMALIZED Displacement	DIAMETRAL NORMALIZED Slope
1	-0.1000000E+01	0.3735000E+00	-0.4987884E+01	0.1862974E+01
2	-0.6712000E+00	0.3732000E+00	-0.3347867E+01	0.1861478E+01
3	-0.5836000E+00	0.3728000E+00	-0.2911926E+01	0.1859483E+01
4	-0.5104000E+00	0.3621000E+00	-0.2545815E+01	0.1806112E+01
5	-0.3935000E+00	0.3556000E+00	-0.1962731E+01	0.1773691E+01
6	-0.3935000E+00	0.3556000E+00	-0.1962731E+01	0.1773691E+01
7	-0.1201000E+00	0.3439000E+00	-0.5990449E+00	0.1715333E+01
8	-0.7454002E-01	0.3412000E+00	-0.3717969E+00	0.1701865E+01
9	-0.7454002E-01	0.3412000E+00	-0.3717969E+00	0.1701865E+01
10	0.6730002E-01	0.3287000E+00	0.3356647E+00	0.1639517E+01
11	0.1412000E+00	0.3177000E+00	0.7042891E+00	0.1584650E+01
12	0.2990000E+00	0.2830000E+00	0.1491377E+01	0.1411571E+01
13	0.3985000E+00	0.2555000E+00	0.1987671E+01	0.1274404E+01
14	0.3985000E+00	0.2555000E+00	0.1987671E+01	0.1274404E+01
15	0.5089000E+00	0.2184000E+00	0.2538335E+01	0.1089354E+01
16	0.5870000E+00	0.1577000E+00	0.2927887E+01	0.7865892E+00
17	0.6346000E+00	0.1151000E+00	0.3165310E+01	0.5741055E+00
18	0.6730000E+00	0.5867000E-01	0.3360835E+01	0.2926391E+00
19	0.6782000E+00	0.4849000E-01	0.3382782E+01	0.2418624E+00
20	0.6875000E+00	0.1604000E-01	0.3429170E+01	0.8000565E-01
21	0.6880000E+00	-0.2295000E-01	0.3435654E+01	-0.1144719E+00
22	0.6753000E+00	-0.6198000E-01	0.3368318E+01	-0.3091490E+00
23	0.6588000E+00	-0.8788000E-01	0.3286817E+01	-0.4383449E+00
24	0.6478000E+00	-0.1017000E+00	0.3231151E+01	-0.5072678E+00
25	0.6341000E+00	-0.1176000E+00	0.3162817E+01	-0.5865752E+00
26	0.6341000E+00	-0.1176000E+00	0.3162817E+01	-0.5865752E+00
27	0.6072000E+00	-0.1431000E+00	0.3028643E+01	-0.7137662E+00
28	0.5765000E+00	-0.1588000E+00	0.2875514E+01	-0.7920759E+00
29	0.5432000E+00	-0.1715000E+00	0.2709418E+01	-0.8554221E+00
30	0.5194000E+00	-0.1778000E+00	0.2590706E+01	-0.8868456E+00
31	0.4582000E+00	-0.1892000E+00	0.2285448E+01	-0.9437075E+00
32	0.3866000E+00	-0.1975000E+00	0.1928315E+01	-0.9851069E+00
33	0.3174000E+00	-0.2028000E+00	0.1583154E+01	-0.1011542E+01
34	0.2615000E+00	-0.2057000E+00	0.1304331E+01	-0.1026087E+01
35	0.2058000E+00	-0.2076000E+00	0.1026505E+01	-0.1035484E+01
36	0.1500000E+00	-0.2089000E+00	0.7481824E+00	-0.1041968E+01
37	0.9412003E-01	-0.2098000E+00	0.4694597E+00	-0.1046457E+01
38	0.3814000E-01	-0.2104000E+00	0.1902378E+00	-0.1049450E+01
39	0.3814000E-01	-0.2104000E+00	0.1902378E+00	-0.1049450E+01
40	-0.1870000E-01	-0.2099000E+00	-0.9327340E-01	-0.1046956E+01
41	-0.7555002E-01	-0.2099000E+00	-0.3768347E+00	-0.1042467E+01
42	-0.1325000E+00	-0.2077000E+00	-0.6608945E+00	-0.1035983E+01
43	-0.1895000E+00	-0.2058000E+00	-0.9452038E+00	-0.1026505E+01
44	-0.2471000E+00	-0.2027000E+00	-0.1232504E+01	-0.1011044E+01
45	-0.2956000E+00	-0.1985000E+00	-0.1474418E+01	-0.9900947E+00
46	-0.3483000E+00	-0.1925000E+00	-0.1737279E+01	-0.9601675E+00
47	-0.3935000E+00	-0.1861000E+00	-0.1962731E+01	-0.9282451E+00
48	-0.4379000E+00	-0.1788000E+00	-0.2184194E+01	-0.8918355E+00
49	-0.4822000E+00	-0.1707000E+00	-0.2405157E+01	-0.8514318E+00
50	-0.5281000E+00	-0.1612000E+00	-0.2634181E+01	-0.8040468E+00
51	-0.5722000E+00	-0.1516000E+00	-0.2854067E+01	-0.7561631E+00
52	-0.6140000E+00	-0.1411000E+00	-0.3062560E+01	-0.7037983E+00
53	-0.6540000E+00	-0.1260000E+00	-0.3262075E+01	-0.6284732E+00
54	-0.6959000E+00	-0.9849000E-01	-0.3471067E+01	-0.4912566E+00
55	-0.7298000E+00	-0.6888001E-01	-0.3640157E+01	-0.3395751E+00
56	-0.7452000E+00	-0.4792000E-01	-0.3716970E+01	-0.2390195E+00
57	-0.7554000E+00	-0.2992000E-01	-0.3768045E+01	-0.1492375E+00
58	-0.7556000E+00	-0.2992000E-01	-0.3768045E+01	-0.1492375E+00
59	-0.7576000E+00	-0.2395000E-01	-0.3778028E+01	-0.1194598E+00
60	-0.7593000E+00	-0.1457000E-01	-0.3787299E+01	-0.7267344E-01
61	-0.7544000E+00	0.5509999E-02	-0.3763856E+01	0.2748525E-01
62	-0.7480000E+00	0.1720000E-01	-0.3730937E+01	0.8579159E-01
63	-0.7396000E+00	0.2786000E-01	-0.3689038E+01	0.1389624E+00
64	-0.7325000E+00	0.3420000E-01	-0.3653625E+01	0.1705856E+00
65	-0.7159000E+00	0.4595000E-01	-0.3570826E+01	0.2291932E+00
66	-0.6993000E+00	0.5546000E-01	-0.3488027E+01	0.2766280E+00
67	-0.6555000E+00	0.7533002E-01	-0.3269557E+01	0.3757373E+00
68	-0.6039000E+00	0.9117001E-01	-0.3012182E+01	0.4547454E+00
69	-0.5713000E+00	0.9854001E-01	-0.2849578E+01	0.4915060E+00
70	-0.5426000E+00	0.1040000E+00	-0.2706425E+01	0.5187397E+00
71	-0.5010000E+00	0.1106000E+00	-0.2498929E+01	0.5516599E+00
72	-0.4830000E+00	0.1129000E+00	-0.2409147E+01	0.5631321E+00
73	-0.4432000E+00	0.1167000E+00	-0.2210629E+01	0.5820660E+00
74	-0.4432000E+00	0.1167000E+00	-0.2210629E+01	0.5820660E+00
75	-0.4110000E+00	0.1189000E+00	-0.2050019E+01	0.5930594E+00
76	-0.3156000E+00	0.1210000E+00	-0.1574176E+01	0.6035339E+00
77	-0.2841000E+00	0.1201000E+00	-0.1417057E+01	0.5990449E+00
78	-0.2205000E+00	0.1162000E+00	-0.1099828E+01	0.5795919E+00
79	-0.2086000E+00	0.1151000E+00	-0.1040472E+01	0.5741055E+00
80	-0.1922000E+00	0.1132000E+00	-0.9586712E+00	0.5646284E+00
81	-0.1325000E+00	0.1052000E+00	-0.6608945E+00	0.5247253E+00
82	-0.1182000E+00	0.1028000E+00	-0.5895678E+00	0.5127544E+00
83	-0.8789003E-01	0.9710997E-01	-0.4383852E+00	0.4843732E+00
84	-0.4781000E-01	0.8643001E-01	-0.2384707E+00	0.4311028E+00
85	-0.1319000E-01	0.7674998E-01	-0.6579018E-01	0.3828200E+00
86	0.3595000E-01	0.5897000E-01	0.1793144E+00	0.2941355E+00
87	0.7817000E-01	0.3796000E-01	0.3899028E+00	0.1893401E+00
88	0.7817000E-01	0.3796000E-01	0.3899028E+00	0.1893401E+00
89	0.1132000E+00	0.1244000E-01	0.5646284E+00	0.6204927E-01
90	0.1379000E+00	-0.1652000E-01	0.6878291E+00	-0.8259979E-01
91	0.1396000E+00	-0.1938000E-01	0.6963884E+00	-0.9626609E-01
92	0.1412000E+00	-0.2212000E-01	0.7042891E+00	-0.1103520E+00
93	0.1466000E+00	-0.3839000E-01	0.7312358E+00	-0.1914040E+00
94	0.1468000E+00	-0.5588000E-01	0.7322212E+00	-0.2787229E+00
95	0.1404000E+00	-0.7505000E-01	0.7002988E+00	-0.3743486E+00
96	0.1275000E+00	-0.9547001E-01	0.6359551E+00	-0.4761932E+00
97	0.1275000E+00	-0.9547001E-01	0.6359551E+00	-0.4761932E+00
98	0.9948999E-01	-0.9899002E-01	0.4962444E+00	-0.4937507E+00
99	0.7024997E-01	-0.1026000E+00	0.3503987E+00	-0.5117567E+00

NORMALIZING CHECK (DIAMETRAL ONLY): 0.9999995E+00

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OF POOR QUALITY

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NATURAL FREQUENCY = 3196 HZ

DIAMETRAL INERTIA NORMALIZED: FACTOR = 0.6292444E+01

Station	INPUT Displacement	INPUT Slope	DIAMETRAL NORMALIZED Displacement	DIAMETRAL NORMALIZED Slope
1	-0.1000000E+01	0.4838000E+00	-0.6292444E+01	0.3044284E+01
2	-0.5739000E+00	0.4830000E+00	-0.3611233E+01	0.3039250E+01
3	-0.4602000E+00	0.4819000E+00	-0.2895782E+01	0.3032329E+01
4	-0.3618000E+00	0.4475000E+00	-0.2276606E+01	0.2815868E+01
5	-0.2134000E+00	0.4279000E+00	-0.1342807E+01	0.2692536E+01
6	-0.2134000E+00	0.4279000E+00	-0.1342807E+01	0.2692536E+01
7	0.1199000E+00	0.3962000E+00	0.7544440E+00	0.2493066E+01
8	0.1739000E+00	0.3895000E+00	0.1094255E+01	0.2450907E+01
9	0.1739000E+00	0.3895000E+00	0.1094255E+01	0.2450907E+01
10	0.3224000E+00	0.3588000E+00	0.2028684E+01	0.2257729E+01
11	0.3937000E+00	0.3340000E+00	0.2477335E+01	0.2101676E+01
12	0.5252000E+00	0.2629000E+00	0.3304791E+01	0.1654284E+01
13	0.5902000E+00	0.2123000E+00	0.3713800E+01	0.1335885E+01
14	0.5902000E+00	0.2123000E+00	0.3713800E+01	0.1335885E+01
15	0.6430000E+00	0.1516000E+00	0.4044041E+01	0.9539346E+00
16	0.6421000E+00	0.6563002E-01	0.4040378E+01	0.4129732E+00
17	0.6192000E+00	0.1345000E-01	0.3896281E+01	0.8463335E-01
18	0.5602000E+00	-0.4438000E-01	0.3525026E+01	-0.2792587E+00
19	0.5475000E+00	-0.5347000E-01	0.3445113E+01	-0.3364570E+00
20	0.5027000E+00	-0.7981002E-01	0.3163211E+01	-0.5022081E+00
21	0.4365000E+00	-0.1056000E+00	0.2746652E+01	-0.6644821E+00
22	0.3592000E+00	-0.1242000E+00	0.2260245E+01	-0.7815214E+00
23	0.3049000E+00	-0.1321000E+00	0.1918566E+01	-0.8312318E+00
24	0.2738000E+00	-0.1352000E+00	0.1722871E+01	-0.8507386E+00
25	0.2395000E+00	-0.1374000E+00	0.1507040E+01	-0.8645816E+00
26	0.2395000E+00	-0.1374000E+00	0.1507040E+01	-0.8645816E+00
27	0.1843000E+00	-0.1384000E+00	0.1159697E+01	-0.8708743E+00
28	0.1339000E+00	-0.1368000E+00	0.8425581E+00	-0.8608063E+00
29	0.8585000E-01	-0.1339000E+00	0.5402063E+00	-0.8425581E+00
30	0.5440000E-01	-0.1283000E+00	0.3423089E+00	-0.8073207E+00
31	-0.1526000E-01	-0.1148000E+00	-0.9602267E-01	-0.7223724E+00
32	-0.8222917E-01	-0.1012000E+00	-0.5174275E+00	-0.6367952E+00
33	-0.1385000E+00	-0.8911997E-01	-0.8715034E+00	-0.5607824E+00
34	-0.1781000E+00	-0.8034998E-01	-0.1120684E+01	-0.5055978E+00
35	-0.2122000E+00	-0.7522001E-01	-0.1335257E+01	-0.4687328E+00
36	-0.2427000E+00	-0.6666001E-01	-0.1527176E+01	-0.4181959E+00
37	-0.2700000E+00	-0.5994000E-01	-0.1698959E+01	-0.3771691E+00
38	-0.2946000E+00	-0.5332000E-01	-0.1853754E+01	-0.3355131E+00
39	-0.2946000E+00	-0.5332000E-01	-0.1853754E+01	-0.3355131E+00
40	-0.3087000E+00	-0.4601000E-01	-0.1892138E+01	-0.2895153E+00
41	-0.3048000E+00	-0.3849000E-01	-0.1912903E+01	-0.2421961E+00
42	-0.3039000E+00	-0.3031000E-01	-0.1912273E+01	-0.1907240E+00
43	-0.3001000E+00	-0.2121000E-01	-0.1888362E+01	-0.1334627E+00
44	-0.2908000E+00	-0.9349000E-02	-0.1829843E+01	-0.5882886E-01
45	-0.2778000E+00	0.4052999E-02	-0.1748041E+01	0.2537742E-01
46	-0.2585000E+00	0.2020000E-01	-0.1626596E+01	0.1271073E+00
47	-0.2370000E+00	0.3528000E-01	-0.1491389E+01	0.2219974E+00
48	-0.2118000E+00	0.4995000E-01	-0.1332739E+01	0.3143076E+00
49	-0.1821000E+00	0.6427997E-01	-0.1145054E+01	0.4044781E+00
50	-0.1475000E+00	0.7478000E-01	-0.9281353E+00	0.4700456E+00
51	-0.1102000E+00	0.8350003E-01	-0.6934273E+00	0.5254192E+00
52	-0.6788999E-01	0.9171999E-01	-0.4271939E+00	0.5771428E+00
53	-0.1802000E-01	0.1008000E+00	-0.1133898E+00	0.6342782E+00
54	0.5319000E-01	0.1125000E+00	0.3346951E+00	0.7079000E+00
55	0.1345000E+00	0.1194000E+00	0.8463339E+00	0.7513180E+00
56	0.1869000E+00	0.1206000E+00	0.1186463E+01	0.7588686E+00
57	0.2433000E+00	0.1194000E+00	0.1530951E+01	0.7513180E+00
58	0.2433000E+00	0.1194000E+00	0.1530951E+01	0.7513180E+00
59	0.2622000E+00	0.1185000E+00	0.1649679E+01	0.7456546E+00
60	0.2917000E+00	0.1164000E+00	0.1835505E+01	0.7324405E+00
61	0.3514000E+00	0.1094000E+00	0.2211164E+01	0.6883932E+00
62	0.3854000E+00	0.1038000E+00	0.2425188E+01	0.6531557E+00
63	0.4144000E+00	0.9780002E-01	0.2607589E+01	0.6154011E+00
64	0.4301000E+00	0.9366000E-01	0.2706380E+01	0.5893505E+00
65	0.4598000E+00	0.8506000E-01	0.2893266E+01	0.5352353E+00
66	0.4829000E+00	0.7780001E-01	0.3038621E+01	0.4850217E+00
67	0.5255000E+00	0.5703000E-01	0.3306679E+01	0.3588580E+00
68	0.5498000E+00	0.3654000E-01	0.3459585E+01	0.2299259E+00
69	0.5589000E+00	0.2502000E-01	0.3516047E+01	0.1574369E+00
70	0.5637000E+00	0.1528000E-01	0.3547050E+01	0.9614855E-01
71	0.5661000E+00	0.1122000E-02	0.3562152E+01	0.7060122E-02
72	0.5642000E+00	-0.4604001E-02	0.3550197E+01	-0.2897042E-01
73	0.5575000E+00	-0.1616000E-01	0.3508038E+01	-0.1016859E+00
74	0.5575000E+00	-0.1616000E-01	0.3508038E+01	-0.1016859E+00
75	0.5497000E+00	-0.2498000E-01	0.3458957E+01	-0.1571853E+00
76	0.5144000E+00	-0.4975000E-01	0.3238091E+01	-0.3130491E+00
77	0.4963000E+00	-0.5673000E-01	0.3122939E+01	-0.3569703E+00
78	0.4547000E+00	-0.6832999E-01	0.2861174E+01	-0.4299626E+00
79	0.4462000E+00	-0.7023001E-01	0.2807608E+01	-0.4419184E+00
80	0.4348000E+00	-0.7305998E-01	0.2738921E+01	-0.4597258E+00
81	0.3860000E+00	-0.8039999E-01	0.2428883E+01	-0.5059124E+00
82	0.3733000E+00	-0.8173001E-01	0.2348969E+01	-0.5142815E+00
83	0.3442000E+00	-0.8381999E-01	0.2165859E+01	-0.5274326E+00
84	0.3025000E+00	-0.8538997E-01	0.1903464E+01	-0.5373114E+00
85	0.2637000E+00	-0.8500999E-01	0.1659317E+01	-0.5349206E+00
86	0.2022000E+00	-0.8095998E-01	0.1272332E+01	-0.5094361E+00
87	0.1417000E+00	-0.7264000E-01	0.8916395E+00	-0.4570831E+00
88	0.1417000E+00	-0.7264000E-01	0.8916395E+00	-0.4570831E+00
89	0.7937998E-01	-0.5873000E-01	0.4994940E+00	-0.3695552E+00
90	0.2264000E-01	-0.3962000E-01	0.1424689E+00	-0.2493066E+00
91	0.1614000E-01	-0.3714000E-01	0.1015600E+00	-0.2337013E+00
92	0.9776998E-02	-0.3459000E-01	0.6152121E-01	-0.2176556E+00
93	-0.2282000E-01	-0.1914000E-01	-0.1435935E+00	-0.1204374E+00
94	-0.5045000E-01	-0.1555000E-02	-0.3174538E+00	-0.9784747E-02
95	-0.7292002E-01	0.1947000E-01	-0.4588451E+00	0.1225138E+00
96	-0.8811998E-01	0.4279000E-01	-0.5544980E+00	0.2692537E+00
97	-0.8811998E-01	0.4279000E-01	-0.5544980E+00	0.2692537E+00
98	-0.7713997E-01	0.4720000E-01	-0.4853989E+00	0.2970033E+00
99	-0.6448001E-01	0.5177000E-01	-0.4057368E+00	0.3257598E+00

NORMALIZING CHECK (DIAMETRAL ONLY): 0.9999971E+00

DRIGINAL PAGE IS
OF POOR QUALITY

NATURAL FREQUENCY = 4357 HZ

DIAMETRAL INERTIA NORMALIZED: FACTOR = 0.5067930E+01

Station	INPUT Displacement	INPUT Slope	DIAMETRAL NORMALIZED Displacement	DIAMETRAL NORMALIZED Slope
1	-0.1000000E+01	0.5674000E+00	-0.5067930E+01	0.2875543E+01
2	-0.4997000E+00	0.5660000E+00	-0.2532444E+01	0.2868448E+01
3	-0.5658000E+00	0.5638000E+00	-0.1853848E+01	0.2857299E+01
4	-0.2490000E+00	0.4902000E+00	-0.1261914E+01	0.2484299E+01
5	-0.8598998E-01	0.4499000E+00	-0.4256553E+00	0.2280061E+01
6	-0.8598998E-01	0.4499000E+00	-0.4256553E+00	0.2280061E+01
7	0.2646000E+00	0.3893000E+00	0.1340974E+01	0.1972944E+01
8	0.3181000E+00	0.3770000E+00	0.1612188E+01	0.1910609E+01
9	0.3181000E+00	0.3770000E+00	0.1612188E+01	0.1910609E+01
10	0.4289000E+00	0.3238000E+00	0.2173635E+01	0.1640995E+01
11	0.4688000E+00	0.2837000E+00	0.2375845E+01	0.1437771E+01
12	0.5019000E+00	0.1778000E+00	0.2543595E+01	0.9010788E+00
13	0.4837000E+00	0.1111000E+00	0.2451357E+01	0.5630471E+00
14	0.4837000E+00	0.1111000E+00	0.2451357E+01	0.5630471E+00
15	0.4248000E+00	0.4154000E-01	0.2152854E+01	0.2105218E+00
16	0.3070000E+00	-0.3749000E-01	0.1555854E+01	-0.1899967E+00
17	0.1936000E+00	-0.7517001E-01	0.9811513E+00	-0.3708205E+00
18	0.3118000E-01	-0.9384000E-01	0.1580181E+00	-0.4755746E+00
19	0.2098000E-02	-0.9454000E-01	0.1063251E-01	-0.4791221E+00
20	-0.8993000E-01	-0.9094000E-01	-0.4557589E+00	-0.4608775E+00
21	-0.2016000E+00	-0.7380998E-01	-0.1021694E+01	-0.3740638E+00
22	-0.3015000E+00	-0.4173000E-01	-0.1527981E+01	-0.2114847E+00
23	-0.3571000E+00	-0.1338000E-01	-0.1809757E+01	-0.6780887E-01
24	-0.3866000E+00	0.5775999E-02	-0.1959262E+01	0.2927236E-01
25	-0.4160000E+00	0.2872000E-01	-0.2108258E+01	0.1455509E+00
26	-0.4160000E+00	0.2872000E-01	-0.2108258E+01	0.1455509E+00
27	-0.4539000E+00	0.6989998E-01	-0.2300333E+01	0.3542482E+00
28	-0.4757000E+00	0.9890997E-01	-0.2410814E+01	0.5012688E+00
29	-0.4880000E+00	0.1251000E+00	-0.2473149E+01	0.6339981E+00
30	-0.4905000E+00	0.1375000E+00	-0.2485819E+01	0.6968403E+00
31	-0.4718000E+00	0.1628000E+00	-0.2391049E+01	0.8250591E+00
32	-0.4334000E+00	0.1842000E+00	-0.2197454E+01	0.9335127E+00
33	-0.3875000E+00	0.2006000E+00	-0.1962809E+01	0.1016626E+01
34	-0.3437000E+00	0.2111000E+00	-0.1741847E+01	0.1069839E+01
35	-0.2952000E+00	0.2188000E+00	-0.1496853E+01	0.1108863E+01
36	-0.2431000E+00	0.2252000E+00	-0.1232014E+01	0.1141297E+01
37	-0.1882000E+00	0.2507000E+00	-0.9537844E+00	0.1169171E+01
38	-0.1318000E+00	0.2556000E+00	-0.6638988E+00	0.1194084E+01
39	-0.1318000E+00	0.2556000E+00	-0.6638988E+00	0.1194084E+01
40	-0.5945000E-01	0.2554000E+00	-0.3012884E+00	0.1192990E+01
41	0.1278000E-01	0.2543000E+00	0.6476814E-01	0.1187416E+01
42	0.8565003E-01	0.2521000E+00	0.4340683E+00	0.1176266E+01
43	0.1588000E+00	0.2264000E+00	0.8047873E+00	0.1157515E+01
44	0.2332000E+00	0.2220000E+00	0.1181841E+01	0.1125080E+01
45	0.2959000E+00	0.2131000E+00	0.1499600E+01	0.1079975E+01
46	0.3627000E+00	0.2002000E+00	0.1838158E+01	0.1014599E+01
47	0.4184000E+00	0.1861000E+00	0.2120421E+01	0.9431418E+00
48	0.4706000E+00	0.1703000E+00	0.2384960E+01	0.8630685E+00
49	0.5196000E+00	0.1525000E+00	0.2633294E+01	0.7728592E+00
50	0.5618000E+00	0.1298000E+00	0.2847163E+01	0.6537630E+00
51	0.5961000E+00	0.1055000E+00	0.3020992E+01	0.5346665E+00
52	0.6169000E+00	0.8077002E-01	0.3126486E+01	0.4093367E+00
53	0.6258000E+00	0.4694000E-01	0.3171511E+01	0.2378086E+00
54	0.6130000E+00	-0.1145000E-01	0.3106641E+01	-0.5802780E-01
55	0.5701000E+00	-0.7110000E-01	0.2889227E+01	-0.3603298E+00
56	0.5260000E+00	-0.1076000E+00	0.2665730E+01	-0.5453891E+00
57	0.4699000E+00	-0.1377000E+00	0.2381420E+01	-0.6978540E+00
58	0.4699000E+00	-0.1377000E+00	0.2381420E+01	-0.6978540E+00
59	0.4455000E+00	-0.1471000E+00	0.2257763E+01	-0.7454925E+00
60	0.4048000E+00	-0.1611000E+00	0.2051497E+01	-0.8164434E+00
61	0.3008000E+00	-0.1865000E+00	0.1528379E+01	-0.9451690E+00
62	0.2321000E+00	-0.1989000E+00	0.1176266E+01	-0.1008011E+01
63	0.1684000E+00	-0.2085000E+00	0.8534394E+00	-0.1056664E+01
64	0.1276000E+00	-0.2130000E+00	0.6466680E+00	-0.1079469E+01
65	0.4405000E-01	-0.2194000E+00	0.2232425E+00	-0.1111983E+01
66	-0.2836000E-01	-0.2224000E+00	-0.1437265E+00	-0.1127108E+01
67	-0.1874000E+00	-0.2214000E+00	-0.9497300E+00	-0.1122040E+01
68	-0.3286000E+00	-0.2099000E+00	-0.1665321E+01	-0.1063758E+01
69	-0.4051000E+00	-0.1999000E+00	-0.2053018E+01	-0.1013079E+01
70	-0.4661000E+00	-0.1896000E+00	-0.2362162E+01	-0.9608795E+00
71	-0.5451000E+00	-0.1717000E+00	-0.2762528E+01	-0.8701636E+00
72	-0.5726000E+00	-0.1635000E+00	-0.2901896E+01	-0.8275928E+00
73	-0.6275000E+00	-0.1445000E+00	-0.3180126E+01	-0.7323160E+00
74	-0.6275000E+00	-0.1445000E+00	-0.3180126E+01	-0.7323160E+00
75	-0.6661000E+00	-0.1286000E+00	-0.3375748E+01	-0.6517358E+00
76	-0.7524000E+00	-0.7535997E-01	-0.3813118E+01	-0.3818177E+00
77	-0.7616000E+00	-0.5497000E-01	-0.3859735E+01	-0.2887208E+00
78	-0.7673000E+00	-0.2198000E-01	-0.3888622E+01	-0.1113931E+00
79	-0.7664000E+00	-0.1549000E-01	-0.3884061E+01	-0.7850218E-01
80	-0.7639000E+00	-0.5222000E-02	-0.3871391E+01	-0.2646473E-01
81	-0.7447000E+00	0.2647000E-01	-0.3774087E+01	0.1341481E+00
82	-0.7361000E+00	0.3384000E-01	-0.3730503E+01	0.1717014E+00
83	-0.7109000E+00	0.4877000E-01	-0.3602791E+01	0.2471629E+00
84	-0.6681000E+00	0.7054999E-01	-0.3385483E+01	0.3565288E+00
85	-0.6231000E+00	0.8580999E-01	-0.3157826E+01	0.4348247E+00
86	-0.5393000E+00	0.1026000E+00	-0.2733134E+01	0.5199695E+00
87	-0.4446000E+00	0.1131000E+00	-0.2253281E+01	0.5731828E+00
88	-0.4446000E+00	0.1131000E+00	-0.2253281E+01	0.5731828E+00
89	-0.3260000E+00	0.1141000E+00	-0.1652144E+01	0.5782507E+00
90	-0.2058000E+00	0.1043000E+00	-0.1038925E+01	0.5285852E+00
91	-0.1898000E+00	0.1006000E+00	-0.9578388E+00	0.5098338E+00
92	-0.1751000E+00	0.9680998E-01	-0.8772587E+00	0.4906262E+00
93	-0.8718002E-01	0.7204998E-01	-0.4418222E+00	0.3651442E+00
94	-0.8676000E-02	0.4187000E-01	-0.4396936E-01	0.2121942E+00
95	0.6388998E-01	0.1437000E-02	0.3237900E+00	0.7282615E-02
96	0.1223000E+00	-0.4502000E-01	0.6198880E+00	-0.2281582E+00
97	0.1223000E+00	-0.4502000E-01	0.6198880E+00	-0.2281582E+00
98	0.1146000E+00	-0.5530000E-01	0.5807848E+00	-0.2802565E+00
99	0.1028000E+00	-0.6688999E-01	0.5209853E+00	-0.3349394E+00

NORMALIZING CHECK (DIAMETRAL ONLY): 0.9999990E+00

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NATURAL FREQUENCY = 5685 HZ

DIAMETRAL INERTIA NORMALIZED: FACTOR = 0.4065351E+01

Station	INPUT Displacement	INPUT Slope	DIAMETRAL NORMALIZED Displacement	DIAMETRAL NORMALIZED Slope
1	-0.1000000E+01	0.6571000E+00	-0.4065351E+01	0.2671342E+01
2	-0.4201000E+00	0.6546000E+00	-0.1707855E+01	0.2661179E+01
3	-0.2645000E+00	0.6511000E+00	-0.1075265E+01	0.2646950E+01
4	-0.1332000E+00	0.5120000E+00	-0.5415047E+00	0.2081460E+01
5	0.3665000E-01	0.4586000E+00	0.1489951E+00	0.1785875E+01
6	0.3665000E-01	0.4586000E+00	0.1489951E+00	0.1785875E+01
7	0.3603000E+00	0.3363000E+00	0.1464746E+01	0.1367177E+01
8	0.4045000E+00	0.3166000E+00	0.1644434E+01	0.1287090E+01
9	0.4045000E+00	0.3166000E+00	0.1644434E+01	0.1287090E+01
10	0.4324000E+00	0.2381000E+00	0.1757857E+01	0.9679401E+00
11	0.4115000E+00	0.1829000E+00	0.1672892E+01	0.7435526E+00
12	0.2771000E+00	0.5101000E-01	0.1126509E+01	0.2075736E+00
13	0.1398000E+00	-0.1922000E-01	0.5683361E+00	-0.7813603E-01
14	0.1398000E+00	-0.1922000E-01	0.5683361E+00	-0.7813603E-01
15	-0.5750000E-01	-0.7713002E-01	-0.2337577E+00	-0.3135686E+00
16	-0.2801000E+00	-0.1130000E+00	-0.1138784E+01	-0.4593044E+00
17	-0.4600000E+00	-0.1094000E+00	-0.1870861E+01	-0.4447493E+00
18	-0.6665000E+00	-0.6829000E-01	-0.2709557E+01	-0.2776228E+00
19	-0.7000000E+00	-0.5704000E-01	-0.2845745E+01	-0.2318876E+00
20	-0.7989000E+00	-0.1399000E-01	-0.3247080E+01	-0.5687426E-01
21	-0.8976000E+00	0.5307000E-01	-0.3649059E+01	0.2157482E+00
22	-0.9450000E+00	0.1355000E+00	-0.3841757E+01	0.5508552E+00
23	-0.9467000E+00	0.1945000E+00	-0.3848668E+01	0.7907109E+00
24	-0.9438000E+00	0.2307000E+00	-0.3833626E+01	0.9378766E+00
25	-0.9332000E+00	0.2715000E+00	-0.3793785E+01	0.1103743E+01
26	-0.9332000E+00	0.2715000E+00	-0.3793785E+01	0.1103743E+01
27	-0.9005000E+00	0.3395000E+00	-0.3660849E+01	0.1379374E+01
28	-0.8487000E+00	0.3830000E+00	-0.3450263E+01	0.1557029E+01
29	-0.7842000E+00	0.4193000E+00	-0.3188648E+01	0.1704601E+01
30	-0.7309000E+00	0.4145000E+00	-0.2971365E+01	0.1685088E+01
31	-0.5678000E+00	0.3989000E+00	-0.2308306E+01	0.1621668E+01
32	-0.3901000E+00	0.3813000E+00	-0.1585895E+01	0.1550117E+01
33	-0.2271000E+00	0.3639000E+00	-0.9232414E+00	0.1479581E+01
34	-0.1028000E+00	0.3501000E+00	-0.4179181E+00	0.1425279E+01
35	0.1308000E-01	0.3381000E+00	0.5317480E-01	0.1374495E+01
36	0.1232000E+00	0.3260000E+00	0.5008513E+00	0.1325304E+01
37	0.2273000E+00	0.3135000E+00	0.9240545E+00	0.1274487E+01
38	0.3253000E+00	0.3085000E+00	0.1322458E+01	0.1228824E+01
39	0.3253000E+00	0.3085000E+00	0.1322458E+01	0.1228824E+01
40	0.3622000E+00	0.2770000E+00	0.1472478E+01	0.1126101E+01
41	0.3890000E+00	0.2531000E+00	0.1581421E+01	0.1028940E+01
42	0.4034000E+00	0.2275000E+00	0.1639962E+01	0.9248675E+00
43	0.4035000E+00	0.1994000E+00	0.1640368E+01	0.8106311E+00
44	0.3819000E+00	0.1637000E+00	0.1552557E+01	0.6654988E+00
45	0.3439000E+00	0.1246000E+00	0.1398074E+01	0.5065427E+00
46	0.2845000E+00	0.7914001E-01	0.1156592E+01	0.3217319E+00
47	0.2178000E+00	0.3861000E-01	0.8854336E+00	0.1569632E+00
48	0.1411000E+00	0.1231000E-02	0.5736218E+00	0.5004447E-02
49	0.5346000E-01	-0.3298000E-01	0.2173337E+00	-0.1337588E+00
50	-0.3895000E-01	-0.5634000E-01	-0.1583454E+00	-0.2298419E+00
51	-0.1331000E+00	-0.7339001E-01	-0.5418981E+00	-0.2983561E+00
52	-0.2329000E+00	-0.8617002E-01	-0.9468204E+00	-0.3503114E+00
53	-0.3496000E+00	-0.9505999E-01	-0.1421247E+01	-0.3864523E+00
54	-0.5128000E+00	-0.9584000E-01	-0.2084712E+01	-0.3814926E+00
55	-0.6770000E+00	-0.7230997E-01	-0.2752242E+01	-0.2939654E+00
56	-0.7719000E+00	-0.4741000E-01	-0.3138044E+01	-0.1927383E+00
57	-0.8476000E+00	-0.1812000E-01	-0.3445791E+01	-0.7366413E-01
58	-0.8476000E+00	-0.1812000E-01	-0.3445791E+01	-0.7366413E-01
59	-0.8657000E+00	-0.6910000E-02	-0.3519374E+01	-0.2809158E-01
60	-0.8902000E+00	0.1198000E-01	-0.3618976E+01	0.4870291E-01
61	-0.9019000E+00	0.5626000E-01	-0.3666540E+01	0.2287167E+00
62	-0.8964000E+00	0.8407003E-01	-0.3644180E+01	0.3417742E+00
63	-0.8836000E+00	0.1106000E+00	-0.3592144E+01	0.4496278E+00
64	-0.8638000E+00	0.1264000E+00	-0.3511650E+01	0.5138603E+00
65	-0.8152000E+00	0.1557000E+00	-0.3314074E+01	0.6329753E+00
66	-0.7651000E+00	0.1794000E+00	-0.3110400E+01	0.7293242E+00
67	-0.6300000E+00	0.2279000E+00	-0.2561171E+01	0.9264937E+00
68	-0.4597000E+00	0.2614000E+00	-0.1868041E+01	0.1062682E+01
69	-0.3544000E+00	0.2746000E+00	-0.1440760E+01	0.1116345E+01
70	-0.2629000E+00	0.2824000E+00	-0.1068780E+01	0.1148055E+01
71	-0.1328000E+00	0.2888000E+00	-0.5398786E+00	0.1174073E+01
72	-0.7824999E-01	0.2888000E+00	-0.3181137E+00	0.1174073E+01
73	0.3915000E-01	0.2856000E+00	0.1591585E+00	0.1161064E+01
74	0.3915000E-01	0.2856000E+00	0.1591585E+00	0.1161064E+01
75	0.1307000E+00	0.2798000E+00	0.5313414E+00	0.1137485E+01
76	0.3845000E+00	0.2456000E+00	0.1563128E+01	0.9984502E+00
77	0.4505000E+00	0.2282000E+00	0.1831440E+01	0.9277133E+00
78	0.5704000E+00	0.1894000E+00	0.2318876E+01	0.7699776E+00
79	0.5908000E+00	0.1813000E+00	0.2401809E+01	0.7370481E+00
80	0.6178000E+00	0.1681000E+00	0.2511574E+01	0.6833856E+00
81	0.7036000E+00	0.1225000E+00	0.2860381E+01	0.4980855E+00
82	0.7186000E+00	0.1106000E+00	0.2921341E+01	0.4496278E+00
83	0.7488000E+00	0.8459002E-01	0.3044340E+01	0.3438681E+00
84	0.7569000E+00	0.4258000E-01	0.3077065E+01	0.1731026E+00
85	0.7595000E+00	0.9764001E-02	0.3087634E+01	0.3969409E-01
86	0.7330000E+00	-0.3988000E-01	0.2979902E+01	-0.1621262E+00
87	0.6761000E+00	-0.8581001E-01	0.2748584E+01	-0.3488478E+00
88	0.6761000E+00	-0.8581001E-01	0.2748584E+01	-0.3488478E+00
89	0.5578000E+00	-0.1249000E+00	0.2267653E+01	-0.5077623E+00
90	0.4158000E+00	-0.1521000E+00	0.1690372E+01	-0.6183400E+00
91	0.3926000E+00	-0.1487000E+00	0.1596057E+01	-0.6045178E+00
92	0.3695000E+00	-0.1451000E+00	0.1502147E+01	-0.5898824E+00
93	0.2377000E+00	-0.1188000E+00	0.9663340E+00	-0.4829637E+00
94	0.1118000E+00	-0.8415997E-01	0.4545863E+00	-0.3421398E+00
95	-0.1355000E-01	-0.2961000E-01	-0.5508558E-01	-0.1203758E+00
96	-0.1201000E+00	0.3489000E-01	-0.4882488E+00	0.1418481E+00
97	-0.1201000E+00	0.3489000E-01	-0.4882488E+00	0.1418481E+00
98	-0.1198000E+00	0.5396000E-01	-0.4870290E+00	0.2193663E+00
99	-0.1122000E+00	0.7397997E-01	-0.4561325E+00	0.3007545E+00

NORMALIZING CHECK (DIAMETRAL ONLY): 0.1000001E+01

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Appendix D. Housing Model Mass Normalized Data

ATD MPOTP MASSNORMALIZATION OUTPUT MAX (X-Z) STIFFNESS PLANE

Number of modes: 4
Number of stations: 56

Station Data

STA. No.	AXIAL Location	WEIGHT (lb)	DIAMETRAL (lb-in**2)	MASS (lb-sec**2/in)	DIAMETRAL (in-lb-sec**2)	POLAR (in-lb-sec**2)
1	0.0	0.0	0.0	0.0	0.0	0.0
2	1.300	0.1181000E+02	0.6039999E+02	0.3056419E-01	0.1563147E+00	0.3126293E+00
3	1.596	0.0	0.0	0.0	0.0	0.0
4	1.596	0.0	0.0	0.0	0.0	0.0
5	2.000	0.0	0.0	0.0	0.0	0.0
6	2.000	0.0	0.0	0.0	0.0	0.0
7	2.330	0.0	0.0	0.0	0.0	0.0
8	2.330	0.0	0.0	0.0	0.0	0.0
9	2.516	0.0	0.0	0.0	0.0	0.0
10	2.453	0.0	0.0	0.0	0.0	0.0
11	2.516	0.1000000E+02	0.5000000E+02	0.2587992E-01	0.1293996E+00	0.2587992E+00
12	3.698	0.6480000E+02	0.6467000E+03	0.1677019E+00	0.1673654E+01	0.3347307E+01
13	3.816	0.0	0.0	0.0	0.0	0.0
14	3.816	0.2391856E+01	0.3602966E+02	0.6190183E-02	0.9324449E-01	0.1864890E+00
15	4.316	0.6477789E+01	0.9456664E+02	0.1676447E-01	0.2447377E+00	0.4894754E+00
16	5.128	0.3319255E+01	0.4348114E+02	0.8590283E-02	0.1125288E+00	0.2250576E+00
17	5.711	0.3022653E+02	0.1473459E+03	0.7822683E-01	0.3813300E+00	0.7626600E+00
18	6.461	0.2784630E+01	0.2869185E+02	0.7206600E-02	0.7477182E-01	0.1495436E+00
19	7.711	0.3292487E+02	0.1609321E+03	0.8520925E-01	0.4164910E+00	0.8329821E+00
20	8.431	0.2784420E+01	0.3535609E+02	0.7206056E-02	0.9150130E-01	0.1830026E+00
21	9.394	0.1430275E+01	0.1857262E+02	0.3701541E-02	0.4806579E-01	0.9613156E-01
22	9.394	0.2725395E+00	0.3539021E+01	0.7053299E-03	0.9158958E-02	0.1831792E-01
23	9.578	0.4267253E+02	0.5421389E+03	0.1104361E+00	0.1403051E+01	0.2806103E+01
24	9.578	0.1267643E+01	0.1644078E+02	0.3280650E-02	0.4260038E-01	0.8520073E-01
25	10.431	0.2621788E+01	0.3324426E+02	0.6785166E-02	0.8603585E-01	0.1720717E+00
26	11.151	0.2924890E+01	0.3093214E+02	0.7569589E-02	0.8005214E-01	0.1601043E+00
27	12.401	0.3278461E+02	0.1586918E+03	0.8484626E-01	0.4112107E+00	0.8224214E+00
28	13.151	0.3382803E+02	0.4211458E+03	0.8754665E-01	0.1089922E+01	0.2179844E+01
29	13.733	0.1117491E+01	0.1513805E+02	0.2892057E-02	0.3915645E-01	0.7831287E-01
30	14.233	0.1429563E+01	0.2077162E+02	0.3699697E-02	0.5375680E-01	0.1075135E+00
31	14.671	0.6950114E+01	0.4884418E+02	0.1798684E-01	0.1264085E+00	0.2528167E+00
32	15.771	0.1063952E+03	0.1635634E+04	0.2753499E+00	0.4233013E+01	0.8466026E+01
33	16.563	0.0	0.0	0.0	0.0	0.0
34	16.563	0.0	0.0	0.0	0.0	0.0
35	17.223	0.6330000E+02	0.6883000E+03	0.1638199E+00	0.1781315E+01	0.3562630E+01
36	20.237	0.0	0.0	0.0	0.0	0.0
37	20.237	0.0	0.0	0.0	0.0	0.0
38	20.640	0.7906000E+02	0.3305000E+04	0.2046867E+00	0.8553314E+01	0.1710663E+02
39	21.673	0.0	0.0	0.0	0.0	0.0
40	21.673	0.0	0.0	0.0	0.0	0.0
41	22.241	0.1680000E+02	0.3490000E+03	0.4347828E-01	0.9032095E+00	0.1806418E+01
42	22.299	0.0	0.0	0.0	0.0	0.0
43	22.513	0.3786000E+02	0.6518000E+03	0.9591897E-01	0.1684785E+01	0.3369566E+01
44	22.897	0.0	0.0	0.0	0.0	0.0
45	22.897	0.0	0.0	0.0	0.0	0.0
46	25.513	0.3795000E+02	0.6376001E+03	0.9821427E-01	0.1658104E+01	0.3380207E+01
47	28.241	0.5283000E+02	0.1752000E+04	0.1367236E+00	0.4534163E+01	0.9068325E+01
48	28.341	0.0	0.0	0.0	0.0	0.0
49	28.341	0.1242000E+02	0.2320000E+03	0.3214286E-01	0.6004142E+00	0.1200828E+01
50	28.513	0.2503000E+02	0.4368999E+03	0.6477743E-01	0.1130695E+01	0.2261387E+01
51	28.613	0.1850000E+02	0.1410000E+03	0.4787786E-01	0.3649969E+00	0.7298138E+00
52	28.713	0.1900000E+02	0.1160000E+03	0.5124225E-01	0.3002071E+00	0.6004142E+00
53	28.813	0.2130000E+02	0.1600000E+03	0.5512424E-01	0.4140788E+00	0.8281575E+00
54	31.813	0.2175000E+02	0.2705000E+03	0.5628883E-01	0.7000519E+00	0.1400104E+01
55	33.313	0.6246001E+02	0.9580000E+03	0.1616460E+00	0.2427536E+01	0.4855072E+01
56	36.813	0.2353999E+02	0.3700000E+02	0.6092132E-01	0.9575570E-01	0.1915114E+00

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NATURAL FREQUENCY: 163.8 HZ

Station	INPUT Displacement	INPUT Slope	DIAMETRAL NORMALIZED Displacement	DIAMETRAL NORMALIZED Slope
1	-0.1000000E+01	0.2986000E-01	-0.1269765E+01	0.3791518E-01
2	-0.9612000E+00	0.2986000E-01	-0.1220497E+01	0.3791518E-01
3	-0.9523000E+00	0.2986000E-01	-0.1209197E+01	0.3791518E-01
4	-0.9523000E+00	0.2986000E-01	-0.1209197E+01	0.3791518E-01
5	-0.9403000E+00	0.2986000E-01	-0.1193959E+01	0.3791518E-01
6	-0.9403000E+00	0.2986000E-01	-0.1193959E+01	0.3791518E-01
7	-0.9304000E+00	0.2986000E-01	-0.1181389E+01	0.3791518E-01
8	-0.9304000E+00	0.2986000E-01	-0.1181389E+01	0.3791518E-01
9	-0.9249000E+00	0.2986000E-01	-0.1174405E+01	0.3791518E-01
10	-0.9249000E+00	0.2986000E-01	-0.1174405E+01	0.3791518E-01
11	-0.9230000E+00	0.2986000E-01	-0.1171992E+01	0.3791518E-01
12	-0.8877000E+00	0.2986000E-01	-0.1127170E+01	0.3791518E-01
13	-0.8842000E+00	0.2986000E-01	-0.1122725E+01	0.3791518E-01
14	-0.8842000E+00	0.2986000E-01	-0.1122725E+01	0.3791518E-01
15	-0.8688000E+00	0.2986000E-01	-0.1103171E+01	0.3791518E-01
16	-0.8437000E+00	0.2984000E-01	-0.1071301E+01	0.3788978E-01
17	-0.8211000E+00	0.2984000E-01	-0.1042603E+01	0.3788978E-01
18	-0.7960000E+00	0.2974000E-01	-0.1010733E+01	0.3776281E-01
19	-0.7529000E+00	0.2946000E-01	-0.9560060E+00	0.3740728E-01
20	-0.7278000E+00	0.2863000E-01	-0.9241349E+00	0.3635337E-01
21	-0.6950000E+00	0.2834000E-01	-0.8824866E+00	0.3598513E-01
22	-0.6950000E+00	0.2834000E-01	-0.8824866E+00	0.3598513E-01
23	-0.6887000E+00	0.2827000E-01	-0.8744871E+00	0.3589625E-01
24	-0.6887000E+00	0.2827000E-01	-0.8744871E+00	0.3589625E-01
25	-0.6587000E+00	0.2792000E-01	-0.8363941E+00	0.3545183E-01
26	-0.6338000E+00	0.2613000E-01	-0.8047770E+00	0.3317895E-01
27	-0.5916000E+00	0.2507000E-01	-0.7511929E+00	0.3183300E-01
28	-0.5677000E+00	0.2430000E-01	-0.7206455E+00	0.3085529E-01
29	-0.5382000E+00	0.2430000E-01	-0.6833875E+00	0.3085529E-01
30	-0.5223000E+00	0.2330000E-01	-0.6631982E+00	0.2958552E-01
31	-0.5075000E+00	0.2286000E-01	-0.6444057E+00	0.2905222E-01
32	-0.4710000E+00	0.2169000E-01	-0.5980592E+00	0.2754120E-01
33	-0.4538000E+00	0.2169000E-01	-0.5762193E+00	0.2754120E-01
34	-0.4538000E+00	0.2169000E-01	-0.5762193E+00	0.2754120E-01
35	-0.4395000E+00	0.2169000E-01	-0.5580616E+00	0.2754120E-01
36	-0.3741000E+00	0.2169000E-01	-0.4750190E+00	0.2754120E-01
37	-0.3741000E+00	0.2169000E-01	-0.4750190E+00	0.2754120E-01
38	-0.3654000E+00	0.2169000E-01	-0.4639721E+00	0.2754120E-01
39	-0.3429000E+00	0.2169000E-01	-0.4354023E+00	0.2754120E-01
40	-0.3429000E+00	0.2169000E-01	-0.4354023E+00	0.2754120E-01
41	-0.3306000E+00	0.2169000E-01	-0.4197842E+00	0.2754120E-01
42	-0.3306000E+00	0.2169000E-01	-0.4197842E+00	0.2754120E-01
43	-0.3268000E+00	0.2169000E-01	-0.4139433E+00	0.2754120E-01
44	-0.3177000E+00	0.2169000E-01	-0.4034043E+00	0.2754120E-01
45	-0.3177000E+00	0.2169000E-01	-0.4034043E+00	0.2754120E-01
46	-0.2609000E+00	0.2169000E-01	-0.3312817E+00	0.2754120E-01
47	-0.2019000E+00	0.2169000E-01	-0.2562385E+00	0.2754120E-01
48	-0.1996000E+00	0.2169000E-01	-0.2534450E+00	0.2754120E-01
49	-0.1996000E+00	0.2169000E-01	-0.2534450E+00	0.2754120E-01
50	-0.1959000E+00	0.2169000E-01	-0.2487469E+00	0.2754120E-01
51	-0.1937000E+00	0.2169000E-01	-0.2459534E+00	0.2754120E-01
52	-0.1915000E+00	0.2169000E-01	-0.2431599E+00	0.2754120E-01
53	-0.1894000E+00	0.2169000E-01	-0.2404935E+00	0.2754120E-01
54	-0.1416000E+00	0.2169000E-01	-0.1797987E+00	0.2754120E-01
55	-0.9176999E-01	0.2169000E-01	-0.1165263E+00	0.2754120E-01
56	-0.1586000E-01	0.2169000E-01	-0.2013847E-01	0.2754120E-01

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NATURAL FREQUENCY: 368.7 HZ

Station	INPUT Displacement	INPUT Slope	DIAMETRAL NORMALIZED Displacement	DIAMETRAL NORMALIZED Slope
1	-0.1000000E+01	0.8032000E-01	-0.9643296E+00	0.7745492E-01
2	-0.8956000E+00	0.8032000E-01	-0.8636536E+00	0.7745492E-01
3	-0.8718000E+00	0.8032000E-01	-0.8407025E+00	0.7745492E-01
4	-0.8718000E+00	0.8032000E-01	-0.8407025E+00	0.7745492E-01
5	-0.8394000E+00	0.8032000E-01	-0.8094583E+00	0.7745492E-01
6	-0.8394000E+00	0.8032000E-01	-0.8094583E+00	0.7745492E-01
7	-0.8129000E+00	0.8032000E-01	-0.7839035E+00	0.7745492E-01
8	-0.8129000E+00	0.8032000E-01	-0.7839035E+00	0.7745492E-01
9	-0.7979000E+00	0.8032000E-01	-0.7694386E+00	0.7745492E-01
10	-0.7979000E+00	0.8032000E-01	-0.7694386E+00	0.7745492E-01
11	-0.7929000E+00	0.8032000E-01	-0.7646169E+00	0.7745492E-01
12	-0.6979000E+00	0.8032000E-01	-0.6730056E+00	0.7745492E-01
13	-0.6884000E+00	0.8032000E-01	-0.6638445E+00	0.7745492E-01
14	-0.6884000E+00	0.8032000E-01	-0.6638445E+00	0.7745492E-01
15	-0.6461000E+00	0.8026999E-01	-0.6230533E+00	0.7740670E-01
16	-0.5765000E+00	0.7990003E-01	-0.5559560E+00	0.7704991E-01
17	-0.5040000E+00	0.7990005E-01	-0.4860221E+00	0.7704991E-01
18	-0.4329000E+00	0.7895997E-01	-0.4165903E+00	0.7612413E-01
19	-0.3078000E+00	0.7683998E-01	-0.2968206E+00	0.7409906E-01
20	-0.2368000E+00	0.7138002E-01	-0.2295104E+00	0.6883383E-01
21	-0.1493000E+00	0.6964999E-01	-0.1439744E+00	0.6716549E-01
22	-0.1493000E+00	0.6964999E-01	-0.1439744E+00	0.6716549E-01
23	-0.1326000E+00	0.6928998E-01	-0.1278701E+00	0.6681836E-01
24	-0.1326000E+00	0.6928998E-01	-0.1278701E+00	0.6681836E-01
25	-0.5466000E-01	0.6733000E-01	-0.5271025E-01	0.6492829E-01
26	0.8051999E-02	0.5808000E-01	0.7764779E-02	0.5600826E-01
27	0.1099000E+00	0.5293000E-01	0.1059798E+00	0.5104196E-01
28	0.1628000E+00	0.4942000E-01	0.1569929E+00	0.4765717E-01
29	0.2271000E+00	0.4942000E-01	0.2189992E+00	0.4765717E-01
30	0.2599000E+00	0.4522000E-01	0.2506292E+00	0.4360696E-01
31	0.2899000E+00	0.4347000E-01	0.2795591E+00	0.4191941E-01
32	0.3614000E+00	0.3882000E-01	0.3485087E+00	0.3743527E-01
33	0.3921000E+00	0.3882000E-01	0.3781136E+00	0.3743527E-01
34	0.3921000E+00	0.3882000E-01	0.3781136E+00	0.3743527E-01
35	0.4178000E+00	0.3882000E-01	0.4028969E+00	0.3743527E-01
36	0.5348000E+00	0.3882000E-01	0.5157254E+00	0.3743527E-01
37	0.5348000E+00	0.3882000E-01	0.5157254E+00	0.3743527E-01
38	0.5504000E+00	0.3882000E-01	0.5307670E+00	0.3743527E-01
39	0.5905000E+00	0.3882000E-01	0.5694366E+00	0.3743527E-01
40	0.5905000E+00	0.3882000E-01	0.5694366E+00	0.3743527E-01
41	0.6126000E+00	0.3882000E-01	0.5907483E+00	0.3743527E-01
42	0.6126000E+00	0.3882000E-01	0.5907483E+00	0.3743527E-01
43	0.6209000E+00	0.3882000E-01	0.5987522E+00	0.3743527E-01
44	0.6358000E+00	0.3882000E-01	0.6131207E+00	0.3743527E-01
45	0.6358000E+00	0.3882000E-01	0.6131207E+00	0.3743527E-01
46	0.7373000E+00	0.3882000E-01	0.7110001E+00	0.3743527E-01
47	0.8432000E+00	0.3882000E-01	0.8131227E+00	0.3743527E-01
48	0.8471000E+00	0.3882000E-01	0.8168836E+00	0.3743527E-01
49	0.8471000E+00	0.3882000E-01	0.8168836E+00	0.3743527E-01
50	0.8538000E+00	0.3882000E-01	0.8233446E+00	0.3743527E-01
51	0.8577000E+00	0.3882000E-01	0.8271055E+00	0.3743527E-01
52	0.8616000E+00	0.3882000E-01	0.8308663E+00	0.3743527E-01
53	0.8655000E+00	0.3882000E-01	0.8346272E+00	0.3743527E-01
54	0.9509000E+00	0.3882000E-01	0.9169818E+00	0.3743527E-01
55	0.1040000E+01	0.3882000E-01	0.1002902E+01	0.3743527E-01
56	0.1176000E+01	0.3882000E-01	0.1134058E+01	0.3743527E-01

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NATURAL FREQUENCY: 718.1 HZ

Station	INPUT Displacement	INPUT Slope	DIAMETRAL NORMALIZED Displacement	DIAMETRAL NORMALIZED Slope
1	-0.1000000E+01	0.9161001E-01	-0.1413673E+01	0.1295066E+00
2	-0.8889000E+00	0.9161001E-01	-0.1245504E+01	0.1295066E+00
3	-0.8538000E+00	0.9161001E-01	-0.1206994E+01	0.1295066E+00
4	-0.8538000E+00	0.9161001E-01	-0.1206994E+01	0.1295066E+00
5	-0.8168000E+00	0.9161001E-01	-0.1154688E+01	0.1295066E+00
6	-0.8168000E+00	0.9161001E-01	-0.1154688E+01	0.1295066E+00
7	-0.7865000E+00	0.9161001E-01	-0.1111854E+01	0.1295066E+00
8	-0.7865000E+00	0.9161001E-01	-0.1111854E+01	0.1295066E+00
9	-0.7695000E+00	0.9161001E-01	-0.1087821E+01	0.1295066E+00
10	-0.7695000E+00	0.9161001E-01	-0.1087821E+01	0.1295066E+00
11	-0.7637000E+00	0.9161001E-01	-0.1079622E+01	0.1295066E+00
12	-0.6555000E+00	0.9161001E-01	-0.9266629E+00	0.1295066E+00
13	-0.6446000E+00	0.9161001E-01	-0.9112538E+00	0.1295066E+00
14	-0.6446000E+00	0.9161001E-01	-0.9112538E+00	0.1295066E+00
15	-0.5903000E+00	0.9138000E-01	-0.8344914E+00	0.1291814E+00
16	-0.4986000E+00	0.8967000E-01	-0.7048575E+00	0.1267641E+00
17	-0.3436000E+00	0.8967000E-01	-0.4857381E+00	0.1267641E+00
18	-0.2319000E+00	0.8552998E-01	-0.3278308E+00	0.1209114E+00
19	-0.3098000E-01	0.7675999E-01	-0.4379560E-01	0.1085135E+00
20	0.7091999E-01	0.5461000E-01	0.1002577E+00	0.7720065E-01
21	0.1891000E+00	0.4782000E-01	0.2673256E+00	0.6760186E-01
22	0.1891000E+00	0.4782000E-01	0.2673256E+00	0.6760186E-01
23	0.2108000E+00	0.4641000E-01	0.2980023E+00	0.6560856E-01
24	0.2108000E+00	0.4641000E-01	0.2980023E+00	0.6560856E-01
25	0.3008000E+00	0.3915000E-01	0.4252329E+00	0.5531704E-01
26	0.3641000E+00	0.5716000E-02	0.5147184E+00	0.8080553E-02
27	0.4459000E+00	-0.1232000E-01	0.6303570E+00	-0.1741645E-01
28	0.4634000E+00	-0.2407000E-01	0.6550962E+00	-0.3402711E-01
29	0.5059000E+00	-0.2407000E-01	0.7151774E+00	-0.3402711E-01
30	0.5049000E+00	-0.3704000E-01	0.7137637E+00	-0.5236246E-01
31	0.5040000E+00	-0.4231000E-01	0.7124914E+00	-0.5981252E-01
32	0.4873000E+00	-0.5590000E-01	0.6888830E+00	-0.7902431E-01
33	0.4430000E+00	-0.5590000E-01	0.6262573E+00	-0.7902431E-01
34	0.4430000E+00	-0.5590000E-01	0.6262573E+00	-0.7902431E-01
35	0.4061000E+00	-0.5590000E-01	0.5740927E+00	-0.7902431E-01
36	0.2376000E+00	-0.5590000E-01	0.3358868E+00	-0.7902431E-01
37	0.2376000E+00	-0.5590000E-01	0.3358868E+00	-0.7902431E-01
38	0.2151000E+00	-0.5590000E-01	0.3040811E+00	-0.7902431E-01
39	0.1573000E+00	-0.5590000E-01	0.2223708E+00	-0.7902431E-01
40	0.1573000E+00	-0.5590000E-01	0.2223708E+00	-0.7902431E-01
41	0.1256000E+00	-0.5590000E-01	0.1775573E+00	-0.7902431E-01
42	0.1256000E+00	-0.5590000E-01	0.1775573E+00	-0.7902431E-01
43	0.1136000E+00	-0.5590000E-01	0.1605953E+00	-0.7902431E-01
44	0.9215999E-01	-0.5590000E-01	0.1302841E+00	-0.7902431E-01
45	0.9215999E-01	-0.5590000E-01	0.1302841E+00	-0.7902431E-01
46	-0.5407000E-01	-0.5590000E-01	-0.7643729E-01	-0.7902431E-01
47	-0.2066000E+00	-0.5590000E-01	-0.2920649E+00	-0.7902431E-01
48	-0.2121000E+00	-0.5590000E-01	-0.2998402E+00	-0.7902431E-01
49	-0.2121000E+00	-0.5590000E-01	-0.2998402E+00	-0.7902431E-01
50	-0.2218000E+00	-0.5590000E-01	-0.3135528E+00	-0.7902431E-01
51	-0.2274000E+00	-0.5590000E-01	-0.3214693E+00	-0.7902431E-01
52	-0.2330000E+00	-0.5590000E-01	-0.3293858E+00	-0.7902431E-01
53	-0.2385000E+00	-0.5590000E-01	-0.3371611E+00	-0.7902431E-01
54	-0.3615000E+00	-0.5590000E-01	-0.5110430E+00	-0.7902431E-01
55	-0.4901000E+00	-0.5590000E-01	-0.6928414E+00	-0.7902431E-01
56	-0.6858000E+00	-0.5590000E-01	-0.9694972E+00	-0.7902431E-01

ORIGINAL PAGE IS
OF POOR QUALITY

NATURAL FREQUENCY: 1197.3 HZ

Station	INPUT Displacement	INPUT Slope	DIAMETRAL NORMALIZED Displacement	DIAMETRAL NORMALIZED Slope
1	-0.1000000E+01	0.2199000E+00	-0.1254463E+01	0.2758564E+00
2	-0.7141000E+00	0.2199000E+00	-0.8958122E+00	0.2758564E+00
3	-0.6490000E+00	0.2199000E+00	-0.8141464E+00	0.2758564E+00
4	-0.6490000E+00	0.2199000E+00	-0.8141464E+00	0.2758564E+00
5	-0.5602000E+00	0.2199000E+00	-0.7027502E+00	0.2758564E+00
6	-0.5602000E+00	0.2199000E+00	-0.7027502E+00	0.2758564E+00
7	-0.4876000E+00	0.2199000E+00	-0.6116763E+00	0.2758564E+00
8	-0.4876000E+00	0.2199000E+00	-0.6116763E+00	0.2758564E+00
9	-0.4467000E+00	0.2199000E+00	-0.5603687E+00	0.2758564E+00
10	-0.4467000E+00	0.2199000E+00	-0.5603687E+00	0.2758564E+00
11	-0.4329000E+00	0.2199000E+00	-0.5430571E+00	0.2758564E+00
12	-0.1730000E+00	0.2199000E+00	-0.2170221E+00	0.2758564E+00
13	-0.1470000E+00	0.2199000E+00	-0.1844061E+00	0.2758564E+00
14	-0.1470000E+00	0.2199000E+00	-0.1844061E+00	0.2758564E+00
15	-0.2791000E-01	0.2189000E+00	-0.3501207E-01	0.2746020E+00
16	0.1660000E+00	0.2122000E+00	0.2082409E+00	0.2661970E+00
17	0.3909000E+00	0.2122000E+00	0.4903697E+00	0.2661970E+00
18	0.5648000E+00	0.1996000E+00	0.7085208E+00	0.2503908E+00
19	0.8368000E+00	0.1777000E+00	0.1049734E+01	0.2229180E+00
20	0.9135000E+00	0.1292000E+00	0.1145951E+01	0.1620766E+00
21	0.9830000E+00	0.1167000E+00	0.1233137E+01	0.1463958E+00
22	0.9830000E+00	0.1167000E+00	0.1233137E+01	0.1463958E+00
23	0.9941000E+00	0.1144000E+00	0.1247062E+01	0.1435106E+00
24	0.9941000E+00	0.1144000E+00	0.1247062E+01	0.1435106E+00
25	0.9449000E+00	0.1025000E+00	0.1185342E+01	0.1285825E+00
26	0.8715000E+00	0.5860000E-01	0.1093265E+01	0.7376242E-01
27	0.6826000E+00	0.4174000E-01	0.8562966E+00	0.5236129E-01
28	0.5565000E+00	0.3436000E-01	0.6981087E+00	0.4310335E-01
29	0.9559000E-01	0.3436000E-01	0.1199141E+00	0.4310335E-01
30	-0.1248000E-01	0.3136000E-01	-0.1565570E-01	0.3933996E-01
31	-0.1442000E+00	0.3104000E-01	-0.1808936E+00	0.3893854E-01
32	-0.4710000E+00	0.3380000E-01	-0.5908521E+00	0.4240085E-01
33	-0.4443000E+00	0.3380000E-01	-0.5573580E+00	0.4240085E-01
34	-0.4443000E+00	0.3380000E-01	-0.5573580E+00	0.4240085E-01
35	-0.4219000E+00	0.3380000E-01	-0.5292580E+00	0.4240085E-01
36	-0.3201000E+00	0.3380000E-01	-0.4015536E+00	0.4240085E-01
37	-0.3201000E+00	0.3380000E-01	-0.4015536E+00	0.4240085E-01
38	-0.3065000E+00	0.3380000E-01	-0.3844929E+00	0.4240085E-01
39	-0.2716000E+00	0.3380000E-01	-0.3407122E+00	0.4240085E-01
40	-0.2716000E+00	0.3380000E-01	-0.3407122E+00	0.4240085E-01
41	-0.2524000E+00	0.3380000E-01	-0.3166264E+00	0.4240085E-01
42	-0.2524000E+00	0.3380000E-01	-0.3166264E+00	0.4240085E-01
43	-0.2451000E+00	0.3380000E-01	-0.3074690E+00	0.4240085E-01
44	-0.2321000E+00	0.3380000E-01	-0.2911609E+00	0.4240085E-01
45	-0.2321000E+00	0.3380000E-01	-0.2911609E+00	0.4240085E-01
46	-0.1437000E+00	0.3380000E-01	-0.1802663E+00	0.4240085E-01
47	-0.5153000E-01	0.3380000E-01	-0.6464263E-01	0.4240085E-01
48	-0.4815000E-01	0.3380000E-01	-0.6040240E-01	0.4240085E-01
49	-0.4815000E-01	0.3380000E-01	-0.6040240E-01	0.4240085E-01
50	-0.4233000E-01	0.3380000E-01	-0.5310142E-01	0.4240085E-01
51	-0.3895000E-01	0.3380000E-01	-0.4886134E-01	0.4240085E-01
52	-0.3557000E-01	0.3380000E-01	-0.4462125E-01	0.4240085E-01
53	-0.3219000E-01	0.3380000E-01	-0.4038117E-01	0.4240085E-01
54	0.4217000E-01	0.3380000E-01	0.5290071E-01	0.4240085E-01
55	0.1199000E+00	0.3380000E-01	0.1504101E+00	0.4240085E-01
56	0.2382000E+00	0.3380000E-01	0.2988131E+00	0.4240085E-01

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NATURAL FREQUENCY: 2095.3 HZ

Station	INPUT Displacement	INPUT Slope	DIAMETRAL NORMALIZED Displacement	DIAMETRAL NORMALIZED Slope
1	-0.1000000E+01	0.4847000E+00	-0.8025891E+00	0.3889180E+00
2	-0.3700000E+00	0.4847000E+00	-0.2968839E+00	0.3889180E+00
3	-0.2265000E+00	0.4847000E+00	-0.1817411E+00	0.3889180E+00
4	-0.2265000E+00	0.4847000E+00	-0.1817411E+00	0.3889180E+00
5	-0.5070000E-01	0.4847000E+00	-0.2463334E-01	0.3889180E+00
6	-0.5070000E-01	0.4847000E+00	-0.2463334E-01	0.3889180E+00
7	0.1292000E+00	0.4847000E+00	0.1036686E+00	0.3889180E+00
8	0.1292000E+00	0.4847000E+00	0.1036686E+00	0.3889180E+00
9	0.2194000E+00	0.4847000E+00	0.1760441E+00	0.3889180E+00
10	0.2194000E+00	0.4847000E+00	0.1760441E+00	0.3889180E+00
11	0.2499000E+00	0.4847000E+00	0.2005170E+00	0.3889180E+00
12	0.8227000E+00	0.4847000E+00	0.6601255E+00	0.3889180E+00
13	0.8800000E+00	0.4847000E+00	0.7061024E+00	0.3889180E+00
14	0.8800000E+00	0.4847000E+00	0.7061024E+00	0.3889180E+00
15	0.1056000E+01	0.4789000E+00	0.8473226E+00	0.3842641E+00
16	0.1288000E+01	0.4473000E+00	0.1033477E+01	0.3589086E+00
17	0.6925000E+00	0.4473000E+00	0.5556544E+00	0.3589086E+00
18	0.5731000E+00	0.4016000E+00	0.4598491E+00	0.3222395E+00
19	0.8025002E-01	0.3412000E+00	0.6439173E-01	0.2737751E+00
20	-0.2474000E+00	0.2319000E+00	-0.1985110E+00	0.1860740E+00
21	-0.7042000E+00	0.2102000E+00	-0.5650424E+00	0.1686622E+00
22	-0.7042000E+00	0.2102000E+00	-0.5650424E+00	0.1686622E+00
23	-0.7917000E+00	0.2070000E+00	-0.6352514E+00	0.1660945E+00
24	-0.7917000E+00	0.2070000E+00	-0.6352514E+00	0.1660945E+00
25	-0.9791000E+00	0.1840000E+00	-0.7856191E+00	0.1476396E+00
26	-0.1178000E+01	0.1012000E+00	-0.9452147E+00	0.8120173E-01
27	-0.1589000E+01	0.6954998E-01	-0.1274996E+01	0.5580614E-01
28	-0.1519000E+01	0.5252000E-01	-0.1218828E+01	0.4214147E-01
29	-0.7465000E+00	0.5252000E-01	-0.5989834E+00	0.4214147E-01
30	-0.5324000E+00	0.2527000E-01	-0.4271919E+00	0.2027637E-01
31	-0.2937000E+00	0.1298000E-01	-0.2356416E+00	0.1041501E-01
32	0.3085000E+00	-0.2392000E-01	0.2411179E+00	-0.1919315E-01
33	0.2816000E+00	-0.2392000E-01	0.2259527E+00	-0.1919315E-01
34	0.2816000E+00	-0.2392000E-01	0.2259527E+00	-0.1919315E-01
35	0.2658000E+00	-0.2392000E-01	0.2132750E+00	-0.1919315E-01
36	0.1937000E+00	-0.2392000E-01	0.1554227E+00	-0.1919315E-01
37	0.1937000E+00	-0.2392000E-01	0.1554227E+00	-0.1919315E-01
38	0.1840000E+00	-0.2392000E-01	0.1476396E+00	-0.1919315E-01
39	0.1593000E+00	-0.2392000E-01	0.1278206E+00	-0.1919315E-01
40	0.1593000E+00	-0.2392000E-01	0.1278206E+00	-0.1919315E-01
41	0.1458000E+00	-0.2392000E-01	0.1169883E+00	-0.1919315E-01
42	0.1458000E+00	-0.2392000E-01	0.1169883E+00	-0.1919315E-01
43	0.1406000E+00	-0.2392000E-01	0.1128159E+00	-0.1919315E-01
44	0.1314000E+00	-0.2392000E-01	0.1054339E+00	-0.1919315E-01
45	0.1314000E+00	-0.2392000E-01	0.1054339E+00	-0.1919315E-01
46	0.6887001E-01	-0.2392000E-01	0.5526054E-01	-0.1919315E-01
47	0.3623000E-02	-0.2392000E-01	0.2907056E-02	-0.1919315E-01
48	0.1231000E-02	-0.2392000E-01	0.9877409E-03	-0.1919315E-01
49	0.1231000E-02	-0.2392000E-01	0.9877409E-03	-0.1919315E-01
50	-0.2898000E-02	-0.2392000E-01	-0.2318904E-02	-0.1919315E-01
51	-0.5282000E-02	-0.2392000E-01	-0.4238218E-02	-0.1919315E-01
52	-0.7674001E-02	-0.2392000E-01	-0.6157532E-02	-0.1919315E-01
53	-0.1007000E-01	-0.2392000E-01	-0.8080058E-02	-0.1919315E-01
54	-0.6269002E-01	-0.2392000E-01	-0.5030179E-01	-0.1919315E-01
55	-0.1177000E+00	-0.2392000E-01	-0.9444118E-01	-0.1919315E-01
56	-0.2014000E+00	-0.2392000E-01	-0.1616811E+00	-0.1919315E-01

ORIGINAL PAGE IS
OF POOR QUALITY

ATD HPOTP MASSNORMALIZATION OUPUT MIN (Y-Z) STIFFNESS PLANE

Number of modes: 4
Number of stations: 56

Station Data

	STA. No.	AXIAL Location	WEIGHT (lb)	DIAMETRAL (lb-in**2)	MASS (lb-sec**2/in)	DIAMETRAL (in-lb-sec**2)	POLAR (in-lb-sec**2)
1	0.0	0.0	0.0	0.0	0.0	0.0	
2	1.300	0.1181000E+02	0.6039999E+02	0.3056419E-01	0.1563147E+00	0.3126293E+00	
3	1.596	0.0	0.0	0.0	0.0	0.0	
4	1.596	0.0	0.0	0.0	0.0	0.0	
5	2.000	0.0	0.0	0.0	0.0	0.0	
6	2.000	0.0	0.0	0.0	0.0	0.0	
7	2.330	0.0	0.0	0.0	0.0	0.0	
8	2.330	0.0	0.0	0.0	0.0	0.0	
9	2.516	0.0	0.0	0.0	0.0	0.0	
10	2.453	0.0	0.0	0.0	0.0	0.0	
11	2.516	0.1000000E+02	0.5000000E+02	0.2587992E-01	0.1293996E+00	0.2587992E+00	
12	3.698	0.6480000E+02	0.6467000E+03	0.1677019E+00	0.1673654E+01	0.3347307E+01	
13	3.816	0.0	0.0	0.0	0.0	0.0	
14	3.816	0.2591856E+01	0.3602966E+02	0.6190103E-02	0.9324449E-01	0.1864890E+00	
15	4.316	0.6477789E+01	0.9456664E+02	0.1676447E-01	0.2447377E+00	0.4894754E+00	
16	5.128	0.3319255E+01	0.4348114E+02	0.8590203E-02	0.1125288E+00	0.2250576E+00	
17	5.711	0.3022653E+02	0.1473459E+03	0.7822603E-01	0.3813300E+00	0.7626600E+00	
18	6.461	0.2784630E+01	0.2889185E+02	0.7206600E-02	0.7477182E-01	0.1495436E+00	
19	7.711	0.3292487E+02	0.1609321E+03	0.8520925E-01	0.4164910E+00	0.8329821E+00	
20	8.431	0.2784420E+01	0.3535609E+02	0.7206056E-02	0.9150130E-01	0.1830026E+00	
21	9.394	0.1430275E+01	0.1857262E+02	0.3701541E-02	0.4806579E-01	0.9613156E-01	
22	9.394	0.2725395E+00	0.3539021E+01	0.7053299E-03	0.9158958E-02	0.1831792E-01	
23	9.578	0.4267253E+02	0.5421389E+03	0.1104361E+00	0.1403051E+01	0.2806103E+01	
24	9.578	0.1267643E+01	0.1646078E+02	0.3280650E-02	0.4260058E-01	0.8520075E-01	
25	10.431	0.2621768E+01	0.3524426E+02	0.6785166E-02	0.8603585E-01	0.1720717E+00	
26	11.151	0.2924890E+01	0.3893214E+02	0.7549589E-02	0.8805214E-01	0.1601843E+00	
27	12.401	0.3278461E+02	0.1588918E+03	0.8484626E-01	0.4112107E+00	0.8224214E+00	
28	13.151	0.3382803E+02	0.4211458E+03	0.8754665E-01	0.1089922E+01	0.2179844E+01	
29	13.733	0.1117491E+01	0.1513005E+02	0.2892857E-02	0.3915645E-01	0.7831287E-01	
30	14.233	0.1429563E+01	0.2077162E+02	0.3699697E-02	0.5375680E-01	0.1075135E+00	
31	14.671	0.6950114E+01	0.4804418E+02	0.1798684E-01	0.1264083E+00	0.2528167E+00	
32	15.771	0.1063952E+03	0.1635636E+04	0.2753499E+00	0.4233013E+01	0.8466026E+01	
33	16.563	0.0	0.0	0.0	0.0	0.0	
34	16.563	0.0	0.0	0.0	0.0	0.0	
35	17.223	0.6330000E+02	0.6883000E+03	0.1638199E+00	0.1781315E+01	0.3562630E+01	
36	20.237	0.0	0.0	0.0	0.0	0.0	
37	20.237	0.0	0.0	0.0	0.0	0.0	
38	20.640	0.7906000E+02	0.3305000E+04	0.2046067E+00	0.8553314E+01	0.1710663E+02	
39	21.673	0.0	0.0	0.0	0.0	0.0	
40	21.673	0.0	0.0	0.0	0.0	0.0	
41	22.241	0.1600000E+02	0.3490000E+03	0.4347828E-01	0.9032095E+00	0.1806418E+01	
42	22.299	0.0	0.0	0.0	0.0	0.0	
43	22.513	0.3706000E+02	0.6510000E+03	0.9591097E-01	0.1684783E+01	0.3369566E+01	
44	22.897	0.0	0.0	0.0	0.0	0.0	
45	22.897	0.0	0.0	0.0	0.0	0.0	
46	25.513	0.3795000E+02	0.6376001E+03	0.9821427E-01	0.1650104E+01	0.3300207E+01	
47	28.241	0.5287[illegible]E+02	0.1752000E+04	0.1367236E+00	0.4534165E+01	0.9068325E+01	
48	28.341	0.0	0.0	0.0	0.0	0.0	
49	28.341	0.1242000E+02	0.2320000E+03	0.3214286E-01	0.6004142E+00	0.1200828E+01	
50	28.513	0.2503[illegible]00E+02	0.4368999E+03	0.6477745E-01	0.1130693E+01	0.2261387E+01	
51	28.613	[illegible]	0.1418000E+03	0.4787786E-01	0.3649069E+00	0.7298138E+00	
52	28.713	0.1980000E+02	0.1160000E+03	0.5124225E-01	0.3002071E+00	0.6004142E+00	
53	28.813	0.2130000E+02	0.1600000E+03	0.5512424E-01	0.4140788E+00	0.8281575E+00	
54	31.813	0.2175000E+02	0.2705000E+03	0.5628883E-01	0.7000519E+00	0.1400104E+01	
55	33.313	0.6246001E+02	0.9380000E+03	0.1616468E+00	0.2427536E+01	0.4855072E+01	
56	34.813	0.2353999E+02	0.3700000E+02	0.6092132E-01	0.9575570E-01	0.1915114E+00	

ORIGINAL PAGE IS
OF POOR QUALITY

NATURAL FREQUENCY: 145.6 HZ

		INPUT		DIAMETRAL NORMALIZED	
	Station	Displacement	Slope	Displacement	Slope
1	-0.1000000E+01	0.2570000E-01	-0.1100957E+01	0.2609267E-01
2	-0.9692000E+00	0.2570000E-01	-0.1067047E+01	0.2609267E-01
3	-0.9622000E+00	0.2570000E-01	-0.1059540E+01	0.2609267E-01
4	-0.9622000E+00	0.2570000E-01	-0.1059540E+01	0.2609267E-01
5	-0.9526000E+00	0.2570000E-01	-0.1048771E+01	0.2609267E-01
6	-0.9526000E+00	0.2570000E-01	-0.1048771E+01	0.2609267E-01
7	-0.9448000E+00	0.2570000E-01	-0.1040184E+01	0.2609267E-01
8	-0.9448000E+00	0.2570000E-01	-0.1040184E+01	0.2609267E-01
9	-0.9404000E+00	0.2570000E-01	-0.1035339E+01	0.2609267E-01
10	-0.9404000E+00	0.2570000E-01	-0.1035339E+01	0.2609267E-01
11	-0.9389000E+00	0.2570000E-01	-0.1033688E+01	0.2609267E-01
12	-0.9189000E+00	0.2570000E-01	-0.1002861E+01	0.2609267E-01
13	-0.9081000E+00	0.2570000E-01	-0.9997790E+00	0.2609267E-01
14	-0.9081000E+00	0.2570000E-01	-0.9997790E+00	0.2609267E-01
15	-0.8960000E+00	0.2571000E-01	-0.9864574E+00	0.2610369E-01
16	-0.8762000E+00	0.2572000E-01	-0.9646584E+00	0.2611469E-01
17	-0.8595000E+00	0.2572000E-01	-0.9460525E+00	0.2611469E-01
18	-0.8397000E+00	0.2570000E-01	-0.9244735E+00	0.2609267E-01
19	-0.8061000E+00	0.2550000E-01	-0.8874813E+00	0.2596056E-01
20	-0.7863000E+00	0.2516000E-01	-0.8656824E+00	0.2549816E-01
21	-0.7603000E+00	0.2500000E-01	-0.8370575E+00	0.2532201E-01
22	-0.7603000E+00	0.2500000E-01	-0.8370575E+00	0.2532201E-01
23	-0.7554000E+00	0.2296000E-01	-0.8316628E+00	0.2527797E-01
24	-0.7554000E+00	0.2296000E-01	-0.8316628E+00	0.2527797E-01
25	-0.7333000E+00	0.2277000E-01	-0.8073316E+00	0.2506879E-01
26	-0.7148000E+00	0.2181000E-01	-0.7869440E+00	0.2401187E-01
27	-0.6835000E+00	0.2125000E-01	-0.7525040E+00	0.2339335E-01
28	-0.6650000E+00	0.2086000E-01	-0.7321564E+00	0.2296596E-01
29	-0.6446000E+00	0.2086000E-01	-0.7096767E+00	0.2296596E-01
30	-0.6322000E+00	0.2034000E-01	-0.6960250E+00	0.2239346E-01
31	-0.6208000E+00	0.2012000E-01	-0.6834741E+00	0.2215125E-01
32	-0.5925000E+00	0.1951000E-01	-0.6523169E+00	0.2147967E-01
33	-0.5770000E+00	0.1951000E-01	-0.6352521E+00	0.2147967E-01
34	-0.5770000E+00	0.1951000E-01	-0.6352521E+00	0.2147967E-01
35	-0.5641000E+00	0.1951000E-01	-0.6210498E+00	0.2147967E-01
36	-0.5053000E+00	0.1951000E-01	-0.5563135E+00	0.2147967E-01
37	-0.5053000E+00	0.1951000E-01	-0.5563135E+00	0.2147967E-01
38	-0.4975000E+00	0.1951000E-01	-0.5477260E+00	0.2147967E-01
39	-0.4773000E+00	0.1951000E-01	-0.5254867E+00	0.2147967E-01
40	-0.4773000E+00	0.1951000E-01	-0.5254867E+00	0.2147967E-01
41	-0.4663000E+00	0.1951000E-01	-0.5133762E+00	0.2147967E-01
42	-0.4663000E+00	0.1951000E-01	-0.5133762E+00	0.2147967E-01
43	-0.4621000E+00	0.1951000E-01	-0.5087522E+00	0.2147967E-01
44	-0.4546000E+00	0.1951000E-01	-0.5004950E+00	0.2147967E-01
45	-0.4546000E+00	0.1951000E-01	-0.5004950E+00	0.2147967E-01
46	-0.4036000E+00	0.1951000E-01	-0.4443461E+00	0.2147967E-01
47	-0.3505000E+00	0.1951000E-01	-0.3856652E+00	0.2147967E-01
48	-0.3484000E+00	0.1951000E-01	-0.3835734E+00	0.2147967E-01
49	-0.3484000E+00	0.1951000E-01	-0.3835734E+00	0.2147967E-01
50	-0.3458000E+00	0.1951000E-01	-0.3798301E+00	0.2147967E-01
51	-0.3431000E+00	0.1951000E-01	-0.3777383E+00	0.2147967E-01
52	-0.3411000E+00	0.1951000E-01	-0.3755363E+00	0.2147967E-01
53	-0.3392000E+00	0.1951000E-01	-0.3734446E+00	0.2147967E-01
54	-0.2963000E+00	0.1951000E-01	-0.3262135E+00	0.2147967E-01
55	-0.2514000E+00	0.1951000E-01	-0.2767805E+00	0.2147967E-01
56	-0.1831000E+00	0.1951000E-01	-0.2015652E+00	0.2147967E-01

ORIGINAL PAGE IS
OF POOR QUALITY

NATURAL FREQUENCY: 279.5 HZ

		INPUT		DIAMETRAL NORMALIZED	
	Station	Displacement	Slope	Displacement	Slope
1	-0.1000000E+01	0.6976002E-01	-0.1048051E+01	0.7311064E-01	
2	-0.9095000E+00	0.6976002E-01	-0.9529744E+00	0.7311064E-01	
3	-0.8887000E+00	0.6976002E-01	-0.9315850E+00	0.7311064E-01	
4	-0.8887000E+00	0.6976002E-01	-0.9315850E+00	0.7311064E-01	
5	-0.8605000E+00	0.6976002E-01	-0.9018305E+00	0.7311064E-01	
6	-0.8605000E+00	0.6976002E-01	-0.9018305E+00	0.7311064E-01	
7	-0.8374000E+00	0.6976002E-01	-0.8776211E+00	0.7311064E-01	
8	-0.8374000E+00	0.6976002E-01	-0.8776211E+00	0.7311064E-01	
9	-0.8245000E+00	0.6976002E-01	-0.8641014E+00	0.7311064E-01	
10	-0.8245000E+00	0.6976002E-01	-0.8641014E+00	0.7311064E-01	
11	-0.8201000E+00	0.6976002E-01	-0.8594901E+00	0.7311064E-01	
12	-0.7376000E+00	0.6976002E-01	-0.7730275E+00	0.7311064E-01	
13	-0.7294000E+00	0.6976002E-01	-0.7644337E+00	0.7311064E-01	
14	-0.7294000E+00	0.6976002E-01	-0.7644337E+00	0.7311064E-01	
15	-0.6933000E+00	0.6974000E-01	-0.7265998E+00	0.7308966E-01	
16	-0.6341000E+00	0.6955999E-01	-0.6645564E+00	0.7290101E-01	
17	-0.5786000E+00	0.6955999E-01	-0.6063906E+00	0.7290101E-01	
18	-0.5192000E+00	0.6906003E-01	-0.5441376E+00	0.7237703E-01	
19	-0.4175000E+00	0.6792998E-01	-0.4375529E+00	0.7119268E-01	
20	-0.3595000E+00	0.6490999E-01	-0.3767670E+00	0.6802768E-01	
21	-0.2844000E+00	0.6393999E-01	-0.2980599E+00	0.6701106E-01	
22	-0.2844000E+00	0.6393999E-01	-0.2980599E+00	0.6701106E-01	
23	-0.2702000E+00	0.6373000E-01	-0.2831779E+00	0.6679100E-01	
24	-0.2702000E+00	0.6373000E-01	-0.2831779E+00	0.6679100E-01	
25	-0.2048000E+00	0.6260997E-01	-0.2137983E+00	0.6561714E-01	
26	-0.1498000E+00	0.5726000E-01	-0.1569950E+00	0.6001024E-01	
27	-0.5962000E-01	0.5425000E-01	-0.6248360E-01	0.5685567E-01	
28	-0.9985998E-02	0.5218000E-01	-0.1046563E-01	0.5468625E-01	
29	0.4562000E-01	0.5218000E-01	0.4781117E-01	0.5468625E-01	
30	0.7758999E-01	0.4965000E-01	0.8131665E-01	0.5203473E-01	
31	0.1067000E+00	0.4859000E-01	0.1118249E+00	0.5092382E-01	
32	0.1776000E+00	0.4574000E-01	0.1861303E+00	0.4793693E-01	
33	0.2138000E+00	0.4574000E-01	0.2240690E+00	0.4793693E-01	
34	0.2138000E+00	0.4574000E-01	0.2240690E+00	0.4793693E-01	
35	0.2440000E+00	0.4574000E-01	0.2557195E+00	0.4793693E-01	
36	0.3818000E+00	0.4574000E-01	0.4001581E+00	0.4793693E-01	
37	0.3818000E+00	0.4574000E-01	0.4001581E+00	0.4793693E-01	
38	0.4005000E+00	0.4574000E-01	0.4195268E+00	0.4793693E-01	
39	0.4475000E+00	0.4574000E-01	0.4689938E+00	0.4793693E-01	
40	0.4475000E+00	0.4574000E-01	0.4689938E+00	0.4793693E-01	
41	0.4735000E+00	0.4574000E-01	0.4962426E+00	0.4793693E-01	
42	0.4735000E+00	0.4574000E-01	0.4962426E+00	0.4793693E-01	
43	0.4833000E+00	0.4574000E-01	0.5065132E+00	0.4793693E-01	
44	0.5088000E+00	0.4574000E-01	0.5248538E+00	0.4793693E-01	
45	0.5088000E+00	0.4574000E-01	0.5248538E+00	0.4793693E-01	
46	0.6205000E+00	0.4574000E-01	0.6503031E+00	0.4793693E-01	
47	0.7452000E+00	0.4574000E-01	0.7809926E+00	0.4793693E-01	
48	0.7498000E+00	0.4574000E-01	0.7858135E+00	0.4793693E-01	
49	0.7498000E+00	0.4574000E-01	0.7858135E+00	0.4793693E-01	
50	0.7577000E+00	0.4574000E-01	0.7940930E+00	0.4793693E-01	
51	0.7623000E+00	0.4574000E-01	0.7989139E+00	0.4793693E-01	
52	0.7668000E+00	0.4574000E-01	0.8036300E+00	0.4793693E-01	
53	0.7714000E+00	0.4574000E-01	0.8084509E+00	0.4793693E-01	
54	0.8720000E+00	0.4574000E-01	0.9138829E+00	0.4793693E-01	
55	0.9772000E+00	0.4574000E-01	0.1024136E+01	0.4793693E-01	
56	0.1137000E+01	0.4574000E-01	0.1191618E+01	0.4793693E-01	

ORIGINAL PAGE IS
OF POOR QUALITY

NATURAL FREQUENCY: 694.0 HZ

	Station	INPUT Displacement	INPUT Slope	DIAMETRAL NORMALIZED Displacement	DIAMETRAL NORMALIZED Slope
1	-0.1000000E+01	0.8868998E-01	-0.1482588E+01	0.1314906E+00	
2	-0.8847000E+00	0.8868998E-01	-0.1311645E+01	0.1314906E+00	
3	-0.8584000E+00	0.8868998E-01	-0.1272653E+01	0.1314906E+00	
4	-0.8584000E+00	0.8868998E-01	-0.1272653E+01	0.1314906E+00	
5	-0.8226000E+00	0.8868998E-01	-0.1219576E+01	0.1314906E+00	
6	-0.8226000E+00	0.8868998E-01	-0.1219576E+01	0.1314906E+00	
7	-0.7933000E+00	0.8868998E-01	-0.1176136E+01	0.1314906E+00	
8	-0.7933000E+00	0.8868998E-01	-0.1176136E+01	0.1314906E+00	
9	-0.7769000E+00	0.8868998E-01	-0.1151822E+01	0.1314906E+00	
10	-0.7769000E+00	0.8868998E-01	-0.1151822E+01	0.1314906E+00	
11	-0.7713000E+00	0.8868998E-01	-0.1143519E+01	0.1314906E+00	
12	-0.6664000E+00	0.8868998E-01	-0.9879965E+00	0.1314906E+00	
13	-0.6560000E+00	0.8868998E-01	-0.9725776E+00	0.1314906E+00	
14	-0.6560000E+00	0.8868998E-01	-0.9725776E+00	0.1314906E+00	
15	-0.6036000E+00	0.8849001E-01	-0.8948900E+00	0.1311942E+00	
16	-0.5153000E+00	0.8692002E-01	-0.7639774E+00	0.1288666E+00	
17	-0.3680000E+00	0.8692002E-01	-0.5455922E+00	0.1288666E+00	
18	-0.2606000E+00	0.8309001E-01	-0.3863623E+00	0.1231882E+00	
19	-0.6739002E-01	0.7493001E-01	-0.9991157E-01	0.1110983E+00	
20	0.3172000E-01	0.5426000E-01	0.4702768E-01	0.8044517E-01	
21	0.1473000E+00	0.4788000E-01	0.2183852E+00	0.7098627E-01	
22	0.1473000E+00	0.4788000E-01	0.2183852E+00	0.7098627E-01	
23	0.1686000E+00	0.4656000E-01	0.2499643E+00	0.6902927E-01	
24	0.1686000E+00	0.4656000E-01	0.2499643E+00	0.6902927E-01	
25	0.2591000E+00	0.3970000E-01	0.3841385E+00	0.5885874E-01	
26	0.3258000E+00	0.8037999E-02	0.4800619E+00	0.1191704E-01	
27	0.4096000E+00	-0.9153999E-02	0.6072680E+00	-0.1357161E-01	
28	0.4314000E+00	-0.2042000E-01	0.6395884E+00	-0.3027444E-01	
29	0.4832000E+00	-0.2042000E-01	0.7163864E+00	-0.3027444E-01	
30	0.4861000E+00	-0.3298000E-01	0.7206860E+00	-0.4889574E-01	
31	0.4892000E+00	-0.3811000E-01	0.7252819E+00	-0.5650142E-01	
32	0.4833000E+00	-0.5140000E-01	0.7165546E+00	-0.7620496E-01	
33	0.4426000E+00	-0.5140000E-01	0.6561934E+00	-0.7620496E-01	
34	0.4426000E+00	-0.5140000E-01	0.6561934E+00	-0.7620496E-01	
35	0.4067000E+00	-0.5140000E-01	0.6059536E+00	-0.7620496E-01	
36	0.2538000E+00	-0.5140000E-01	0.3762807E+00	-0.7620496E-01	
37	0.2538000E+00	-0.5140000E-01	0.3762807E+00	-0.7620496E-01	
38	0.2331000E+00	-0.5140000E-01	0.3455912E+00	-0.7620496E-01	
39	0.1808000E+00	-0.5140000E-01	0.2668658E+00	-0.7620496E-01	
40	0.1808000E+00	-0.5140000E-01	0.2668658E+00	-0.7620496E-01	
41	0.1508000E+00	-0.5140000E-01	0.2235742E+00	-0.7620496E-01	
42	0.1508000E+00	-0.5140000E-01	0.2235742E+00	-0.7620496E-01	
43	0.1398000E+00	-0.5140000E-01	0.2072658E+00	-0.7620496E-01	
44	0.1201000E+00	-0.5140000E-01	0.1780588E+00	-0.7620496E-01	
45	0.1201000E+00	-0.5140000E-01	0.1780588E+00	-0.7620496E-01	
46	-0.1440000E-01	-0.5140000E-01	-0.2134927E-01	-0.7620496E-01	
47	-0.1546000E+00	-0.5140000E-01	-0.2292881E+00	-0.7620496E-01	
48	-0.1597000E+00	-0.5140000E-01	-0.2367692E+00	-0.7620496E-01	
49	-0.1597000E+00	-0.5140000E-01	-0.2367692E+00	-0.7620496E-01	
50	-0.1686000E+00	-0.5140000E-01	-0.2499643E+00	-0.7620496E-01	
51	-0.1737000E+00	-0.5140000E-01	-0.2575254E+00	-0.7620496E-01	
52	-0.1789000E+00	-0.5140000E-01	-0.2652349E+00	-0.7620496E-01	
53	-0.1840000E+00	-0.5140000E-01	-0.2727962E+00	-0.7620496E-01	
54	-0.2971000E+00	-0.5140000E-01	-0.4404768E+00	-0.7620496E-01	
55	-0.4153000E+00	-0.5140000E-01	-0.6157187E+00	-0.7620496E-01	
56	-0.5952000E+00	-0.5140000E-01	-0.8824342E+00	-0.7620496E-01	

ORIGINAL PAGE IS
OF POOR QUALITY

NATURAL FREQUENCY: 1196.5 HZ

		INPUT		DIAMETRAL NORMALIZED	
	Station	Displacement	Slope	Displacement	Slope
1	-0.1000000E+01	0.2192000E+00	-0.1267117E+01	0.2777519E+00	
2	-0.7150000E+00	0.2192000E+00	-0.9059683E+00	0.2777519E+00	
3	-0.6502000E+00	0.2192000E+00	-0.8238792E+00	0.2777519E+00	
4	-0.6502000E+00	0.2192000E+00	-0.8238792E+00	0.2777519E+00	
5	-0.5616000E+00	0.2192000E+00	-0.7116126E+00	0.2777519E+00	
6	-0.5616000E+00	0.2192000E+00	-0.7116126E+00	0.2777519E+00	
7	-0.4893000E+00	0.2192000E+00	-0.6200001E+00	0.2777519E+00	
8	-0.4893000E+00	0.2192000E+00	-0.6200001E+00	0.2777519E+00	
9	-0.4485000E+00	0.2192000E+00	-0.5683017E+00	0.2777519E+00	
10	-0.4485000E+00	0.2192000E+00	-0.5683017E+00	0.2777519E+00	
11	-0.4347000E+00	0.2192000E+00	-0.5508155E+00	0.2777519E+00	
12	-0.1756000E+00	0.2192000E+00	-0.2225056E+00	0.2777519E+00	
13	-0.1497000E+00	0.2192000E+00	-0.1896873E+00	0.2777519E+00	
14	-0.1497000E+00	0.2192000E+00	-0.1896873E+00	0.2777519E+00	
15	-0.3094000E-01	0.2162000E+00	-0.3920458E-01	0.2764848E+00	
16	0.1625000E+00	0.2116000E+00	0.2059065E+00	0.2681218E+00	
17	0.3874000E+00	0.2116000E+00	0.4908809E+00	0.2681218E+00	
18	0.5612000E+00	0.1990000E+00	0.7111058E+00	0.2521561E+00	
19	0.8333000E+00	0.1771000E+00	0.1055888E+01	0.2244063E+00	
20	0.9104000E+00	0.1288000E+00	0.1153583E+01	0.1632046E+00	
21	0.9804000E+00	0.1162000E+00	0.1242281E+01	0.1472589E+00	
22	0.9804000E+00	0.1162000E+00	0.1242281E+01	0.1472589E+00	
23	0.9916000E+00	0.1139000E+00	0.1256473E+01	0.1443245E+00	
24	0.9916000E+00	0.1139000E+00	0.1256473E+01	0.1443245E+00	
25	0.9656000E+00	0.1020000E+00	0.1198185E+01	0.1292459E+00	
26	0.8752000E+00	0.5809000E-01	0.1108980E+01	0.7368679E-01	
27	0.6913000E+00	0.4081000E-01	0.8759574E+00	0.5171102E-01	
28	0.5669000E+00	0.3324000E-01	0.7183284E+00	0.4211896E-01	
29	0.1102000E+00	0.3324000E-01	0.1396362E+00	0.4211896E-01	
30	0.2731000E-02	0.3000000E-01	0.3460495E-02	0.3801350E-01	
31	-0.1282000E+00	0.2957000E-01	-0.1624443E+00	0.3746863E-01	
32	-0.4536000E+00	0.3204000E-01	-0.5747640E+00	0.4059841E-01	
33	-0.4282000E+00	0.3204000E-01	-0.5425793E+00	0.4059841E-01	
34	-0.4282000E+00	0.3204000E-01	-0.5425793E+00	0.4059841E-01	
35	-0.4071000E+00	0.3204000E-01	-0.5158432E+00	0.4059841E-01	
36	-0.3105000E+00	0.3204000E-01	-0.3934397E+00	0.4059841E-01	
37	-0.3105000E+00	0.3204000E-01	-0.3934397E+00	0.4059841E-01	
38	-0.2976000E+00	0.3204000E-01	-0.3770938E+00	0.4059841E-01	
39	-0.2645000E+00	0.3204000E-01	-0.3351523E+00	0.4059841E-01	
40	-0.2645000E+00	0.3204000E-01	-0.3351523E+00	0.4059841E-01	
41	-0.2463000E+00	0.3204000E-01	-0.3120908E+00	0.4059841E-01	
42	-0.2463000E+00	0.3204000E-01	-0.3120908E+00	0.4059841E-01	
43	-0.2395000E+00	0.3204000E-01	-0.3034744E+00	0.4059841E-01	
44	-0.2272000E+00	0.3204000E-01	-0.2878888E+00	0.4059841E-01	
45	-0.2272000E+00	0.3204000E-01	-0.2878888E+00	0.4059841E-01	
46	-0.1433000E+00	0.3204000E-01	-0.1815777E+00	0.4059841E-01	
47	-0.5594000E-01	0.3204000E-01	-0.7088244E-01	0.4059841E-01	
48	-0.5273000E-01	0.3204000E-01	-0.6681502E-01	0.4059841E-01	
49	-0.5273000E-01	0.3204000E-01	-0.6681502E-01	0.4059841E-01	
50	-0.4721000E-01	0.3204000E-01	-0.5982057E-01	0.4059841E-01	
51	-0.4401000E-01	0.3204000E-01	-0.5576580E-01	0.4059841E-01	
52	-0.4080000E-01	0.3204000E-01	-0.5169836E-01	0.4059841E-01	
53	-0.3760000E-01	0.3204000E-01	-0.4764358E-01	0.4059841E-01	
54	0.3289000E-01	0.3204000E-01	0.4167546E-01	0.4059841E-01	
55	0.1066000E+00	0.3204000E-01	0.1350746E+00	0.4059841E-01	
56	0.2167000E+00	0.3204000E-01	0.2771183E+00	0.4059841E-01	

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NATURAL FREQUENCY: 2095.2 HZ

	Station	INPUT Displacement	INPUT Slope	DIAMETRAL NORMALIZED Displacement	DIAMETRAL NORMALIZED Slope
1	-0.1000000E+01	0.4842000E+00	-0.8025152E+00	0.3885778E+00	
2	-0.3705000E+00	0.4842000E+00	-0.2973319E+00	0.3885778E+00	
3	-0.2272000E+00	0.4842000E+00	-0.1823314E+00	0.3885778E+00	
4	-0.2272000E+00	0.4842000E+00	-0.1823314E+00	0.3885778E+00	
5	-0.3154000E-01	0.4842000E+00	-0.2531133E-01	0.3885778E+00	
6	-0.3154000E-01	0.4842000E+00	-0.2531133E-01	0.3885778E+00	
7	0.1283000E+00	0.4842000E+00	0.1029627E+00	0.3885778E+00	
8	0.1283000E+00	0.4842000E+00	0.1029627E+00	0.3885778E+00	
9	0.2183000E+00	0.4842000E+00	0.1751890E+00	0.3885778E+00	
10	0.2183000E+00	0.4842000E+00	0.1751890E+00	0.3885778E+00	
11	0.2488000E+00	0.4842000E+00	0.1996457E+00	0.3885778E+00	
12	0.8211000E+00	0.4842000E+00	0.6589452E+00	0.3885778E+00	
13	0.8763000E+00	0.4842000E+00	0.7048491E+00	0.3885778E+00	
14	0.8763000E+00	0.4842000E+00	0.7048491E+00	0.3885778E+00	
15	0.1054000E+01	0.4785000E+00	0.8458509E+00	0.3840035E+00	
16	0.1286000E+01	0.4469000E+00	0.1032034E+01	0.3586440E+00	
17	0.6924000E+00	0.4469000E+00	0.5556615E+00	0.3586440E+00	
18	0.5734000E+00	0.4012000E+00	0.4601622E+00	0.3219691E+00	
19	0.8170003E-01	0.3408000E+00	0.6556547E-01	0.2734972E+00	
20	-0.2457000E+00	0.2315000E+00	-0.1971779E+00	0.1857823E+00	
21	-0.7022000E+00	0.2098000E+00	-0.5635262E+00	0.1683677E+00	
22	-0.7022000E+00	0.2098000E+00	-0.5635262E+00	0.1683677E+00	
23	-0.7897000E+00	0.2066000E+00	-0.6337462E+00	0.1657996E+00	
24	-0.7897000E+00	0.2066000E+00	-0.6337462E+00	0.1657996E+00	
25	-0.9794000E+00	0.1836000E+00	-0.7859833E+00	0.1473418E+00	
26	-0.1180000E+01	0.1009000E+00	-0.9469681E+00	0.8097374E-01	
27	-0.1595000E+01	0.6945997E-01	-0.1280011E+01	0.5574268E-01	
28	-0.1525000E+01	0.5256000E-01	-0.1223835E+01	0.4218020E-01	
29	-0.7514000E+00	0.5256000E-01	-0.6030999E+00	0.4218020E-01	
30	-0.5368000E+00	0.2542000E-01	-0.4307901E+00	0.2039994E-01	
31	-0.2976000E+00	0.1318000E-01	-0.2388285E+00	0.1057715E-01	
32	0.2983000E+00	-0.2363000E-01	0.2393903E+00	-0.1896343E-01	
33	0.2796000E+00	-0.2363000E-01	0.2243832E+00	-0.1896343E-01	
34	0.2796000E+00	-0.2363000E-01	0.2243832E+00	-0.1896343E-01	
35	0.2640000E+00	-0.2363000E-01	0.2118440E+00	-0.1896343E-01	
36	0.1928000E+00	-0.2363000E-01	0.1547249E+00	-0.1896343E-01	
37	0.1928000E+00	-0.2363000E-01	0.1547249E+00	-0.1896343E-01	
38	0.1833000E+00	-0.2363000E-01	0.1471010E+00	-0.1896343E-01	
39	0.1589000E+00	-0.2363000E-01	0.1275197E+00	-0.1896343E-01	
40	0.1589000E+00	-0.2363000E-01	0.1275197E+00	-0.1896343E-01	
41	0.1454000E+00	-0.2363000E-01	0.1166857E+00	-0.1896343E-01	
42	0.1454000E+00	-0.2363000E-01	0.1166857E+00	-0.1896343E-01	
43	0.1404000E+00	-0.2363000E-01	0.1126731E+00	-0.1896343E-01	
44	0.1313000E+00	-0.2363000E-01	0.1053702E+00	-0.1896343E-01	
45	0.1313000E+00	-0.2363000E-01	0.1053702E+00	-0.1896343E-01	
46	0.6950003E-01	-0.2363000E-01	0.5577483E-01	-0.1896343E-01	
47	0.5843990E-02	-0.2363000E-01	0.4047882E-02	-0.1896343E-01	
48	0.2681000E-02	-0.2363000E-01	0.2151543E-02	-0.1896343E-01	
49	0.2681000E-02	-0.2363000E-01	0.2151543E-02	-0.1896343E-01	
50	-0.1390000E-02	-0.2363000E-01	-0.1115496E-02	-0.1896343E-01	
51	-0.3753000E-02	-0.2363000E-01	-0.3011839E-02	-0.1896343E-01	
52	-0.6115999E-02	-0.2363000E-01	-0.4908182E-02	-0.1896343E-01	
53	-0.8478999E-02	-0.2363000E-01	-0.6804522E-02	-0.1896343E-01	
54	-0.6046000E-01	-0.2363000E-01	-0.4852007E-01	-0.1896343E-01	
55	-0.1148000E+00	-0.2363000E-01	-0.9212869E-01	-0.1896343E-01	
56	-0.1975000E+00	-0.2363000E-01	-0.1584967E+00	-0.1896343E-01	

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Appendix E. Whirl Frequency Map Mode Shapes

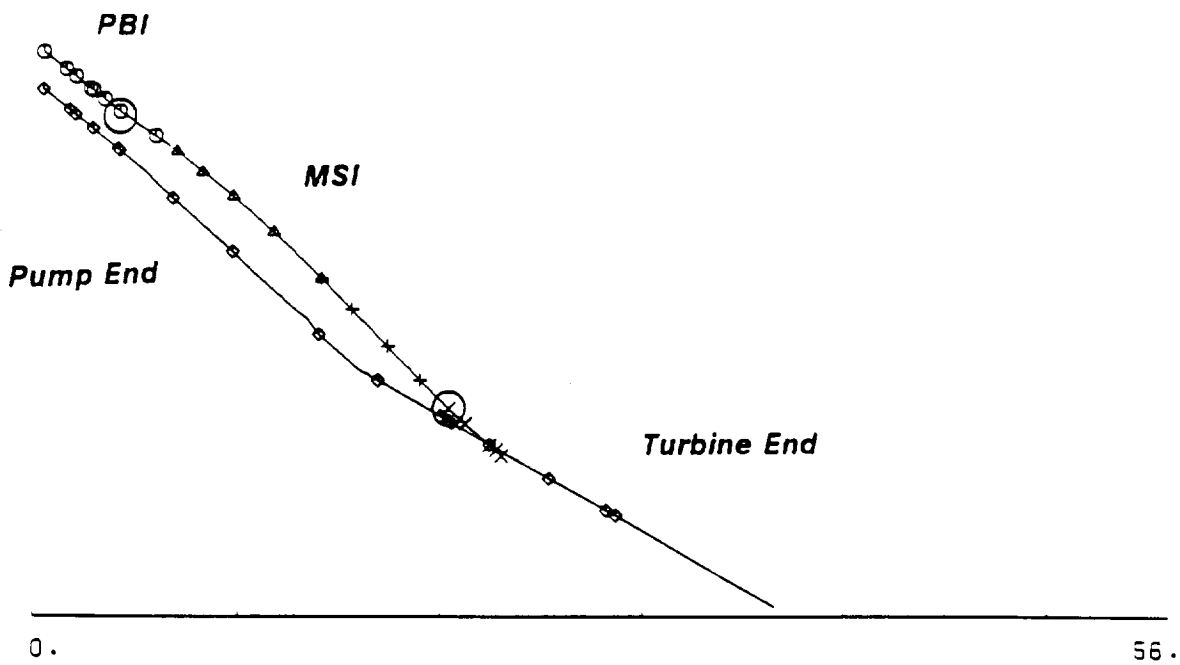


Figure 82. Housing Bounce, Forward Whirl at 65% (X-Z Plane)

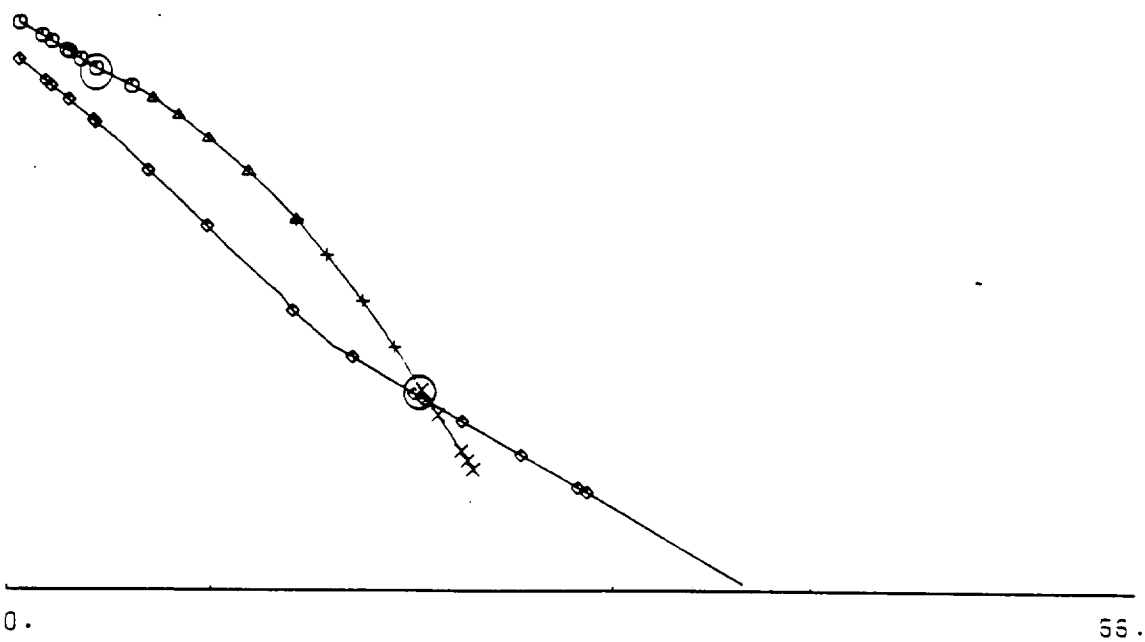


Figure 83. Housing Bounce, Backward Whirl at 65% (X-Z Plane)

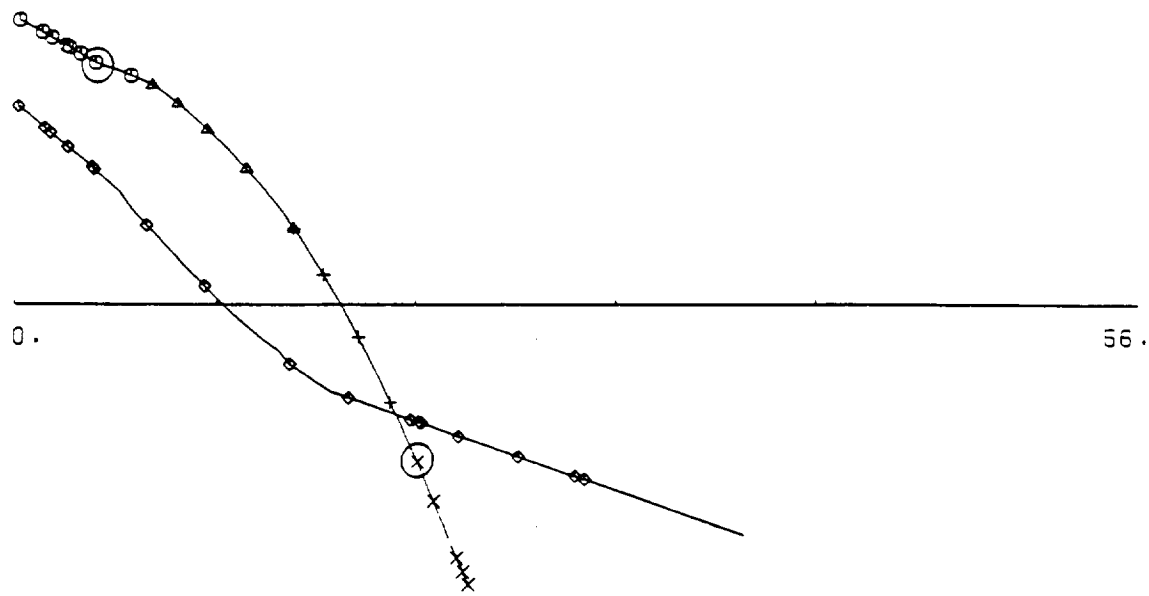


Figure 84. Housing Pitch, Forward Whirl at 65% (X-Z Plane)

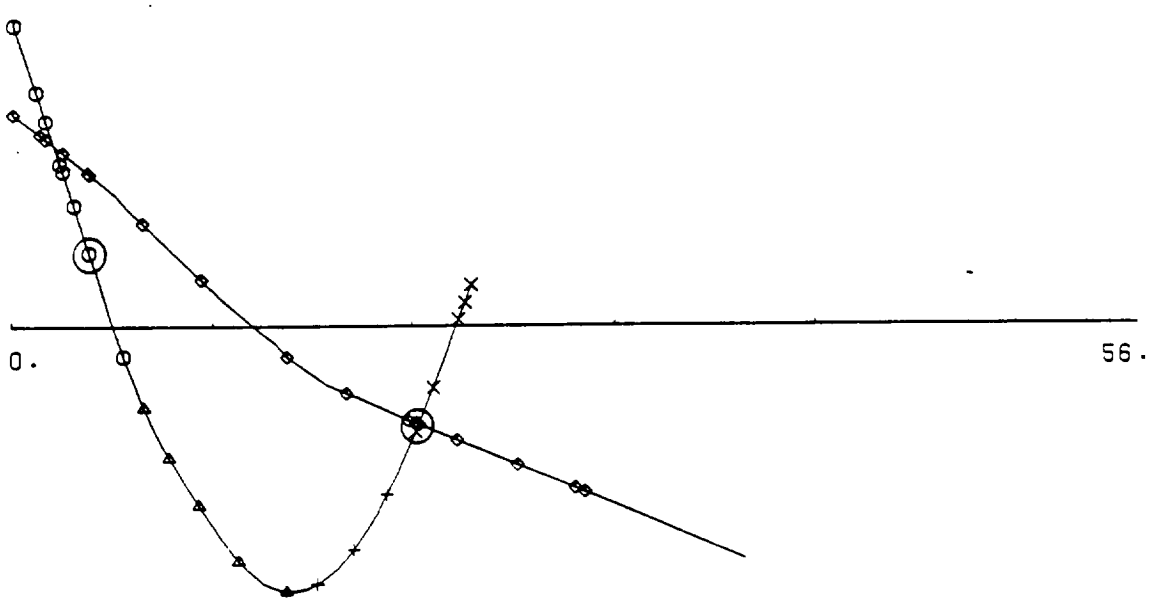


Figure 85. Housing Pitch, Backward Whirl at 65% (X-Z Plane)

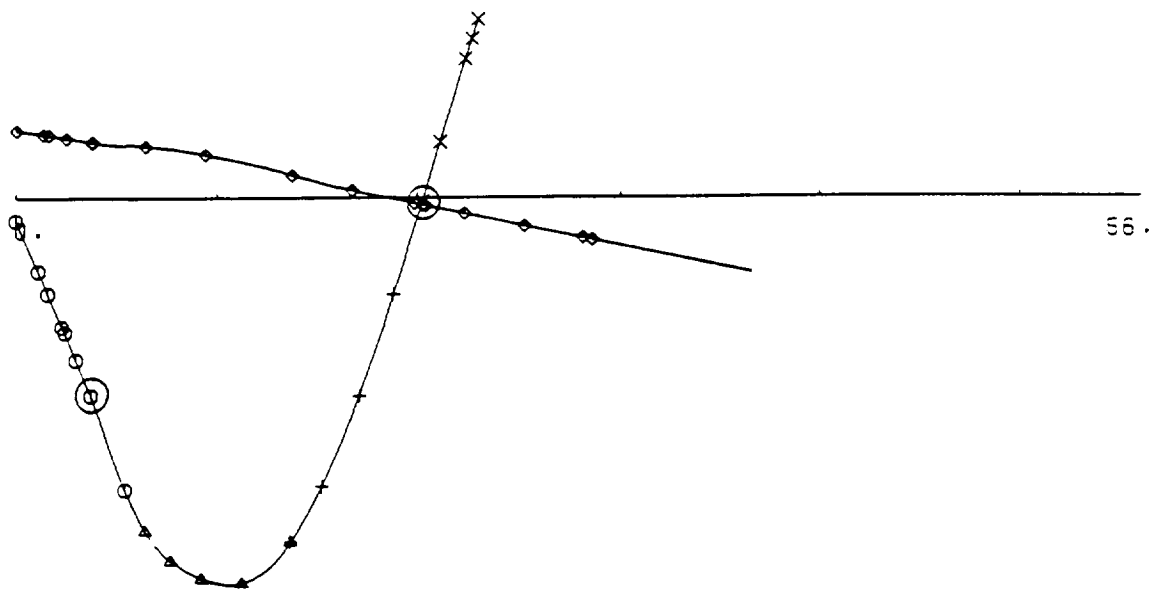


Figure 86. Rotor Pump Bounce, Forward Whirl at 65% (X-Z Plane)

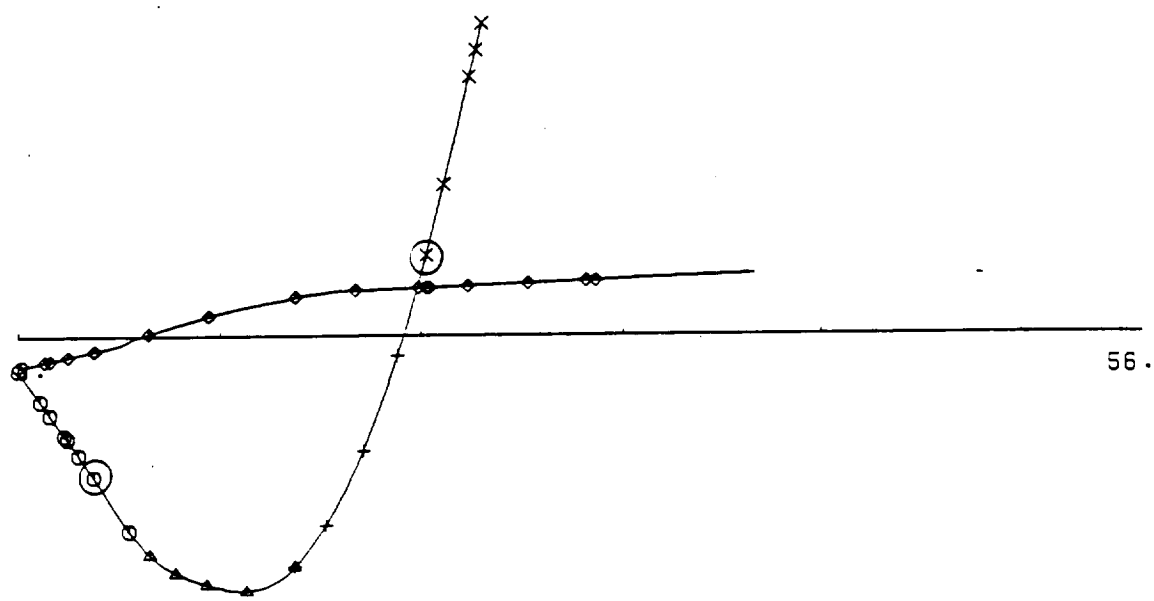


Figure 87. Rotor Pump Bounce, Backward Whirl at 65% (X-Z Plane)

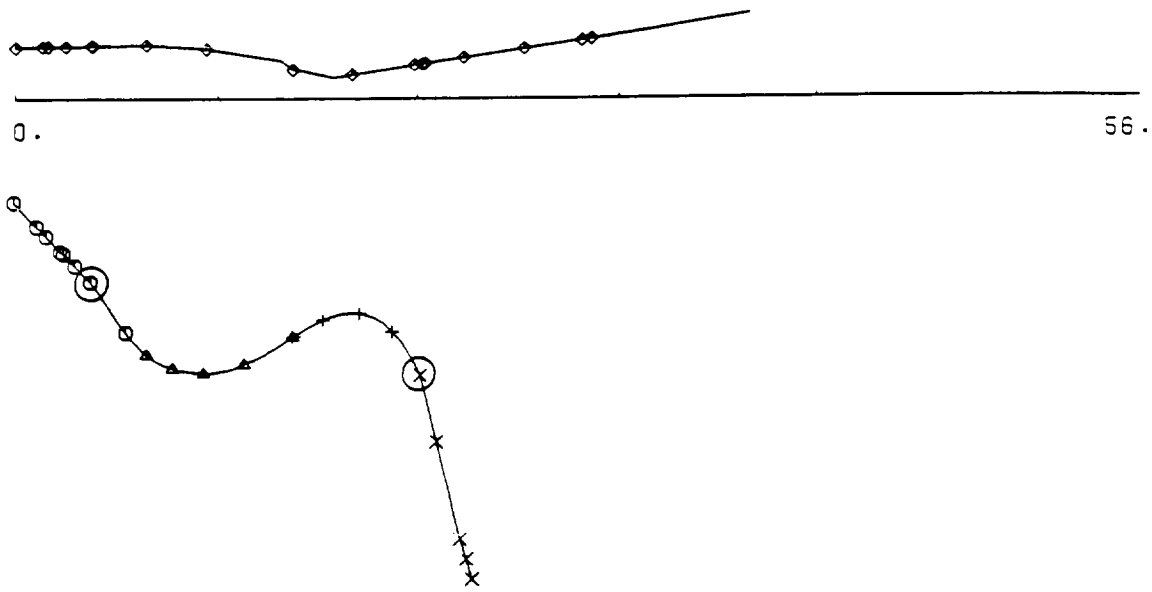


Figure 88. Rotor Turbine Bounce, Forward Whirl at 65% (X-Z Plane)

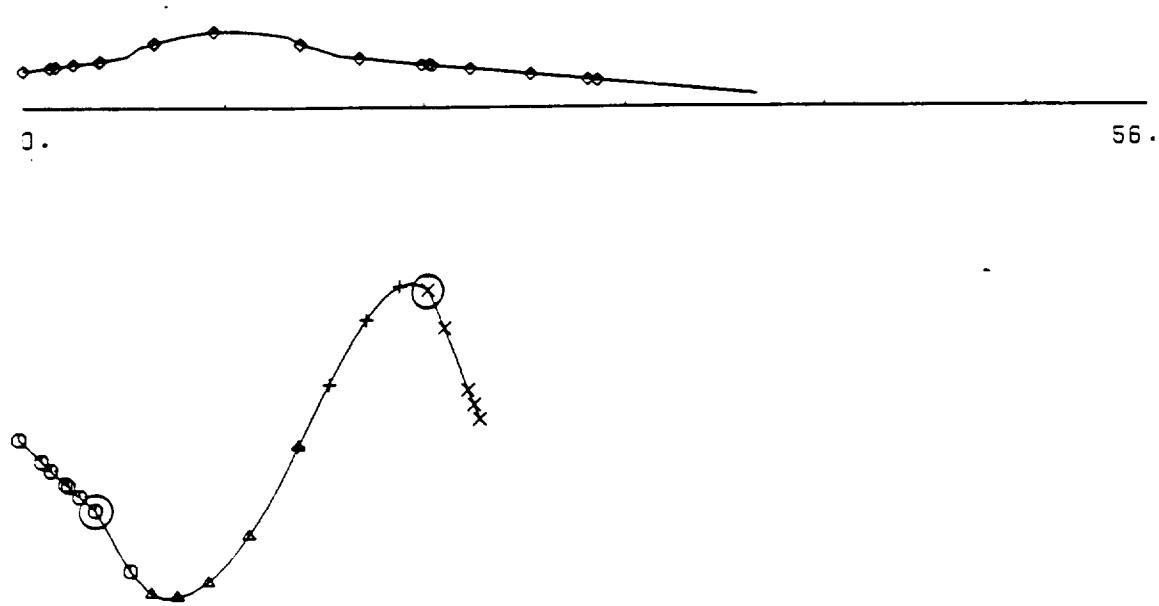


Figure 89. Rotor Turbine Bounce, Backward Whirl at 65% (X-Z Plane)

C-3.

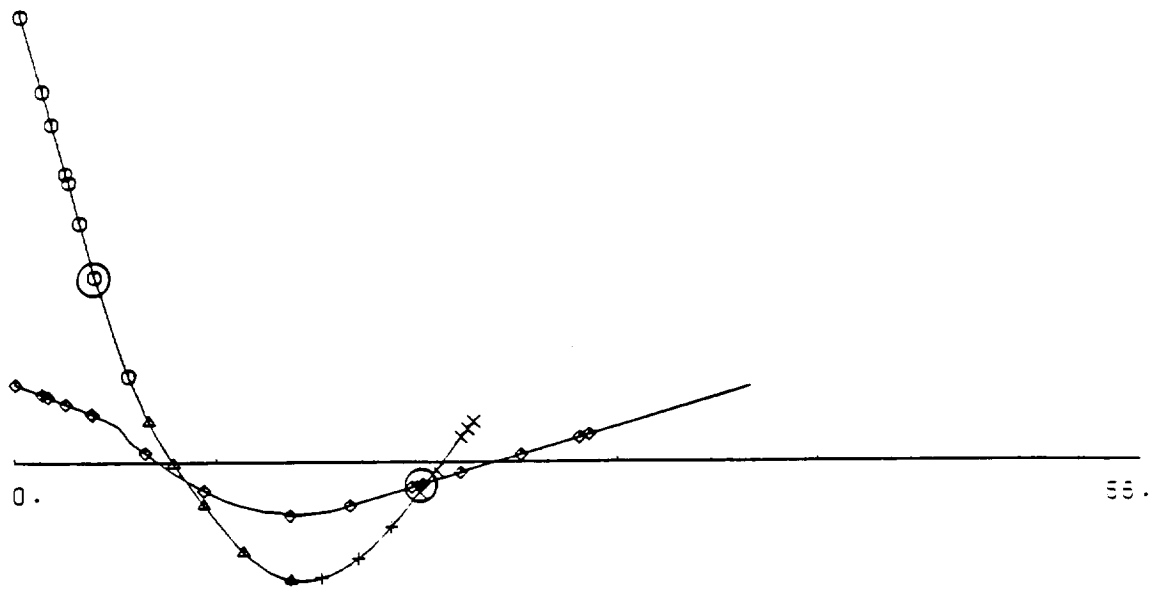


Figure 90. Housing 1st Bending, Forward Whirl at 65% (X-Z Plane)

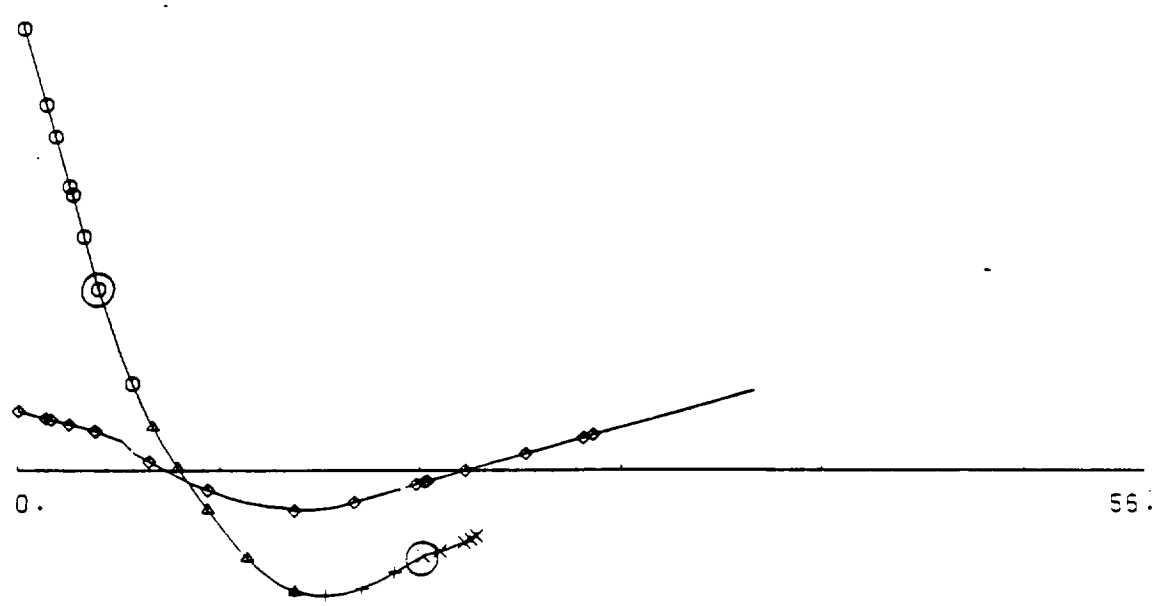


Figure 91. Housing 1st Bending, Backward Whirl at 65% (X-Z Plane)

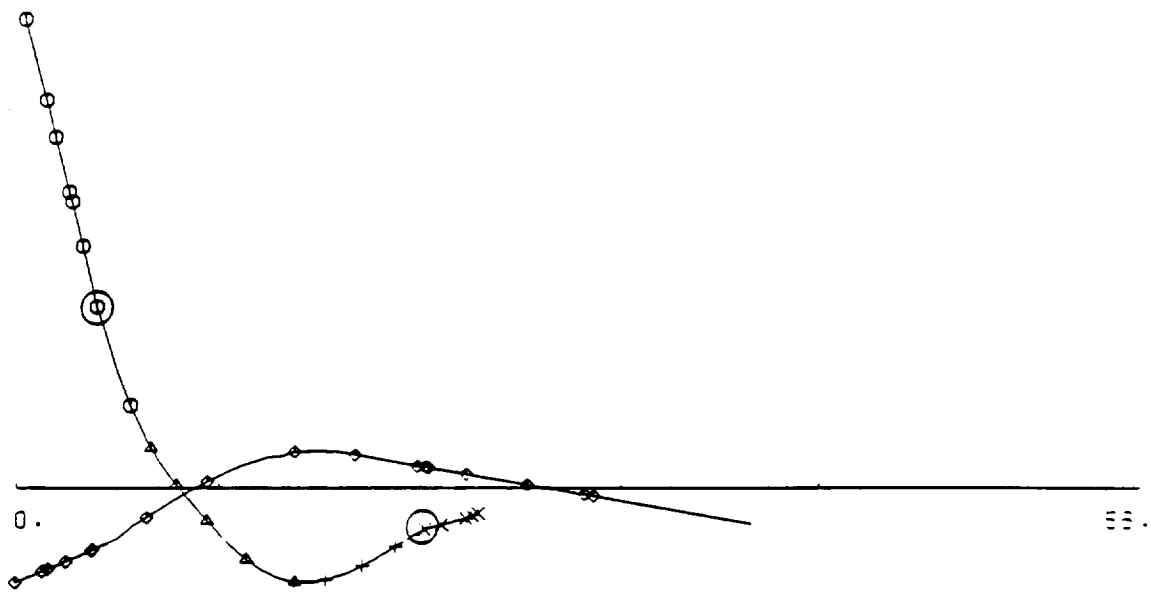


Figure 92. Rotor 1st Bending, Forward Whirl at 65% (X-Z Plane)

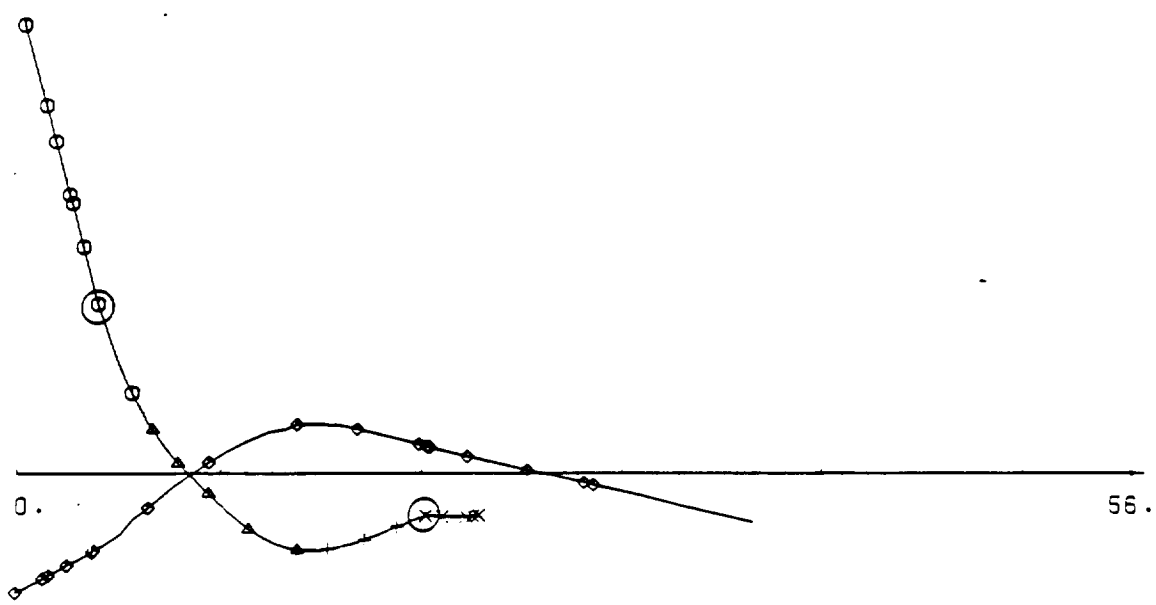


Figure 93. Rotor 1st Bending, Backward Whirl at 65% (X-Z Plane)

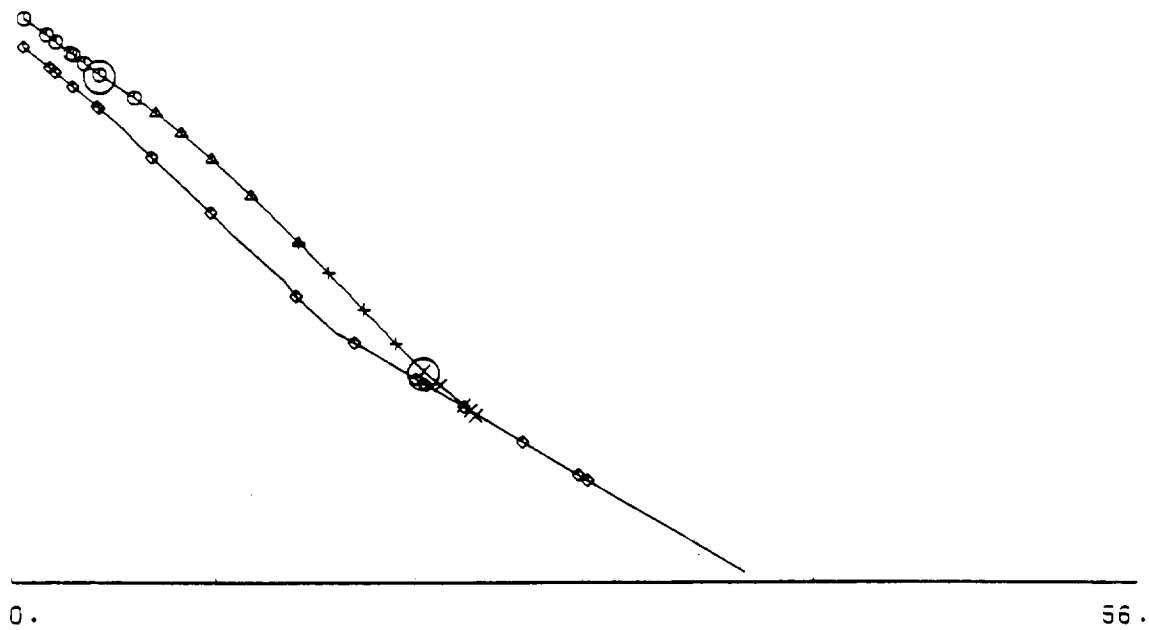


Figure 94. Housing Bounce, Forward Whirl at 90% (X-Z Plane)

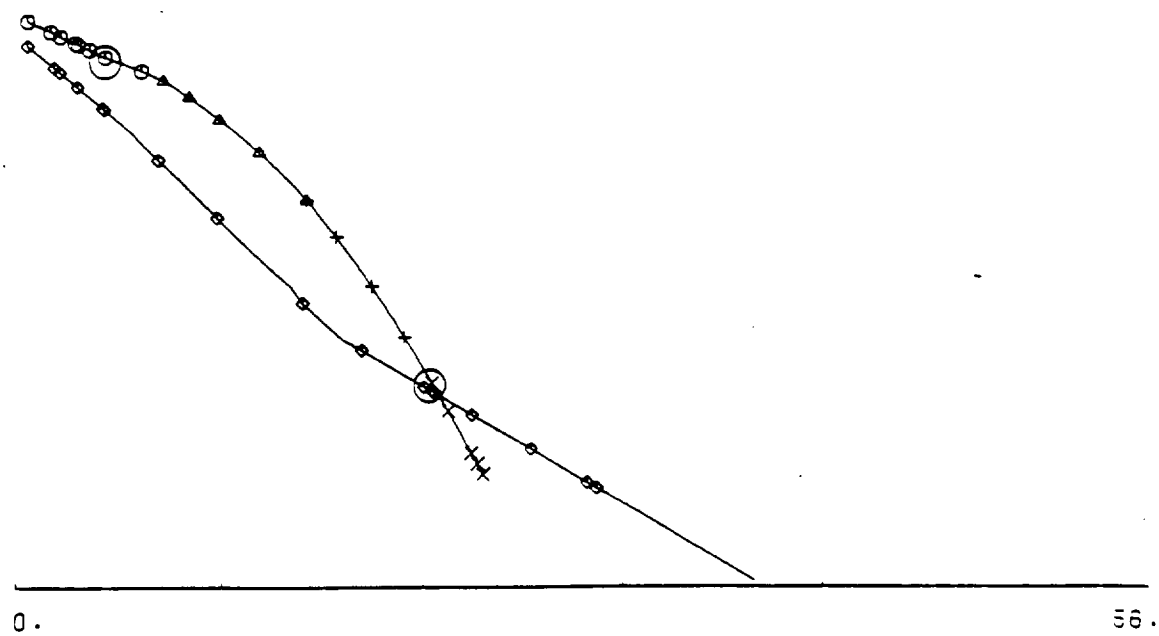


Figure 95. Housing Bounce, Backward Whirl at 90% (X-Z Plane)

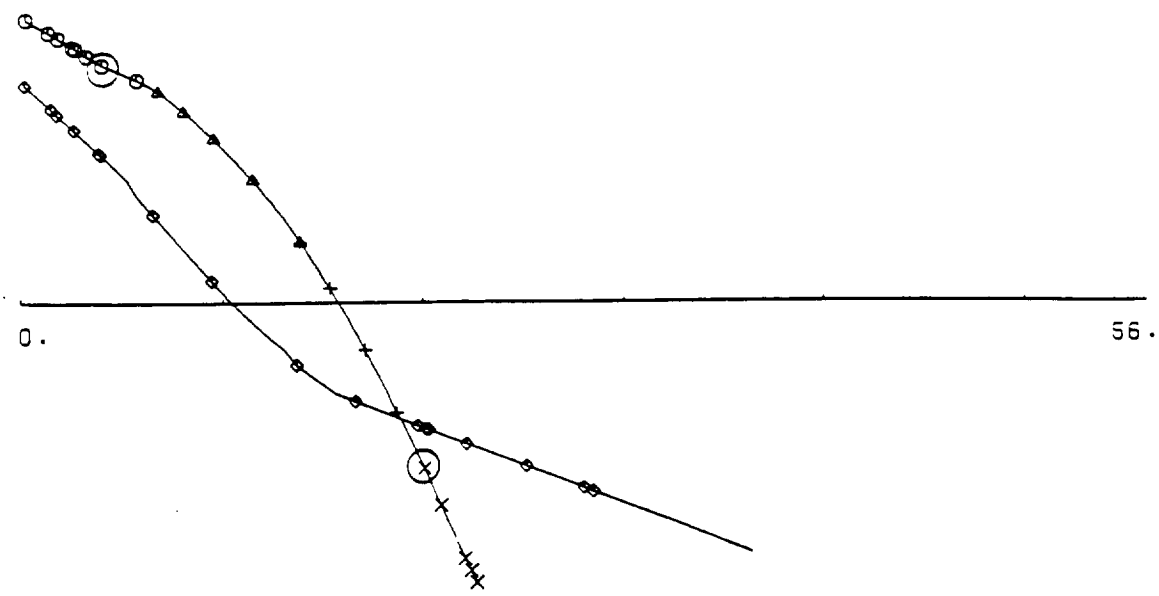


Figure 96. Housing Pitch, Forward Whirl at 90% (X-Z Plane)

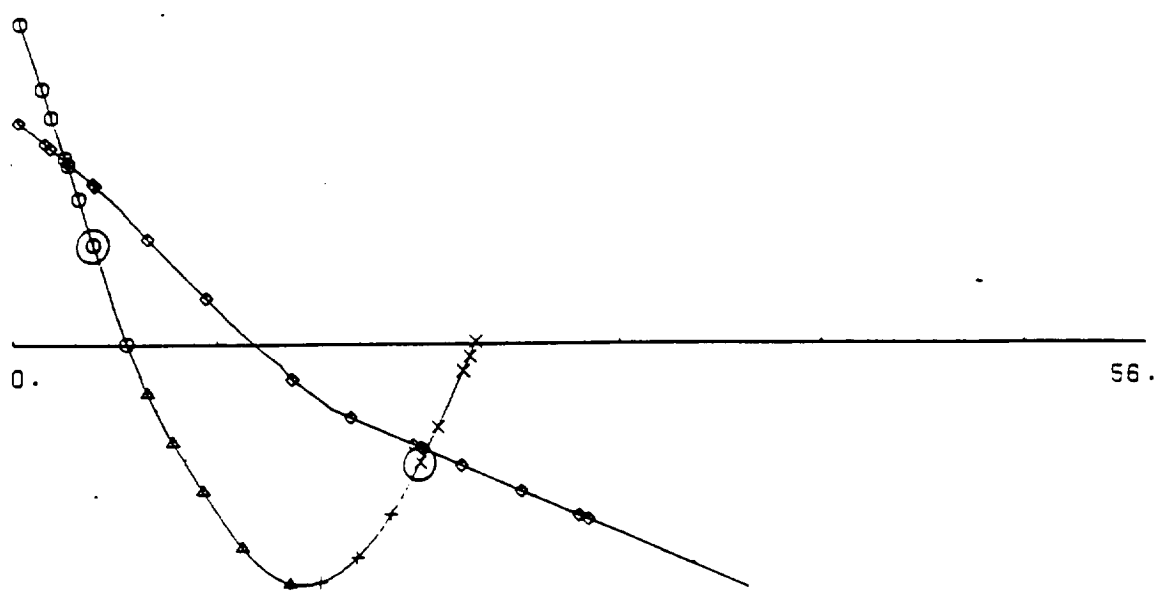


Figure 97. Housing Pitch, Backward Whirl at 90% (X-Z Plane)

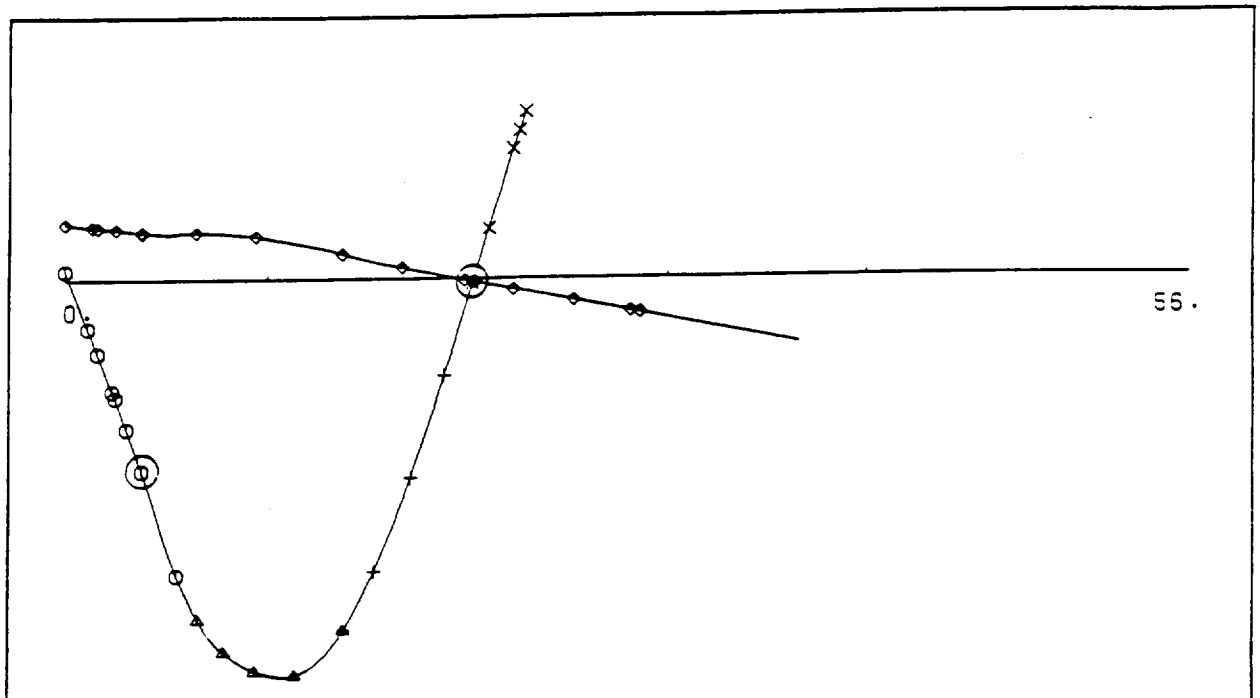


Figure 98. Rotor Pump Bounce, Forward Whirl at 90% (X-Z Plane)

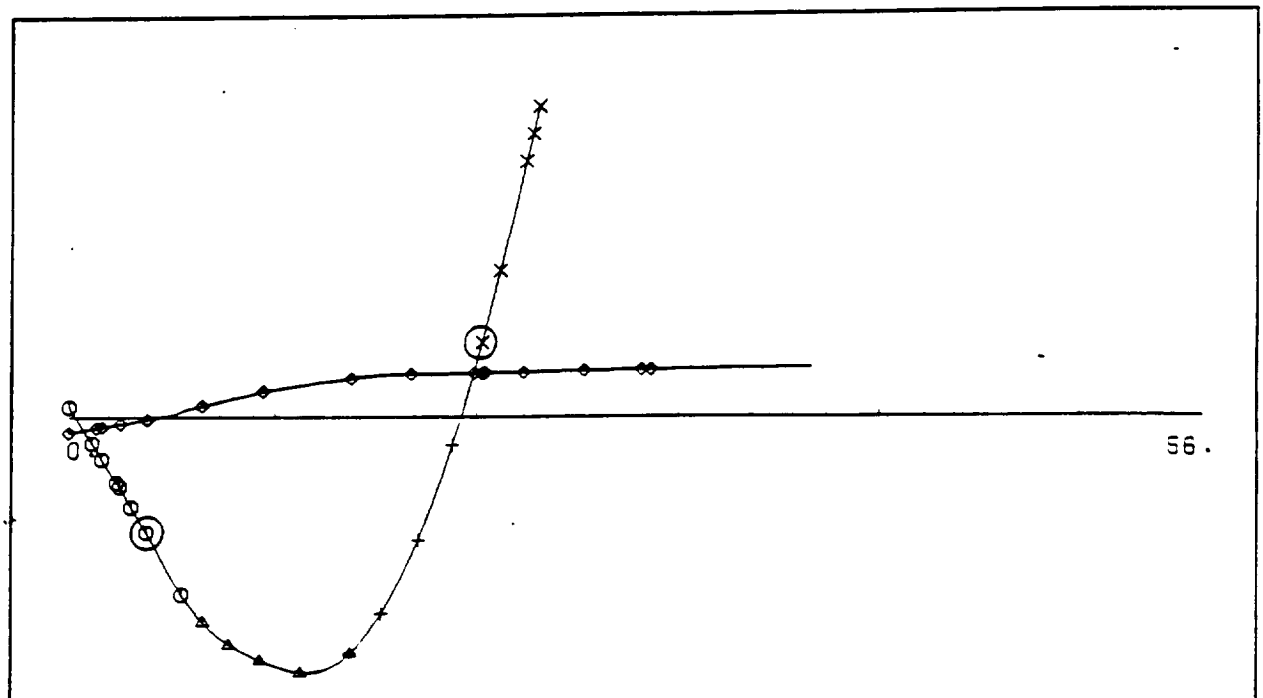


Figure 99. Rotor Pump Bounce, Backward Whirl at 90% (X-Z Plane)

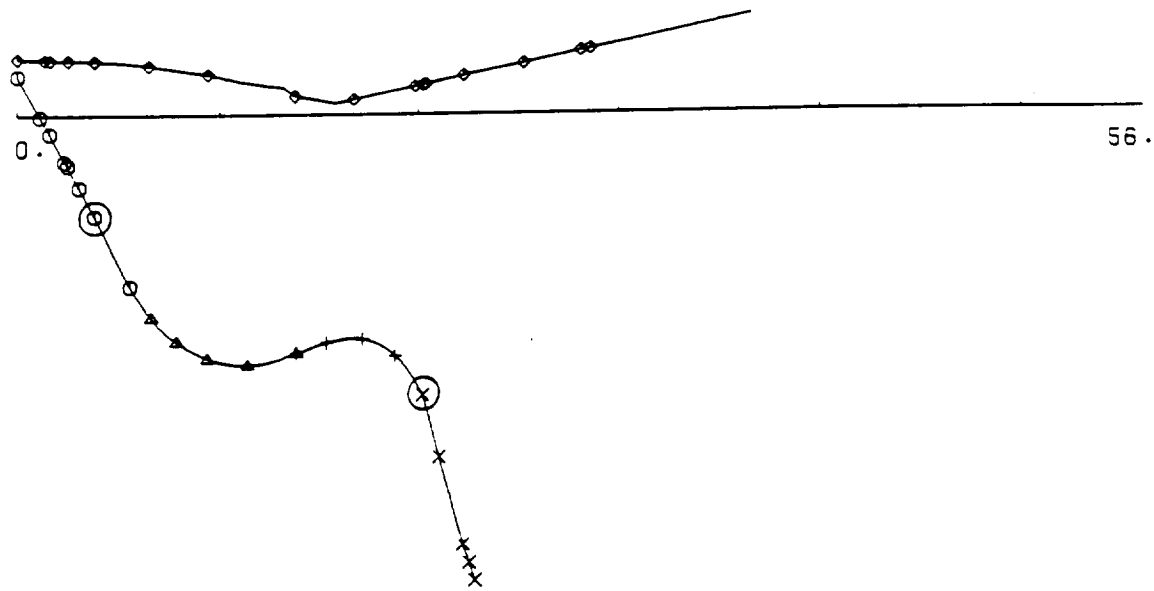


Figure 100. Rotor Turbine Bounce, Forward Whirl at 90% (X-Z Plane)

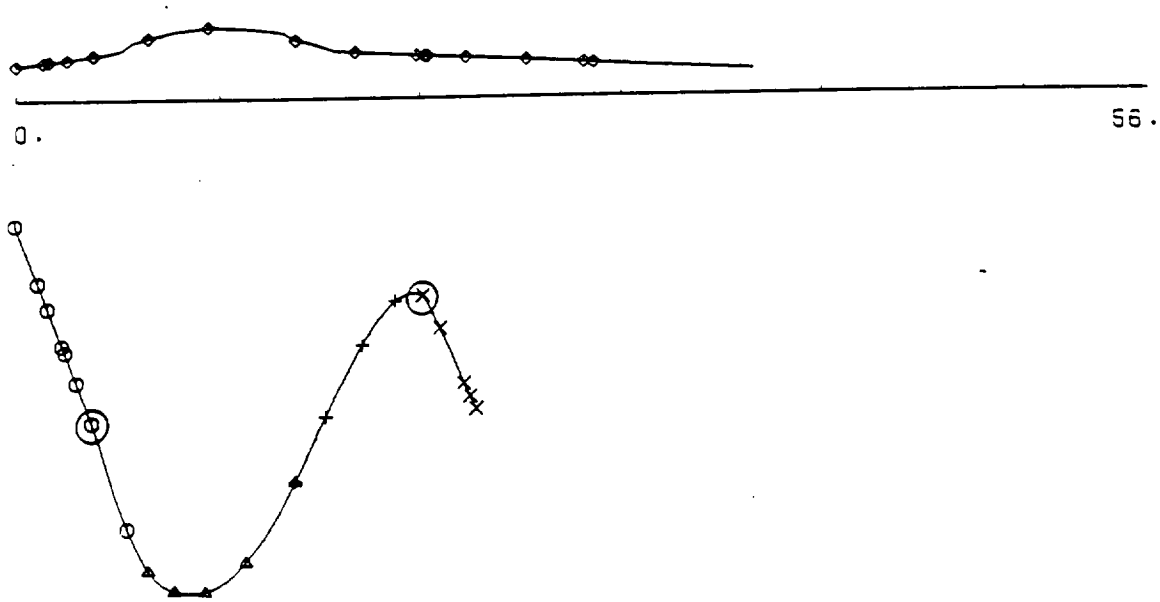


Figure 101. Rotor Turbine Bounce, Backward Whirl at 90% (X-Z Plane)

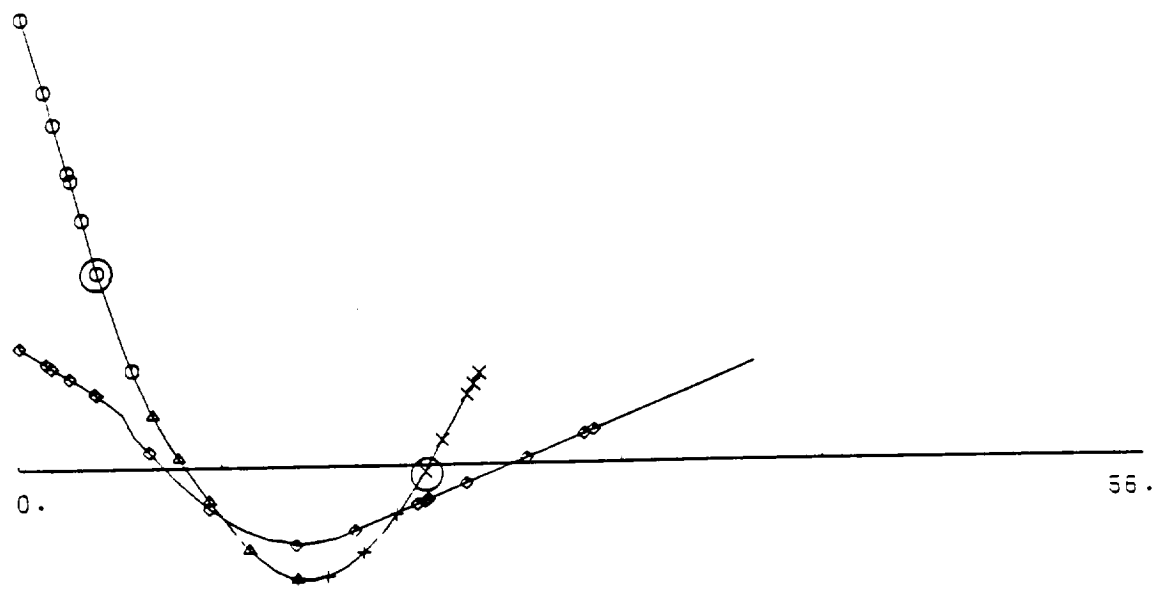


Figure 102. Housing 1st Bending, Forward Whirl at 90% (X-Z Plane)

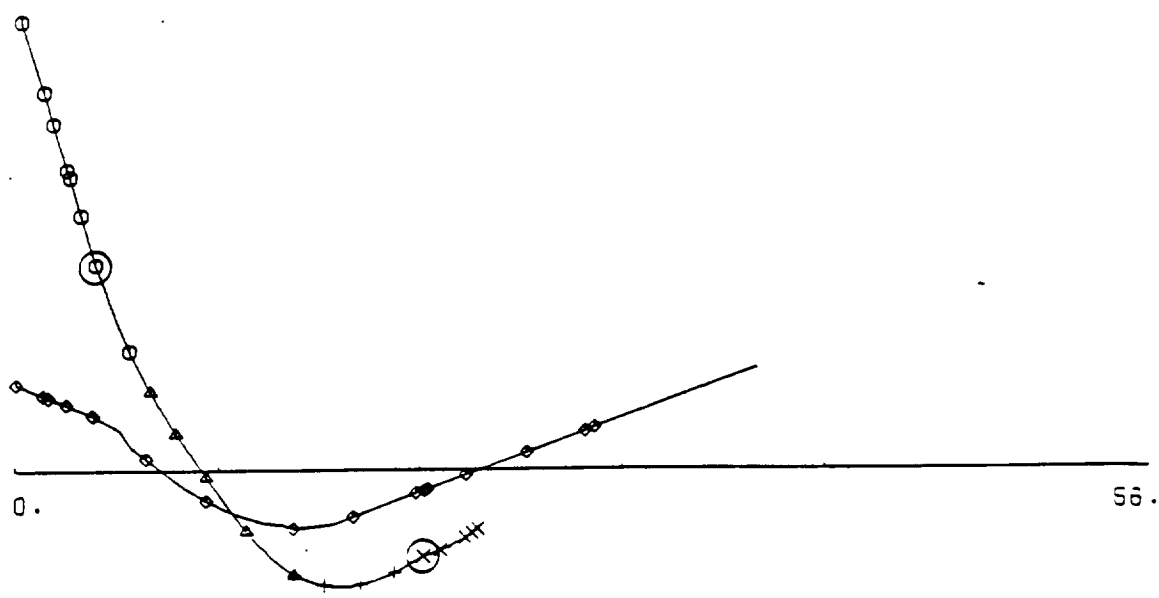


Figure 103. Housing 1st Bending, Backward Whirl at 90% (X-Z Plane)

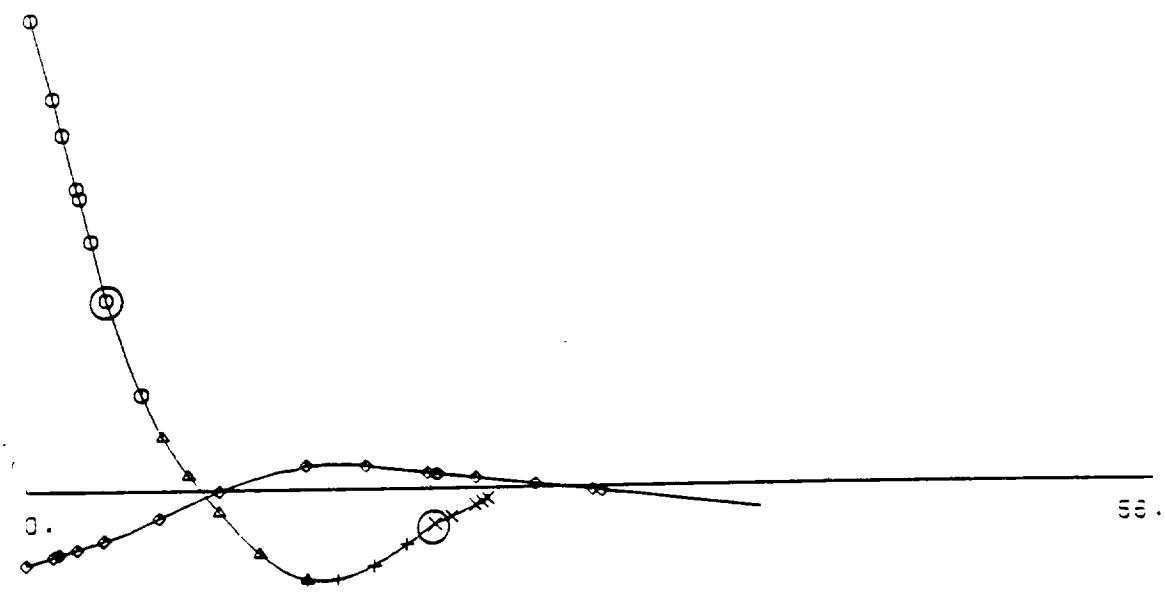


Figure 104. Rotor 1st Bending, Forward Whirl at 90% (X-Z Plane)

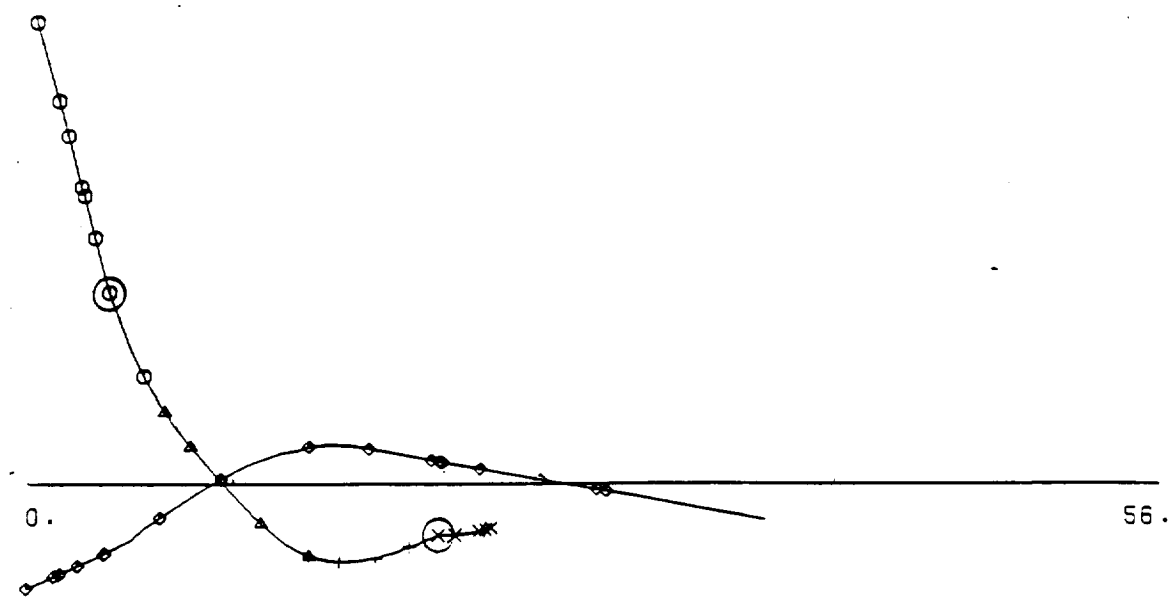


Figure 105. Rotor 1st Bending, Backward Whirl at 90% (X-Z Plane)

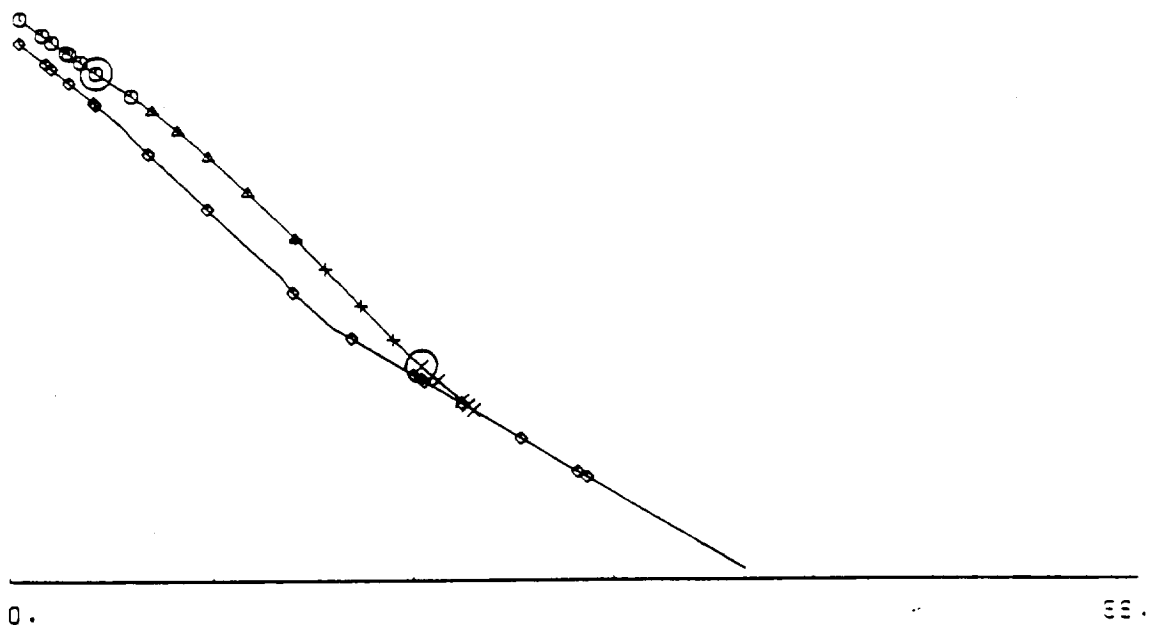


Figure 106. Housing Bounce, Forward Whirl at 109% (X-Z Plane)

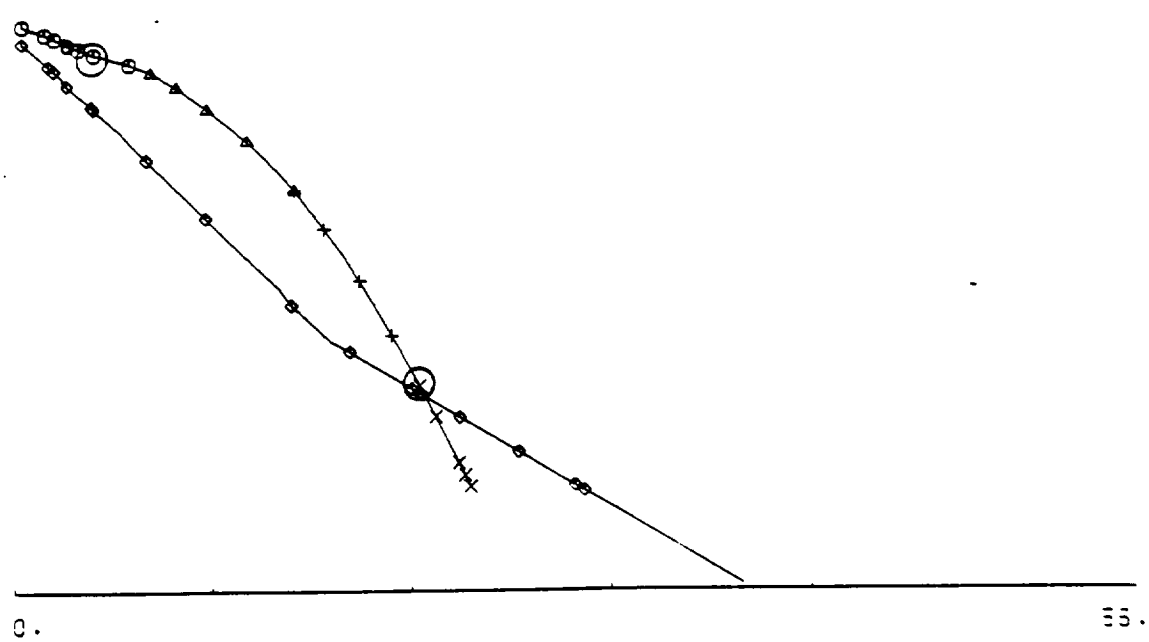


Figure 107. Housing Bounce, Backward Whirl at 109% (X-Z Plane)

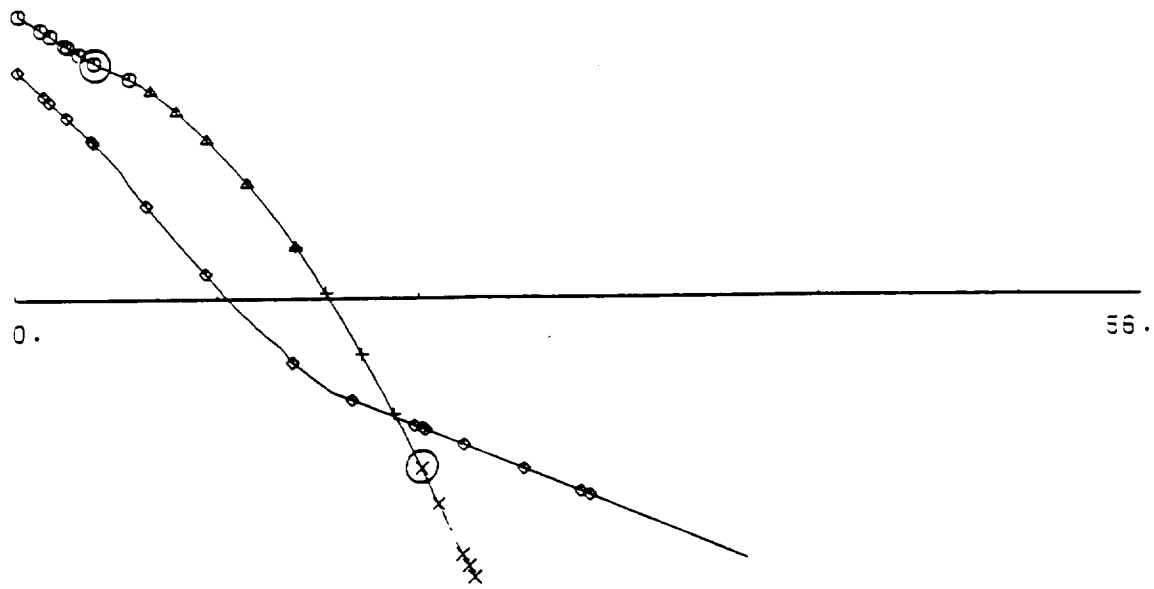


Figure 108. Housing Pitch, Forward Whirl at 109% (X-Z Plane)

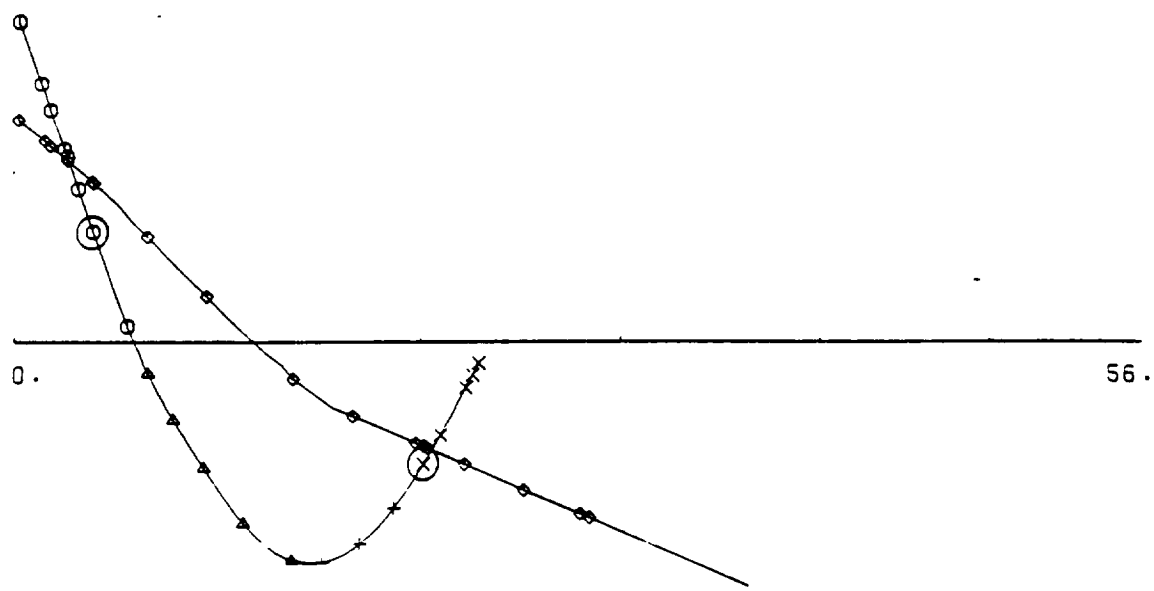


Figure 109. Housing Pitch, Backward Whirl at 109% (X-Z Plane)

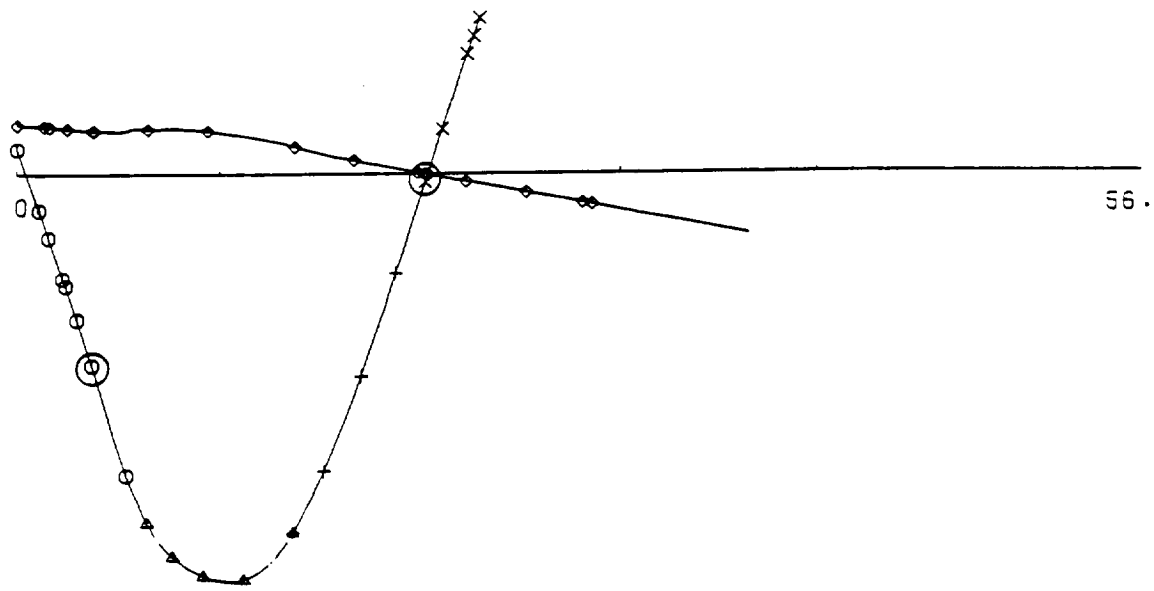


Figure 110. Rotor Pump Bounce, Forward Whirl at 109% (X-Z Plane)

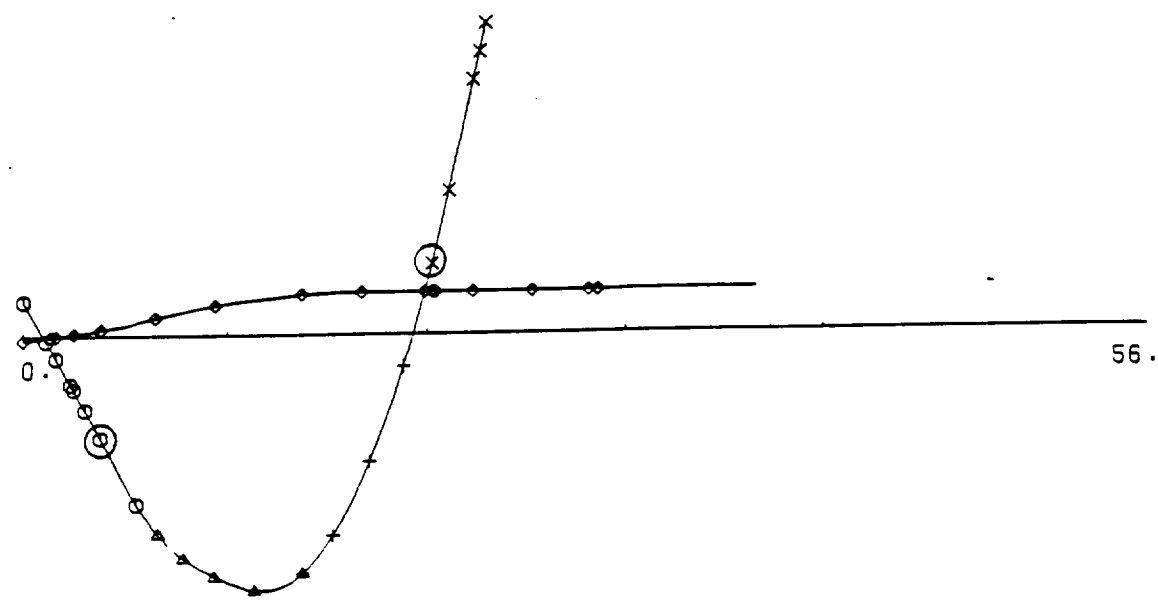


Figure 111. Rotor Pump Bounce, Backward Whirl at 109% (X-Z Plane)

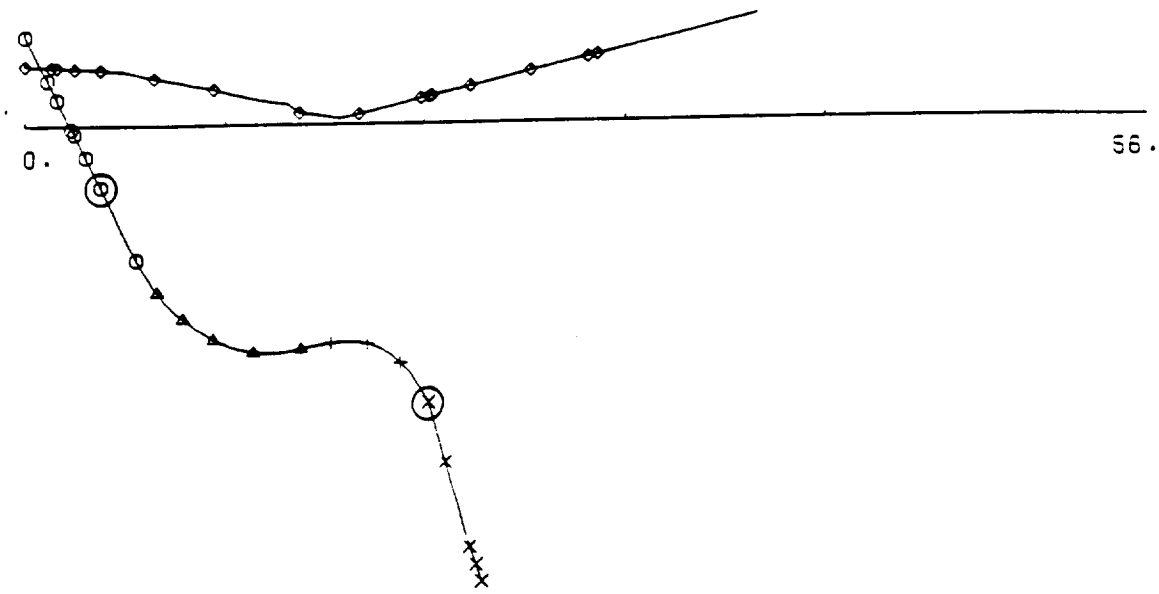


Figure 112. Rotor Turbine Bounce, Forward Whirl at 109% (X-Z Plane)

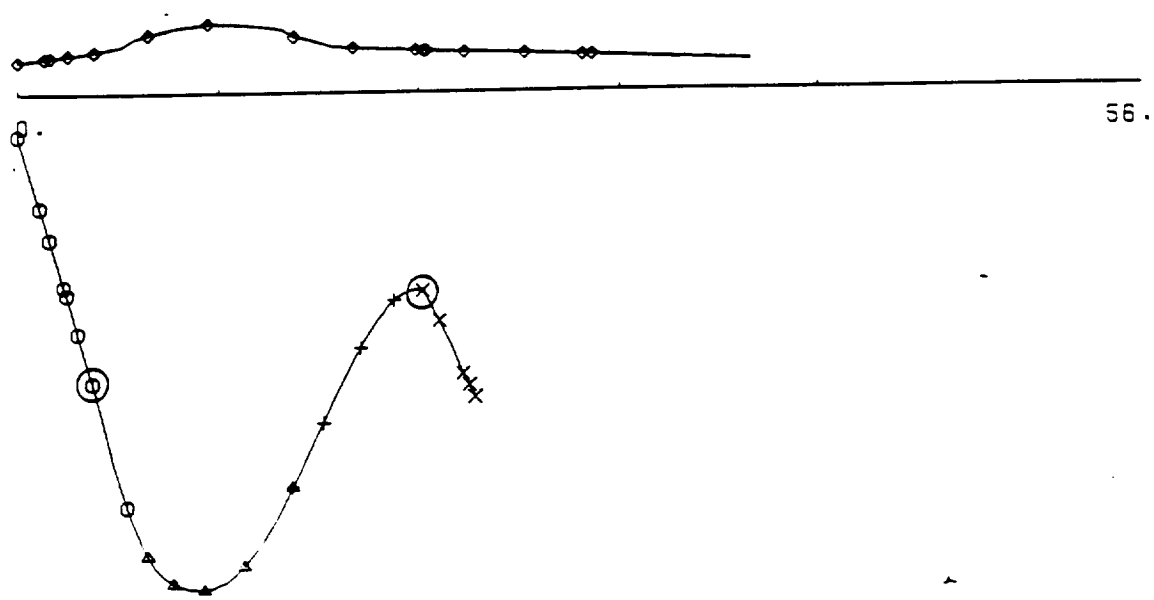


Figure 113. Rotor Turbine Bounce, Backward Whirl at 109% (X-Z Plane)

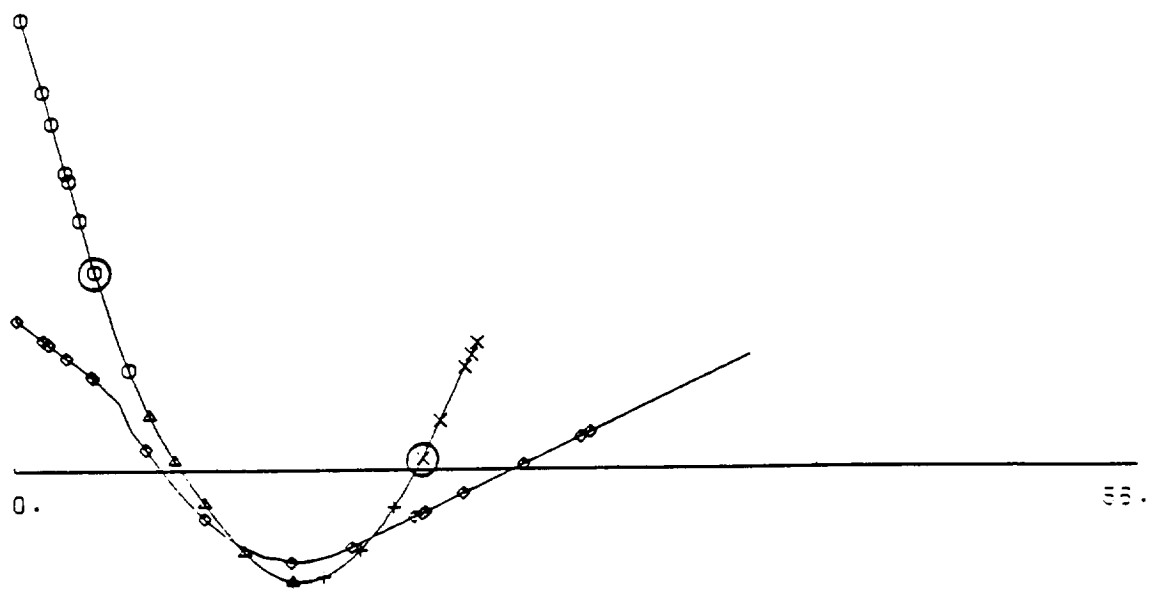


Figure 114. Housing 1st Bending, Forward Whirl at 109% (X-Z Plane)

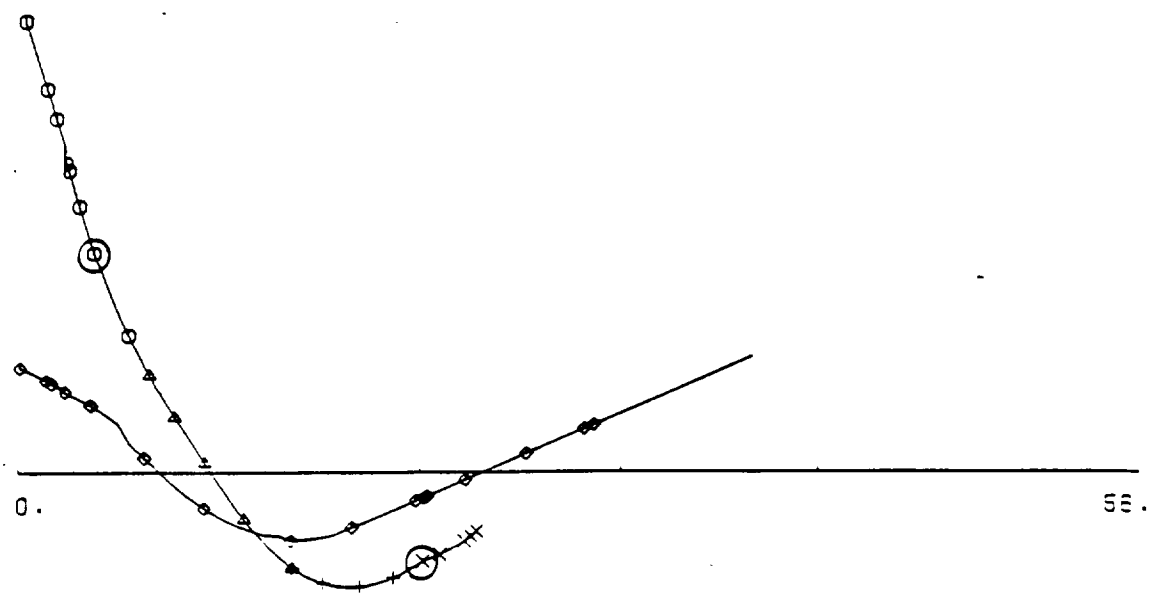


Figure 115. Housing 1st Bending, Backward Whirl at 109% (X-Z Plane)

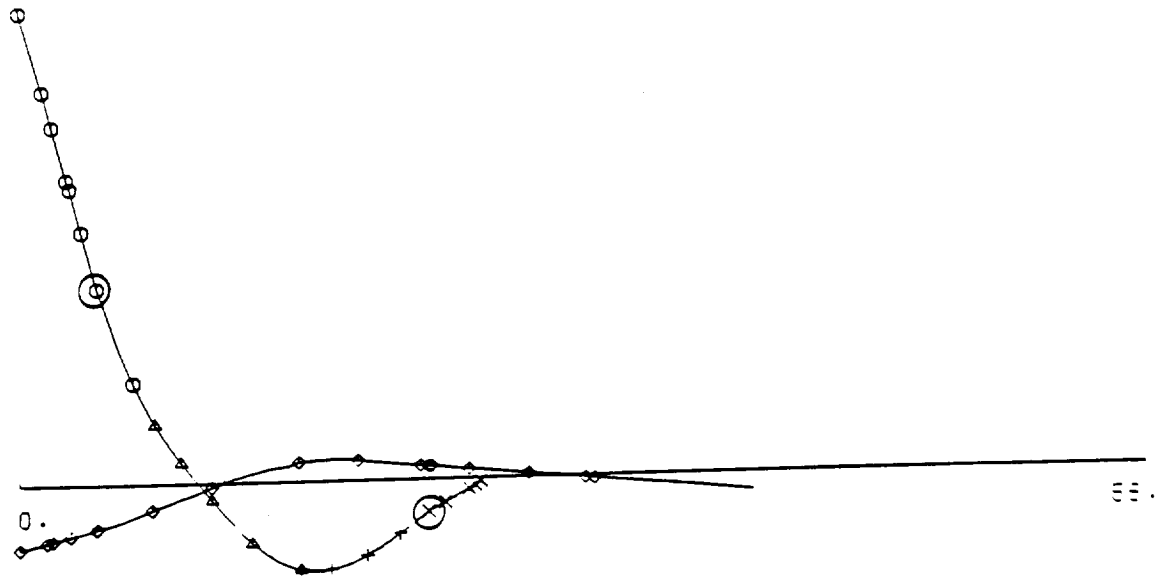


Figure 116. Rotor 1st Bending, Forward Whirl at 109% (X-Z Plane)

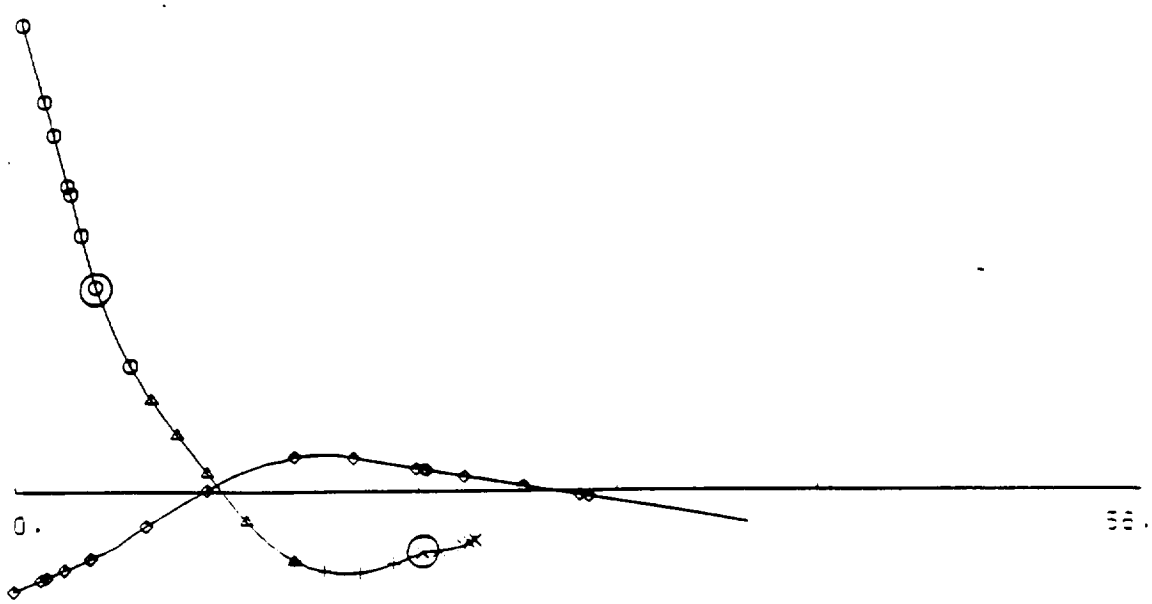


Figure 117. Rotor 1st Bending, Backward Whirl at 109% (X-Z Plane)

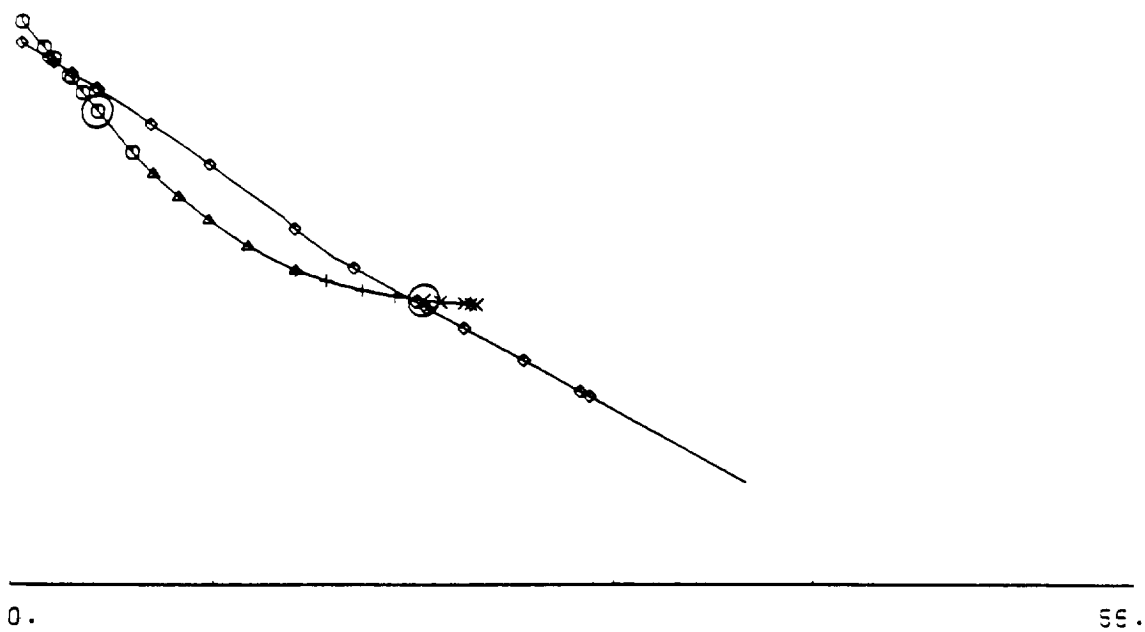


Figure 118. Housing Bounce, Forward Whirl at 65% (Y-Z Plane)

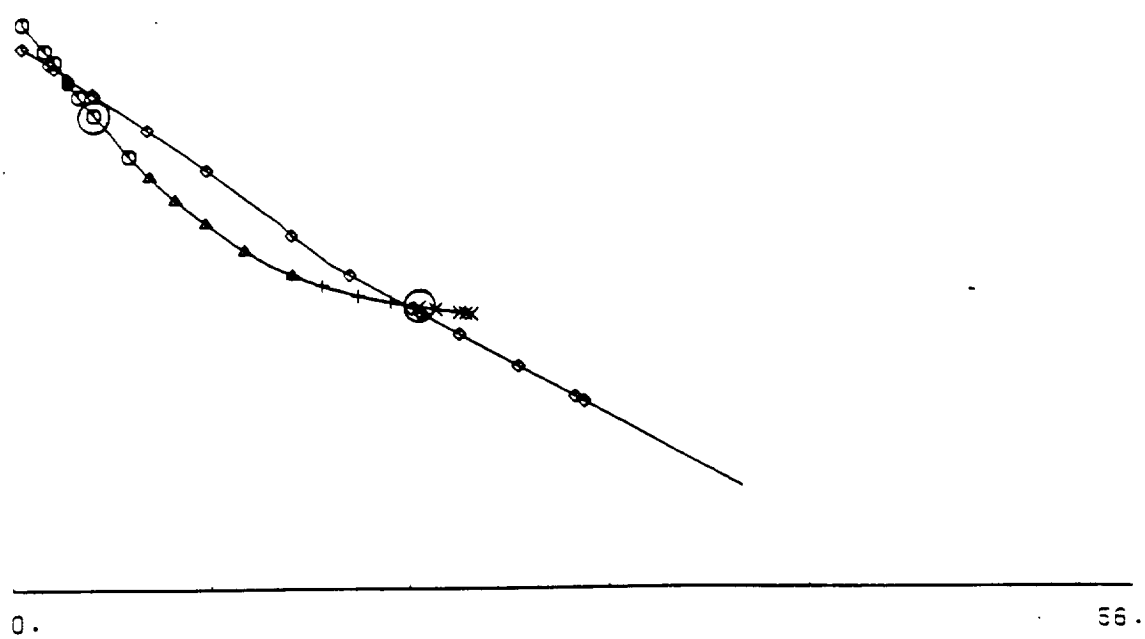


Figure 119. Housing Bounce, Backward Whirl at 65% (Y-Z Plane)

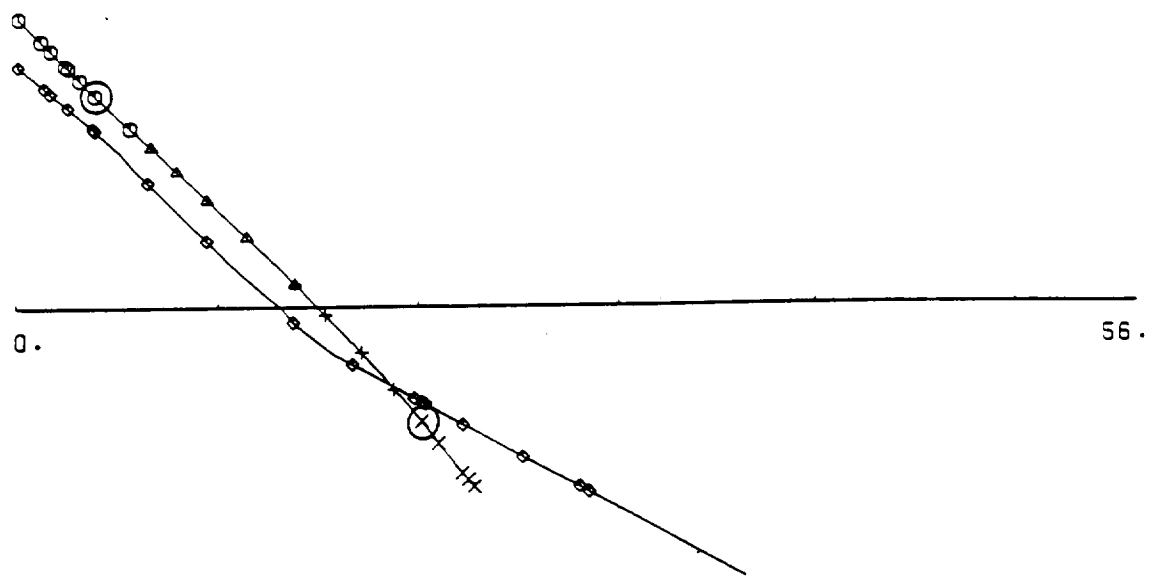


Figure 120. Housing Pitch, Forward Whirl at 65% (Y-Z Plane)

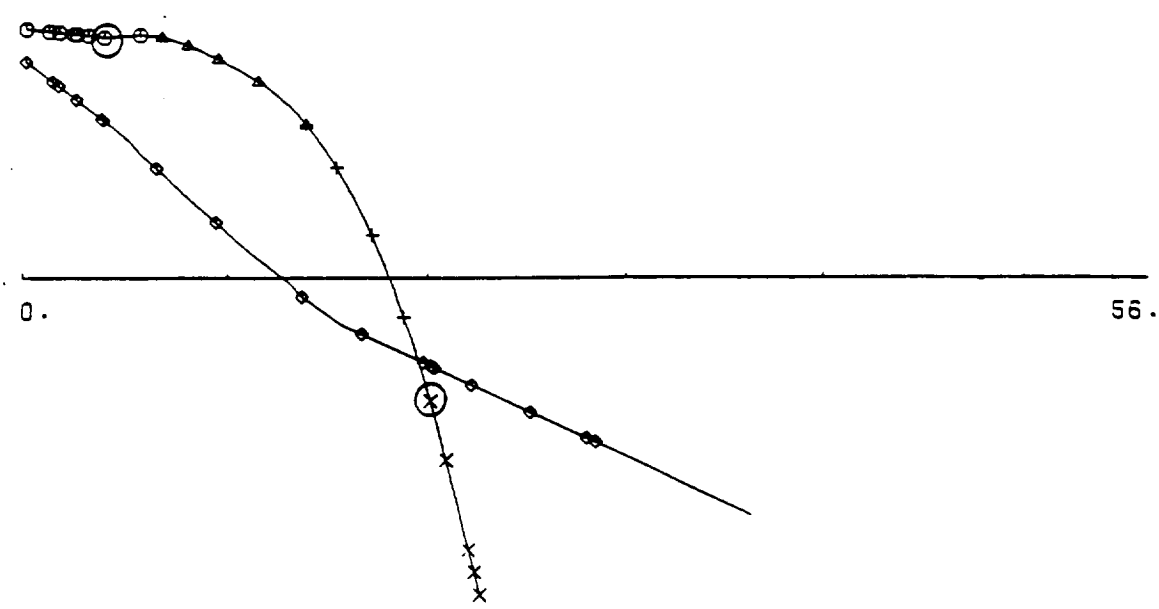


Figure 121. Housing Pitch, Backward Whirl at 65% (Y-Z Plane)

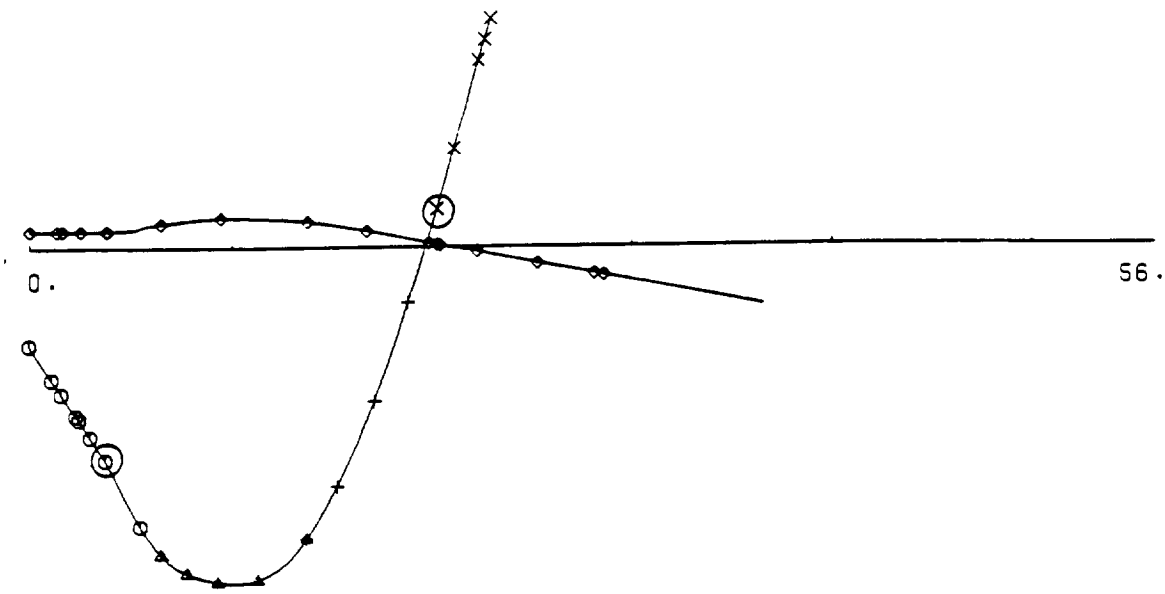


Figure 122. Rotor Pump Bounce, Forward Whirl at 65% (Y-Z Plane)

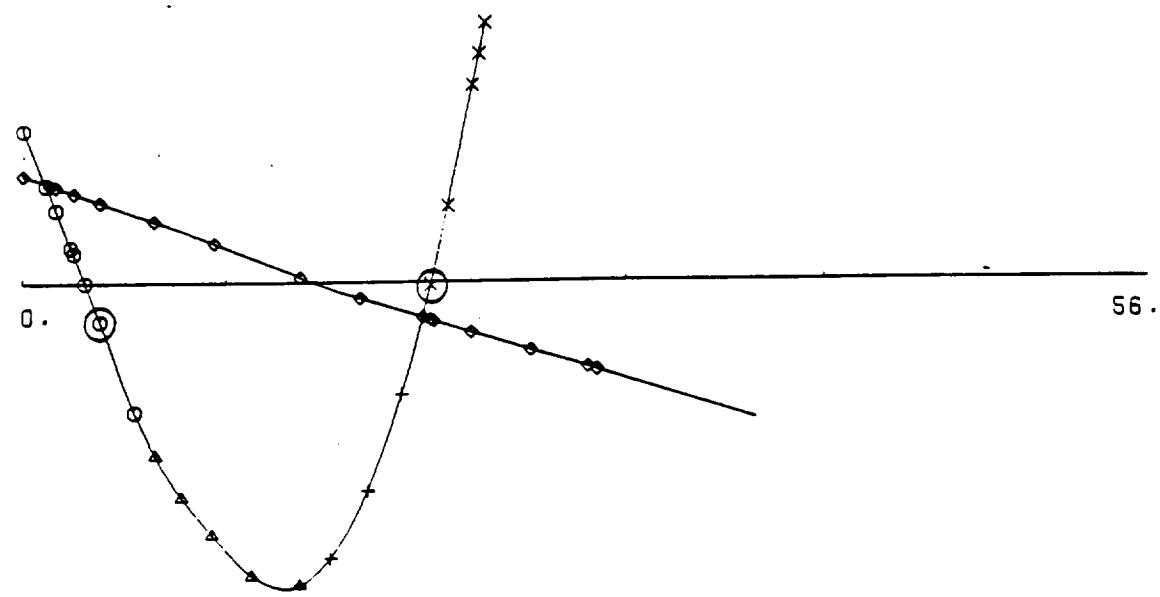


Figure 123. Rotor Pump Bounce, Backward Whirl at 65% (Y-Z Plane)

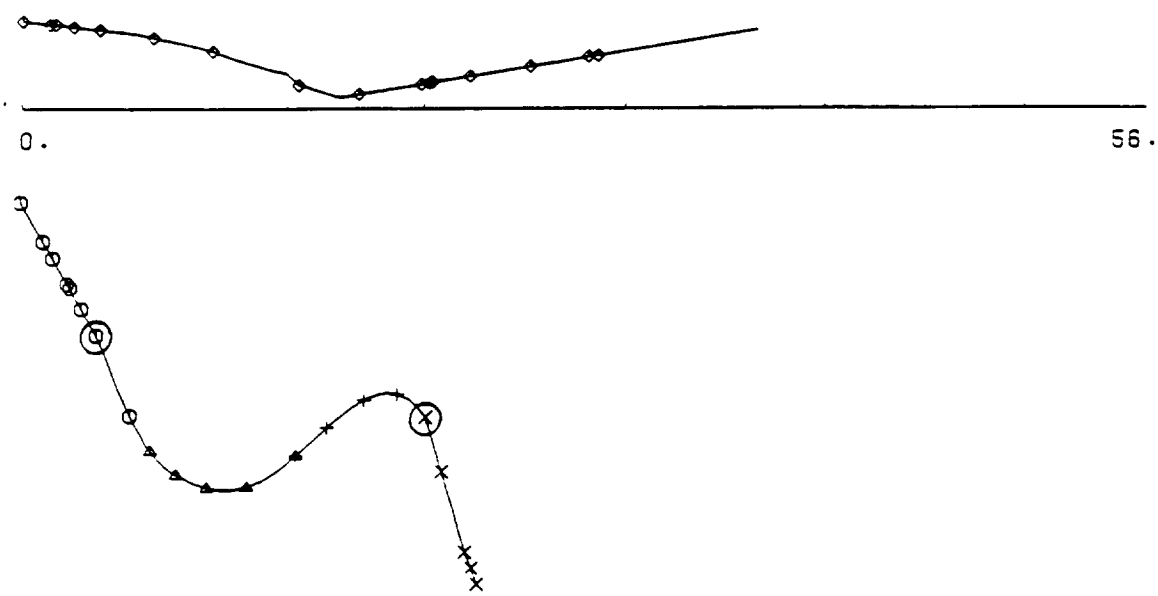


Figure 124. Rotor Turbine Bounce, Forward Whirl at 65% (Y-Z Plane)

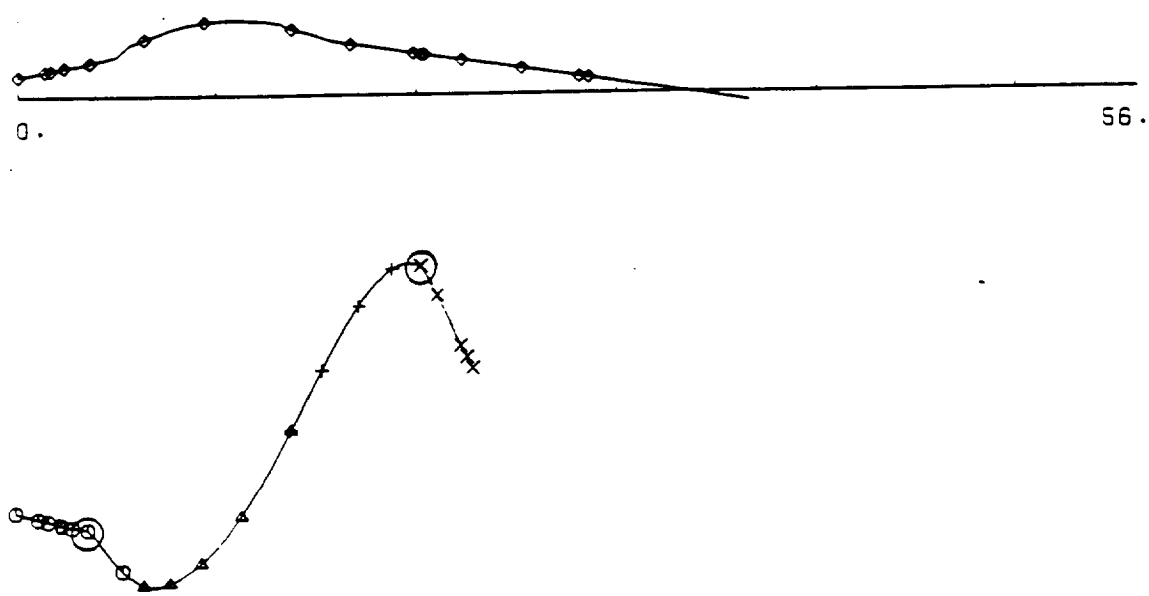


Figure 125. Rotor Turbine Bounce, Backward Whirl at 65% (Y-Z Plane)

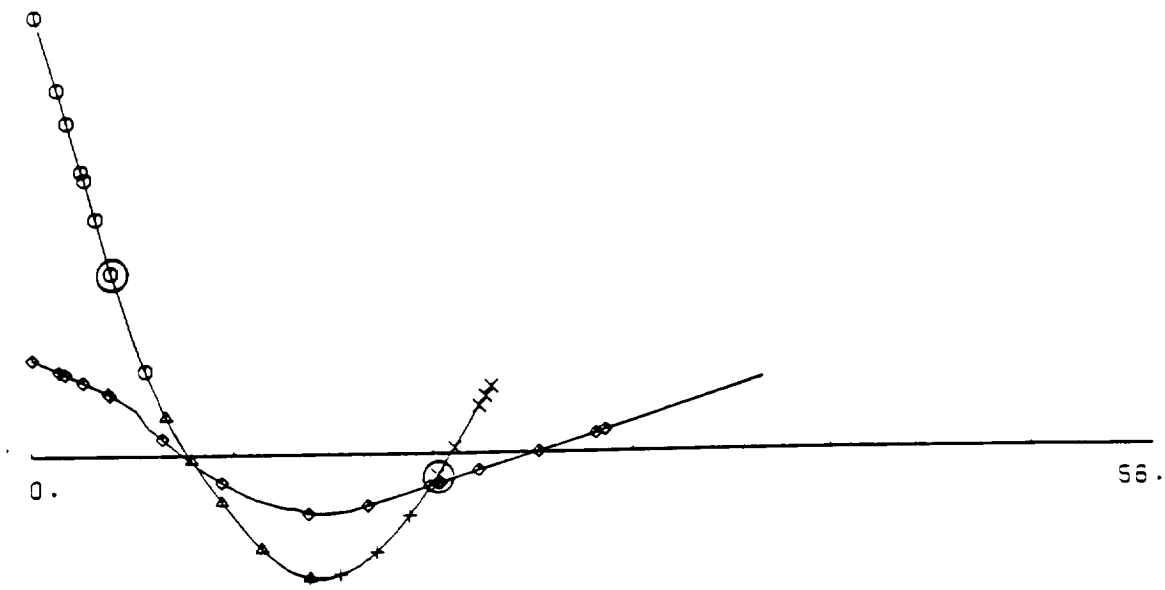


Figure 126. Housing 1st Bending, Forward Whirl at 65% (Y-Z Plane)

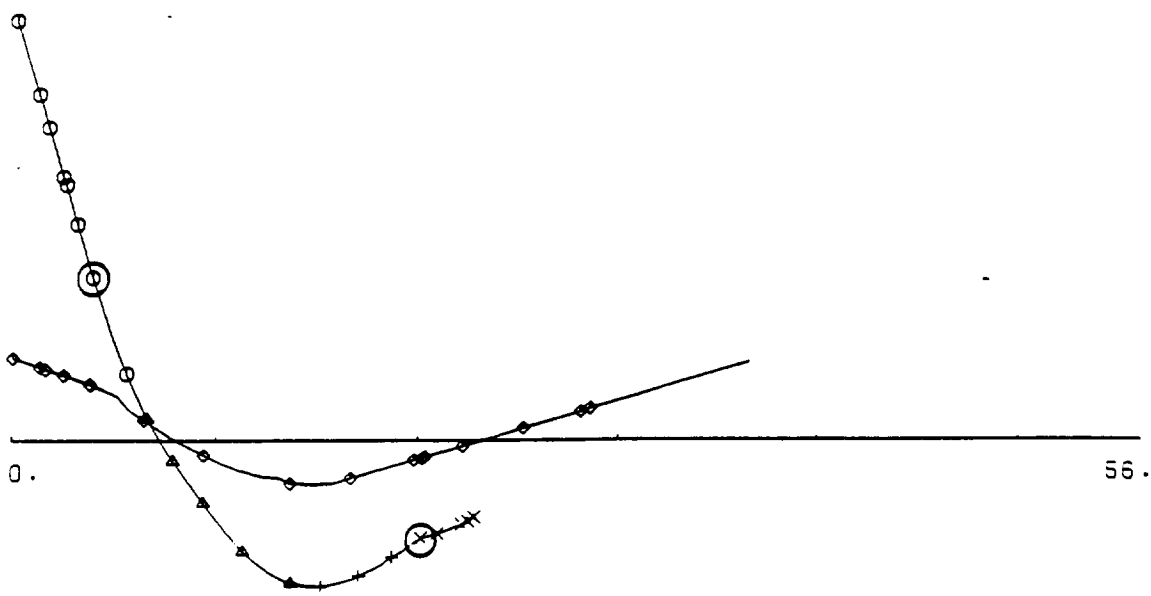


Figure 127. Housing 1st Bending, Backward Whirl at 65% (Y-Z Plane)

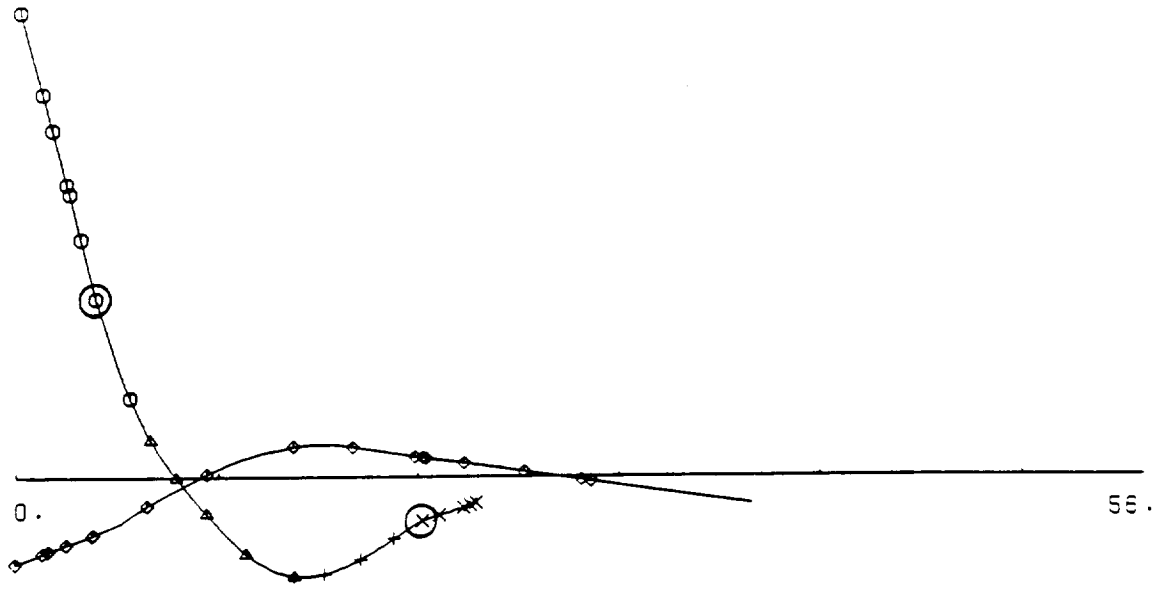


Figure 128. Rotor 1st Bending, Forward Whirl at 65% (Y-Z Plane)

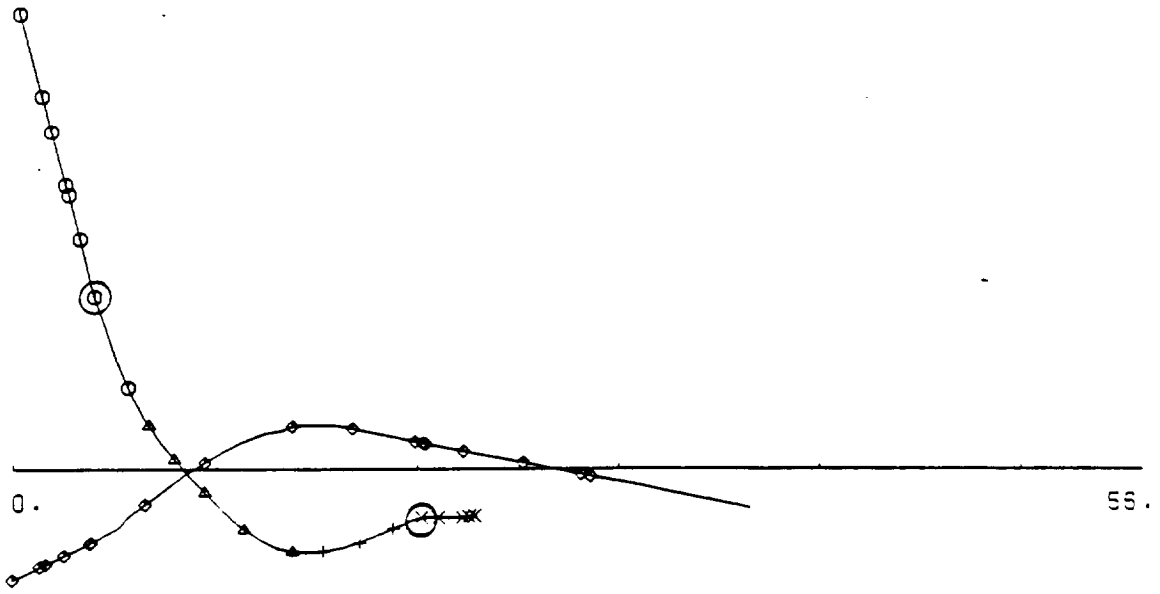


Figure 129. Rotor 1st Bending, Backward Whirl at 65% (Y-Z Plane)

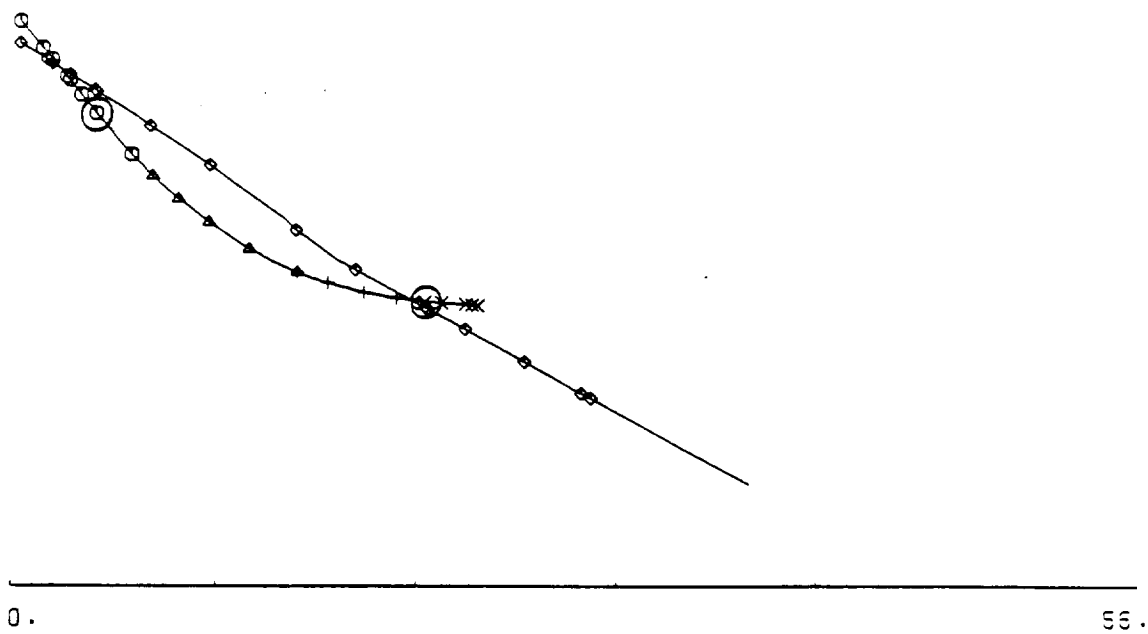


Figure 130. Housing Bounce, Forward Whirl at 90% (Y-Z Plane)

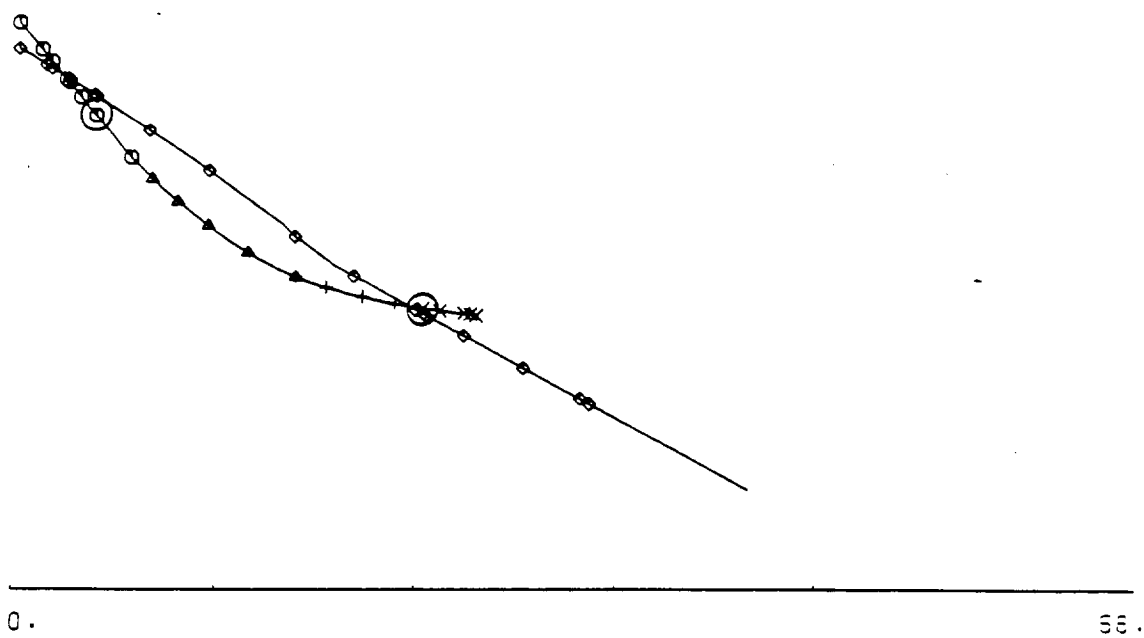


Figure 131. Housing Bounce, Backward Whirl at 90% (Y-Z Plane)

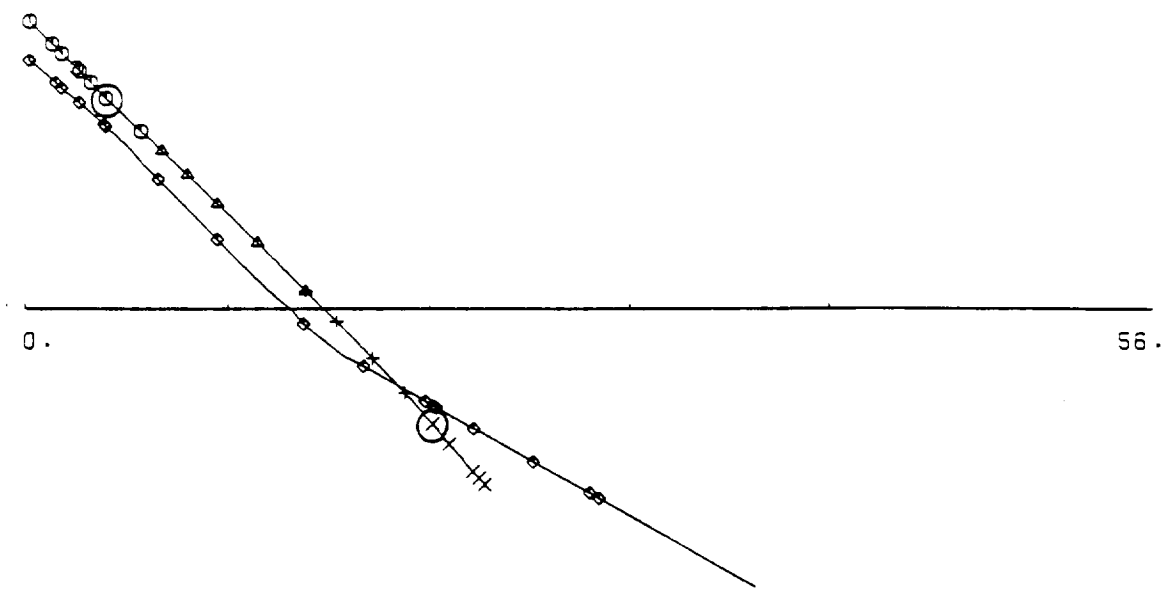


Figure 132. Housing Pitch, Forward Whirl at 90% (Y-Z Plane)

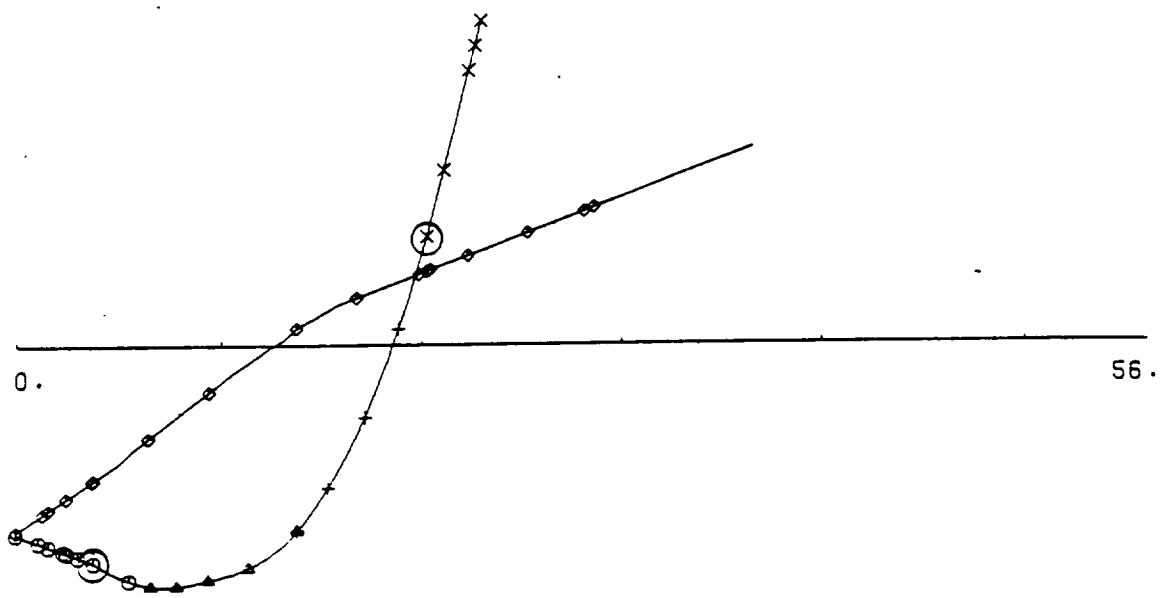


Figure 133. Housing Pitch, Backward Whirl at 90% (Y-Z Plane)

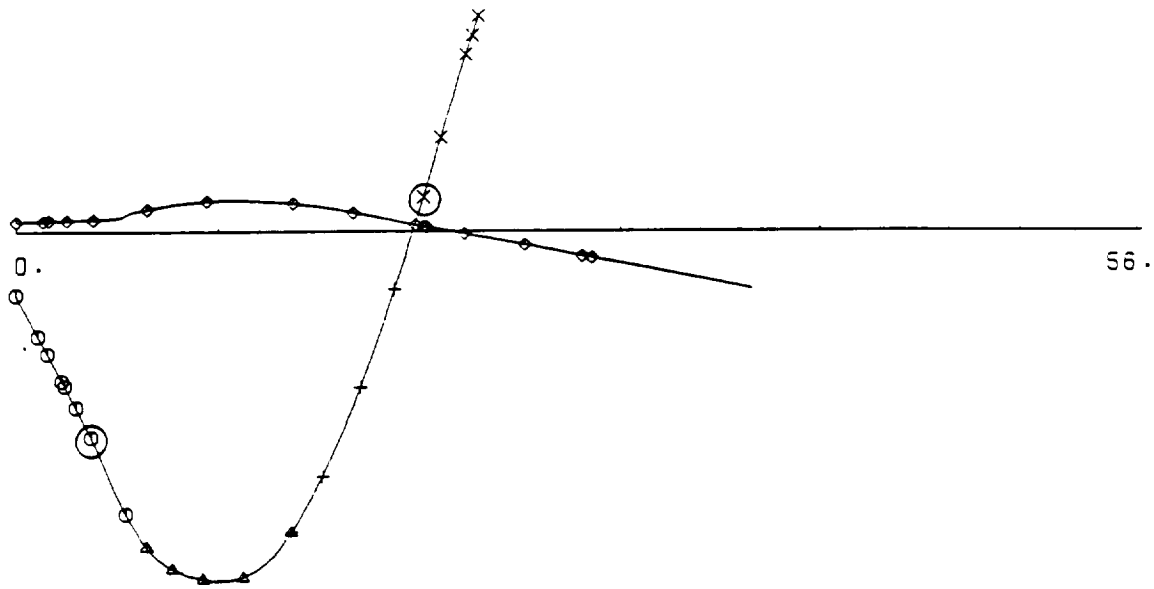


Figure 134. Rotor Pump Bounce, Forward Whirl at 90% (Y-Z Plane)

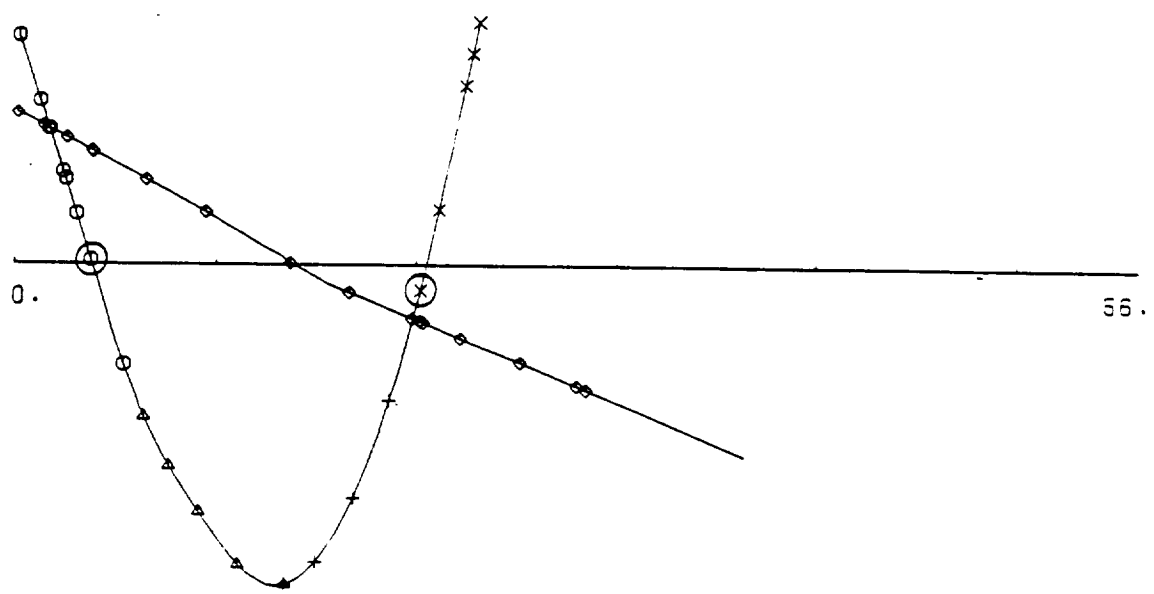


Figure 135. Rotor Pump Bounce, Backward Whirl at 90% (Y-Z Plane)

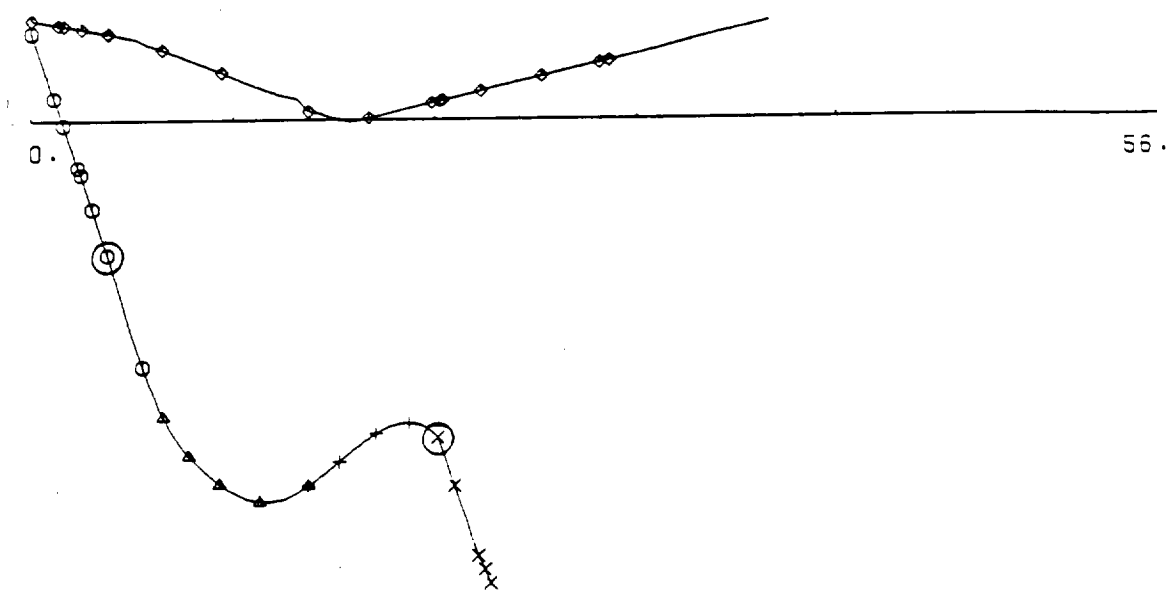


Figure 136. Rotor Turbine Bounce, Forward Whirl at 90% (Y-Z Plane)

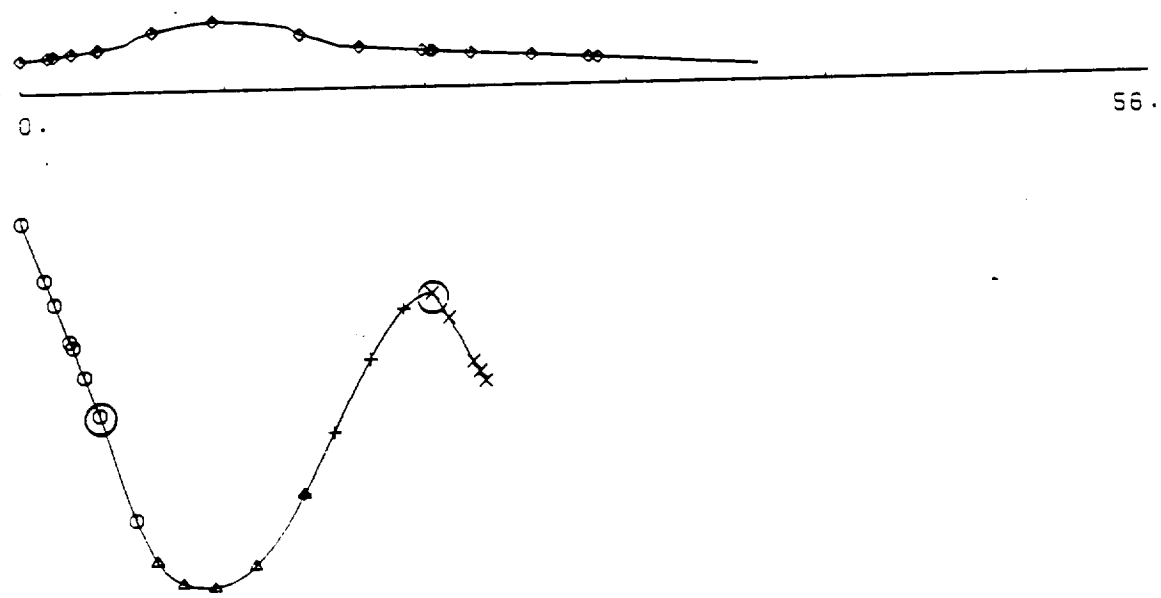


Figure 137. Rotor Turbine Bounce, Backward Whirl at 90% (Y-Z Plane)

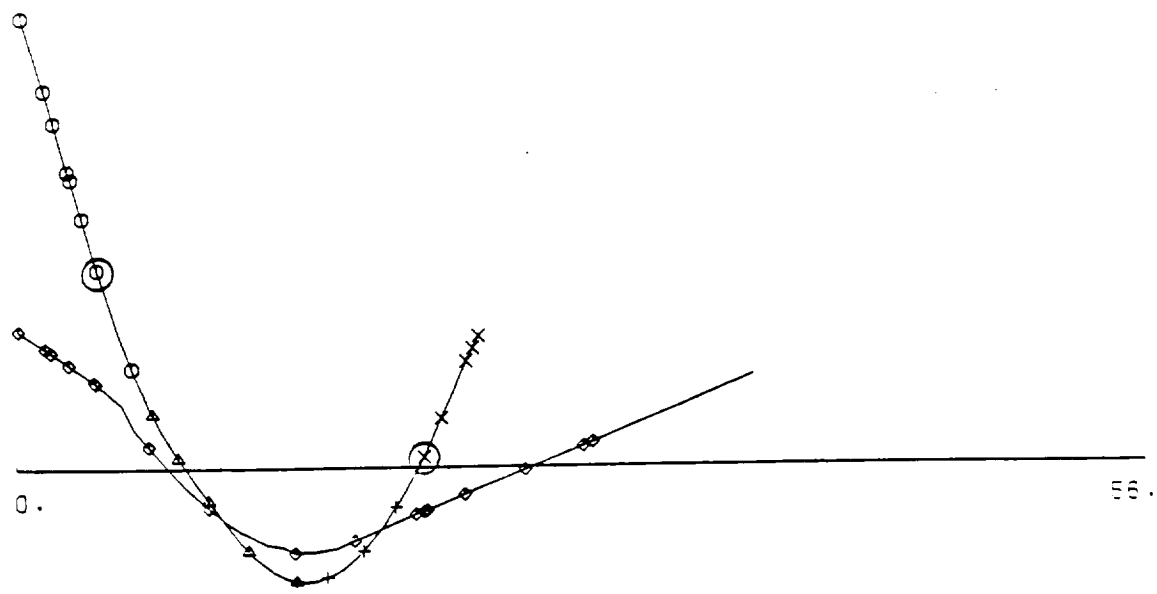


Figure 138. Housing 1st Bending, Forward Whirl at 90% (Y-Z Plane)

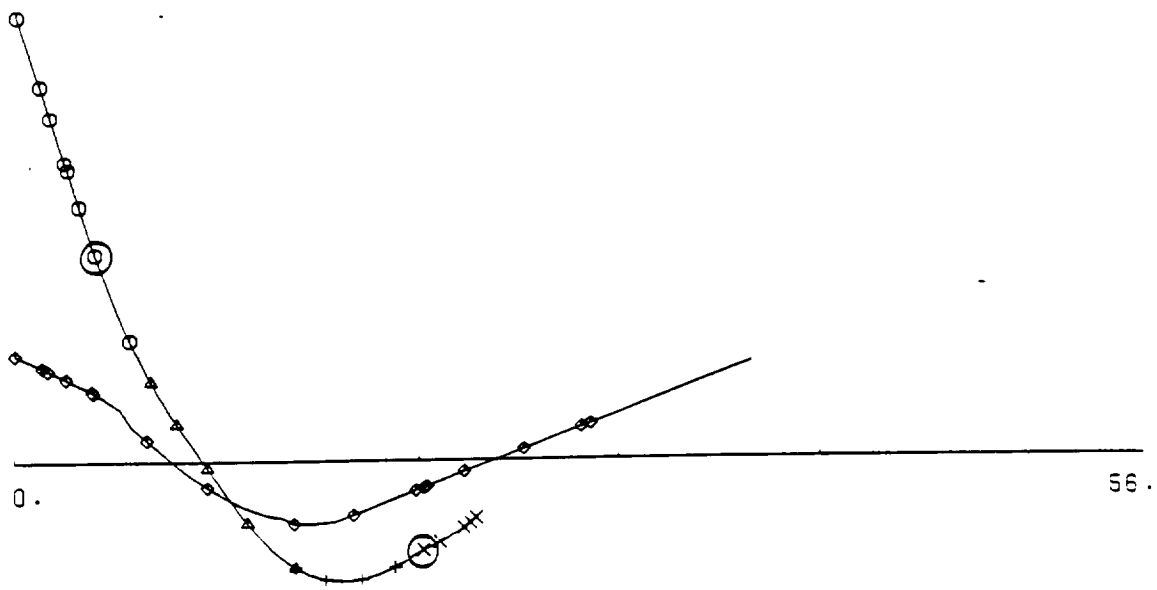


Figure 139. Housing 1st Bending, Backward Whirl at 90% (Y-Z Plane)

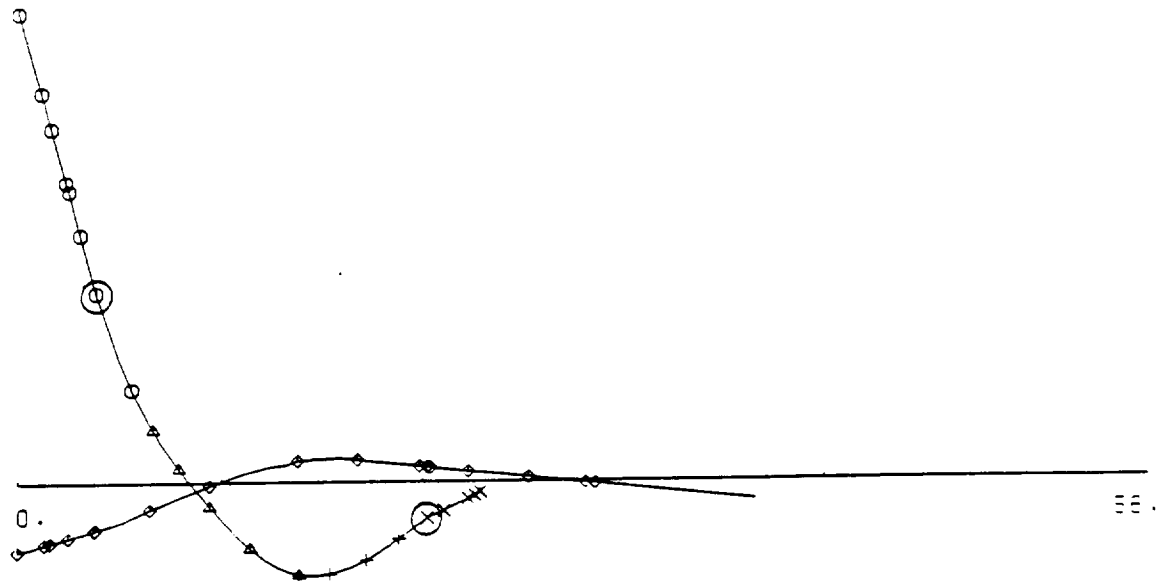


Figure 140. Rotor 1st Bending, Forward Whirl at 90% (Y-Z Plane)

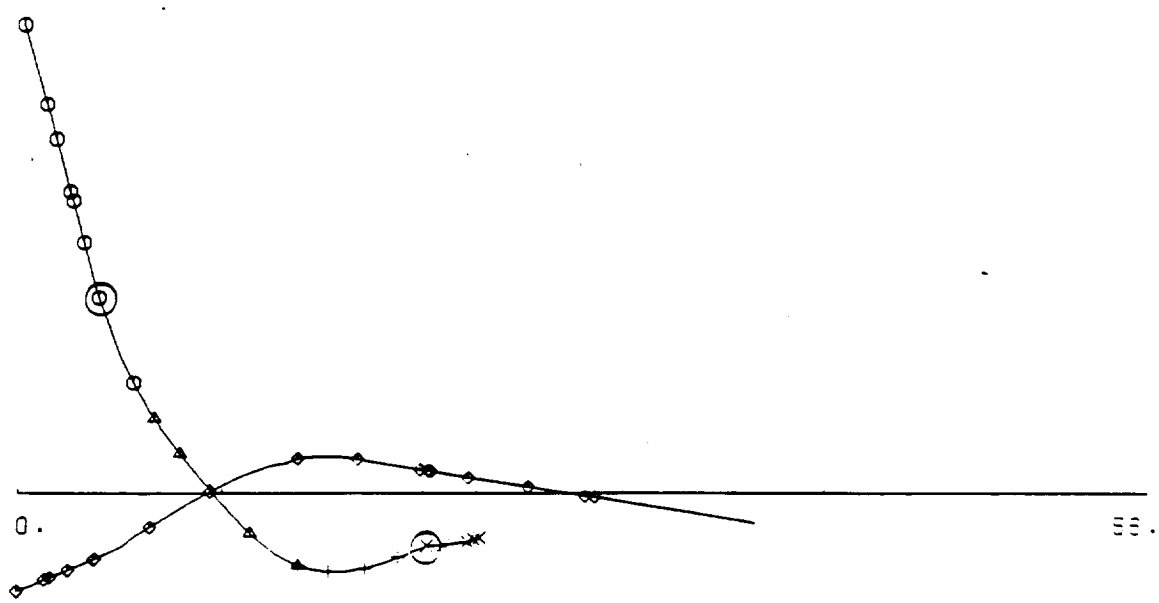


Figure 141. Rotor 1st Bending, Backward Whirl at 90% (Y-Z Plane)

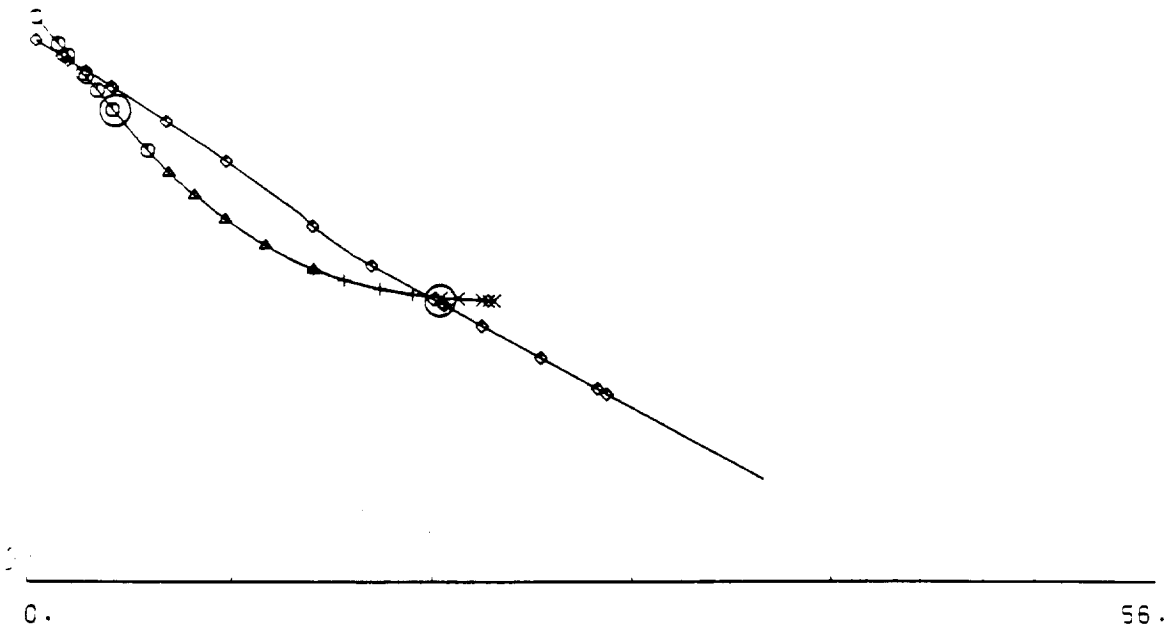


Figure 142. Housing Bounce, Forward Whirl at 109% (Y-Z Plane)

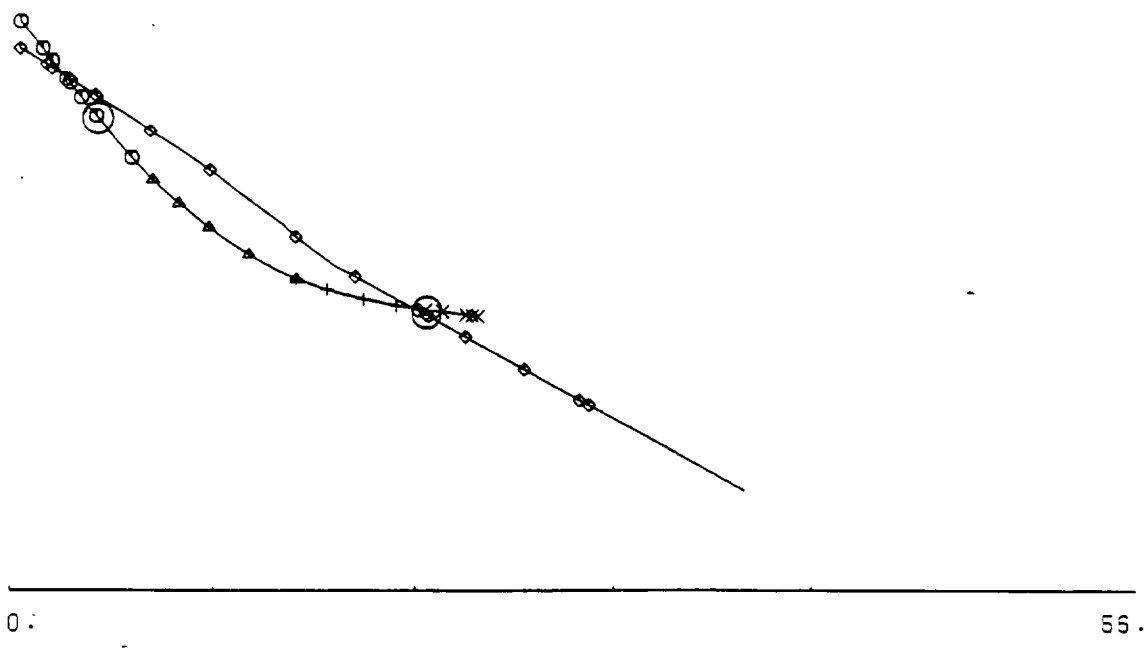


Figure 143. Housing Bounce, Backward Whirl at 109% (Y-Z Plane)

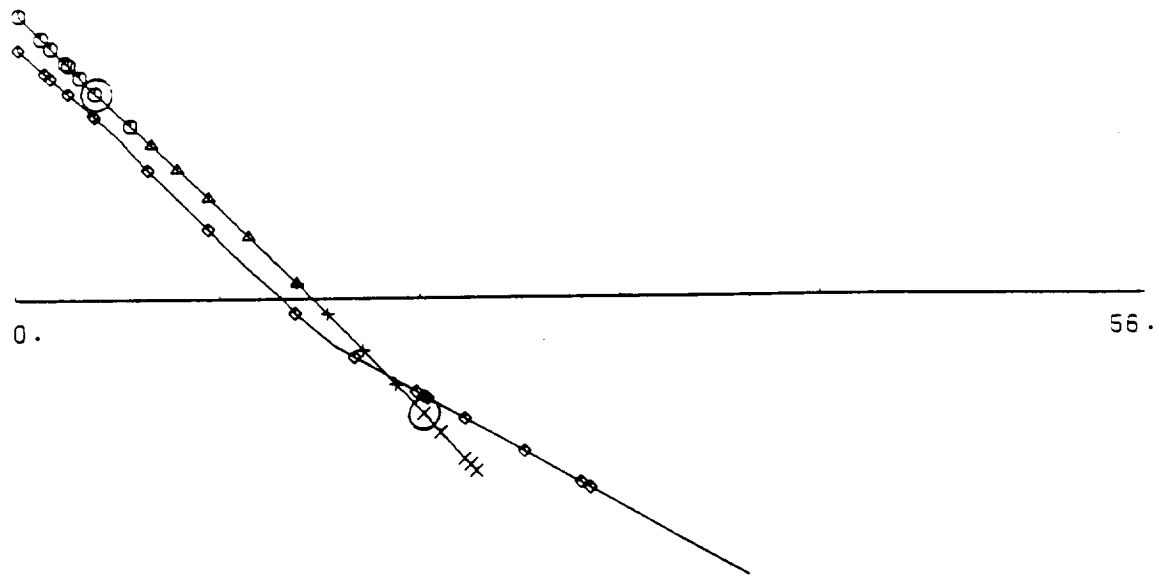


Figure 144. Housing Pitch, Forward Whirl at 109% (Y-Z Plane)

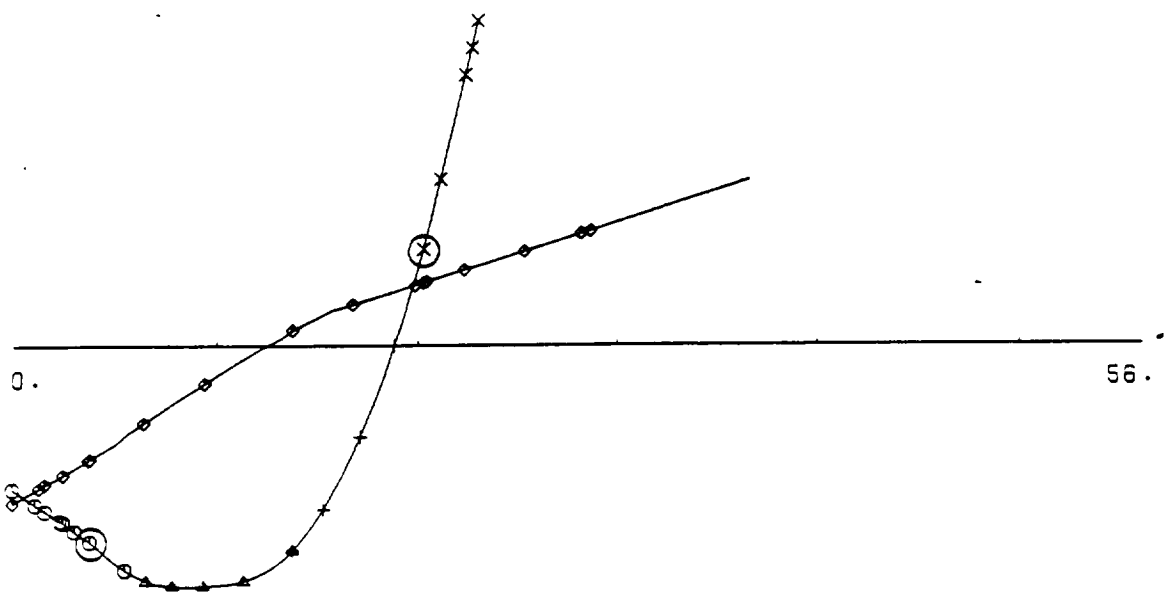


Figure 145. Housing Pitch, Backward Whirl at 109% (Y-Z Plane)

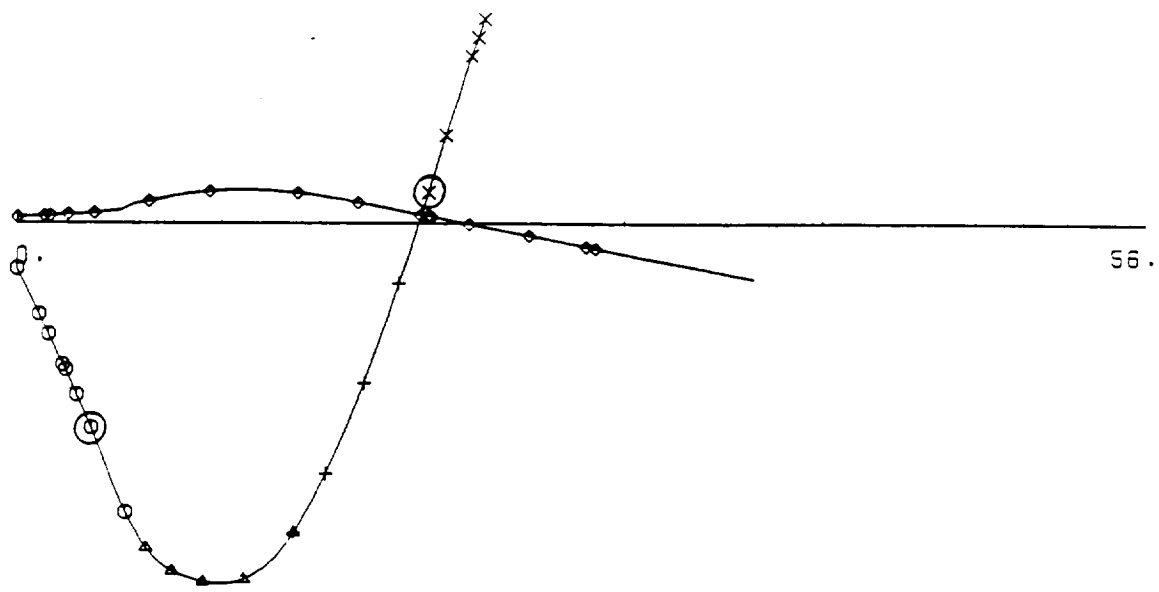


Figure 146. Rotor Pump Bounce, Forward Whirl at 109% (Y-Z Plane)

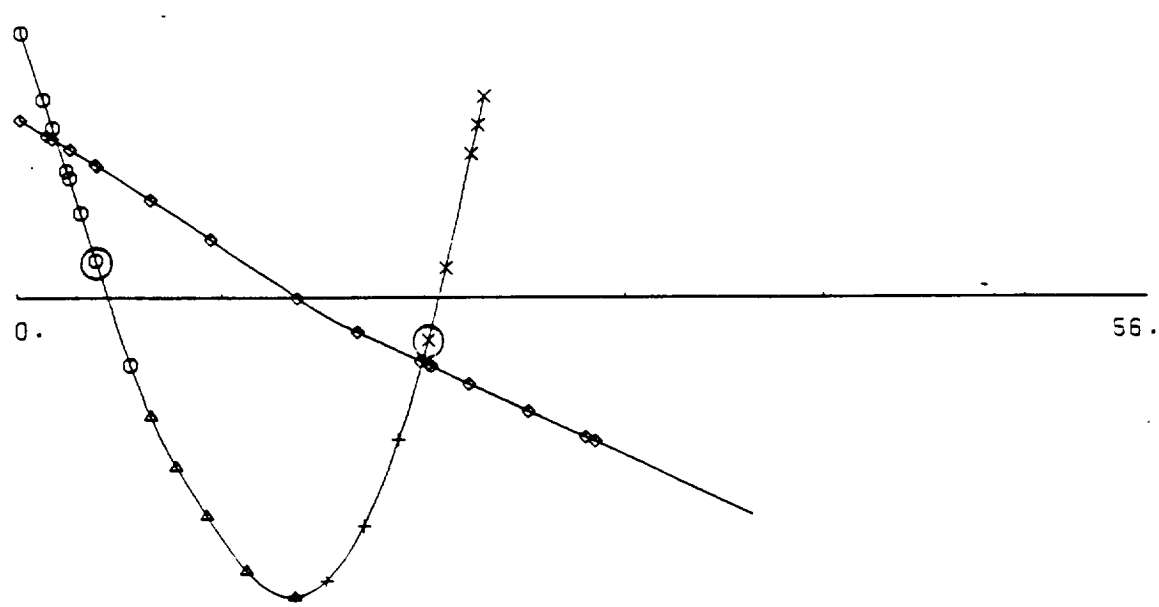


Figure 147. Rotor Pump Bounce, Backward Whirl at 109% (Y-Z Plane)

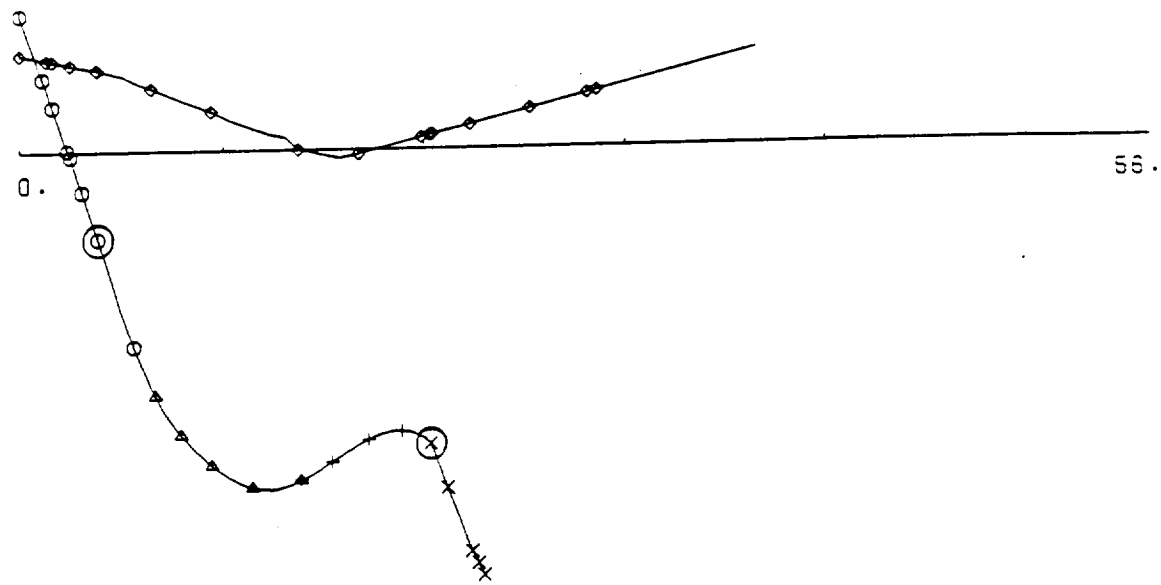


Figure 148. Rotor Turbine Bounce, Forward Whirl at 109% (Y-Z Plane)

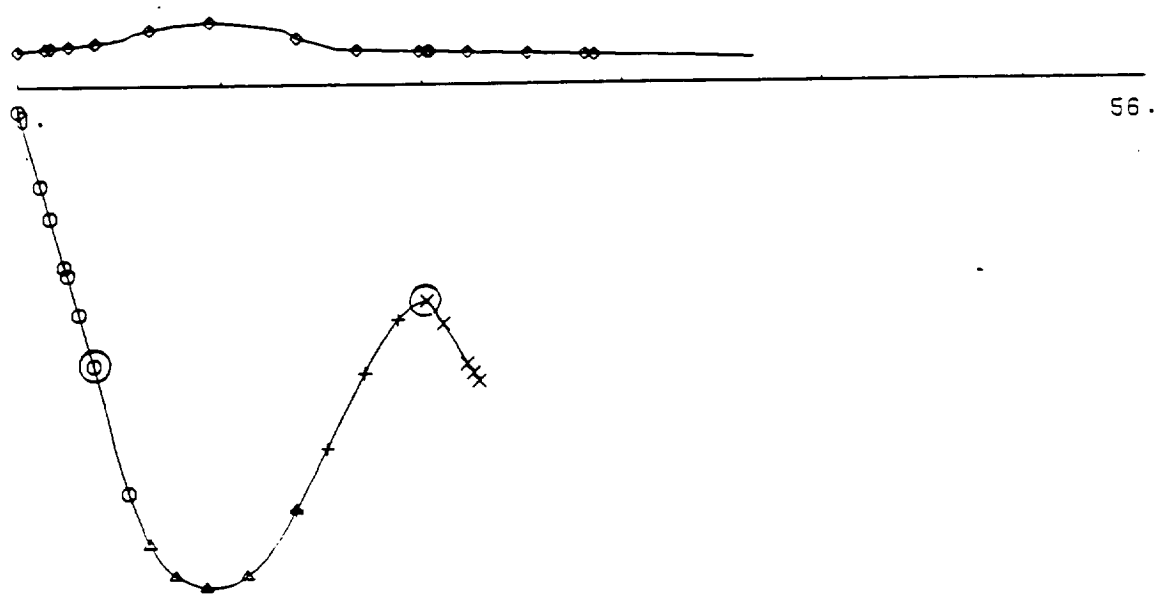


Figure 149. Rotor Turbine Bounce, Backward Whirl at 109% (Y-Z Plane)

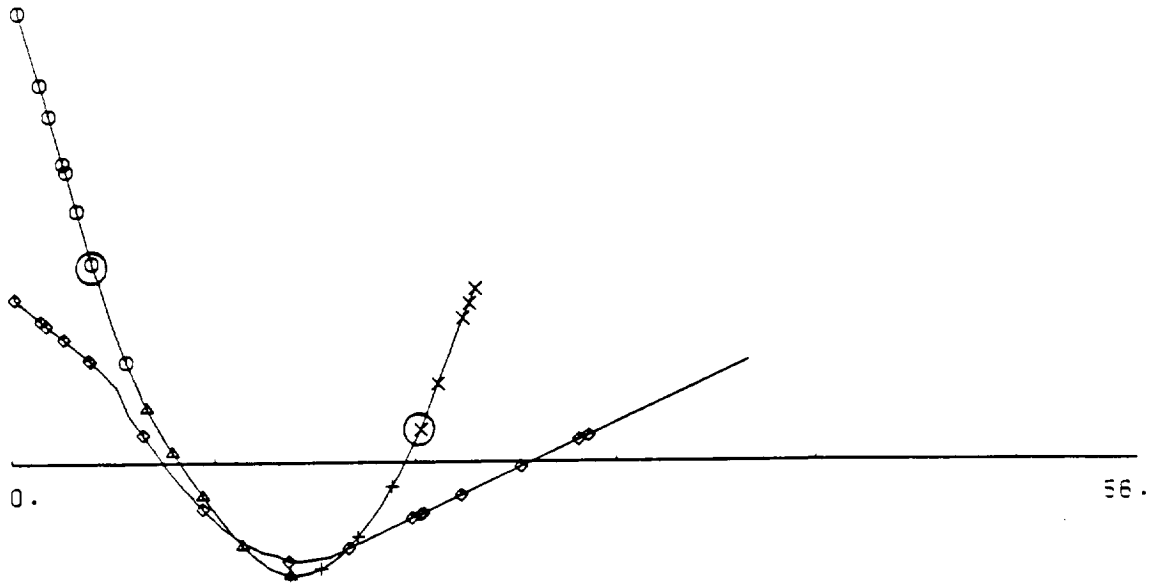


Figure 150. Housing 1st Bending, Forward Whirl at 109% (Y-Z Plane)

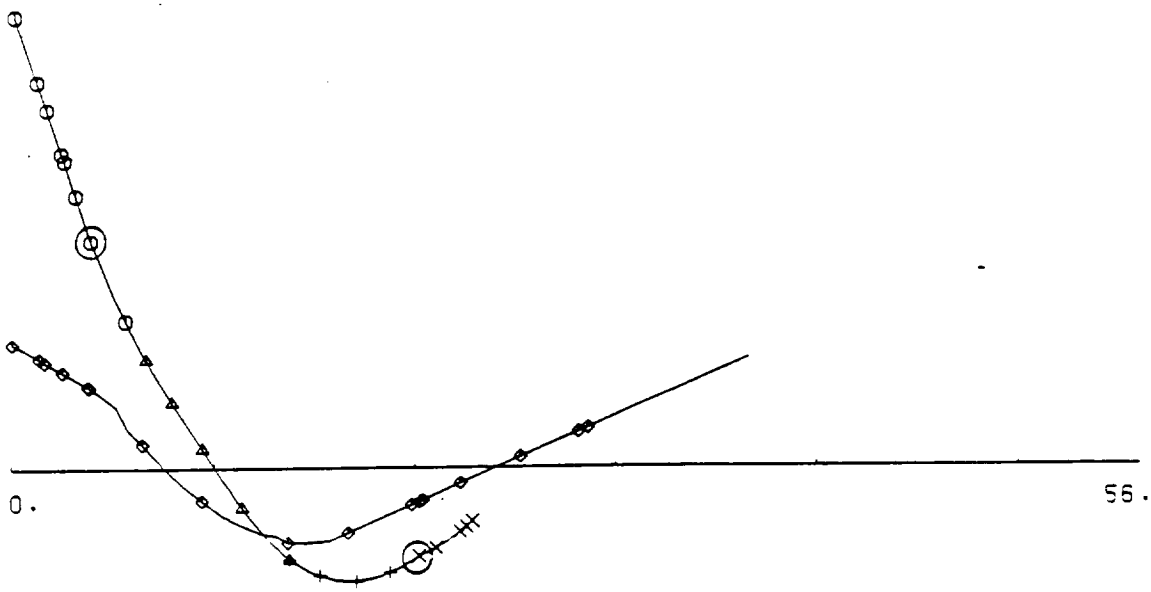


Figure 151. Housing 1st Bending, Backward Whirl at 109% (Y-Z Plane)

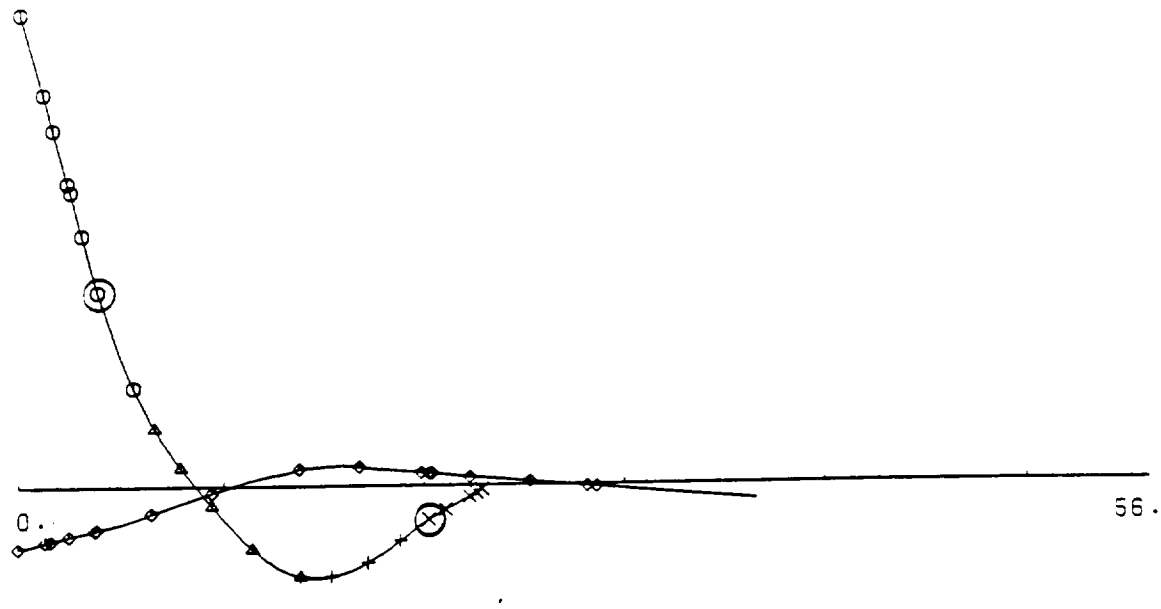


Figure 152. Rotor 1st Bending, Forward Whirl at 109% (Y-Z Plane)

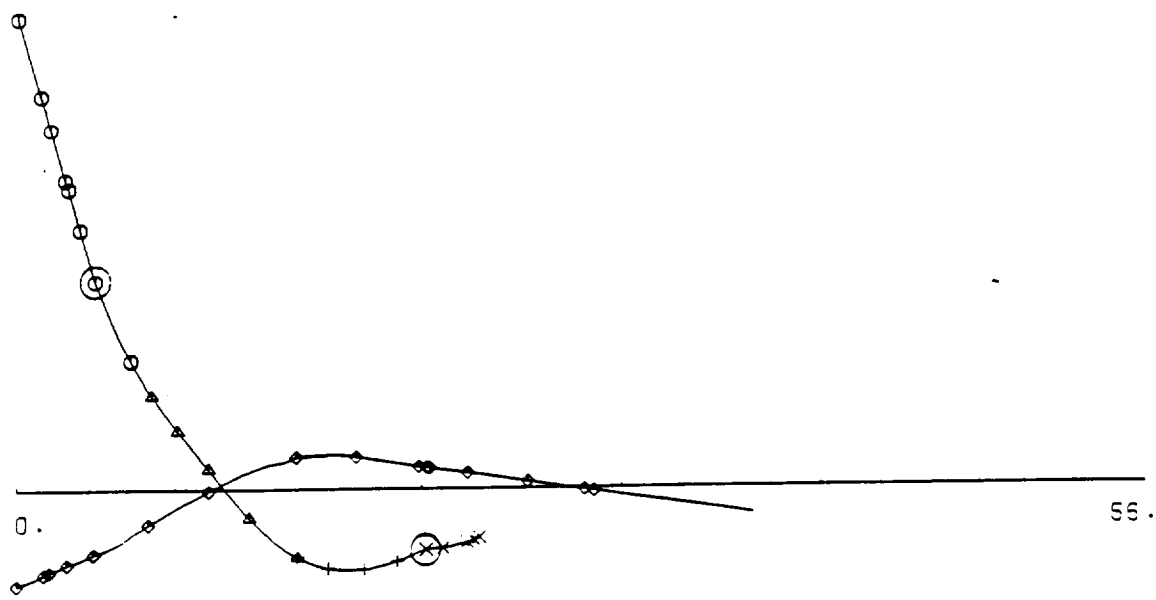
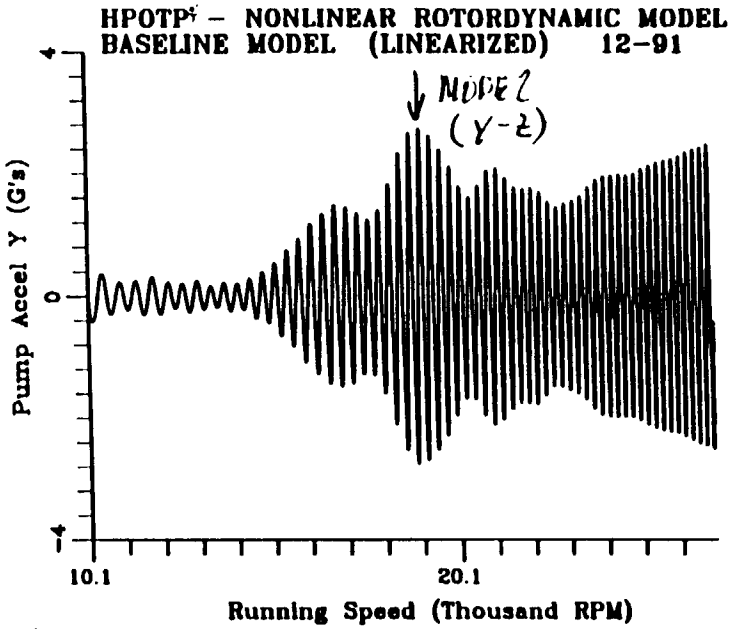
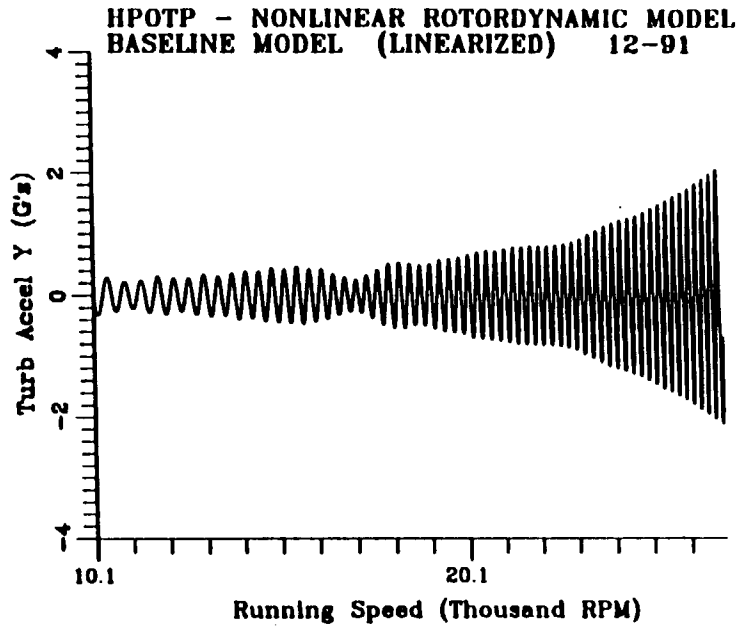
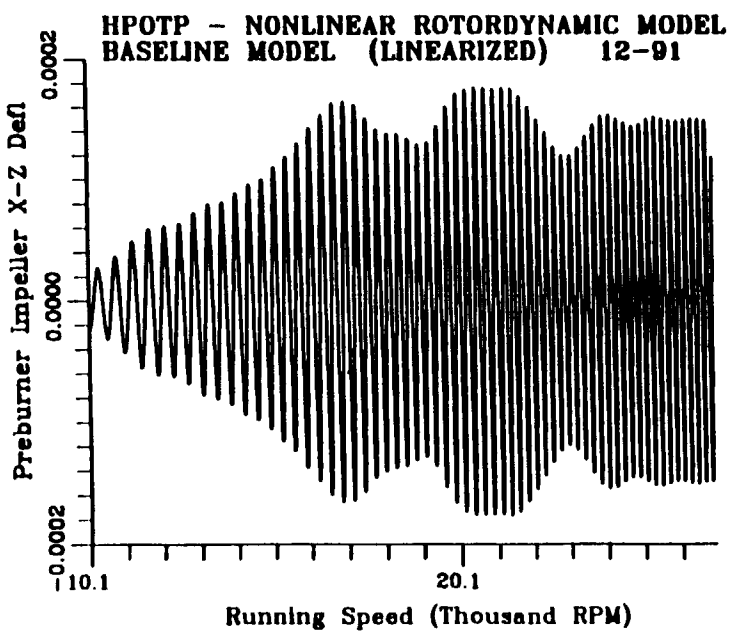


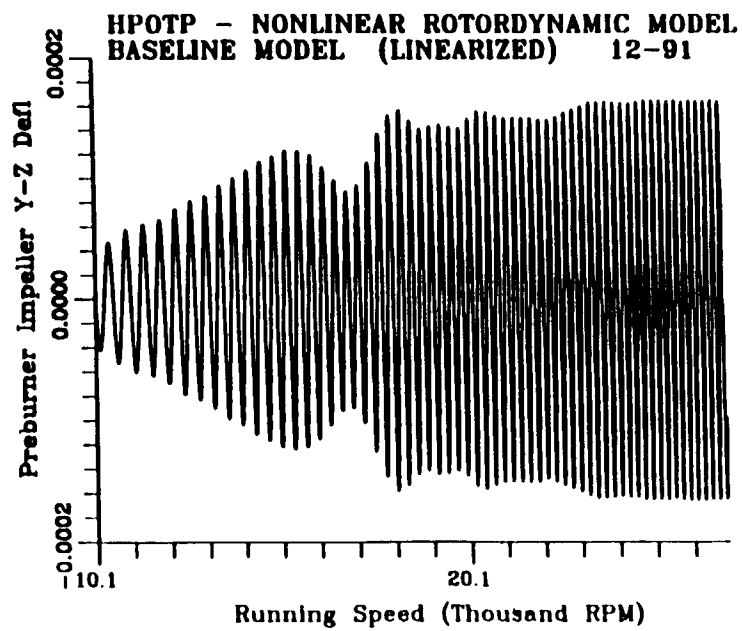
Figure 153. Rotor 1st Bending, Backward Whirl at 109% (Y-Z Plane)

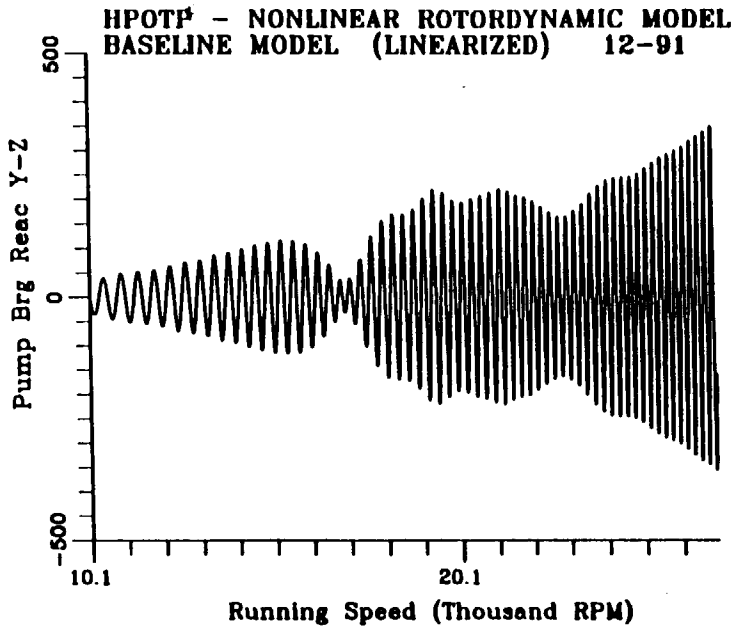
Appendix F. Linear Speed Transient Forced Response Plots

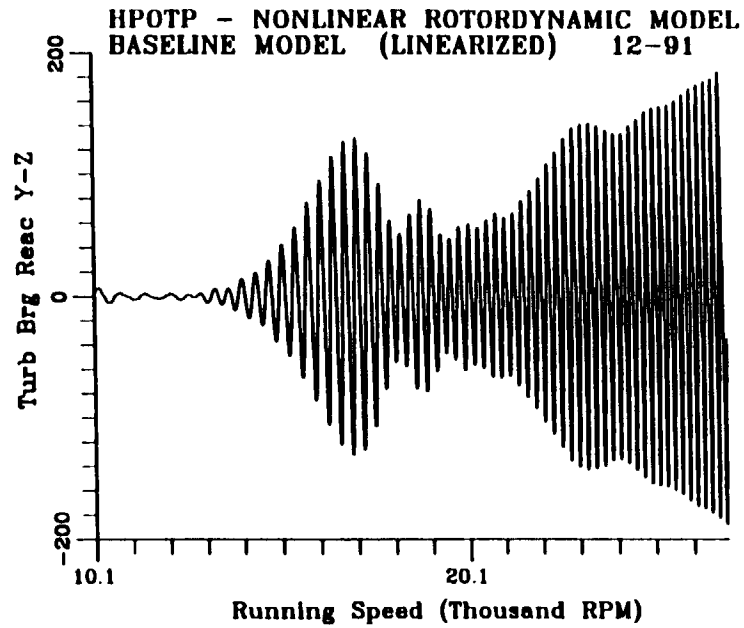

HPOTP - NONLINEAR ROTORDYNAMIC MODEL
BASELINE MODEL (LINEARIZED) 12-91
MODE 2
(Y-Z)
Pump Accel Y (G's)
4
0
-4
10.1
20.1
Running Speed (Thousand RPM)

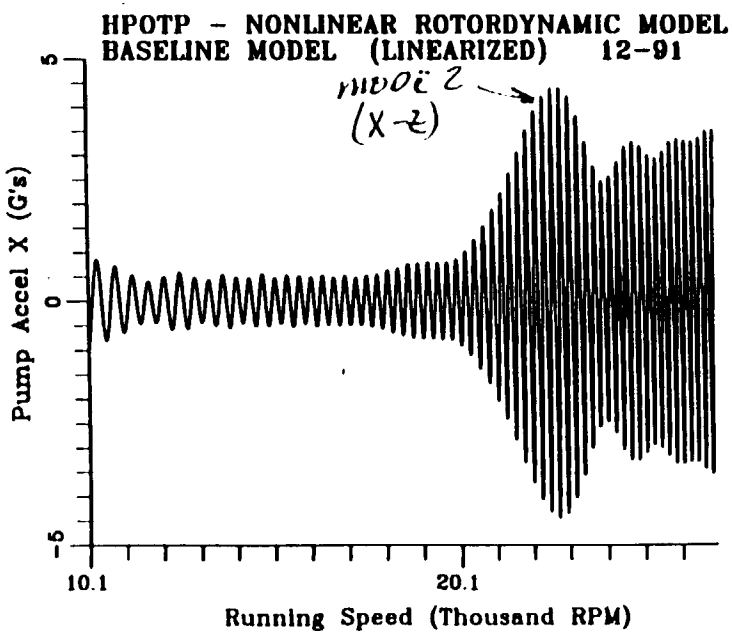

HPOTP - NONLINEAR ROTORDYNAMIC MODEL
BASELINE MODEL (LINEARIZED) 12-91
Turb Accel Y (G's)
4
2
0
-2
-4
10.1
20.1
Running Speed (Thousand RPM)

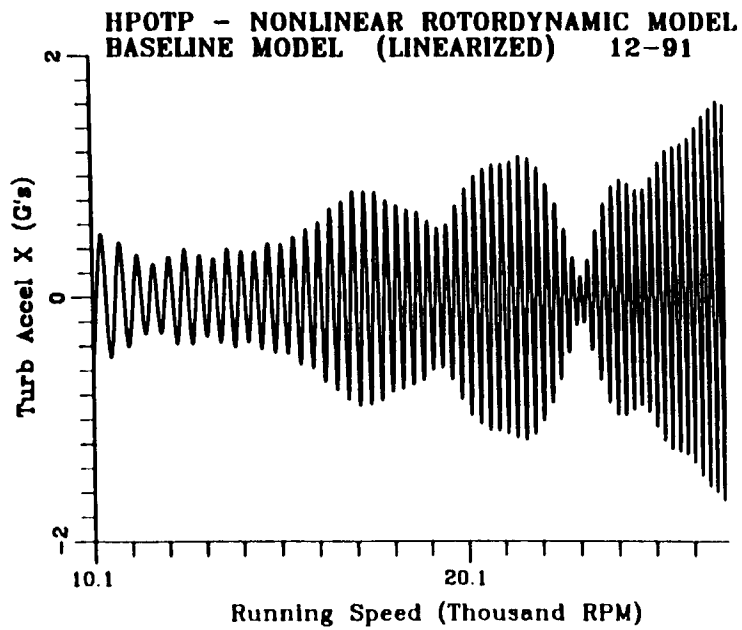

HPOTP - NONLINEAR ROTORDYNAMIC MODEL
BASELINE MODEL (LINEARIZED) 12-91
Preburner Impeller X-Z Defl
0.0002
0.0000
-0.0002
10.1
20.1
Running Speed (Thousand RPM)

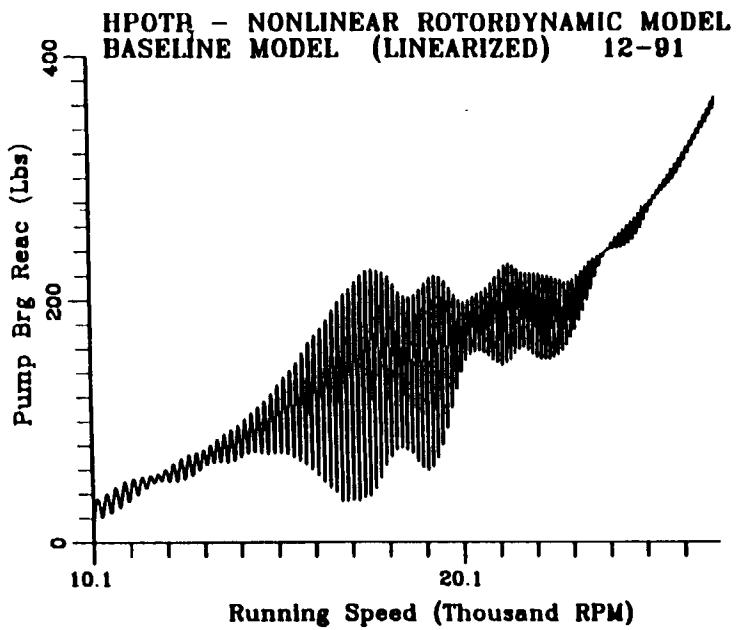

HPOTP - NONLINEAR ROTORDYNAMIC MODEL
BASELINE MODEL (LINEARIZED) 12-91
Preburner Impeller Y-Z Defl
0.0002
0.0000
-0.0002
10.1
20.1
Running Speed (Thousand RPM)

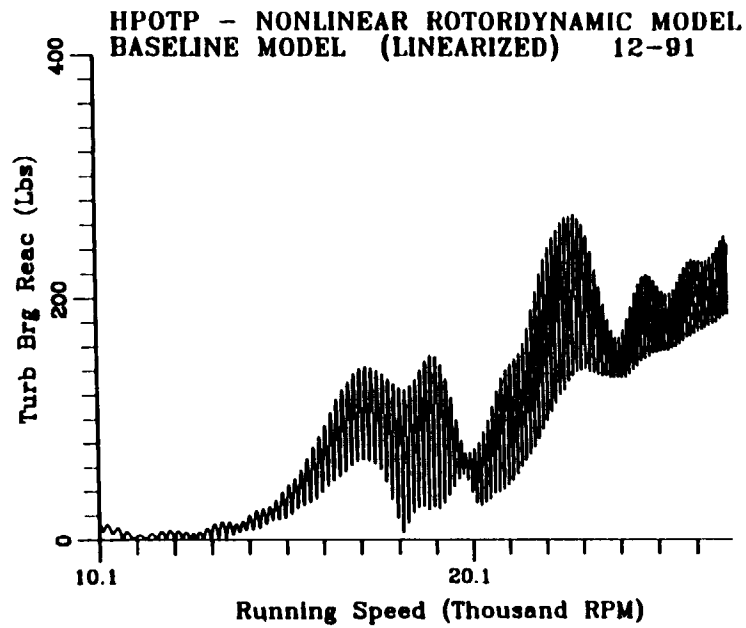

HPOTP - NONLINEAR ROTORDYNAMIC MODEL
BASELINE MODEL (LINEARIZED) 12-91
Pump Brg Reac Y-Z
500
0
-500
10.1
20.1
Running Speed (Thousand RPM)

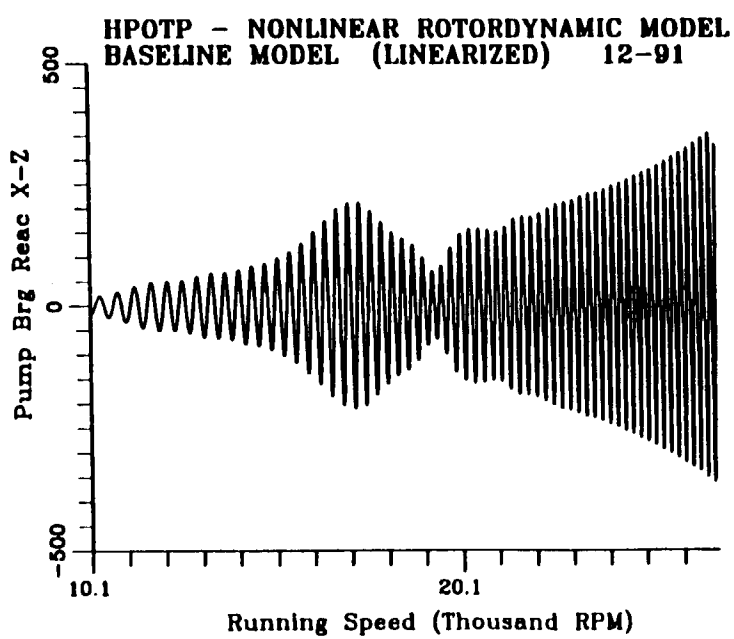

HPOTP - NONLINEAR ROTORDYNAMIC MODEL
BASELINE MODEL (LINEARIZED) 12-91
Turb Brg Reac Y-Z
200
0
-200
10.1
20.1
Running Speed (Thousand RPM)

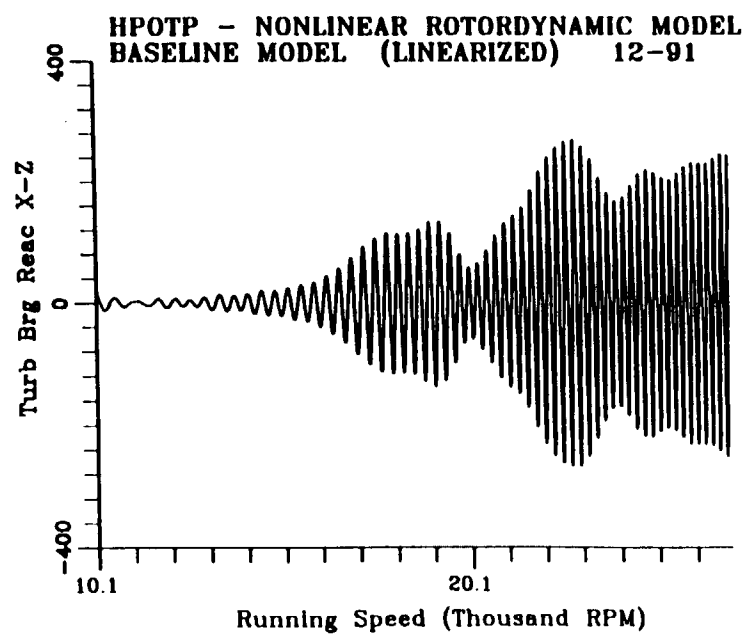

HPOTP - NONLINEAR ROTORDYNAMIC MODEL
BASELINE MODEL (LINEARIZED) 12-91
mode 2
(X-Z)
Pump Accel X (G's)
5
0
-5
10.1
20.1
Running Speed (Thousand RPM)

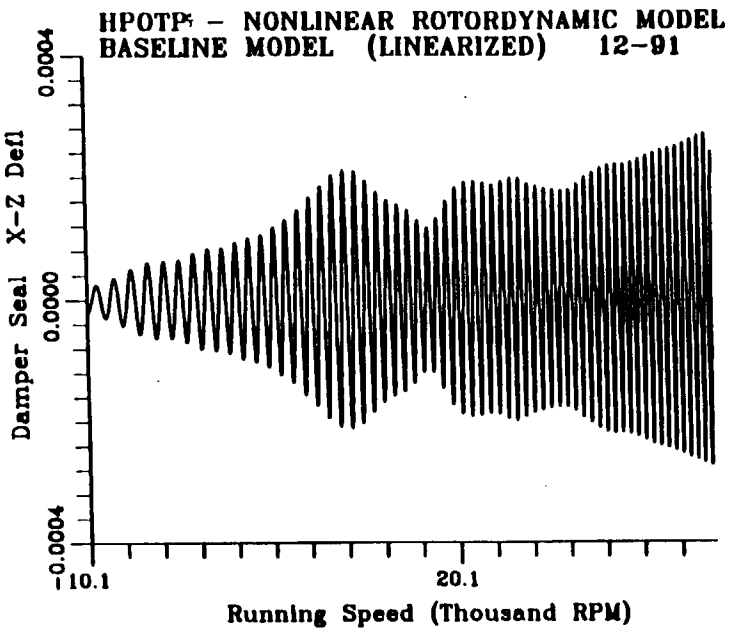

HPOTP - NONLINEAR ROTORDYNAMIC MODEL
BASELINE MODEL (LINEARIZED) 12-91
Turb Accel X (G's)
2
0
-2
10.1
20.1
Running Speed (Thousand RPM)

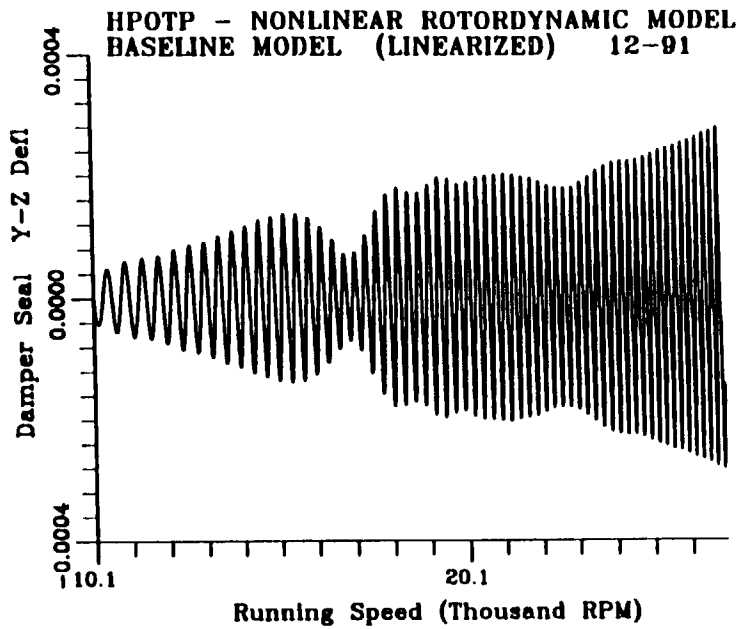

HPOTP - NONLINEAR ROTORDYNAMIC MODEL
BASELINE MODEL (LINEARIZED) 12-91
Pump Brg Reac (Lbs)
400
200
0
10.1
20.1
Running Speed (Thousand RPM)

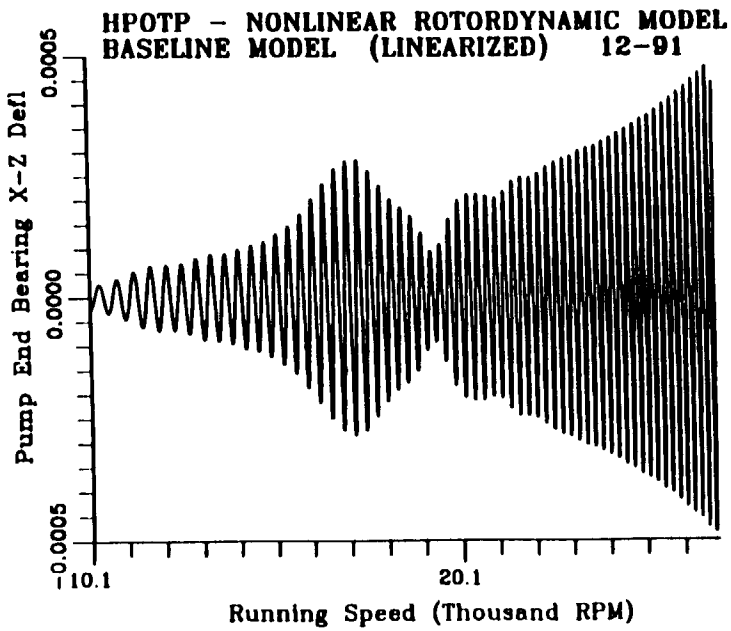

HPOTP - NONLINEAR ROTORDYNAMIC MODEL
BASELINE MODEL (LINEARIZED) 12-91
Turb Brg Reac (Lbs)
400
200
0
10.1
20.1
Running Speed (Thousand RPM)

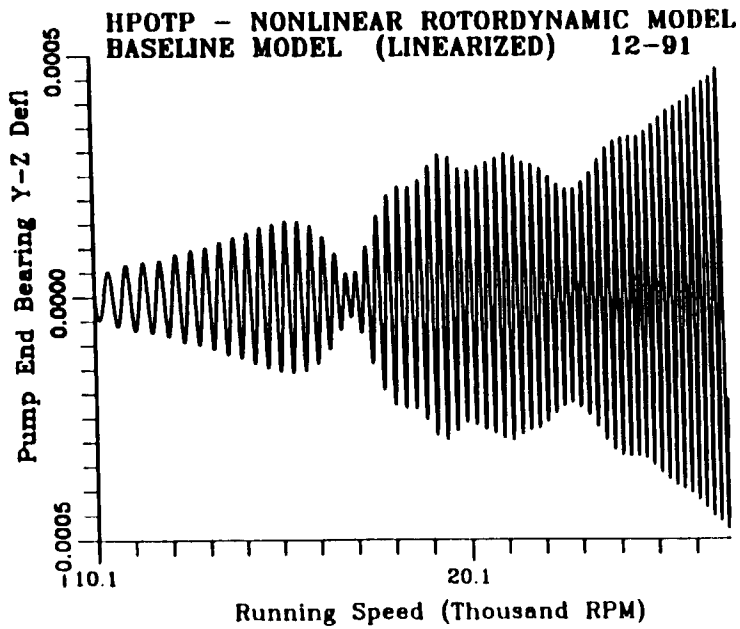

HPOTP - NONLINEAR ROTORDYNAMIC MODEL
BASELINE MODEL (LINEARIZED) 12-91
Pump Brg Reac X-Z
500
0
-500
10.1
20.1
Running Speed (Thousand RPM)

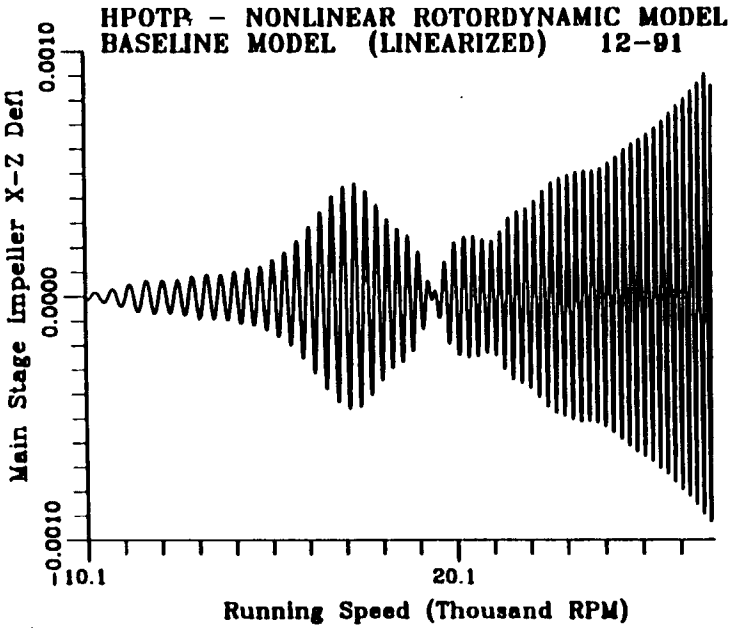

HPOTP - NONLINEAR ROTORDYNAMIC MODEL
BASELINE MODEL (LINEARIZED) 12-91
Turb Brg Reac X-Z
400
0
-400
10.1
20.1
Running Speed (Thousand RPM)

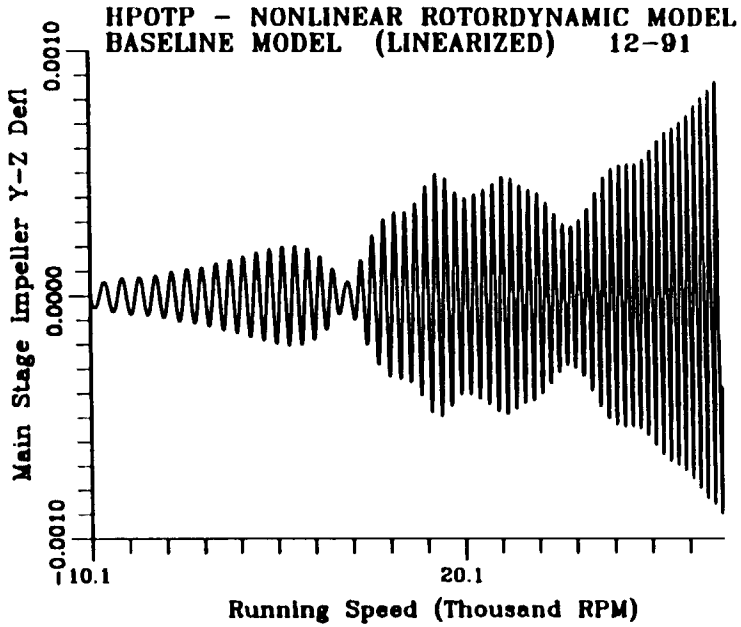

HPOTP - NONLINEAR ROTORDYNAMIC MODEL
BASELINE MODEL (LINEARIZED) 12-91
Damper Seal X-Z Defl
0.0004
0.0000
-0.0004
-10.1
20.1
Running Speed (Thousand RPM)

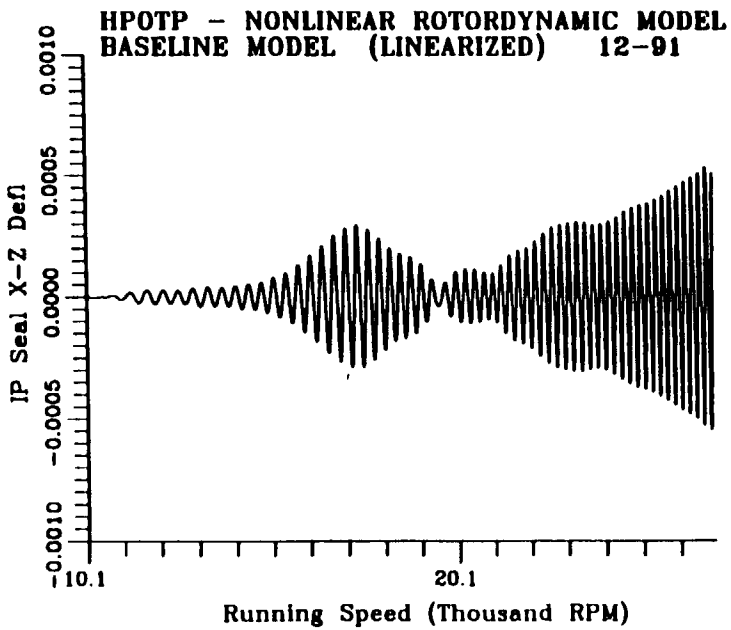

HPOTP - NONLINEAR ROTORDYNAMIC MODEL
BASELINE MODEL (LINEARIZED) 12-91
Damper Seal Y-Z Defl
0.0004
0.0000
-0.0004
-10.1
20.1
Running Speed (Thousand RPM)

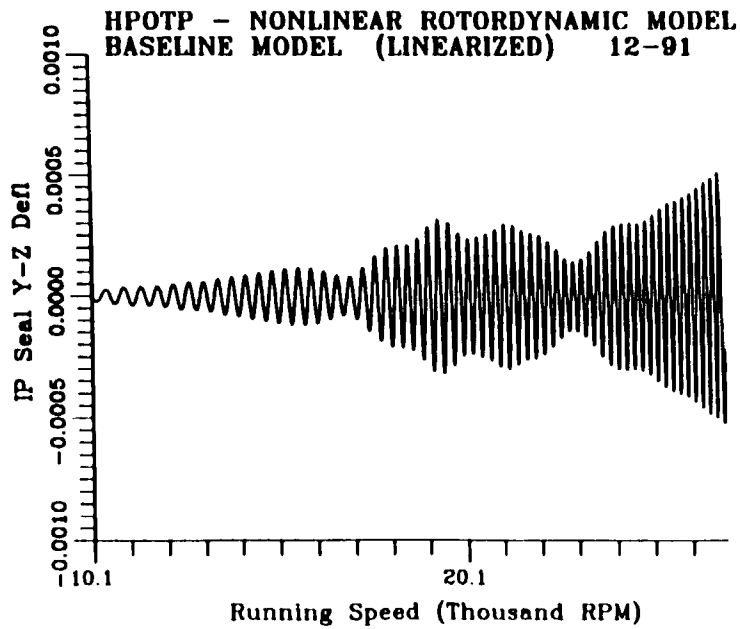

HPOTP - NONLINEAR ROTORDYNAMIC MODEL
BASELINE MODEL (LINEARIZED) 12-91
Pump End Bearing X-Z Defl
0.0005
0.0000
-0.0005
-10.1
20.1
Running Speed (Thousand RPM)

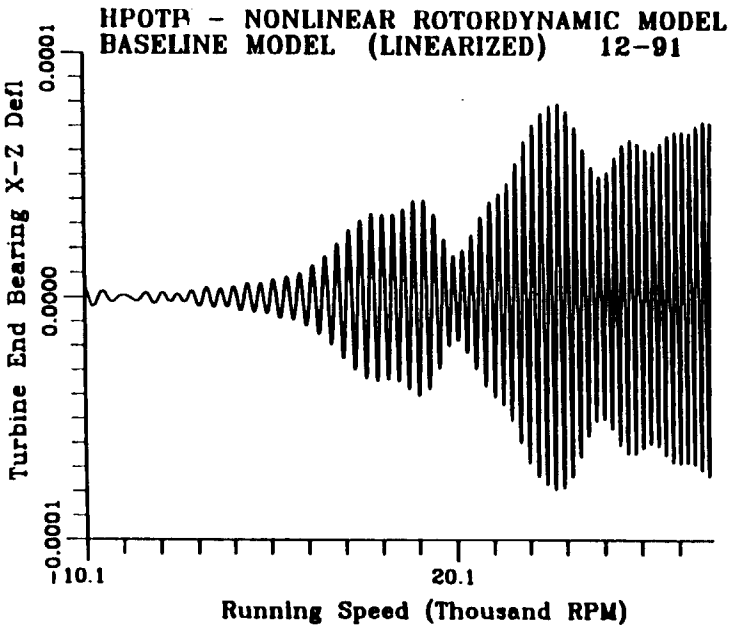

HPOTP - NONLINEAR ROTORDYNAMIC MODEL
BASELINE MODEL (LINEARIZED) 12-91
Pump End Bearing Y-Z Defl
0.0005
0.0000
-0.0005
-10.1
20.1
Running Speed (Thousand RPM)

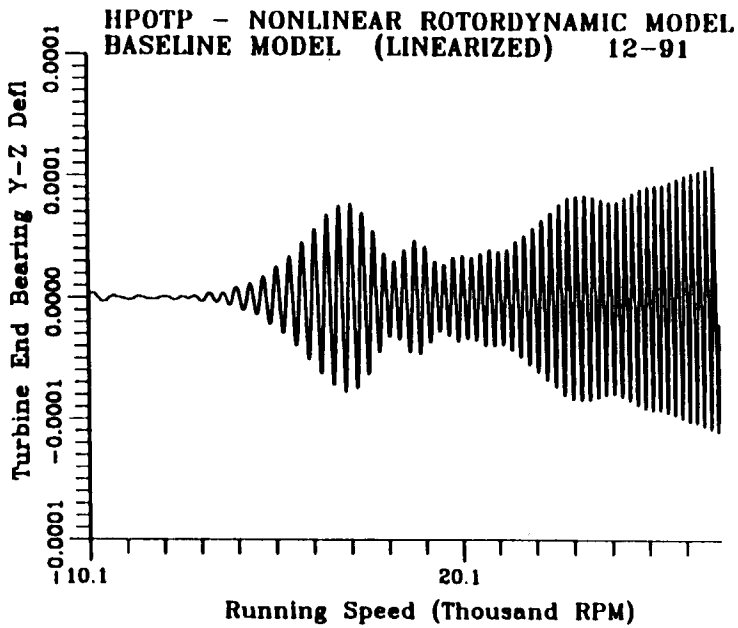

HPOTP - NONLINEAR ROTORDYNAMIC MODEL
BASELINE MODEL (LINEARIZED) 12-91
Main Stage Impeller X-Z Defl
0.0010
0.0000
-0.0010
-10.1
20.1
Running Speed (Thousand RPM)

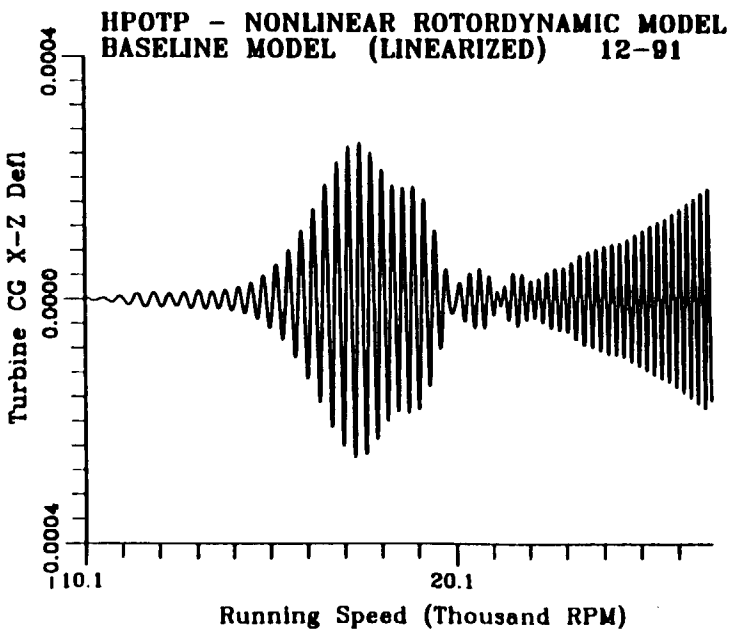

HPOTP - NONLINEAR ROTORDYNAMIC MODEL
BASELINE MODEL (LINEARIZED) 12-91
Main Stage Impeller Y-Z Defl
0.0010
0.0000
-0.0010
-10.1
20.1
Running Speed (Thousand RPM)

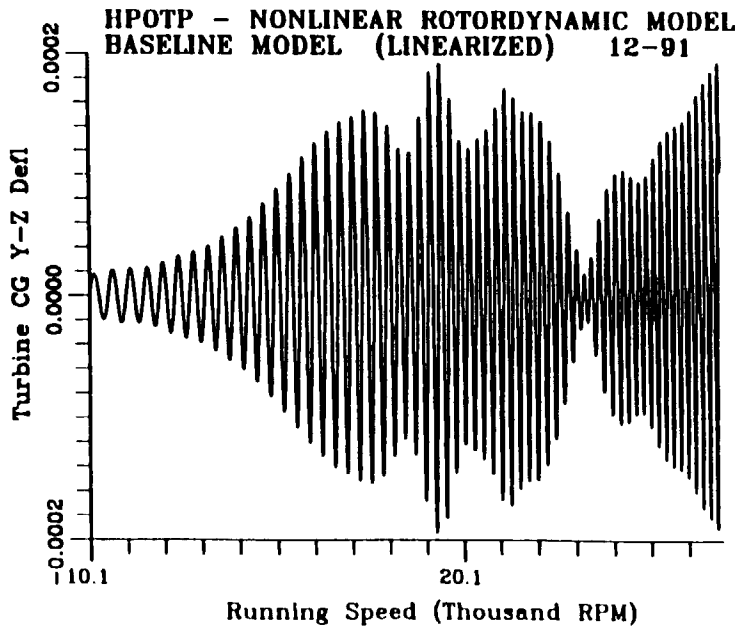

HPOTP - NONLINEAR ROTORDYNAMIC MODEL
BASELINE MODEL (LINEARIZED) 12-91
IP Seal X-Z Defl
0.0010
0.0005
0.0000
-0.0005
-0.0010
-10.1
20.1
Running Speed (Thousand RPM)

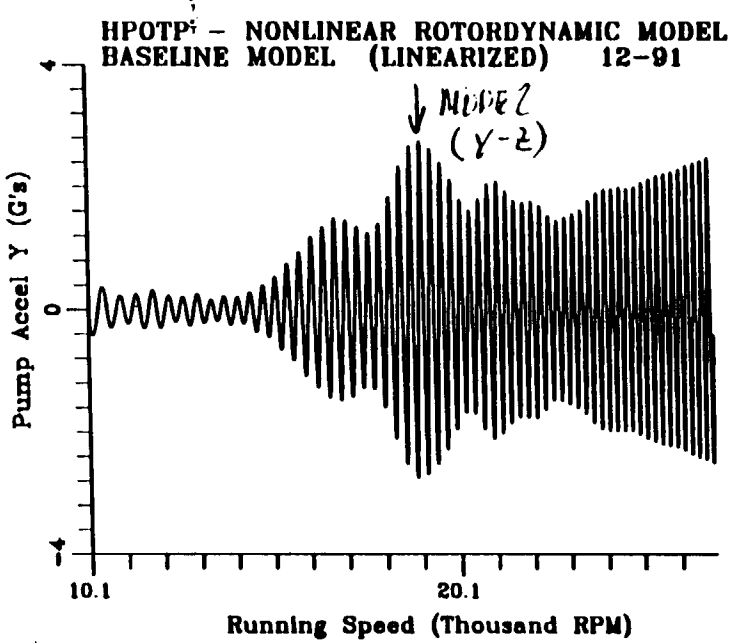

HPOTP - NONLINEAR ROTORDYNAMIC MODEL
BASELINE MODEL (LINEARIZED) 12-91
IP Seal Y-Z Defl
0.0010
0.0005
0.0000
-0.0005
-0.0010
-10.1
20.1
Running Speed (Thousand RPM)

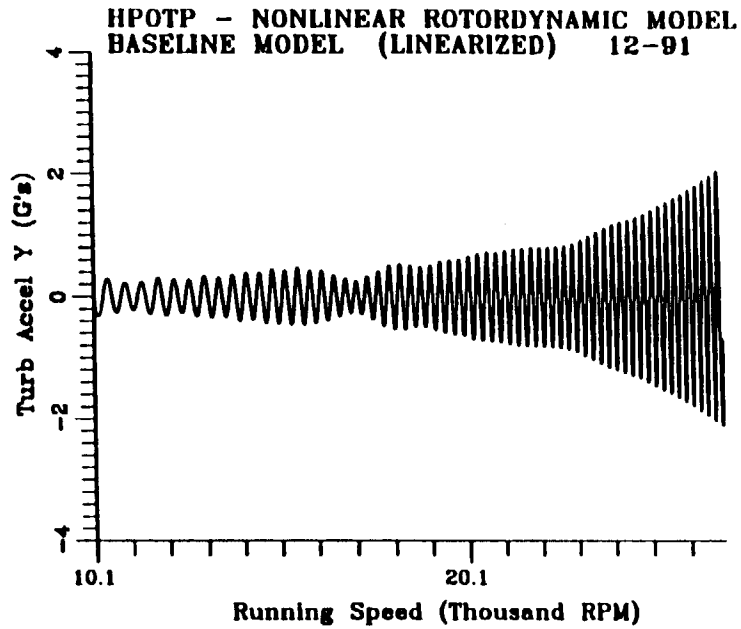

HPOTP - NONLINEAR ROTORDYNAMIC MODEL
BASELINE MODEL (LINEARIZED) 12-91
Turbine End Bearing X-Z Defl
0.0001
0.0000
-0.0001
-10.1
20.1
Running Speed (Thousand RPM)

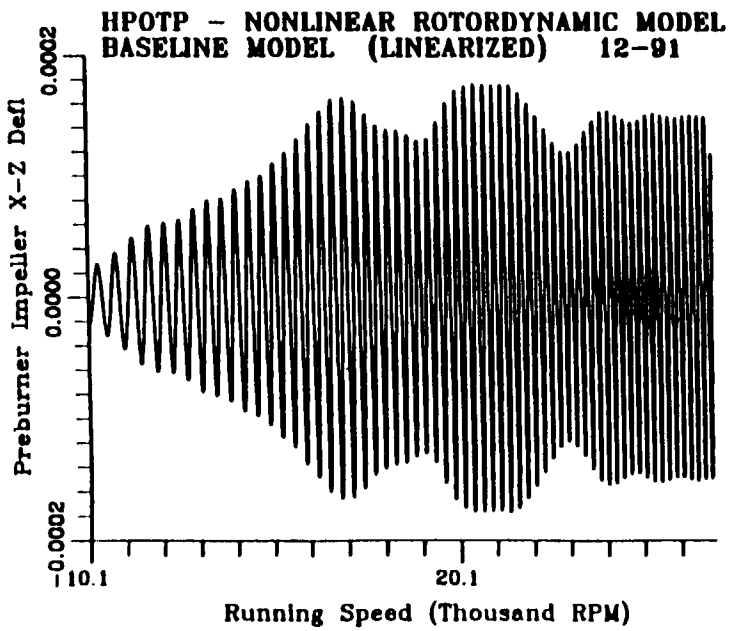

HPOTP - NONLINEAR ROTORDYNAMIC MODEL
BASELINE MODEL (LINEARIZED) 12-91
Turbine End Bearing Y-Z Defl
0.0001
0.0001
0.0000
-0.0001
-0.0001
-10.1
20.1
Running Speed (Thousand RPM)

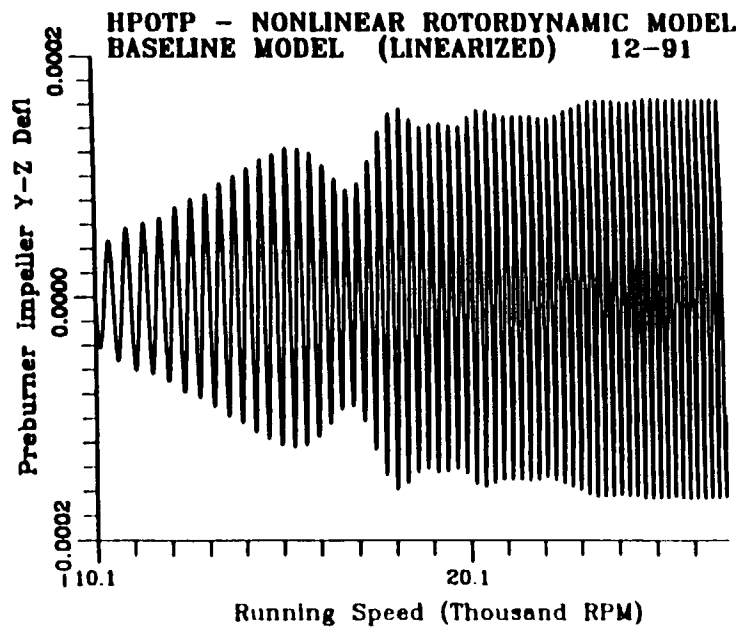

HPOTP - NONLINEAR ROTORDYNAMIC MODEL
BASELINE MODEL (LINEARIZED) 12-91
Turbine CG X-Z Defl
0.0004
0.0000
-0.0004
-10.1
20.1
Running Speed (Thousand RPM)

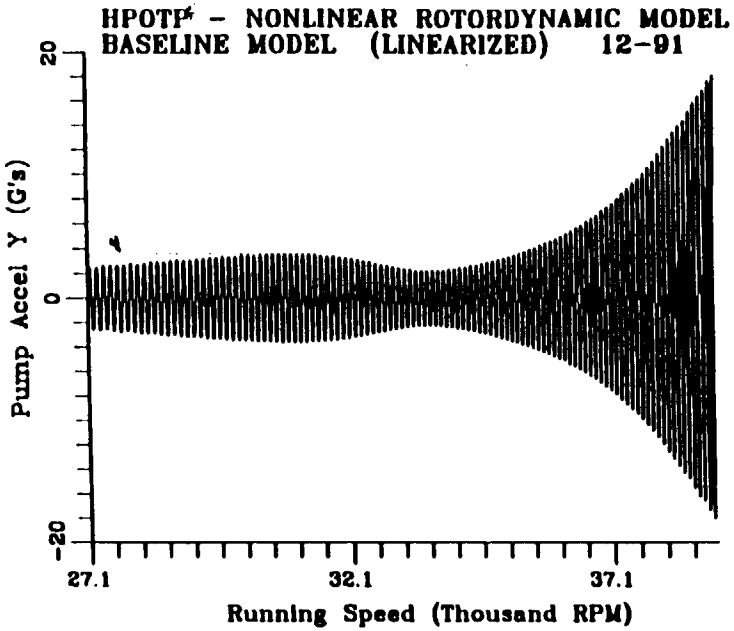

HPOTP - NONLINEAR ROTORDYNAMIC MODEL
BASELINE MODEL (LINEARIZED) 12-91
Turbine CG Y-Z Defl
0.0002
0.0000
-0.0002
-10.1
20.1
Running Speed (Thousand RPM)

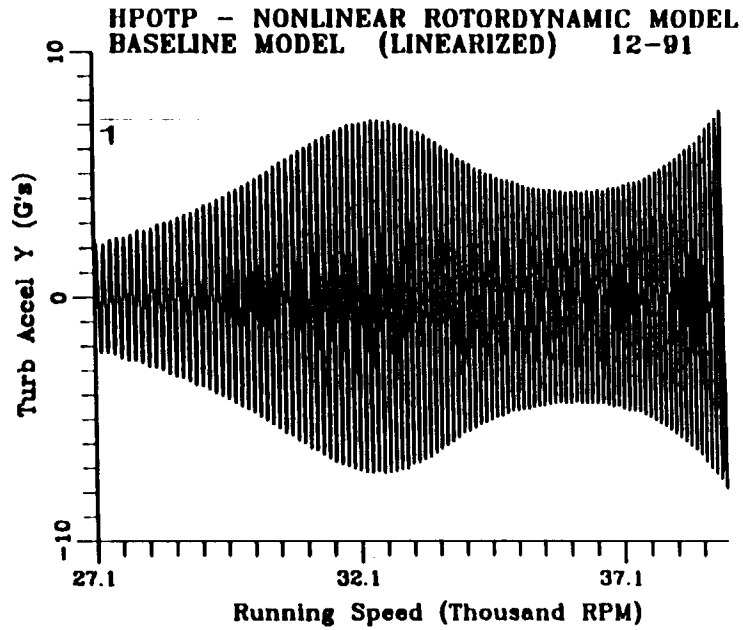

HPOTP - NONLINEAR ROTORDYNAMIC MODEL
BASELINE MODEL (LINEARIZED) 12-91
MODE 2
(Y-Z)
Pump Accel Y (G's)
4
0
-4
10.1
20.1
Running Speed (Thousand RPM)

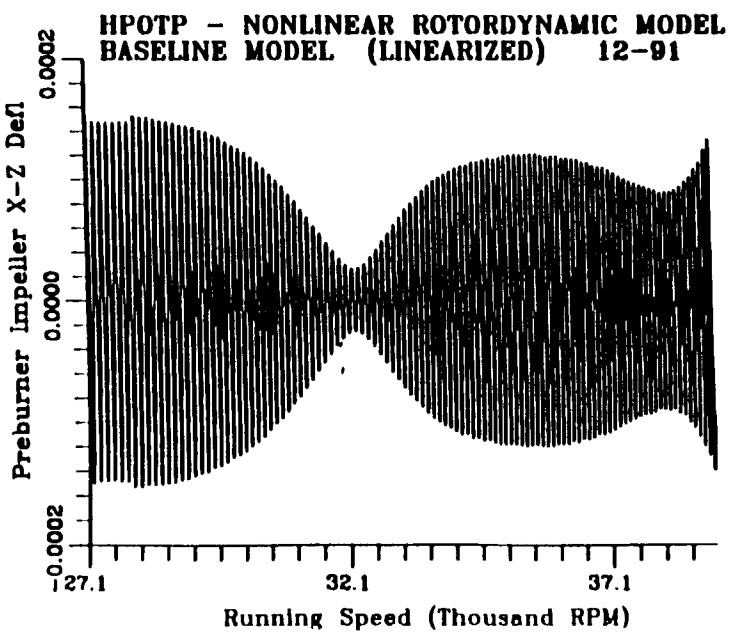

HPOTP - NONLINEAR ROTORDYNAMIC MODEL
BASELINE MODEL (LINEARIZED) 12-91
Turb Accel Y (G's)
4
2
0
-2
-4
10.1
20.1
Running Speed (Thousand RPM)

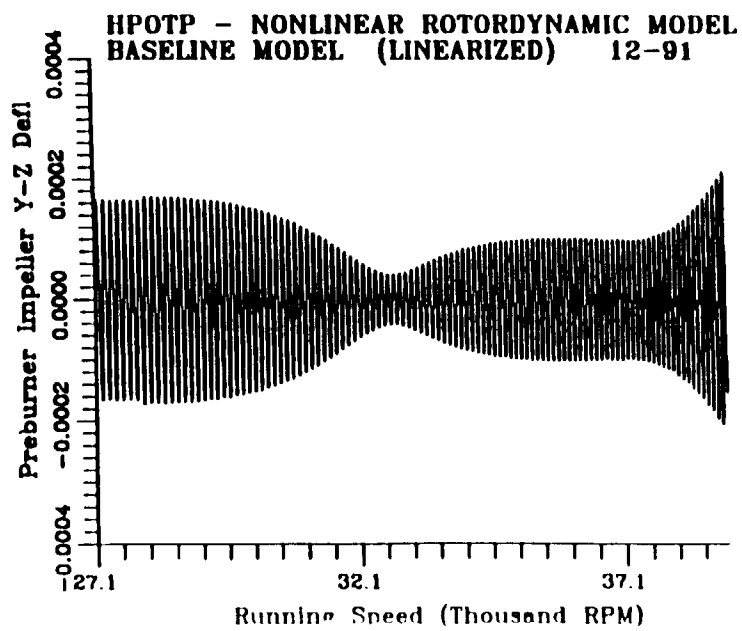

HPOTP - NONLINEAR ROTORDYNAMIC MODEL
BASELINE MODEL (LINEARIZED) 12-91
Preburner Impeller X-Z Defl
0.0002
0.0000
-0.0002
-10.1
20.1
Running Speed (Thousand RPM)

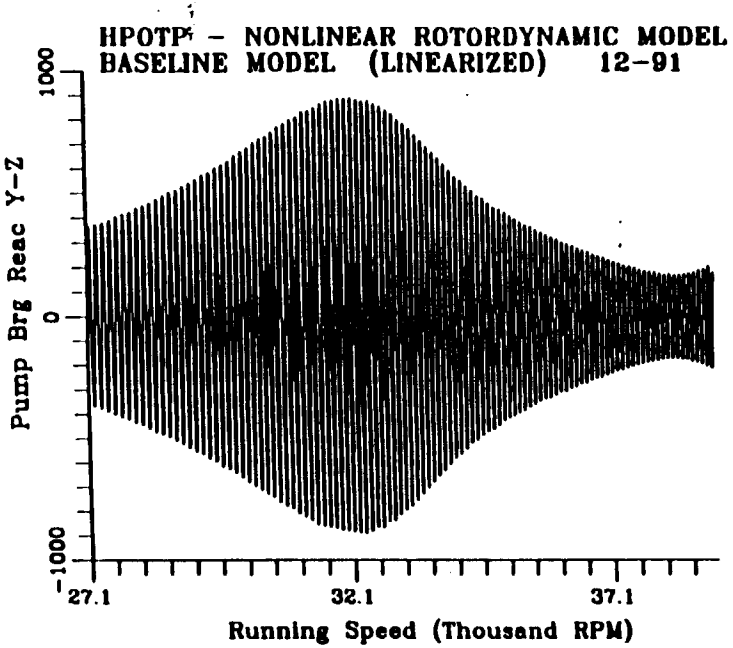

HPOTP - NONLINEAR ROTORDYNAMIC MODEL
BASELINE MODEL (LINEARIZED) 12-91
Preburner Impeller Y-Z Defl
0.0002
0.0000
-0.0002
-10.1
20.1
Running Speed (Thousand RPM)

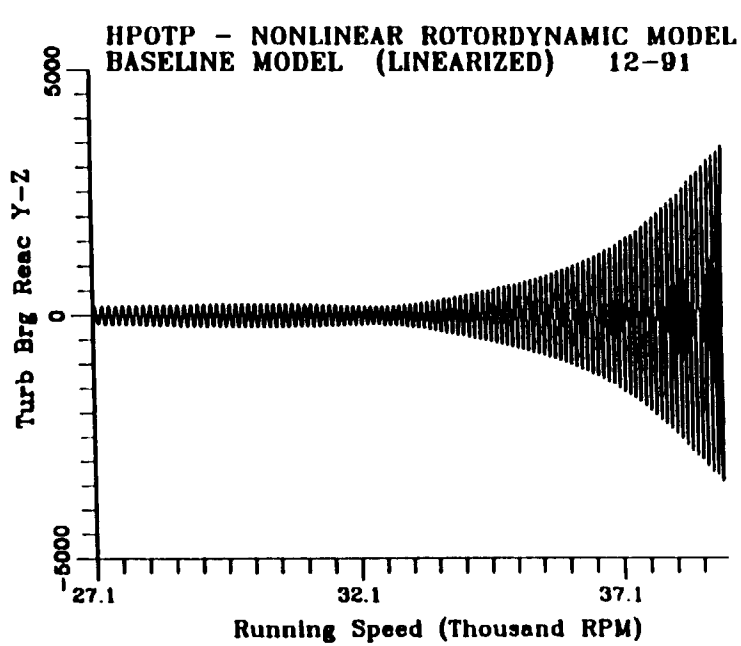

HPOTP - NONLINEAR ROTORDYNAMIC MODEL
BASELINE MODEL (LINEARIZED) 12-91
Pump Accel Y (G's)
20
0
-20
27.1
32.1
37.1
Running Speed (Thousand RPM)

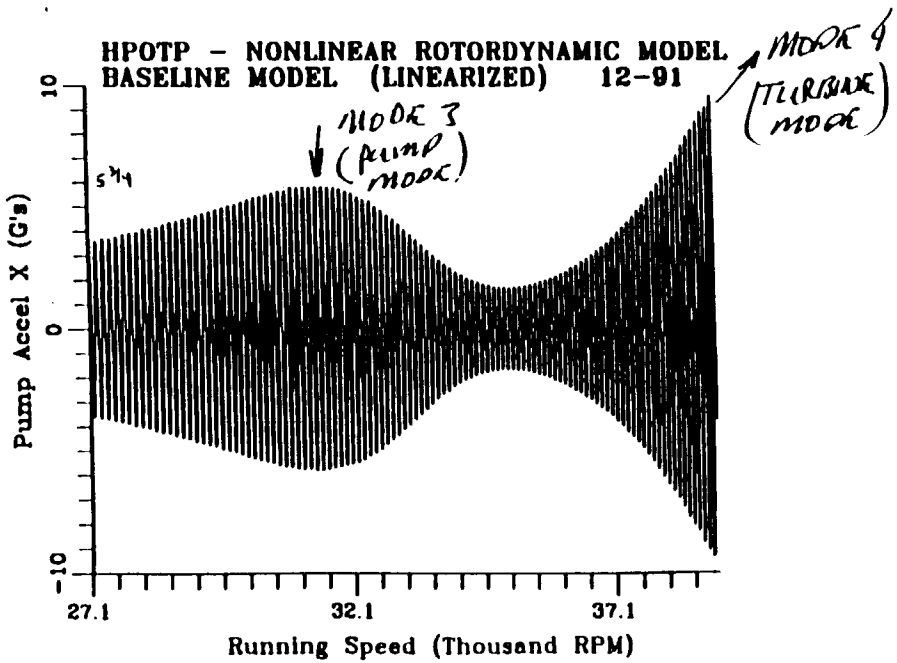

HPOTP - NONLINEAR ROTORDYNAMIC MODEL
BASELINE MODEL (LINEARIZED) 12-91
Turb Accel Y (G's)
10
0
-10
27.1
32.1
37.1
Running Speed (Thousand RPM)

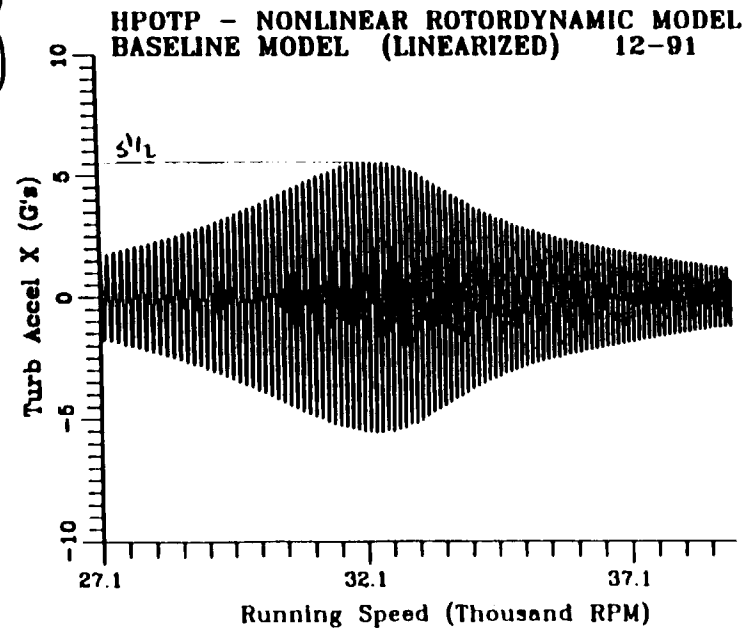

HPOTP - NONLINEAR ROTORDYNAMIC MODEL
BASELINE MODEL (LINEARIZED) 12-91
Preburner Impeller X-Z Defl
0.0002
0.0000
-0.0002
27.1
32.1
37.1
Running Speed (Thousand RPM)

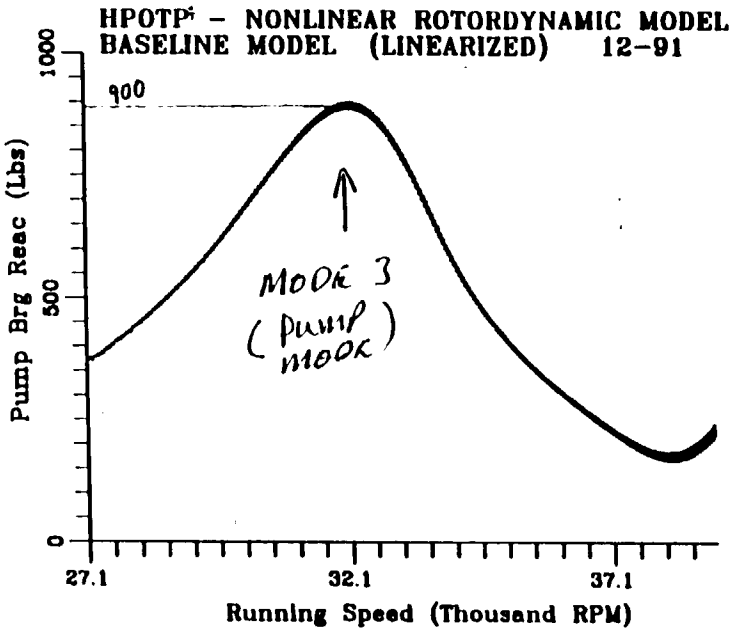

HPOTP - NONLINEAR ROTORDYNAMIC MODEL
BASELINE MODEL (LINEARIZED) 12-91
Preburner Impeller Y-Z Defl
0.0004
0.0002
0.0000
-0.0002
-0.0004
27.1
32.1
37.1
Running Speed (Thousand RPM)

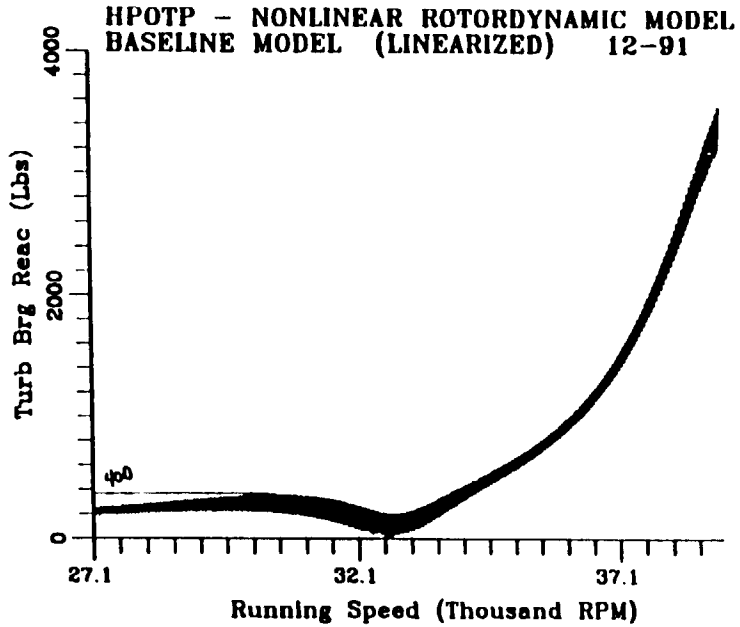

HPOTP - NONLINEAR ROTORDYNAMIC MODEL
BASELINE MODEL (LINEARIZED) 12-91
Pump Brg Reac Y-Z
1000
0
-1000
27.1
32.1
37.1
Running Speed (Thousand RPM)

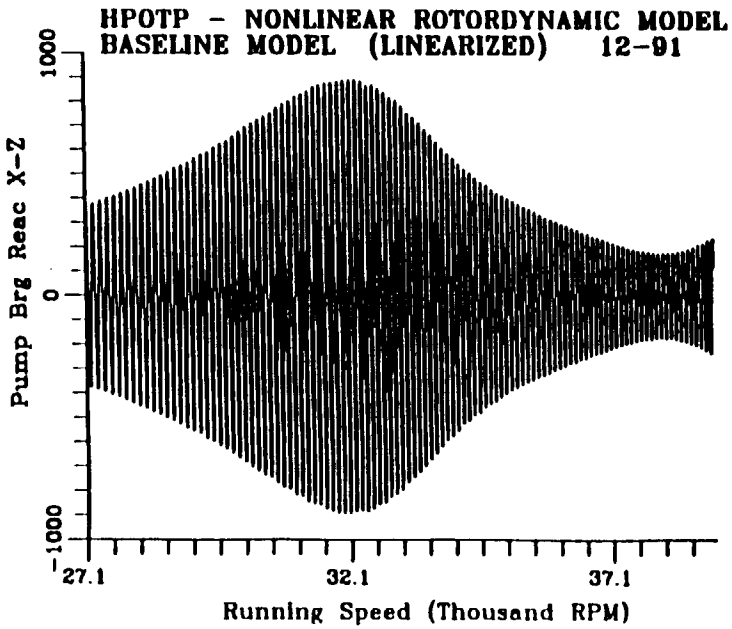

HPOTP - NONLINEAR ROTORDYNAMIC MODEL
BASELINE MODEL (LINEARIZED) 12-91
Turb Brg Reac Y-Z
5000
0
-5000
27.1
32.1
37.1
Running Speed (Thousand RPM)

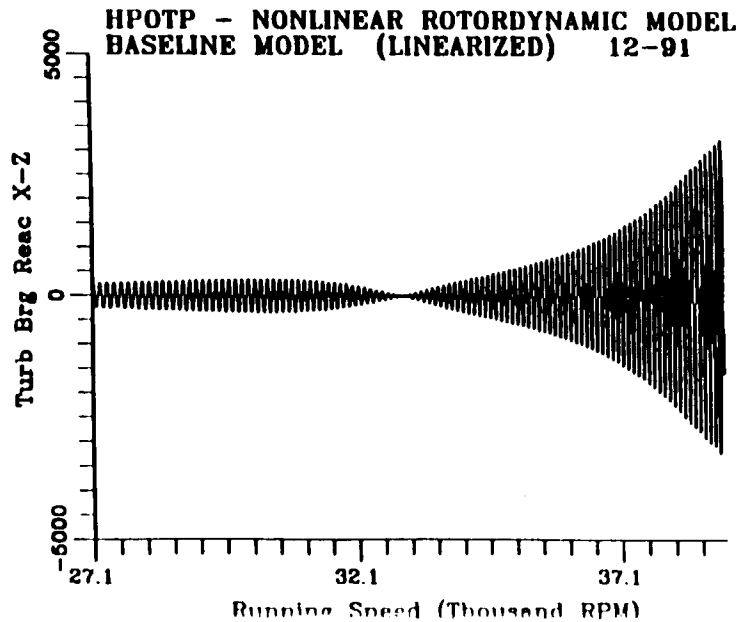

HPOTP - NONLINEAR ROTORDYNAMIC MODEL
BASELINE MODEL (LINEARIZED) 12-91
MODE 3
(PUMP MODE)
MODE 4
(TURBINE MODE)
5¾
Pump Accel X (G's)
10
0
-10
27.1
32.1
37.1
Running Speed (Thousand RPM)

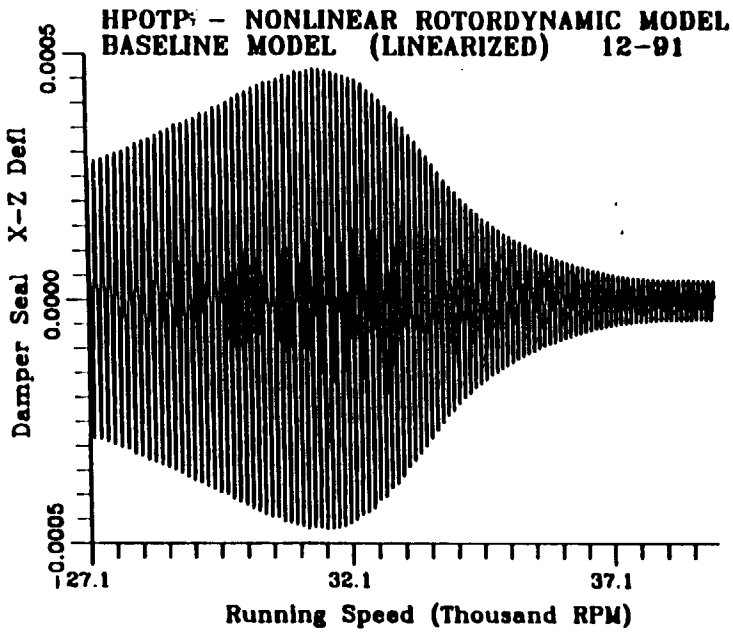

HPOTP - NONLINEAR ROTORDYNAMIC MODEL
BASELINE MODEL (LINEARIZED) 12-91
5½
Turb Accel X (G's)
10
5
0
-5
-10
27.1
32.1
37.1
Running Speed (Thousand RPM)

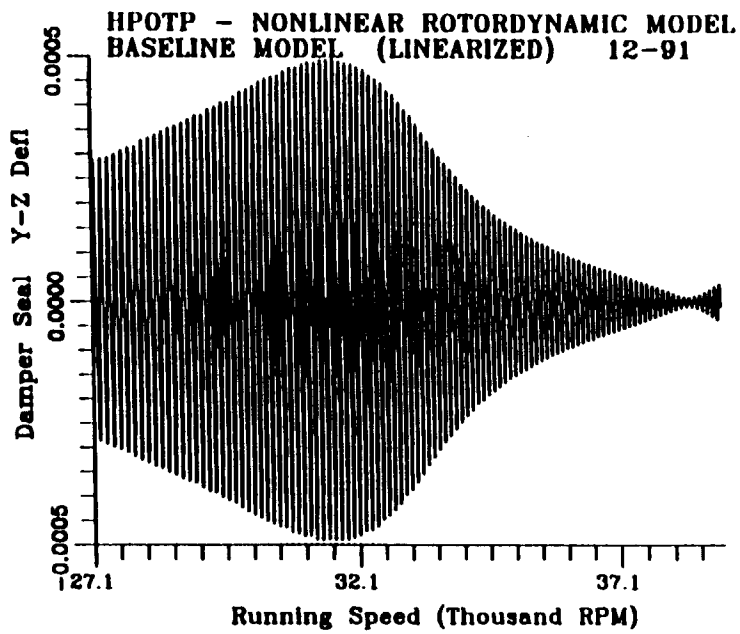

HPOTP - NONLINEAR ROTORDYNAMIC MODEL
BASELINE MODEL (LINEARIZED) 12-91
Pump Brg Reac (Lbs)
1000
500
0
900
MODE 3
(pump mode)
27.1
32.1
37.1
Running Speed (Thousand RPM)

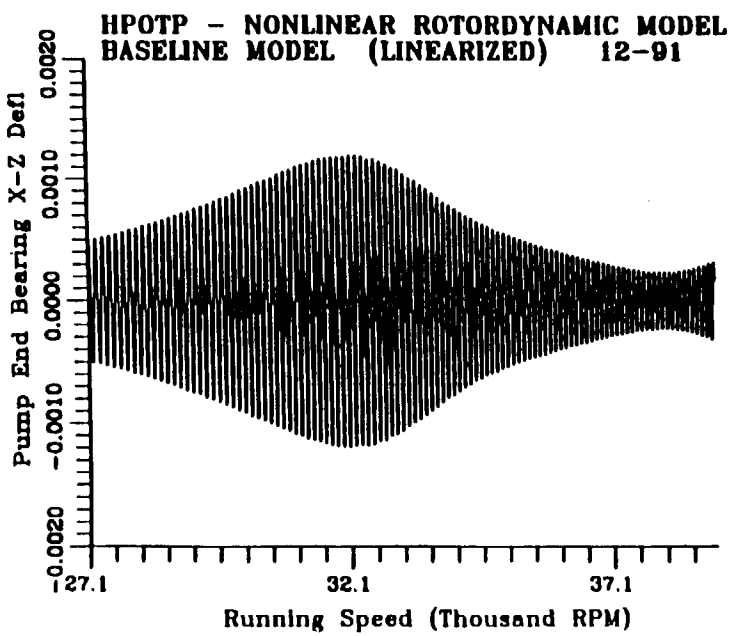

HPOTP - NONLINEAR ROTORDYNAMIC MODEL
BASELINE MODEL (LINEARIZED) 12-91
Turb Brg Reac (Lbs)
4000
2000
0
400
27.1
32.1
37.1
Running Speed (Thousand RPM)

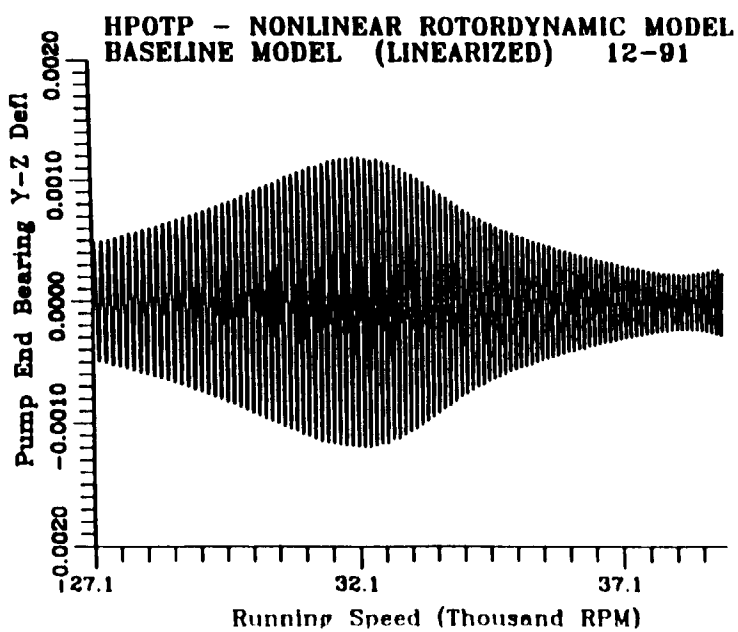

HPOTP - NONLINEAR ROTORDYNAMIC MODEL
BASELINE MODEL (LINEARIZED) 12-91
Pump Brg Reac X-Z
1000
0
-1000
27.1
32.1
37.1
Running Speed (Thousand RPM)

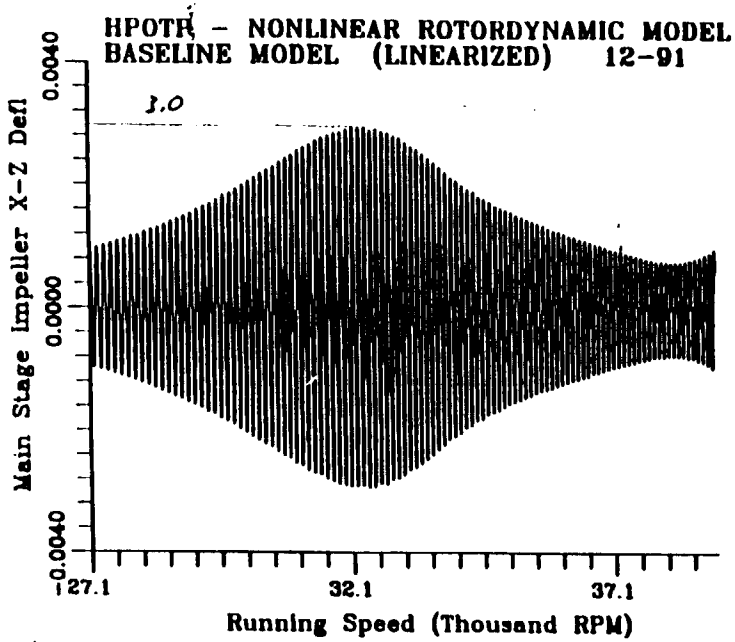

HPOTP - NONLINEAR ROTORDYNAMIC MODEL
BASELINE MODEL (LINEARIZED) 12-91
Turb Brg Reac X-Z
5000
0
-5000
27.1
32.1
37.1
Running Speed (Thousand RPM)

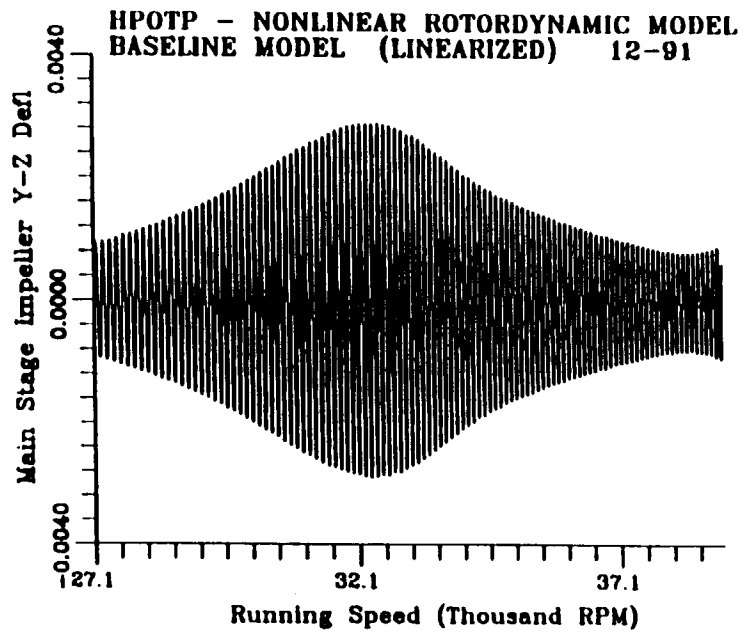

HPOTP - NONLINEAR ROTORDYNAMIC MODEL
BASELINE MODEL (LINEARIZED) 12-91
Damper Seal X-Z Defl
0.0005
0.0000
-0.0005
27.1
32.1
37.1
Running Speed (Thousand RPM)

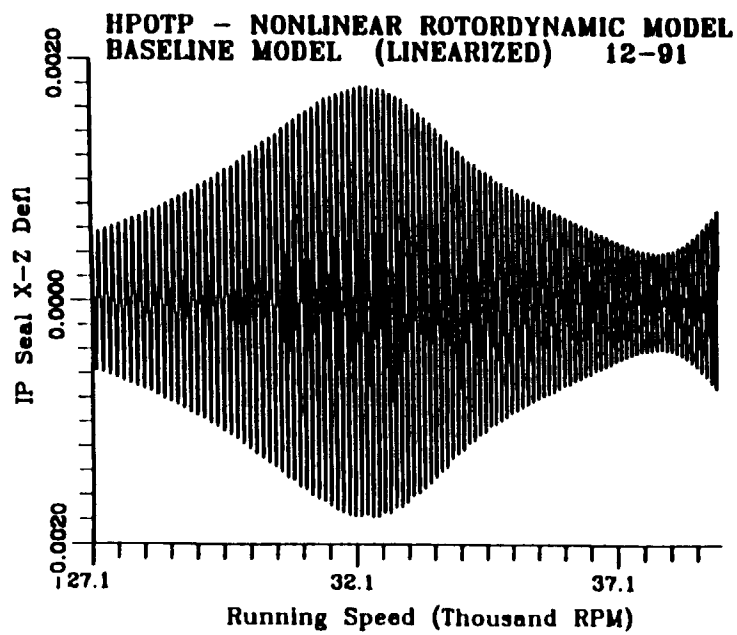

HPOTP - NONLINEAR ROTORDYNAMIC MODEL
BASELINE MODEL (LINEARIZED) 12-91
Damper Seal Y-Z Defl
0.0005
0.0000
-0.0005
27.1
32.1
37.1
Running Speed (Thousand RPM)

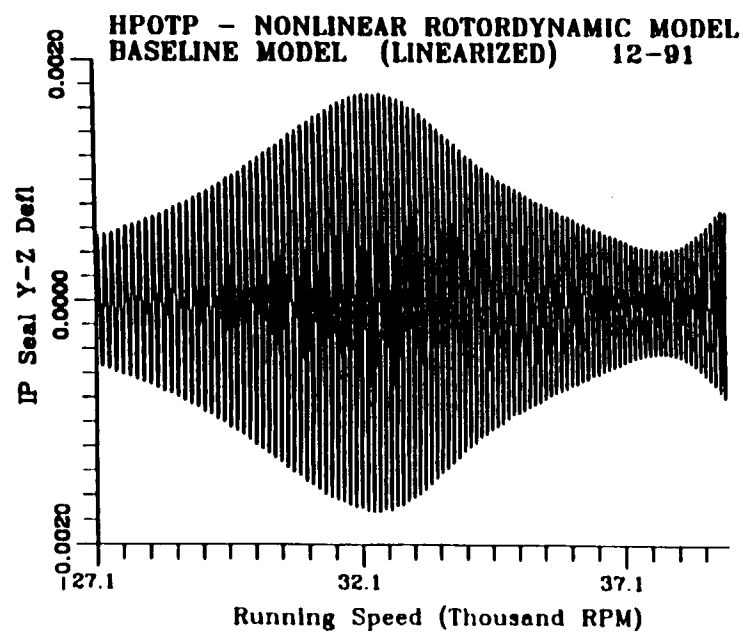

HPOTP - NONLINEAR ROTORDYNAMIC MODEL
BASELINE MODEL (LINEARIZED) 12-91
Pump End Bearing X-Z Defl
0.0020
0.0010
0.0000
-0.0010
-0.0020
27.1
32.1
37.1
Running Speed (Thousand RPM)

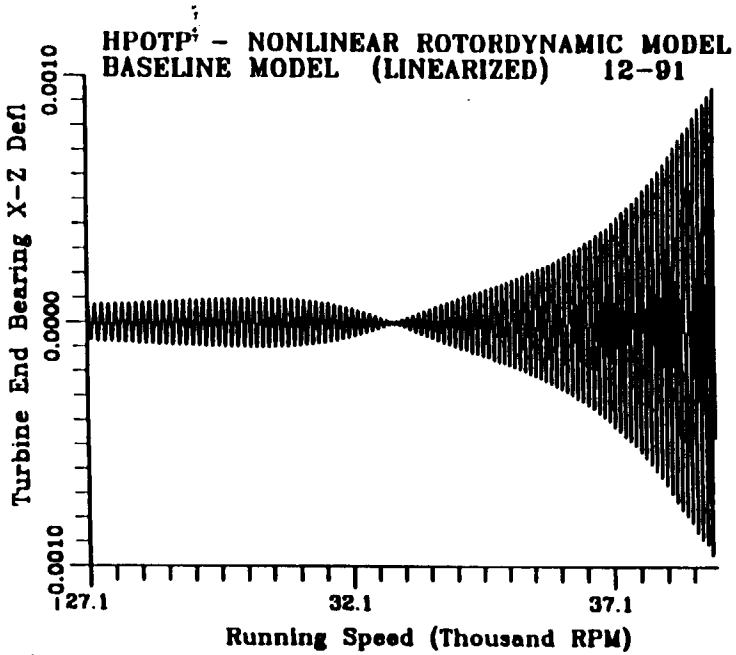

HPOTP - NONLINEAR ROTORDYNAMIC MODEL
BASELINE MODEL (LINEARIZED) 12-91
Pump End Bearing Y-Z Defl
0.0020
0.0010
0.0000
-0.0010
-0.0020
27.1
32.1
37.1
Running Speed (Thousand RPM)

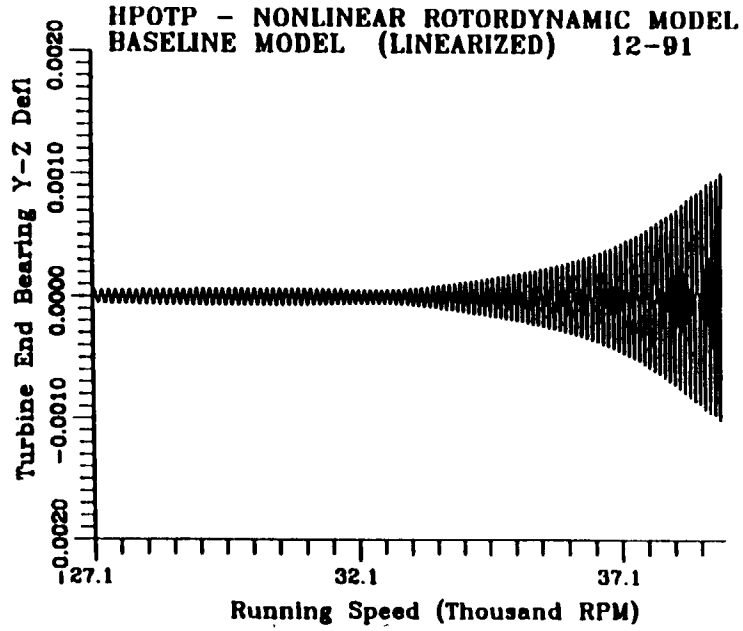

HPOTP - NONLINEAR ROTORDYNAMIC MODEL
BASELINE MODEL (LINEARIZED) 12-91
3.0
Main Stage Impeller X-Z Defl
0.0040
0.0000
-0.0040
27.1
32.1
37.1
Running Speed (Thousand RPM)

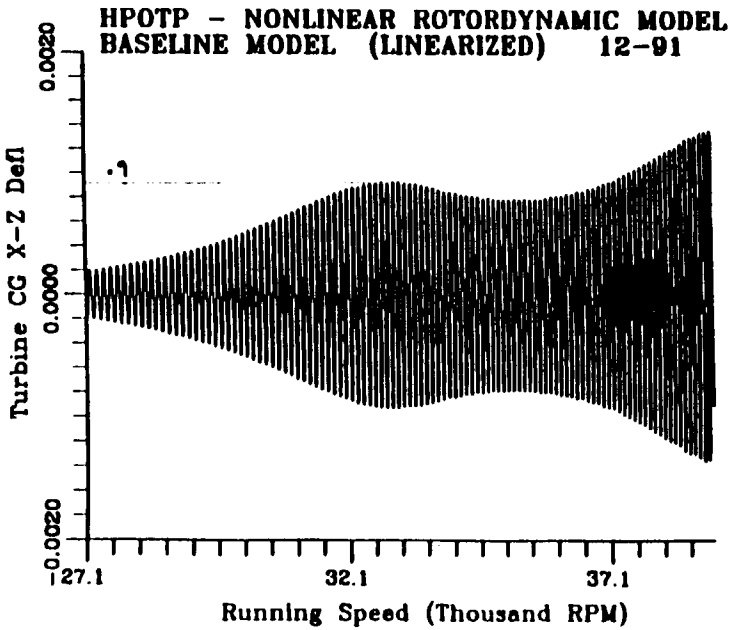

HPOTP - NONLINEAR ROTORDYNAMIC MODEL
BASELINE MODEL (LINEARIZED) 12-91
Main Stage Impeller Y-Z Defl
0.0040
0.0000
-0.0040
27.1
32.1
37.1
Running Speed (Thousand RPM)

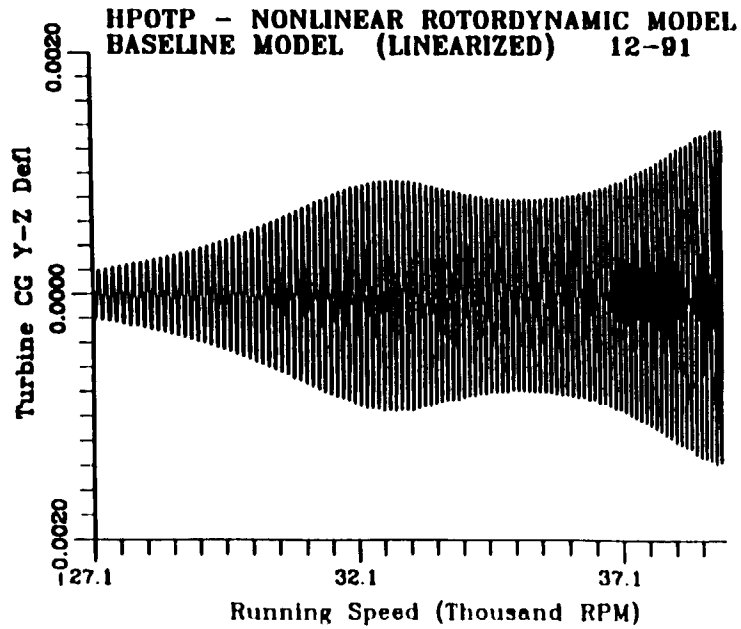

HPOTP - NONLINEAR ROTORDYNAMIC MODEL
BASELINE MODEL (LINEARIZED) 12-91
IP Seal X-Z Defl
0.0020
0.0000
-0.0020
27.1
32.1
37.1
Running Speed (Thousand RPM)

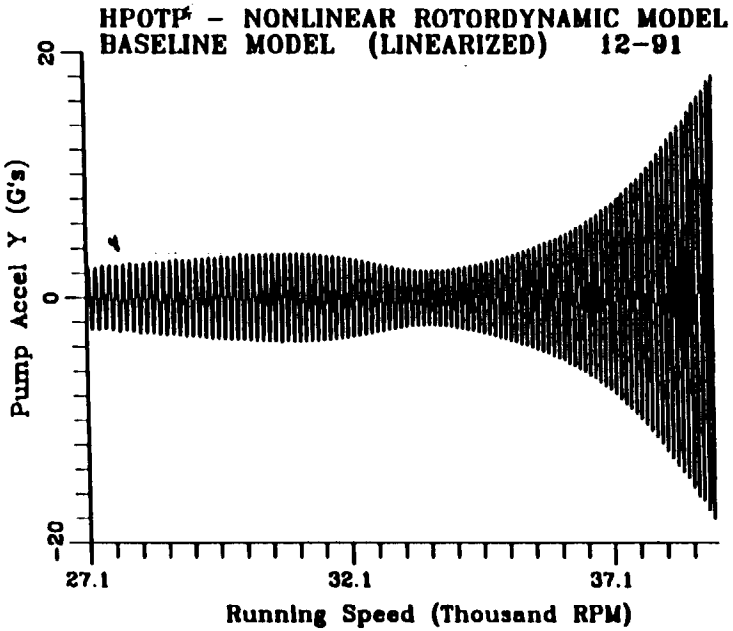

HPOTP - NONLINEAR ROTORDYNAMIC MODEL
BASELINE MODEL (LINEARIZED) 12-91
IP Seal Y-Z Defl
0.0020
0.0000
-0.0020
27.1
32.1
37.1
Running Speed (Thousand RPM)

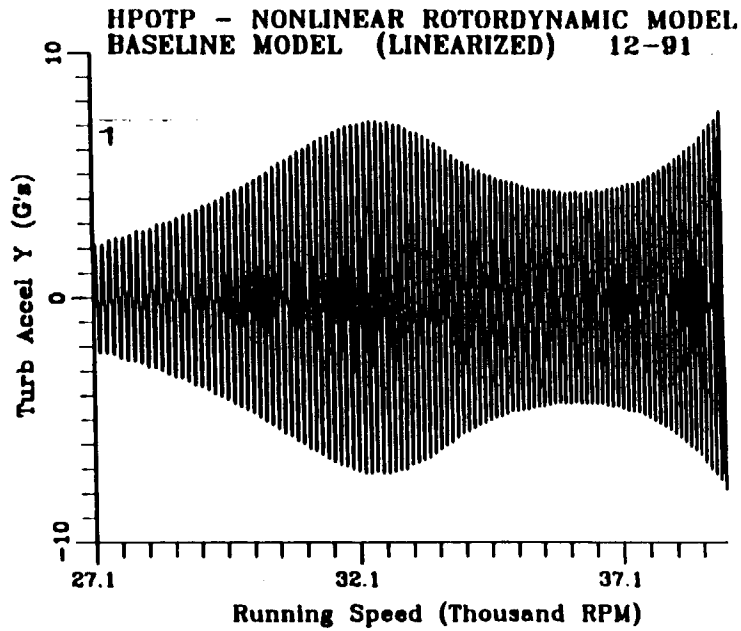

HPOTP - NONLINEAR ROTORDYNAMIC MODEL
BASELINE MODEL (LINEARIZED) 12-91
Turbine End Bearing X-Z Defl
0.0010
0.0000
-0.0010
-27.1
32.1
37.1
Running Speed (Thousand RPM)

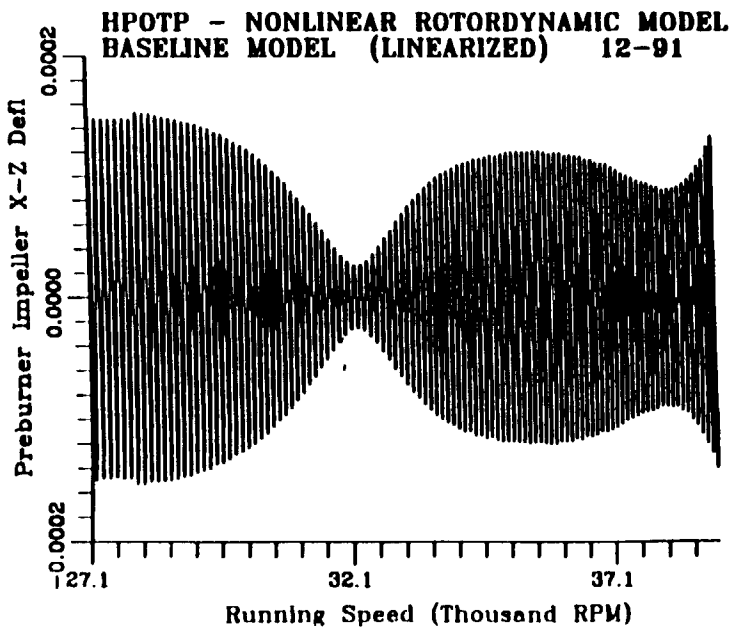

HPOTP - NONLINEAR ROTORDYNAMIC MODEL
BASELINE MODEL (LINEARIZED) 12-91
Turbine End Bearing Y-Z Defl
0.0020
0.0010
0.0000
-0.0010
-0.0020
-27.1
32.1
37.1
Running Speed (Thousand RPM)

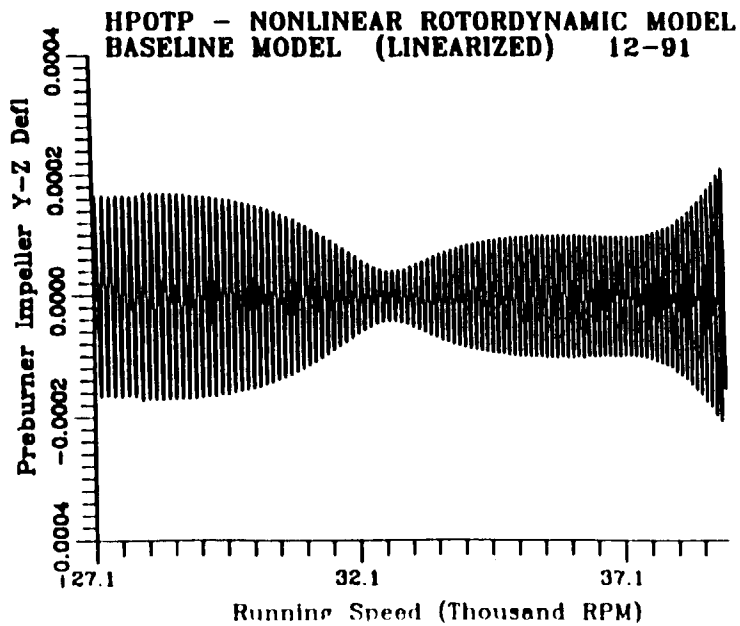

HPOTP - NONLINEAR ROTORDYNAMIC MODEL
BASELINE MODEL (LINEARIZED) 12-91
Turbine CG X-Z Defl
0.0020
0.0000
-0.0020
-27.1
32.1
37.1
Running Speed (Thousand RPM)


HPOTP - NONLINEAR ROTORDYNAMIC MODEL
BASELINE MODEL (LINEARIZED) 12-91
Turbine CG Y-Z Defl
0.0020
0.0000
-0.0020
-27.1
32.1
37.1
Running Speed (Thousand RPM)


HPOTP - NONLINEAR ROTORDYNAMIC MODEL
BASELINE MODEL (LINEARIZED) 12-91
Pump Accel Y (G's)
20
0
-20
27.1
32.1
37.1
Running Speed (Thousand RPM)

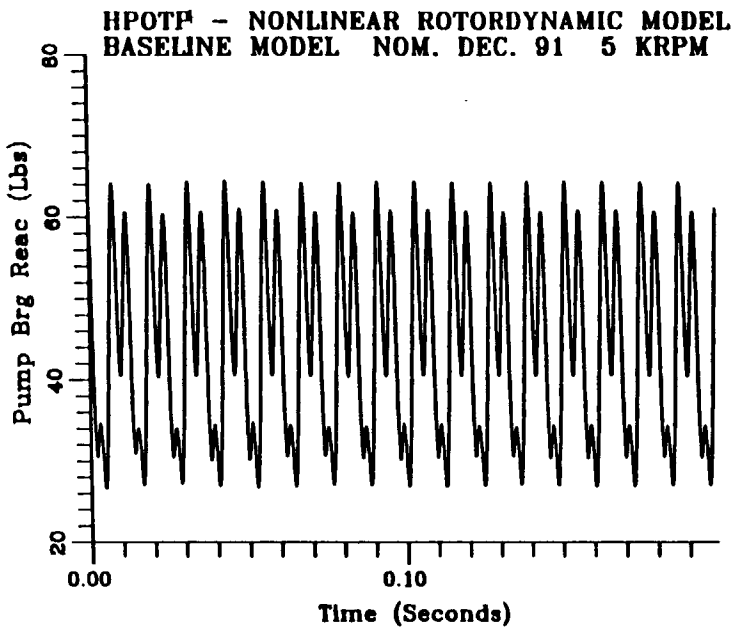

HPOTP - NONLINEAR ROTORDYNAMIC MODEL
BASELINE MODEL (LINEARIZED) 12-91
Turb Accel Y (G's)
10
0
-10
27.1
32.1
37.1
Running Speed (Thousand RPM)

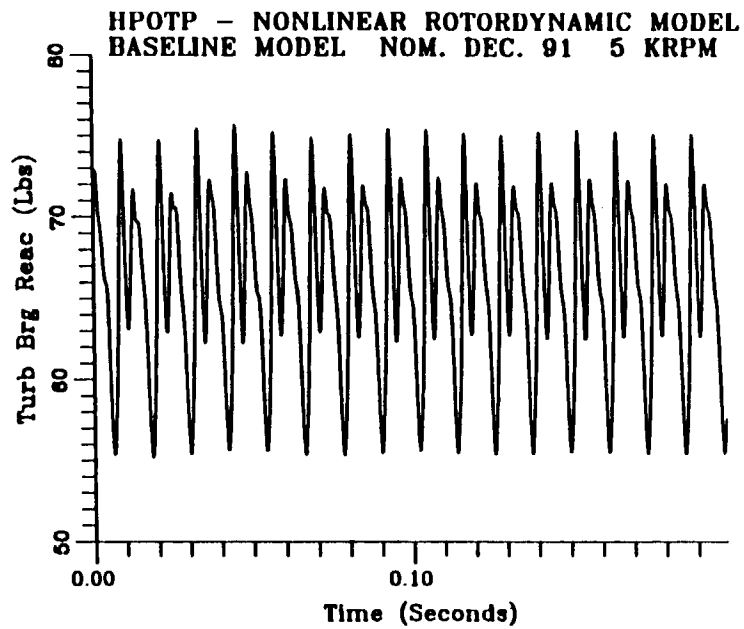

HPOTP - NONLINEAR ROTORDYNAMIC MODEL
BASELINE MODEL (LINEARIZED) 12-91
Preburner Impeller X-Z Defl
0.0002
0.0000
-0.0002
27.1
32.1
37.1
Running Speed (Thousand RPM)

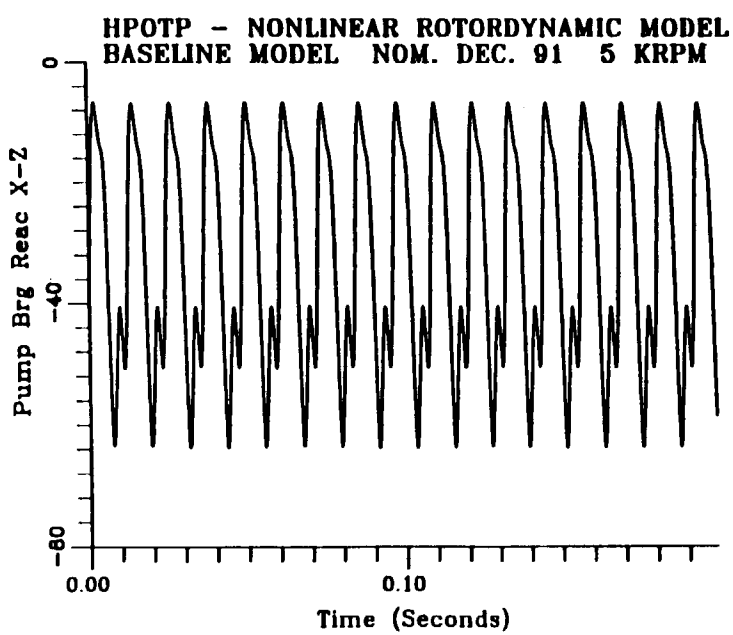

HPOTP - NONLINEAR ROTORDYNAMIC MODEL
BASELINE MODEL (LINEARIZED) 12-91
Preburner Impeller Y-Z Defl
0.0004
0.0002
0.0000
-0.0002
-0.0004
27.1
32.1
37.1
Running Speed (Thousand RPM)

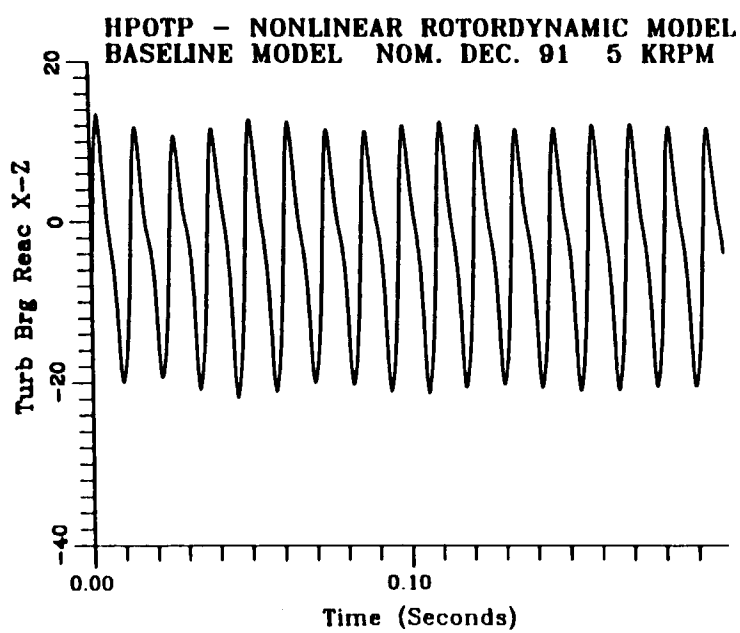
Appendix G. Nonlinear Steady State Time Transient Forced Response Plots

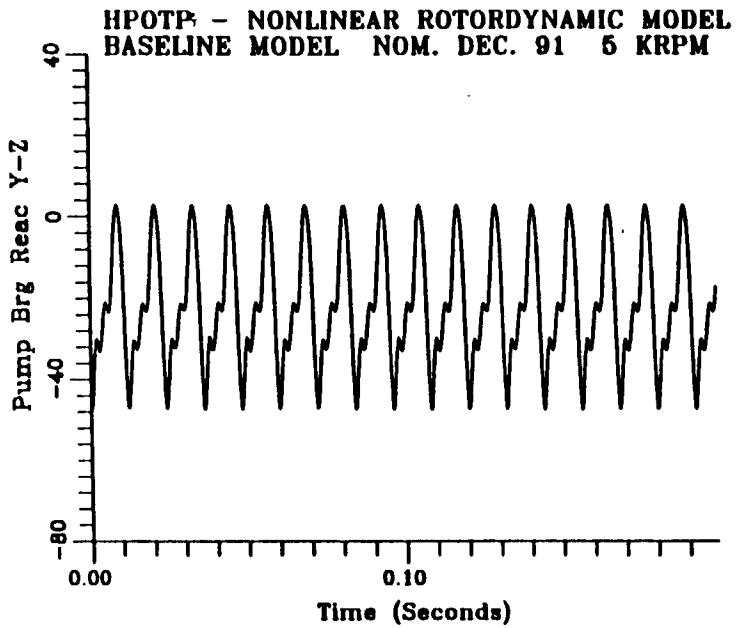
(5 KPM, 65% RPL, 90% RPL, 109% RPL and 31 KRPM)

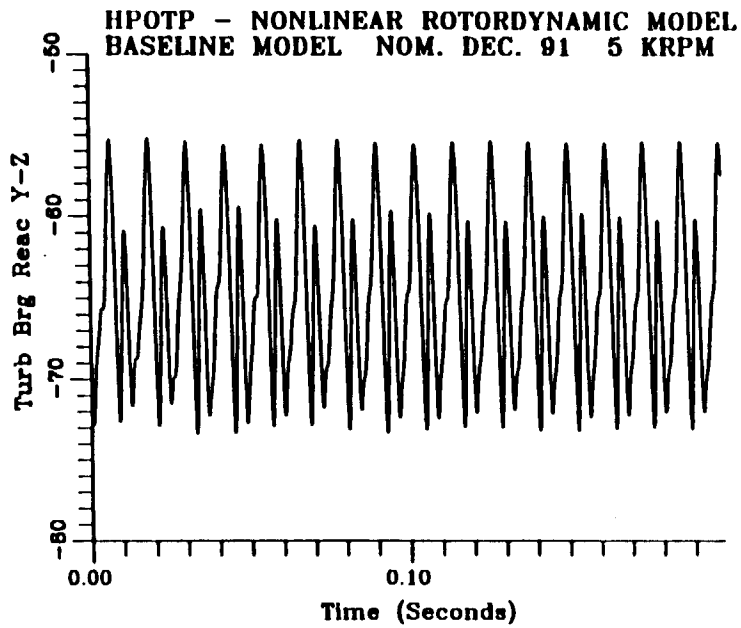

HPOTP - NONLINEAR ROTORDYNAMIC MODEL
BASELINE MODEL NOM. DEC. 91 5 KRPM
Pump Brg Reac (Lbs)
80
60
40
20
0.00
0.10
Time (Seconds)

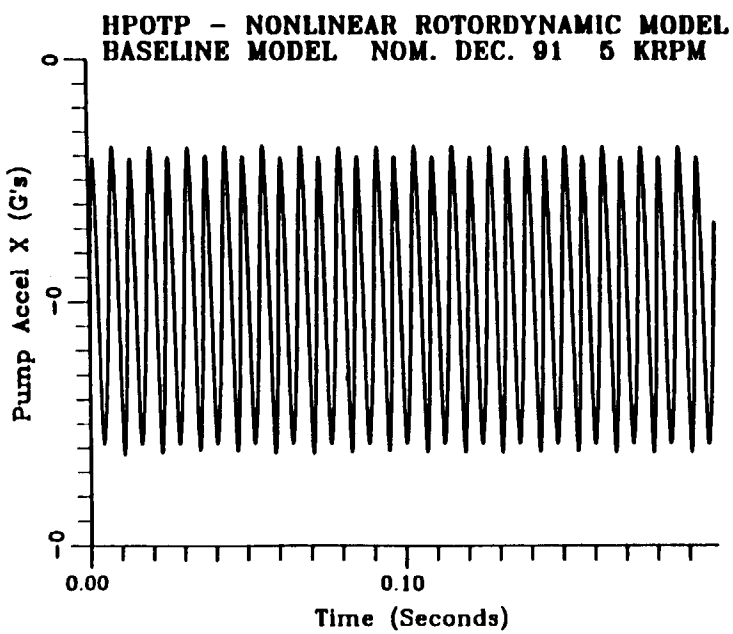

HPOTP - NONLINEAR ROTORDYNAMIC MODEL
BASELINE MODEL NOM. DEC. 91 5 KRPM
Turb Brg Reac (Lbs)
80
70
60
50
0.00
0.10
Time (Seconds)

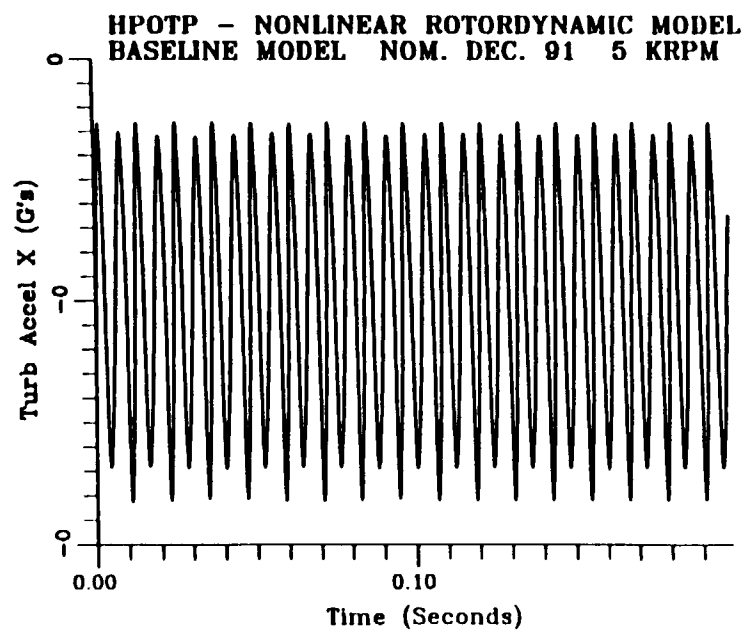

HPOTP - NONLINEAR ROTORDYNAMIC MODEL
BASELINE MODEL NOM. DEC. 91 5 KRPM
Pump Brg Reac X-Z
0
-40
-80
0.00
0.10
Time (Seconds)

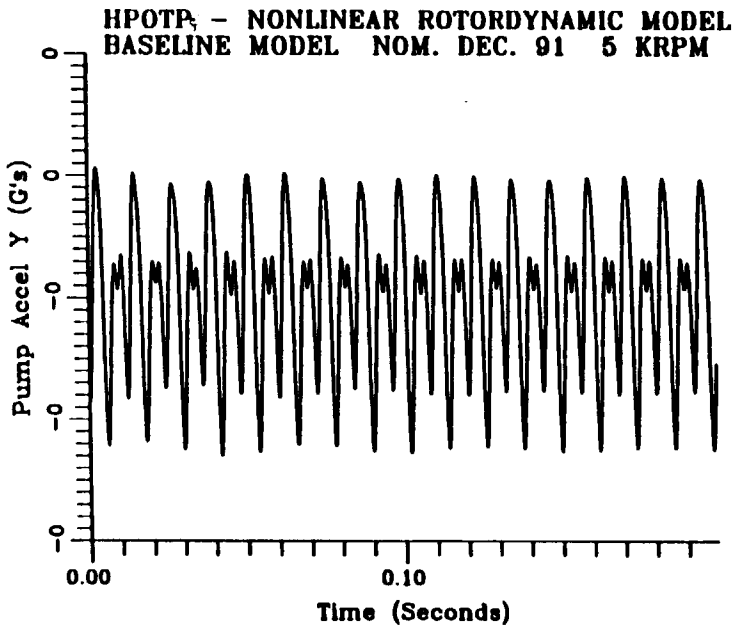

HPOTP - NONLINEAR ROTORDYNAMIC MODEL
BASELINE MODEL NOM. DEC. 91 5 KRPM
Turb Brg Reac X-Z
20
0
-20
-40
0.00
0.10
Time (Seconds)

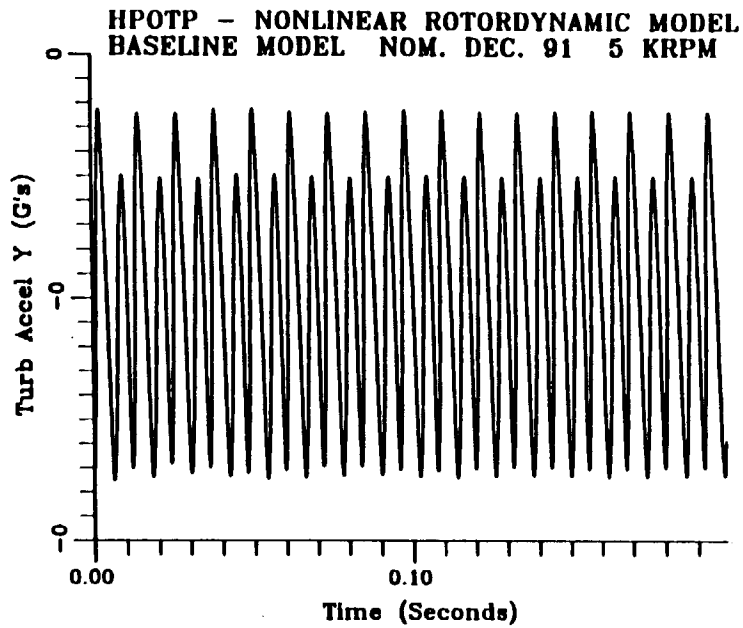

HPOTP - NONLINEAR ROTORDYNAMIC MODEL
BASELINE MODEL NOM. DEC. 91 5 KRPM
Pump Brg Reac Y-Z
40
0
-40
-80
0.00
0.10
Time (Seconds)

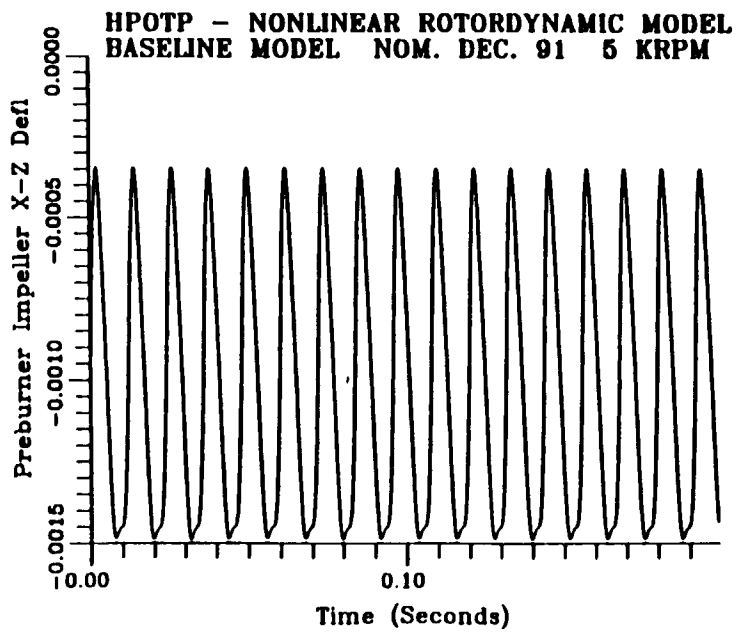

HPOTP - NONLINEAR ROTORDYNAMIC MODEL
BASELINE MODEL NOM. DEC. 91 5 KRPM
Turb Brg Reac Y-Z
-50
-60
-70
-80
0.00
0.10
Time (Seconds)

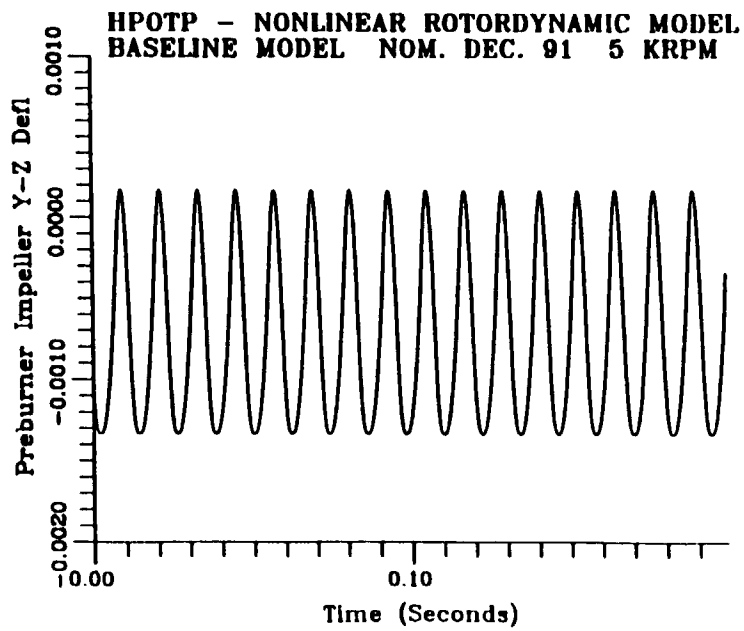

HPOTP - NONLINEAR ROTORDYNAMIC MODEL
BASELINE MODEL NOM. DEC. 91 5 KRPM
Pump Accel X (G's)
0
-0
-0
0.00
0.10
Time (Seconds)


HPOTP - NONLINEAR ROTORDYNAMIC MODEL
BASELINE MODEL NOM. DEC. 91 5 KRPM
Turb Accel X (G's)
0
-0
-0
0.00
0.10
Time (Seconds)









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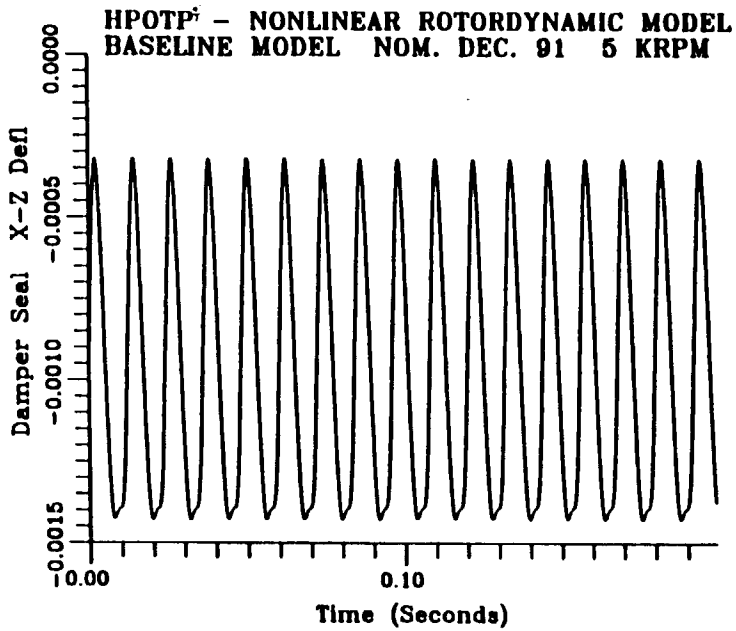
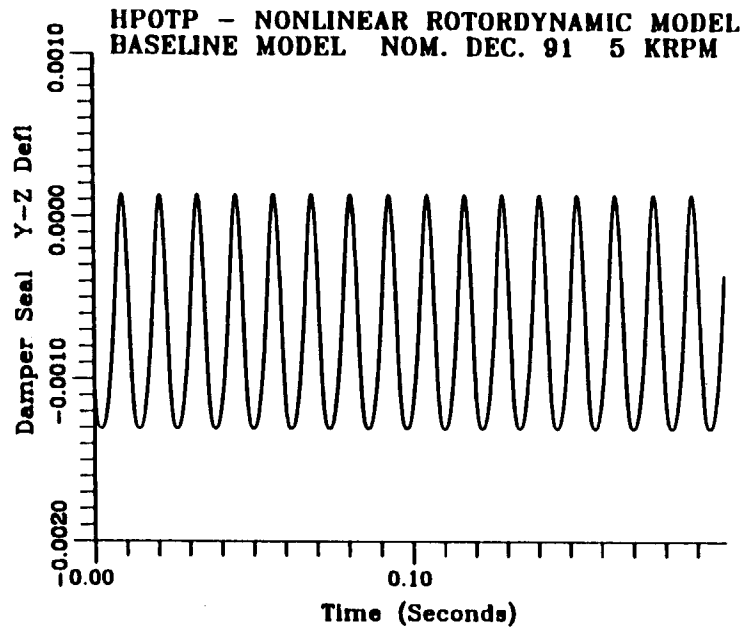
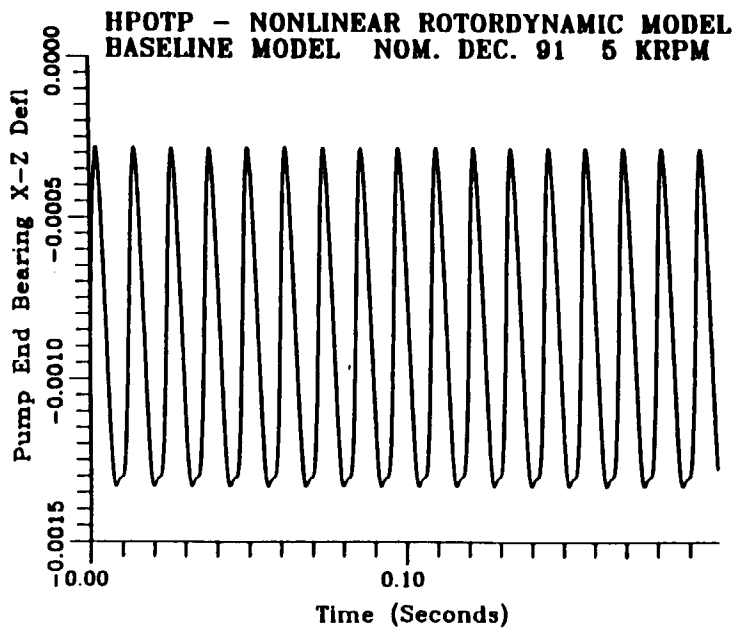
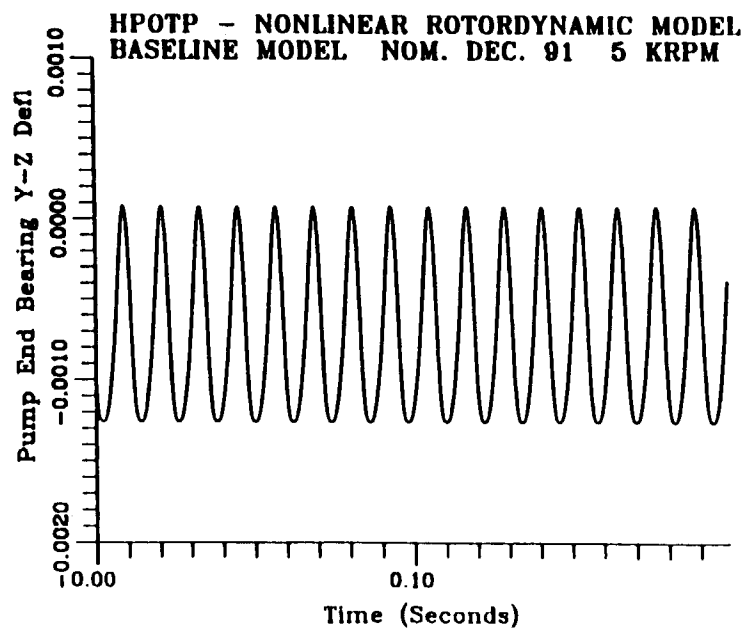
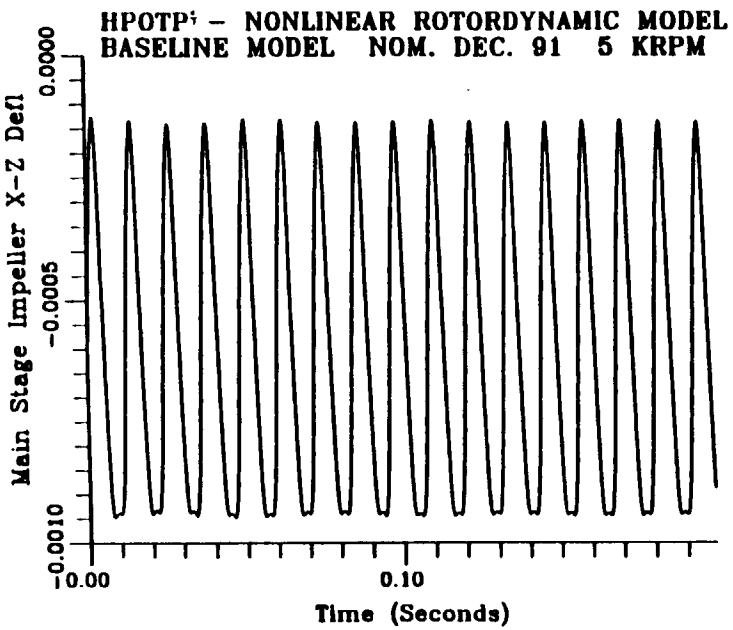

HPOTP - NONLINEAR ROTORDYNAMIC MODEL
BASELINE MODEL NOM. DEC. 91 5 KRPM
Damper Seal X-Z Defl
0.0000
-0.0005
-0.0010
-0.0015
0.00
0.10
Time (Seconds)

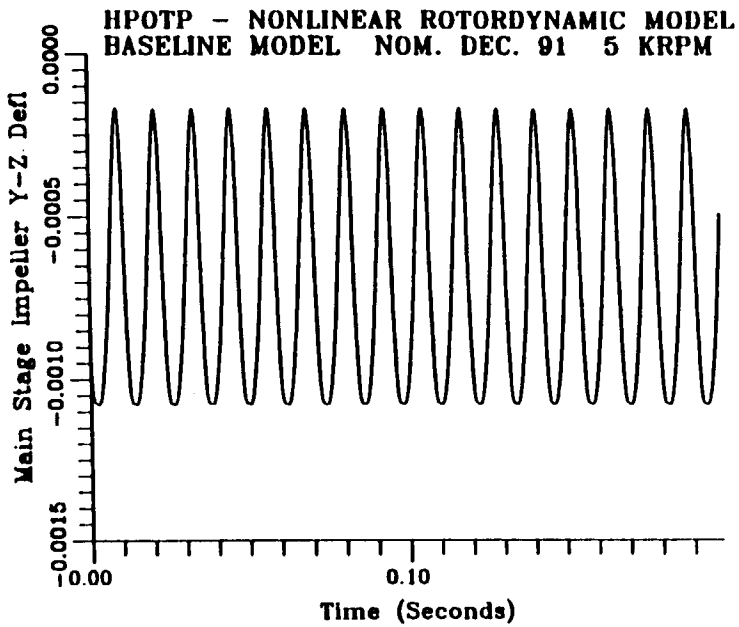

HPOTP - NONLINEAR ROTORDYNAMIC MODEL
BASELINE MODEL NOM. DEC. 91 5 KRPM
Damper Seal Y-Z Defl
0.0010
0.0000
-0.0010
-0.0020
0.00
0.10
Time (Seconds)

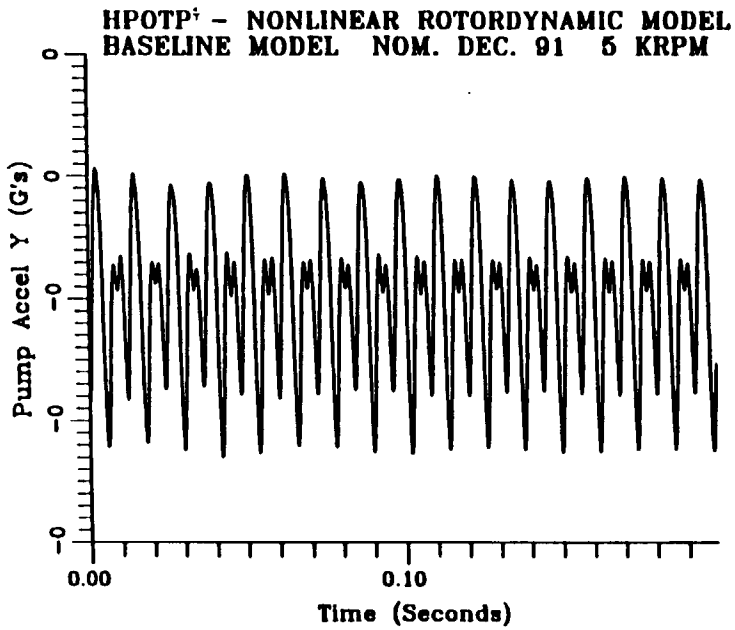

HPOTP - NONLINEAR ROTORDYNAMIC MODEL
BASELINE MODEL NOM. DEC. 91 5 KRPM
Pump End Bearing X-Z Defl
0.0000
-0.0005
-0.0010
-0.0015
0.00
0.10
Time (Seconds)

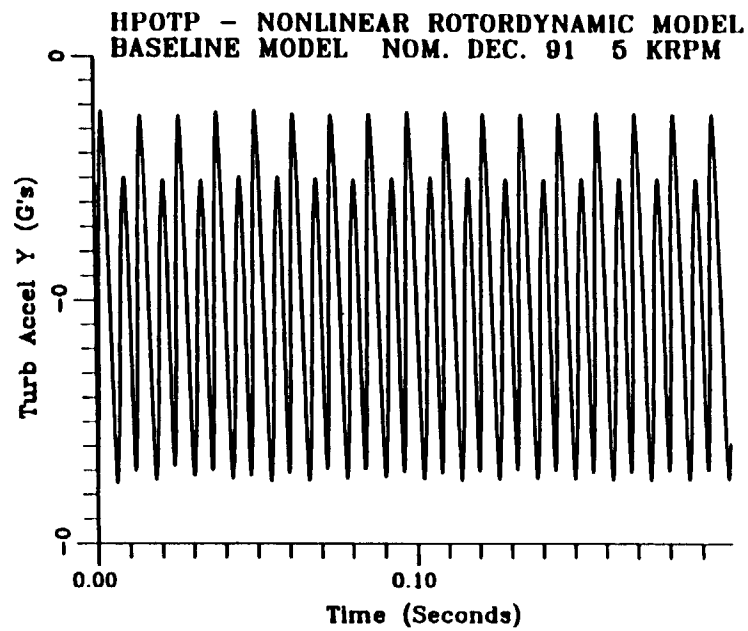

HPOTP - NONLINEAR ROTORDYNAMIC MODEL
BASELINE MODEL NOM. DEC. 91 5 KRPM
Pump End Bearing Y-Z Defl
0.0010
0.0000
-0.0010
-0.0020
0.00
0.10
Time (Seconds)

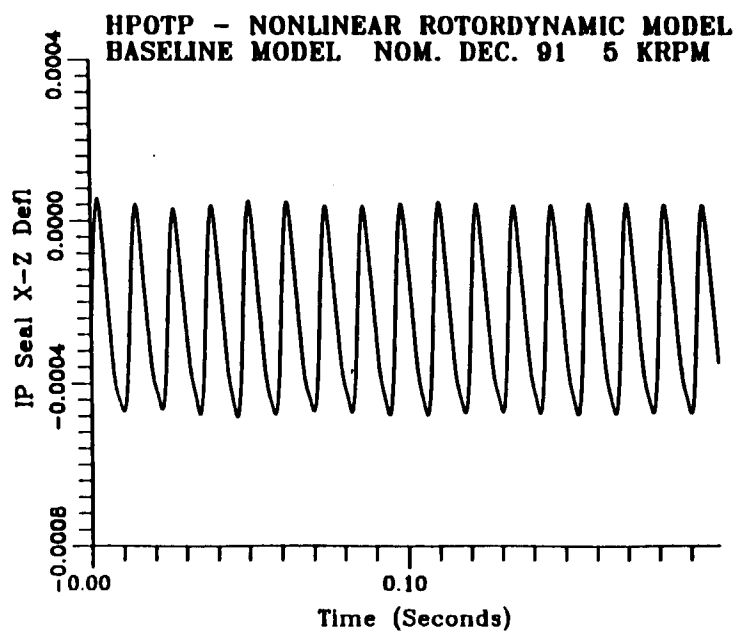
234

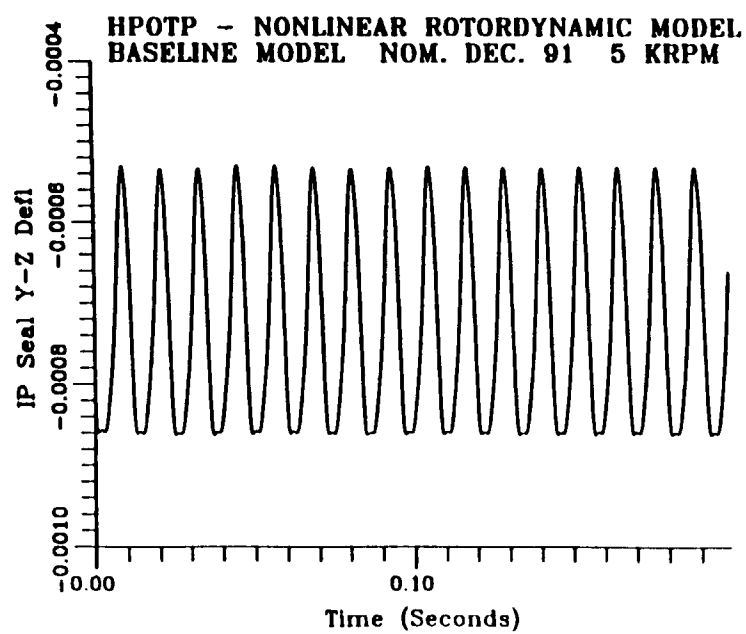

HPOTP - NONLINEAR ROTORDYNAMIC MODEL
BASELINE MODEL NOM. DEC. 91 5 KRPM
Main Stage Impeller X-Z Defl
0.0000
-0.0005
-0.0010
0.00
0.10
Time (Seconds)

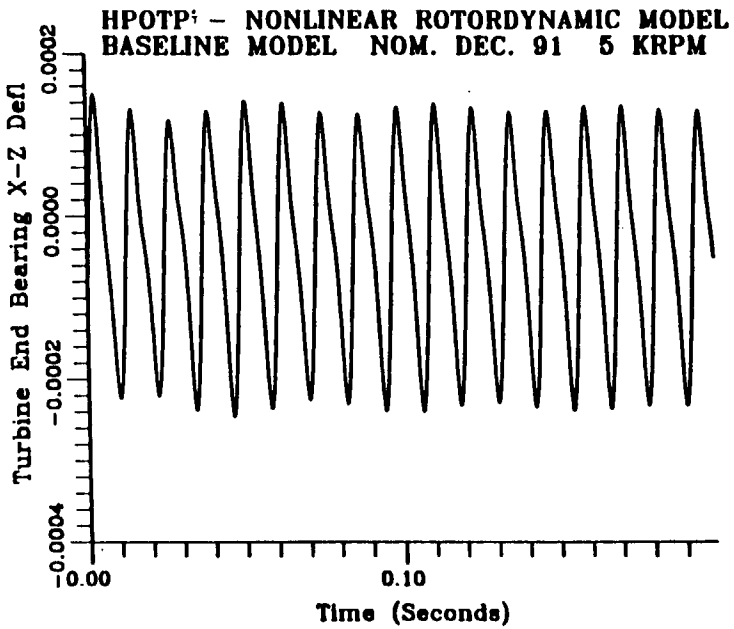

HPOTP - NONLINEAR ROTORDYNAMIC MODEL
BASELINE MODEL NOM. DEC. 91 5 KRPM
Main Stage Impeller Y-Z Defl
0.0000
-0.0005
-0.0010
-0.0015
0.00
0.10
Time (Seconds)

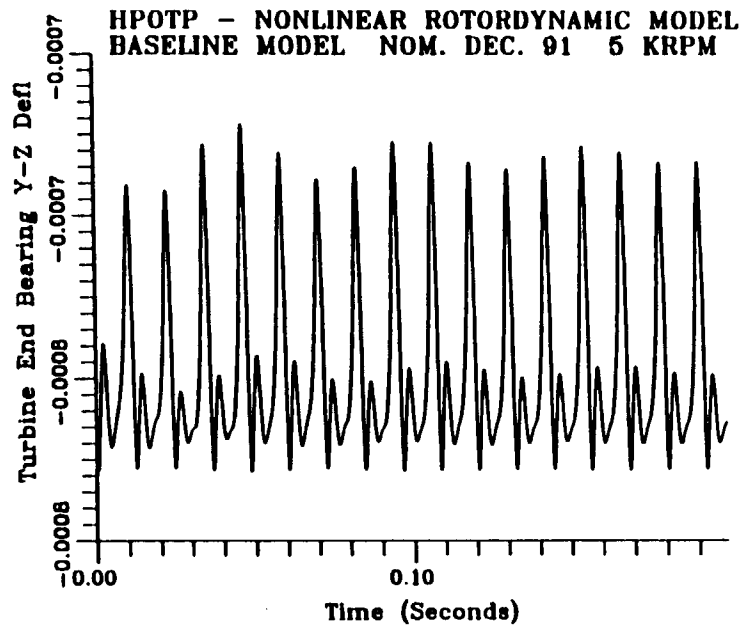

HPOTP - NONLINEAR ROTORDYNAMIC MODEL
BASELINE MODEL NOM. DEC. 91 5 KRPM
Pump Accel Y (G's)
0
0
-0
-0
-0
0.00
0.10
Time (Seconds)

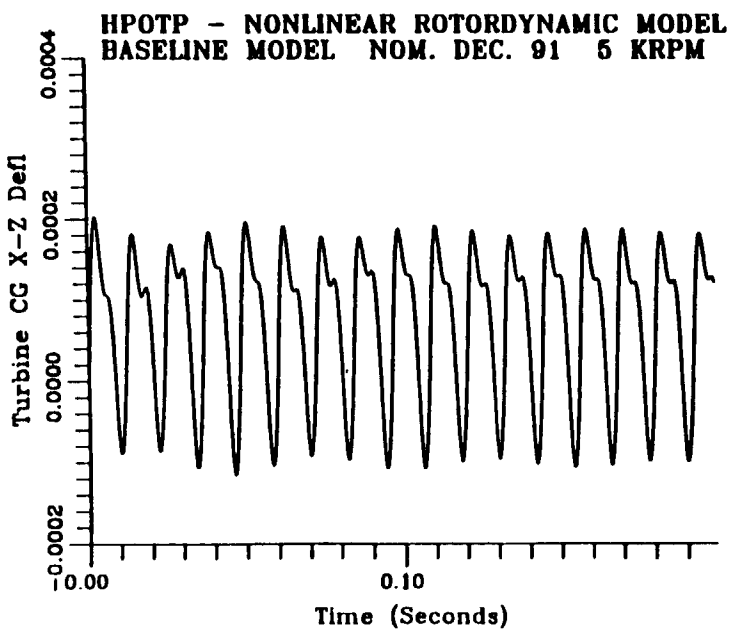

HPOTP - NONLINEAR ROTORDYNAMIC MODEL
BASELINE MODEL NOM. DEC. 91 5 KRPM
Turb Accel Y (G's)
0
-0
-0
0.00
0.10
Time (Seconds)

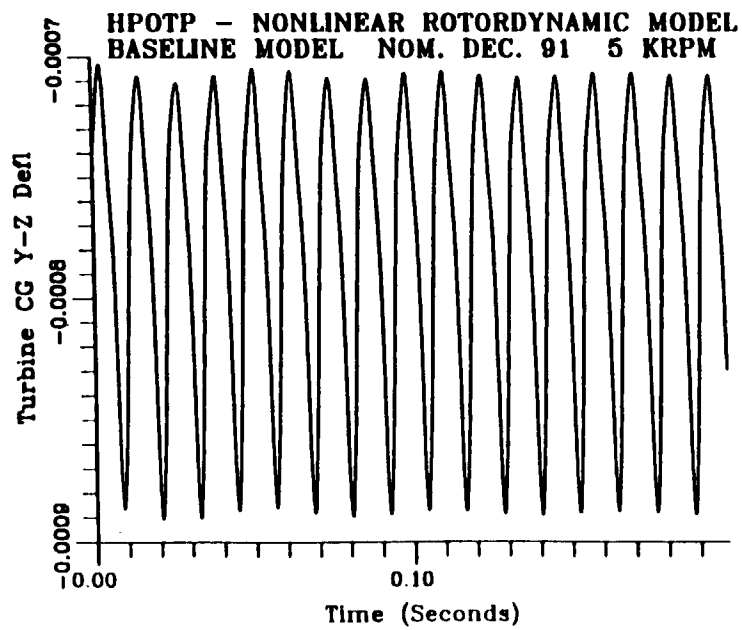

HPOTP - NONLINEAR ROTORDYNAMIC MODEL
BASELINE MODEL NOM. DEC. 91 5 KRPM
IP Seal X-Z Defl
0.0004
0.0000
-0.0004
-0.0008
0.00
0.10
Time (Seconds)

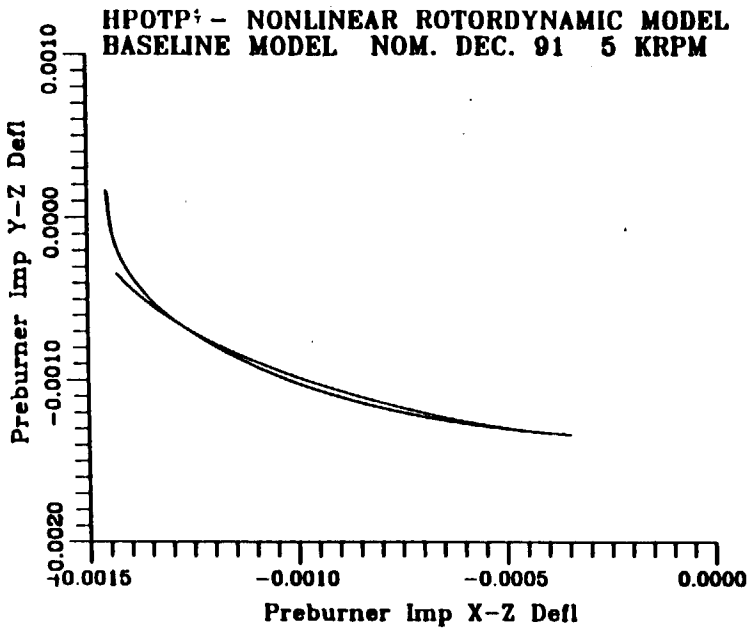

HPOTP - NONLINEAR ROTORDYNAMIC MODEL
BASELINE MODEL NOM. DEC. 91 5 KRPM
IP Seal Y-Z Defl
-0.0004
-0.0008
-0.0008
-0.0010
0.00
0.10
Time (Seconds)

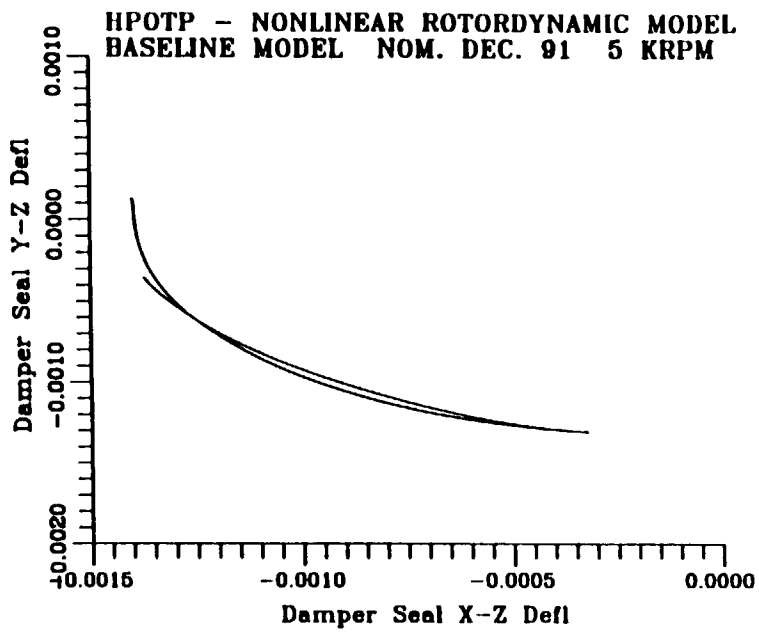

HPOTP - NONLINEAR ROTORDYNAMIC MODEL
BASELINE MODEL NOM. DEC. 91 5 KRPM
Turbine End Bearing X-Z Defl
0.0002
0.0000
-0.0002
-0.0004
0.00
0.10
Time (Seconds)

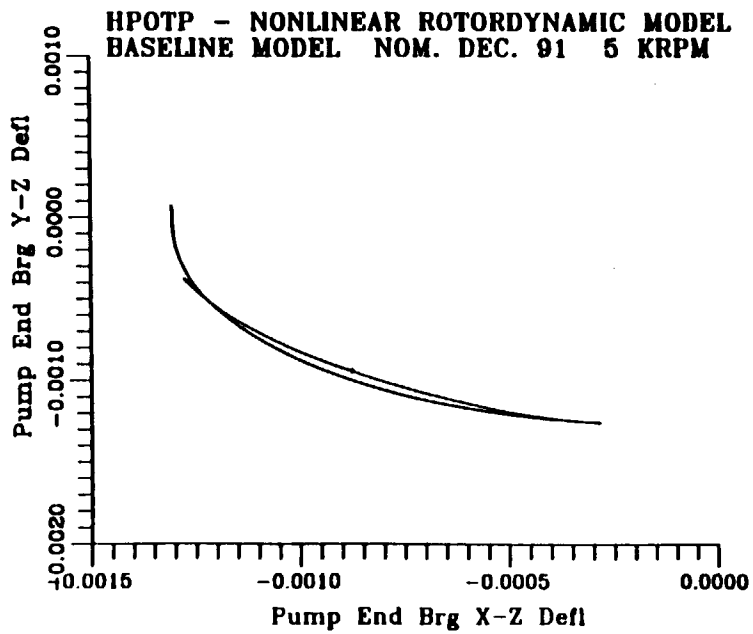

HPOTP - NONLINEAR ROTORDYNAMIC MODEL
BASELINE MODEL NOM. DEC. 91 5 KRPM
Turbine End Bearing Y-Z Defl
-0.0007
-0.0007
-0.0008
-0.0008
0.00
0.10
Time (Seconds)

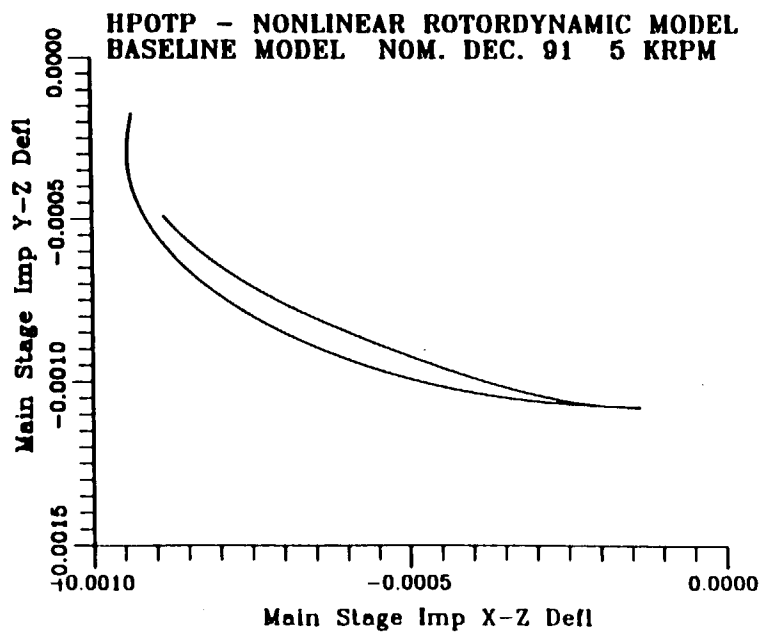

HPOTP - NONLINEAR ROTORDYNAMIC MODEL
BASELINE MODEL NOM. DEC. 91 5 KRPM
Turbine CG X-Z Defl
0.0004
0.0002
0.0000
-0.0002
0.00
0.10
Time (Seconds)

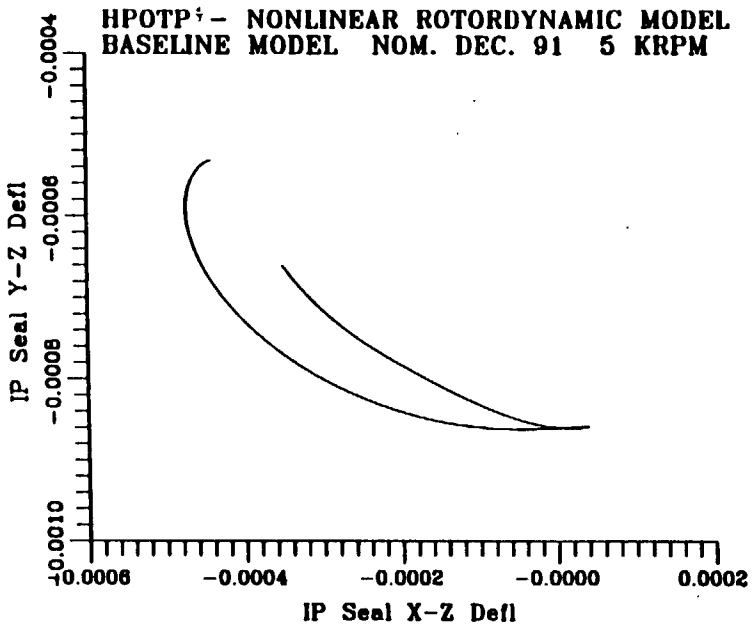

HPOTP - NONLINEAR ROTORDYNAMIC MODEL
BASELINE MODEL NOM. DEC. 91 5 KRPM
Turbine CG Y-Z Defl
-0.0007
-0.0008
-0.0009
0.00
0.10
Time (Seconds)

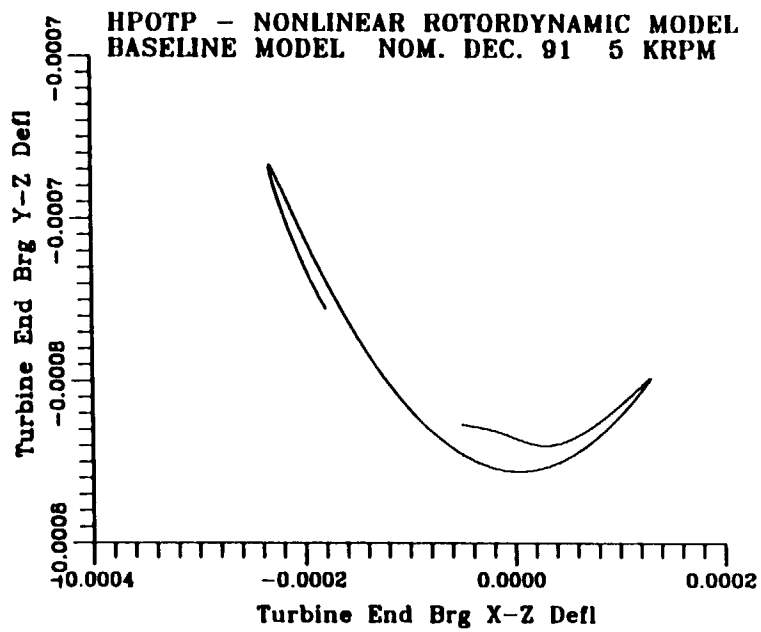

HPOTP - NONLINEAR ROTORDYNAMIC MODEL
BASELINE MODEL NOM. DEC. 91 5 KRPM
Preburner Imp Y-Z Defl
0.0010
0.0000
-0.0010
-0.0020
-0.0015
-0.0010
-0.0005
0.0000
Preburner Imp X-Z Defl

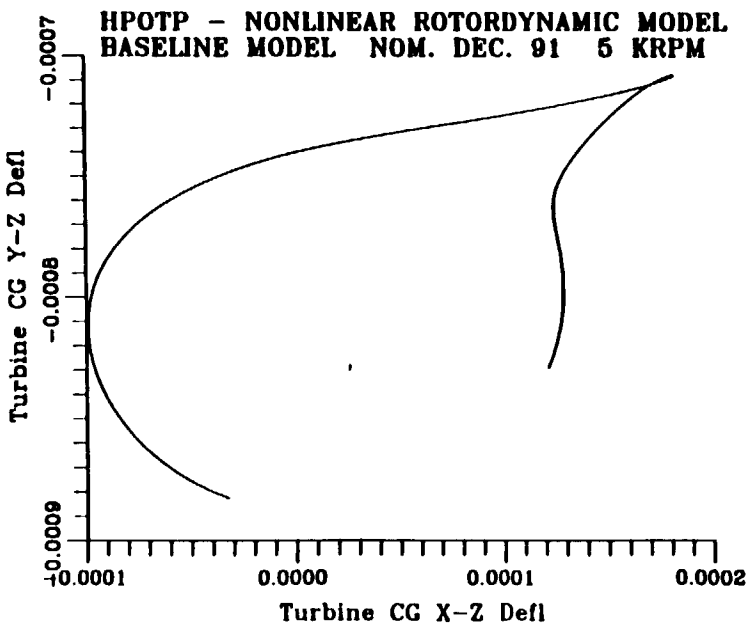

HPOTP - NONLINEAR ROTORDYNAMIC MODEL
BASELINE MODEL NOM. DEC. 91 5 KRPM
Damper Seal Y-Z Defl
0.0010
0.0000
-0.0010
-0.0020
-0.0015
-0.0010
-0.0005
0.0000
Damper Seal X-Z Defl

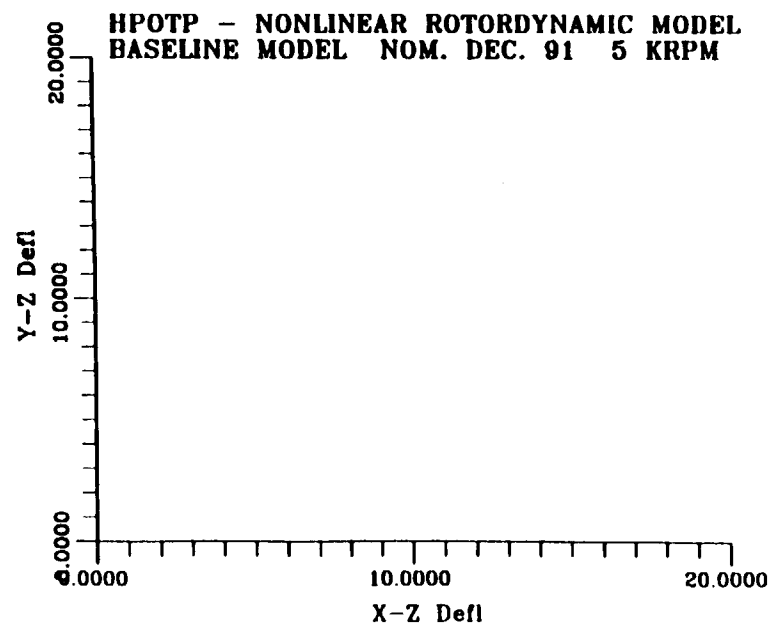

HPOTP - NONLINEAR ROTORDYNAMIC MODEL
BASELINE MODEL NOM. DEC. 91 5 KRPM
Pump End Brg Y-Z Defl
0.0010
0.0000
-0.0010
-0.0020
-0.0015
-0.0010
-0.0005
0.0000
Pump End Brg X-Z Defl

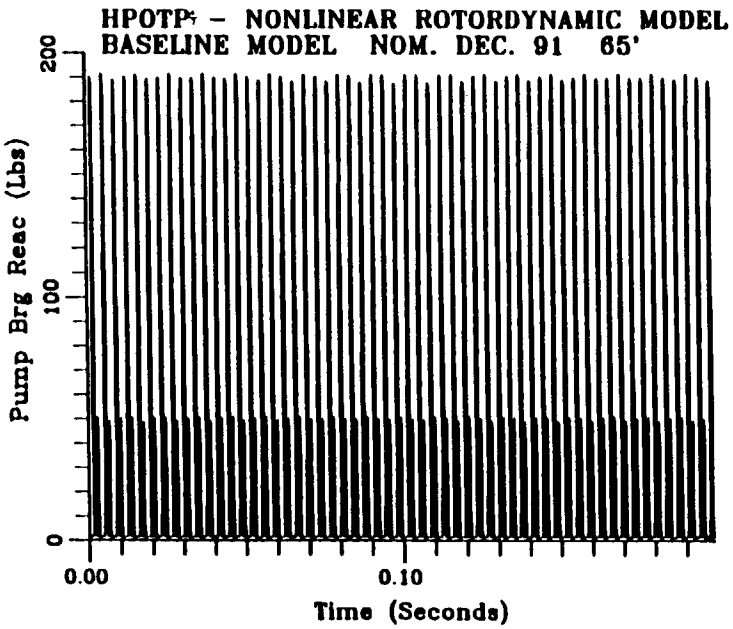

HPOTP - NONLINEAR ROTORDYNAMIC MODEL
BASELINE MODEL NOM. DEC. 91 5 KRPM
Main Stage Imp Y-Z Defl
0.0000
-0.0005
-0.0010
-0.0015
-0.0010
-0.0005
0.0000
Main Stage Imp X-Z Defl

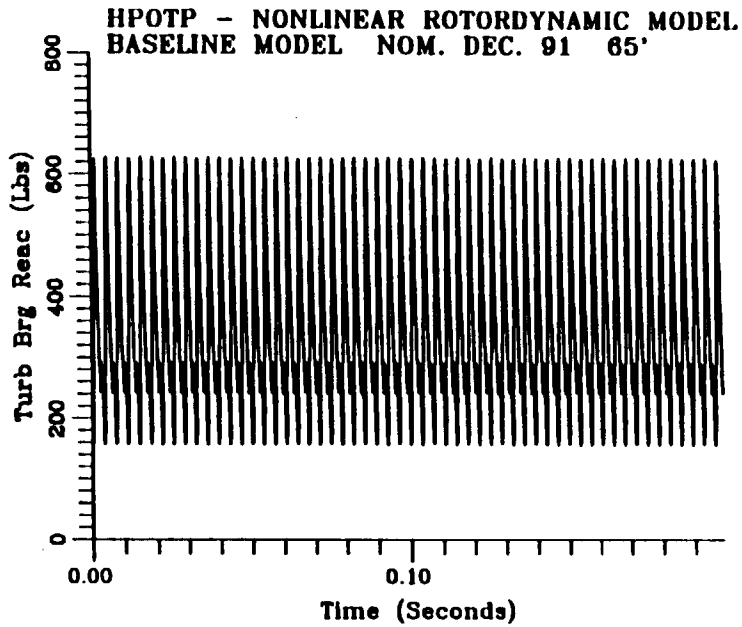

HPOTP - NONLINEAR ROTORDYNAMIC MODEL
BASELINE MODEL NOM. DEC. 91 5 KRPM
IP Seal Y-Z Defl
-0.0004
-0.0006
-0.0008
-0.0010
-0.0006
-0.0004
-0.0002
-0.0000
0.0002
IP Seal X-Z Defl

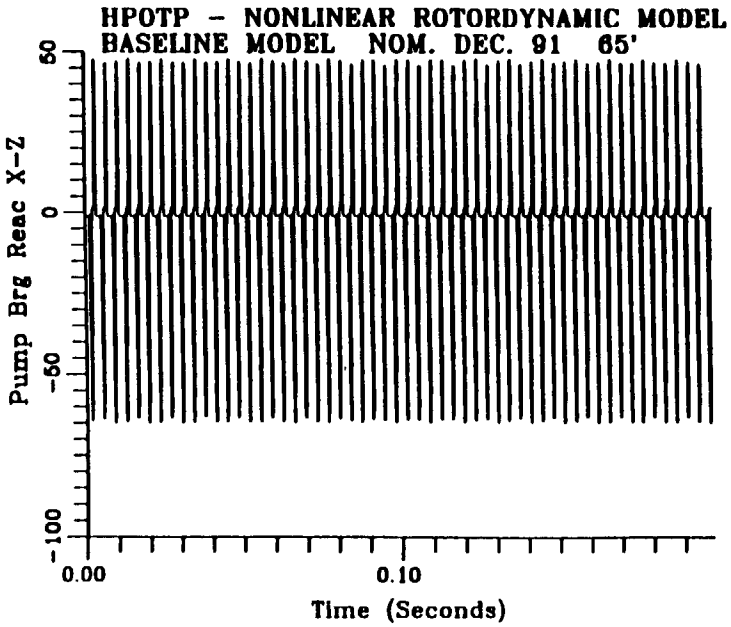

HPOTP - NONLINEAR ROTORDYNAMIC MODEL
BASELINE MODEL NOM. DEC. 91 5 KRPM
Turbine End Brg Y-Z Defl
-0.0007
-0.0007
-0.0008
-0.0008
-0.0004
-0.0002
0.0000
0.0002
Turbine End Brg X-Z Defl

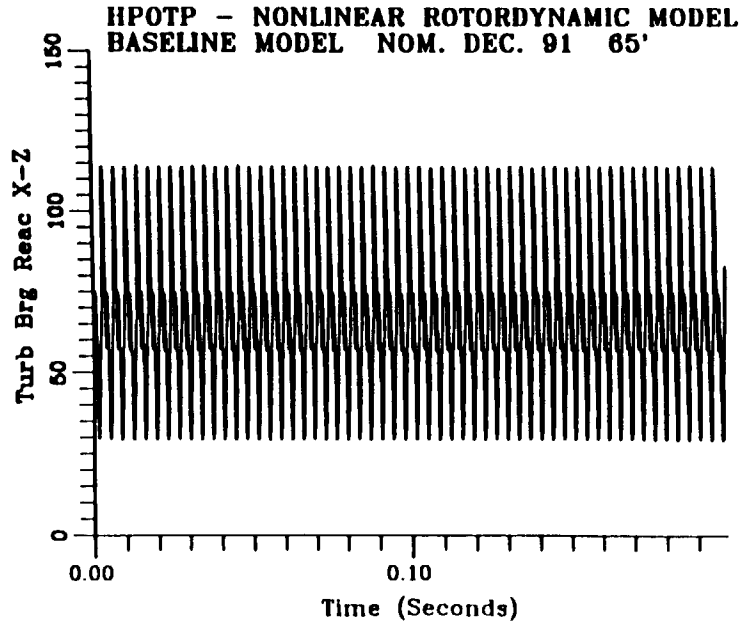

HPOTP - NONLINEAR ROTORDYNAMIC MODEL
BASELINE MODEL NOM. DEC. 91 5 KRPM
Turbine CG Y-Z Defl
-0.0007
-0.0008
-0.0009
-0.0001
0.0000
0.0001
0.0002
Turbine CG X-Z Defl

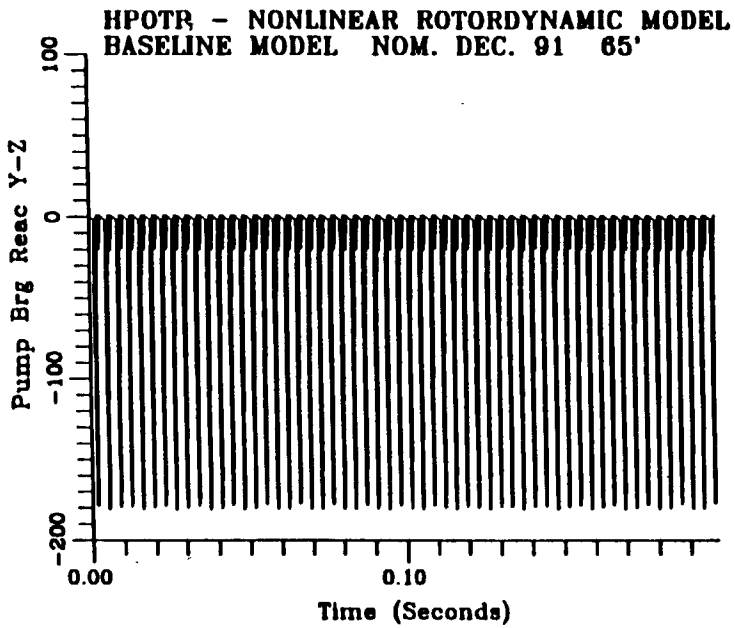

HPOTP - NONLINEAR ROTORDYNAMIC MODEL
BASELINE MODEL NOM. DEC. 91 5 KRPM
Y-Z Defl
20.0000
10.0000
0.0000
0.0000
10.0000
20.0000
X-Z Defl

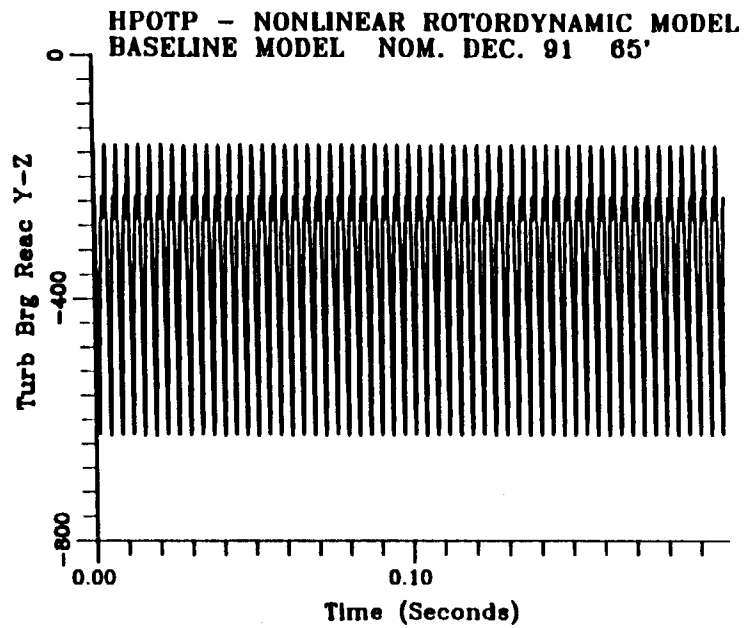

HPOTP - NONLINEAR ROTORDYNAMIC MODEL
BASELINE MODEL NOM. DEC. 91 65'
Pump Brg Reac (Lbs)
200
100
0
0.00
0.10
Time (Seconds)

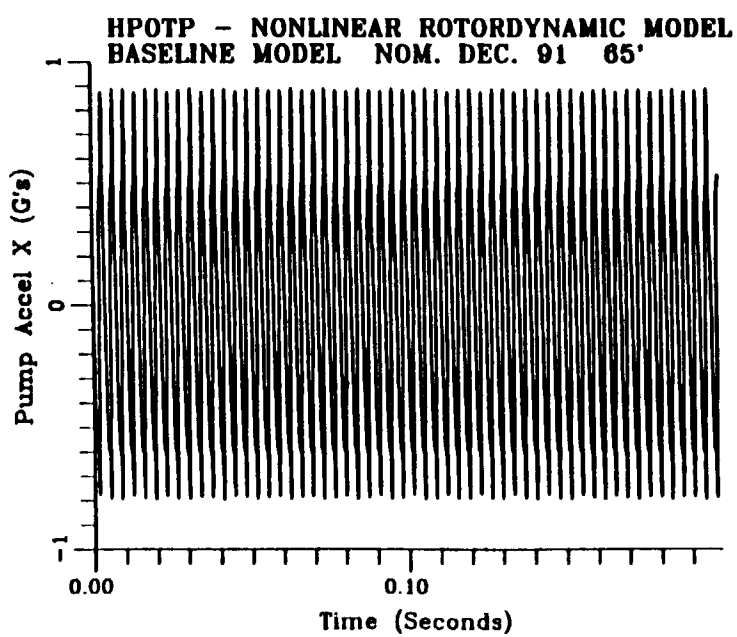

HPOTP - NONLINEAR ROTORDYNAMIC MODEL
BASELINE MODEL NOM. DEC. 91 65'
Turb Brg Reac (Lbs)
800
600
400
200
0
0.00
0.10
Time (Seconds)

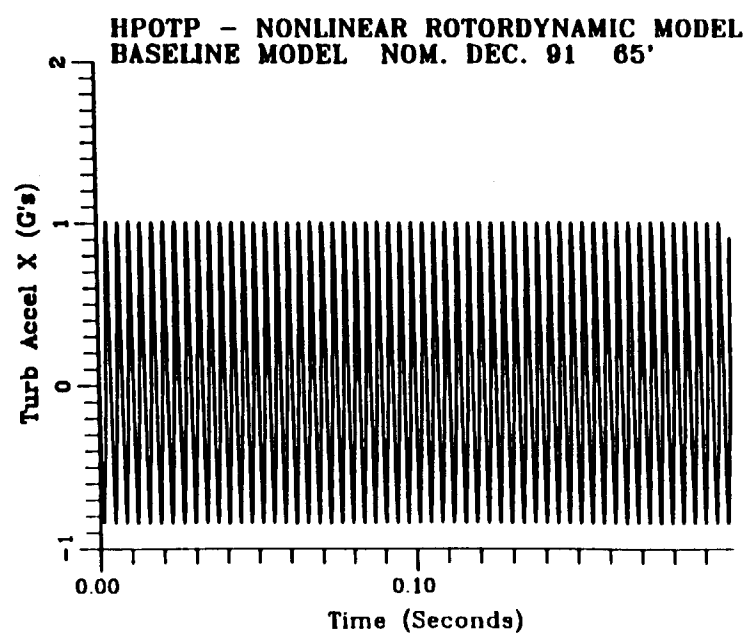

HPOTP - NONLINEAR ROTORDYNAMIC MODEL
BASELINE MODEL NOM. DEC. 91 65'
Pump Brg Reac X-Z
50
0
-50
-100
0.00
0.10
Time (Seconds)

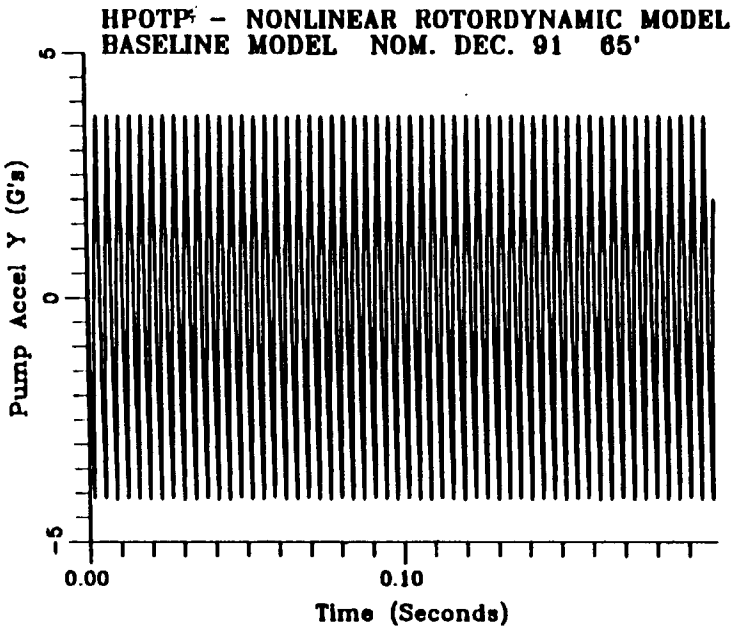

HPOTP - NONLINEAR ROTORDYNAMIC MODEL
BASELINE MODEL NOM. DEC. 91 65'
Turb Brg Reac X-Z
150
100
50
0
0.00
0.10
Time (Seconds)

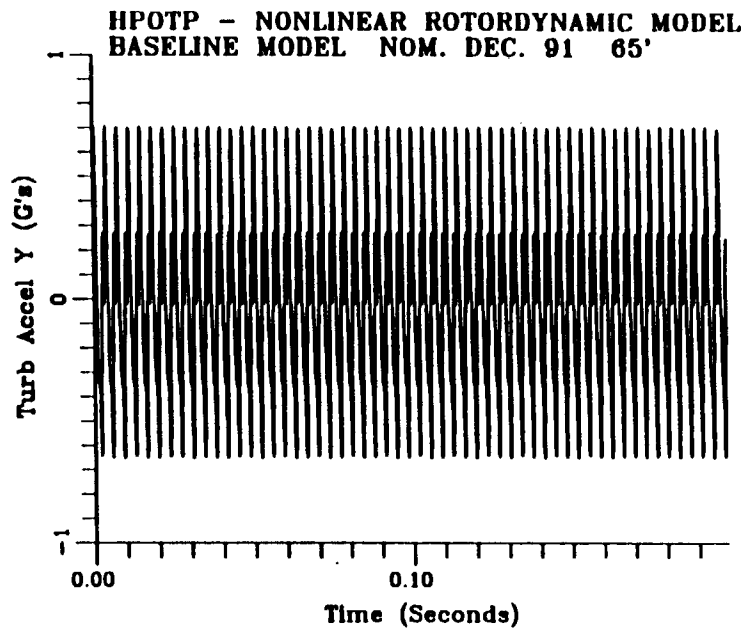

HPOTP - NONLINEAR ROTORDYNAMIC MODEL
BASELINE MODEL NOM. DEC. 91 65'
Pump Brg Reac Y-Z
100
0
-100
-200
0.00
0.10
Time (Seconds)

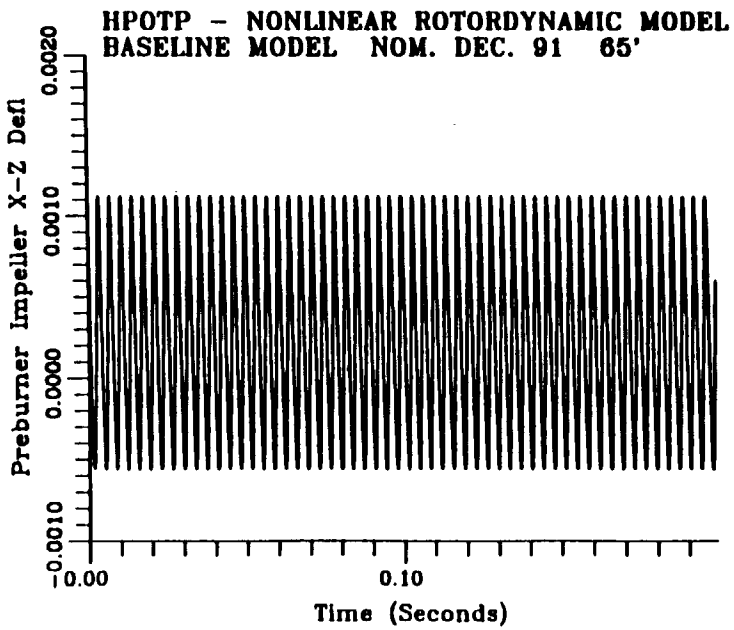

HPOTP - NONLINEAR ROTORDYNAMIC MODEL
BASELINE MODEL NOM. DEC. 91 65'
Turb Brg Reac Y-Z
0
-400
-800
0.00
0.10
Time (Seconds)

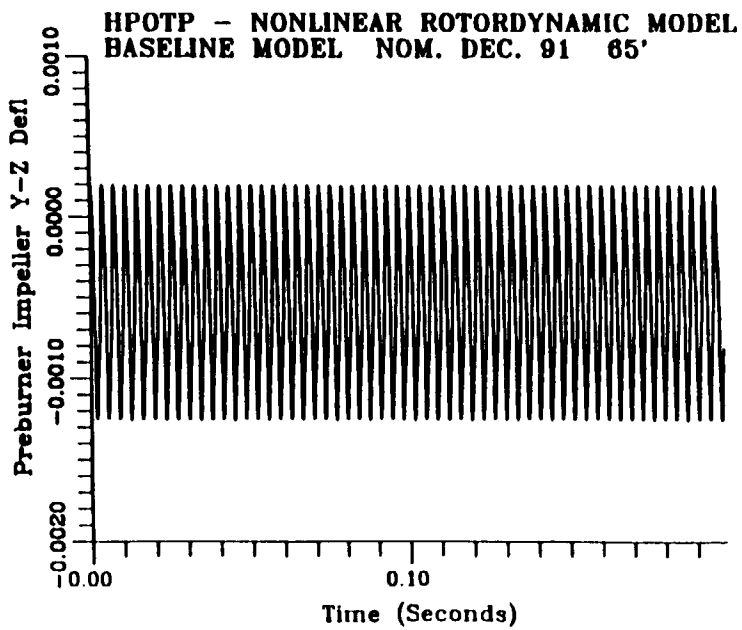

HPOTP - NONLINEAR ROTORDYNAMIC MODEL
BASELINE MODEL NOM. DEC. 91 65'
Pump Accel X (G's)
1
0
-1
0.00
0.10
Time (Seconds)

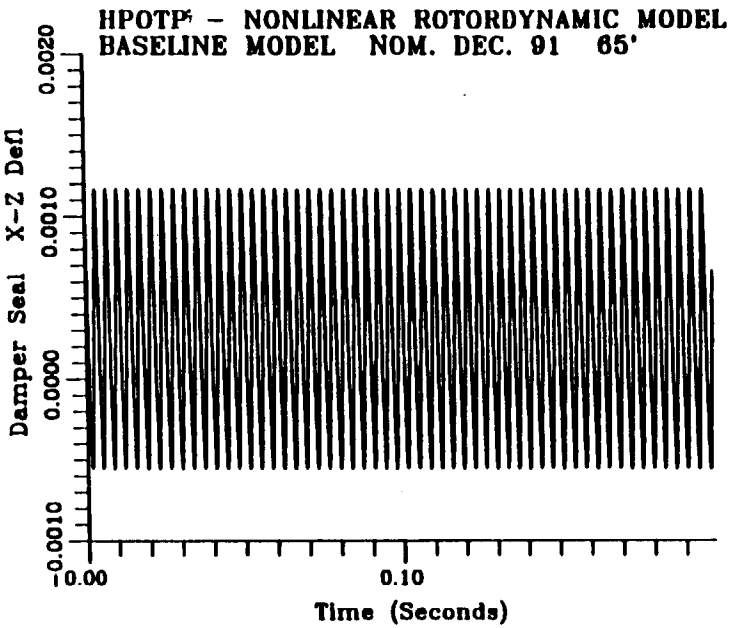

HPOTP - NONLINEAR ROTORDYNAMIC MODEL
BASELINE MODEL NOM. DEC. 91 65'
Turb Accel X (G's)
2
1
0
-1
0.00
0.10
Time (Seconds)

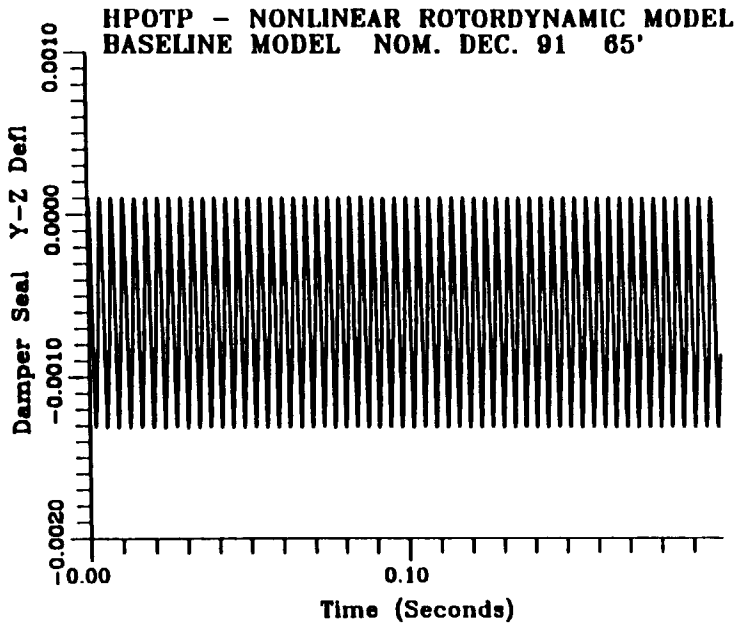

HPOTP - NONLINEAR ROTORDYNAMIC MODEL
BASELINE MODEL NOM. DEC. 91 65'
Pump Accel Y (G's)
5
0
-5
0.00
0.10
Time (Seconds)

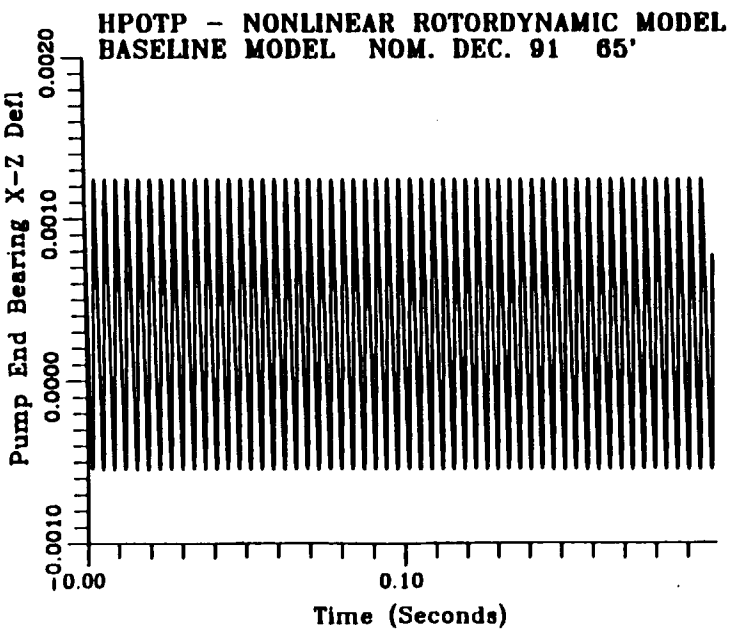

HPOTP - NONLINEAR ROTORDYNAMIC MODEL
BASELINE MODEL NOM. DEC. 91 65'
Turb Accel Y (G's)
1
0
-1
0.00
0.10
Time (Seconds)

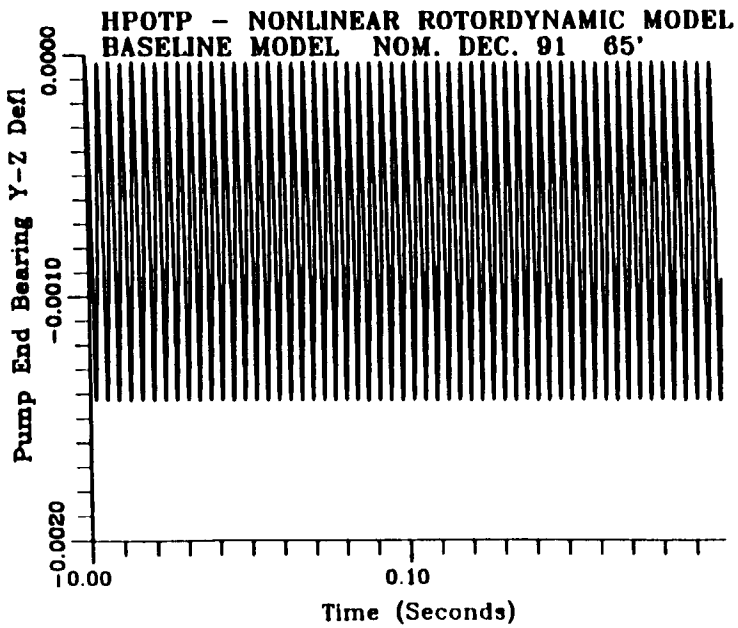

HPOTP - NONLINEAR ROTORDYNAMIC MODEL
BASELINE MODEL NOM. DEC. 91 65'
Preburner Impeller X-Z Defl
0.0020
0.0010
0.0000
-0.0010
0.00
0.10
Time (Seconds)

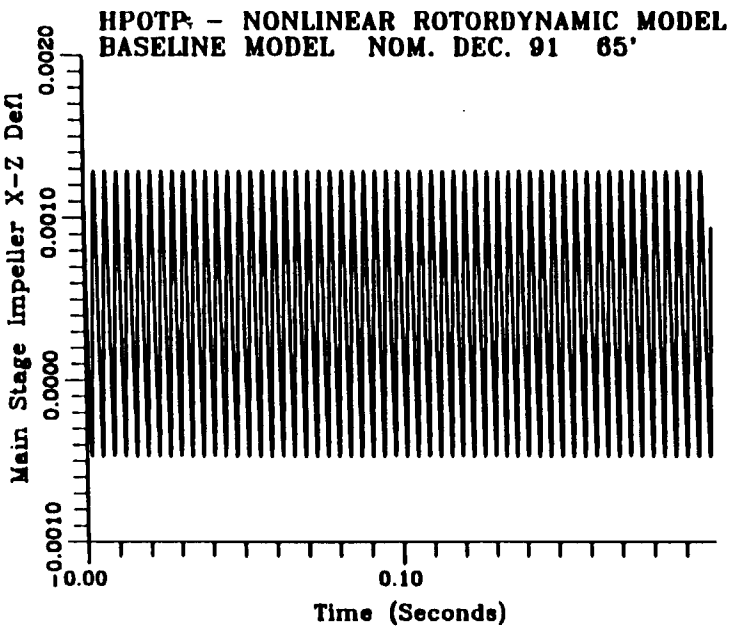

HPOTP - NONLINEAR ROTORDYNAMIC MODEL
BASELINE MODEL NOM. DEC. 91 65'
Preburner Impeller Y-Z Defl
0.0010
0.0000
-0.0010
-0.0020
0.00
0.10
Time (Seconds)

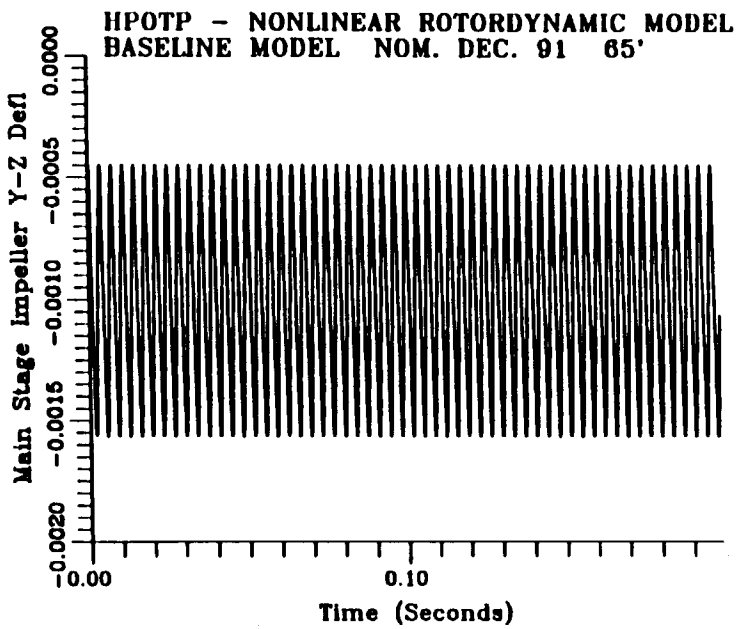

HPOTP - NONLINEAR ROTORDYNAMIC MODEL
BASELINE MODEL NOM. DEC. 91 65'
Damper Seal X-Z Defl
0.0020
0.0010
0.0000
-0.0010
0.00
0.10
Time (Seconds)

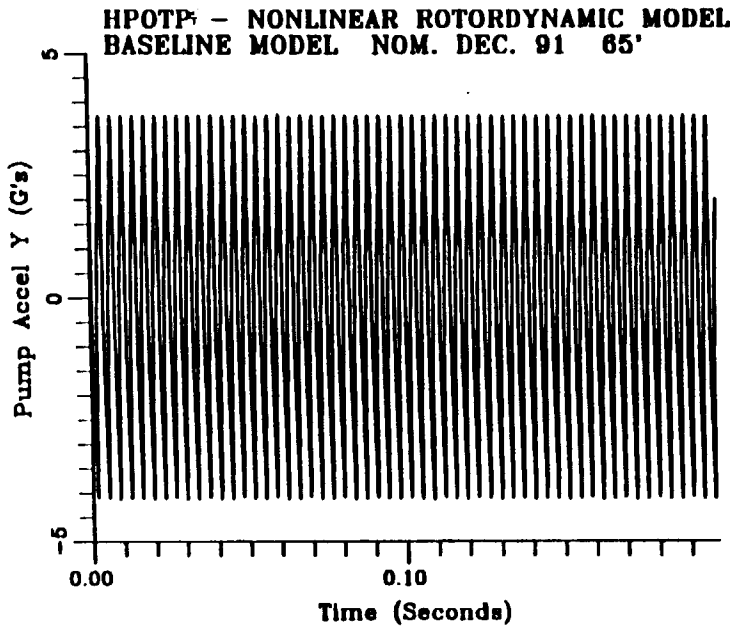

HPOTP - NONLINEAR ROTORDYNAMIC MODEL
BASELINE MODEL NOM. DEC. 91 65'
Damper Seal Y-Z Defl
0.0010
0.0000
-0.0010
-0.0020
0.00
0.10
Time (Seconds)

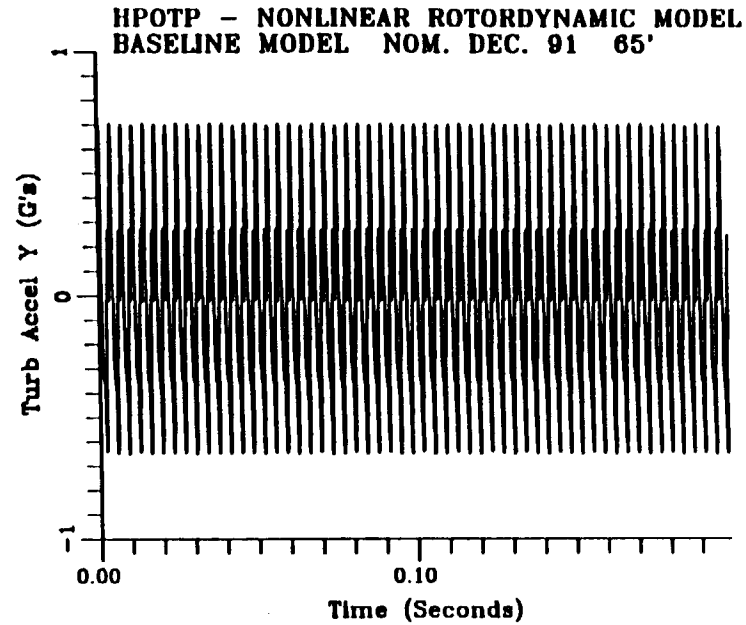

HPOTP - NONLINEAR ROTORDYNAMIC MODEL
BASELINE MODEL NOM. DEC. 91 65'
Pump End Bearing X-Z Defl
0.0020
0.0010
0.0000
-0.0010
0.00
0.10
Time (Seconds)

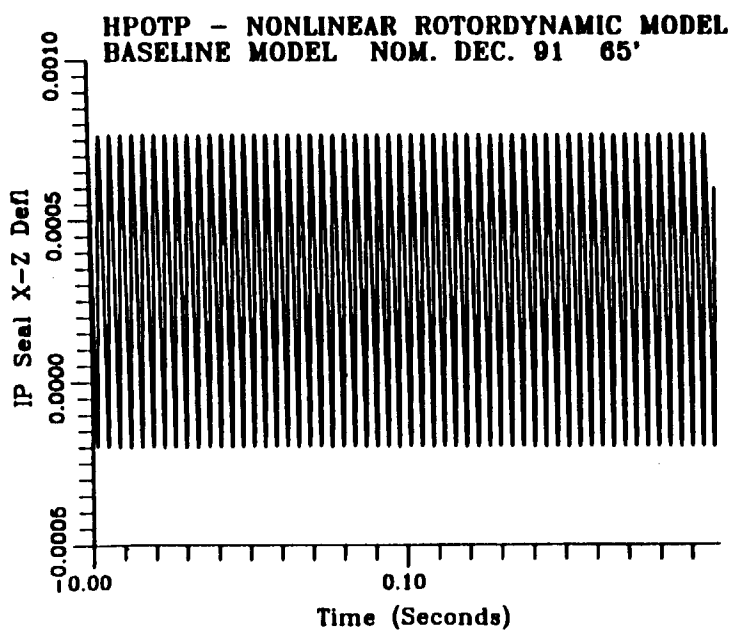

HPOTP - NONLINEAR ROTORDYNAMIC MODEL
BASELINE MODEL NOM. DEC. 91 65'
Pump End Bearing Y-Z Defl
0.0000
-0.0010
-0.0020
0.00
0.10
Time (Seconds)

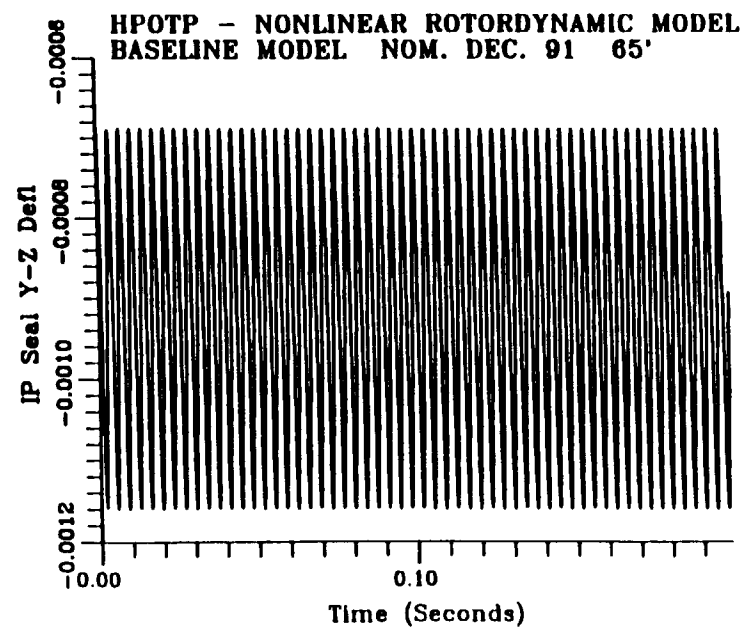

HPOTP - NONLINEAR ROTORDYNAMIC MODEL
BASELINE MODEL NOM. DEC. 91 65'
Main Stage Impeller X-Z Defl
0.0020
0.0010
0.0000
-0.0010
0.00
0.10
Time (Seconds)

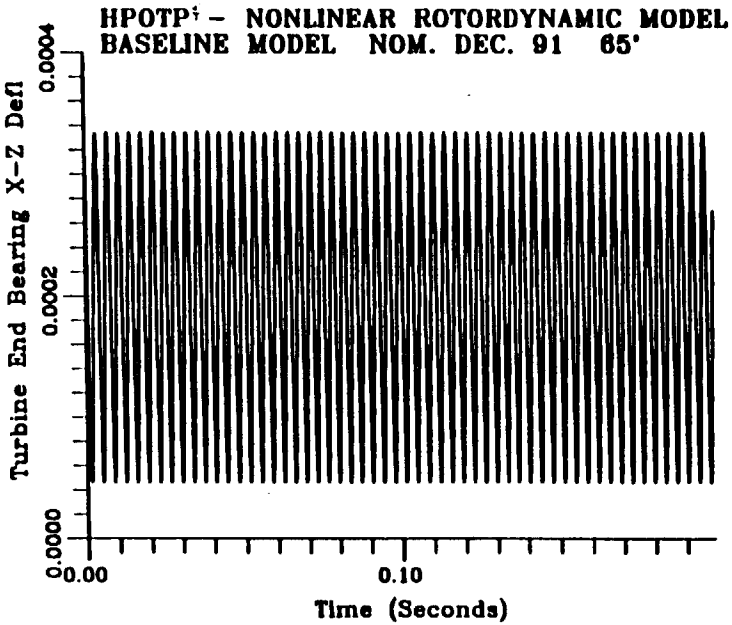

HPOTP - NONLINEAR ROTORDYNAMIC MODEL
BASELINE MODEL NOM. DEC. 91 65'
Main Stage Impeller Y-Z Defl
0.0000
-0.0005
-0.0010
-0.0015
-0.0020
0.00
0.10
Time (Seconds)

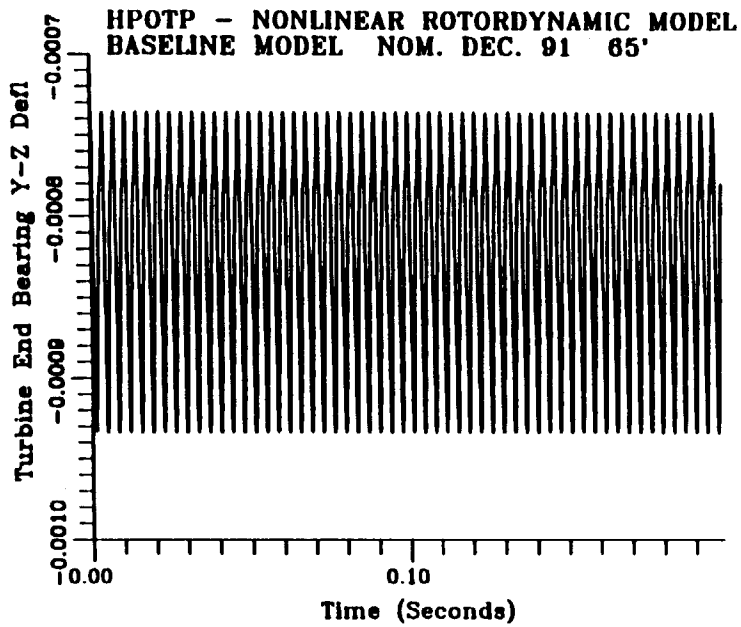

HPOTP - NONLINEAR ROTORDYNAMIC MODEL
BASELINE MODEL NOM. DEC. 91 65'
Pump Accel Y (G's)
5
0
-5
0.00
0.10
Time (Seconds)

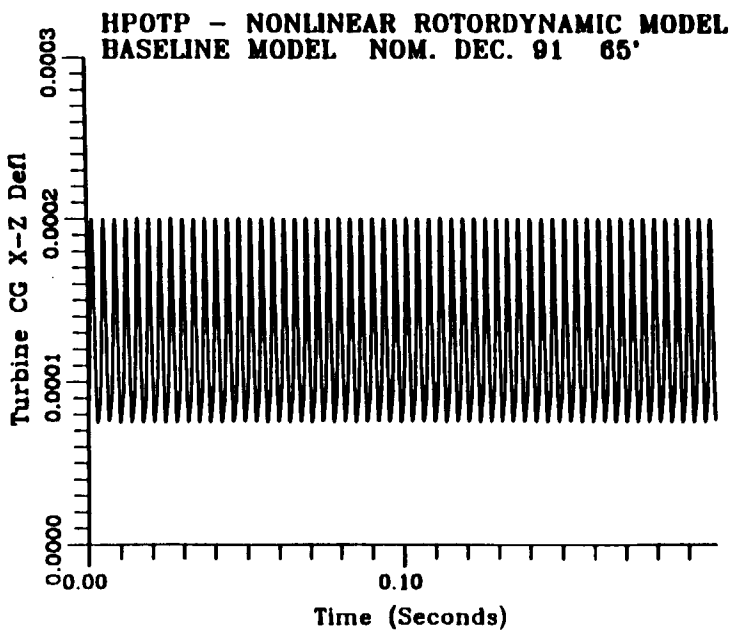

HPOTP - NONLINEAR ROTORDYNAMIC MODEL
BASELINE MODEL NOM. DEC. 91 65'
Turb Accel Y (G's)
1
0
-1
0.00
0.10
Time (Seconds)

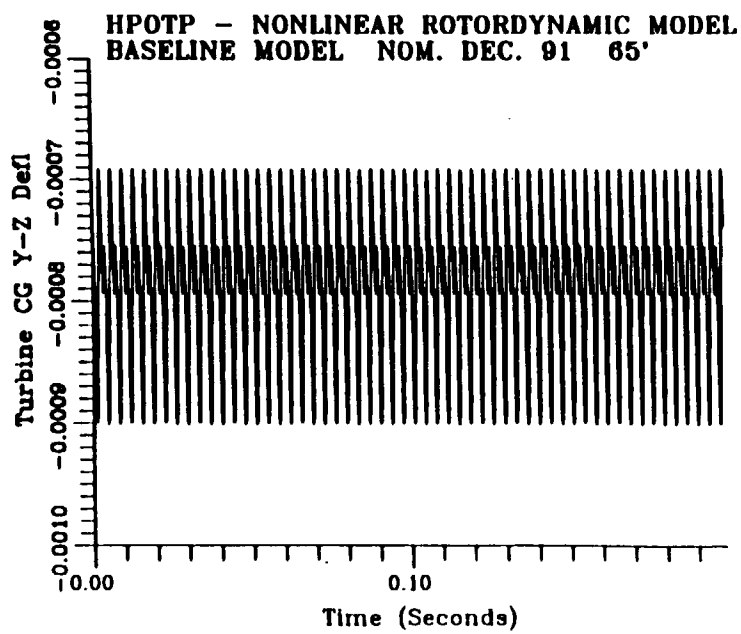

HPOTP - NONLINEAR ROTORDYNAMIC MODEL
BASELINE MODEL NOM. DEC. 91 65'
IP Seal X-Z Defl
0.0010
0.0005
0.0000
-0.0005
0.00
0.10
Time (Seconds)

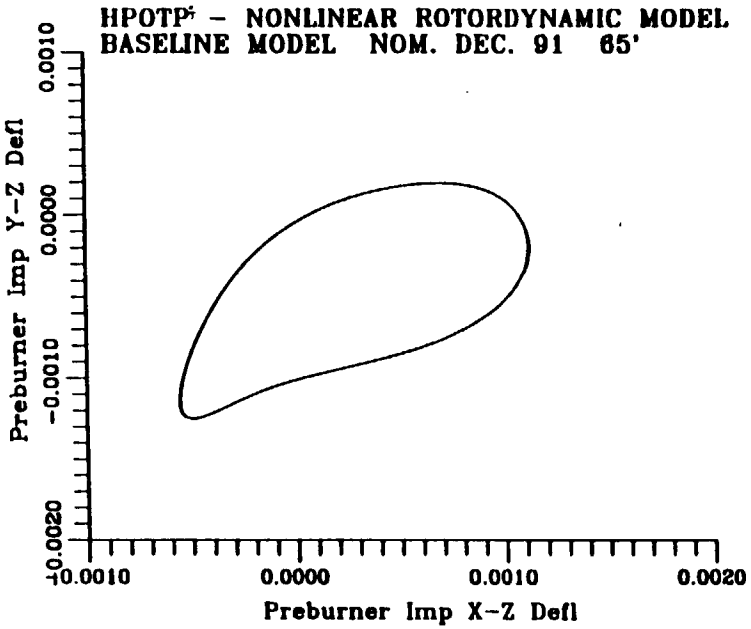

HPOTP - NONLINEAR ROTORDYNAMIC MODEL
BASELINE MODEL NOM. DEC. 91 65'
IP Seal Y-Z Defl
-0.0006
-0.0008
-0.0010
-0.0012
0.00
0.10
Time (Seconds)

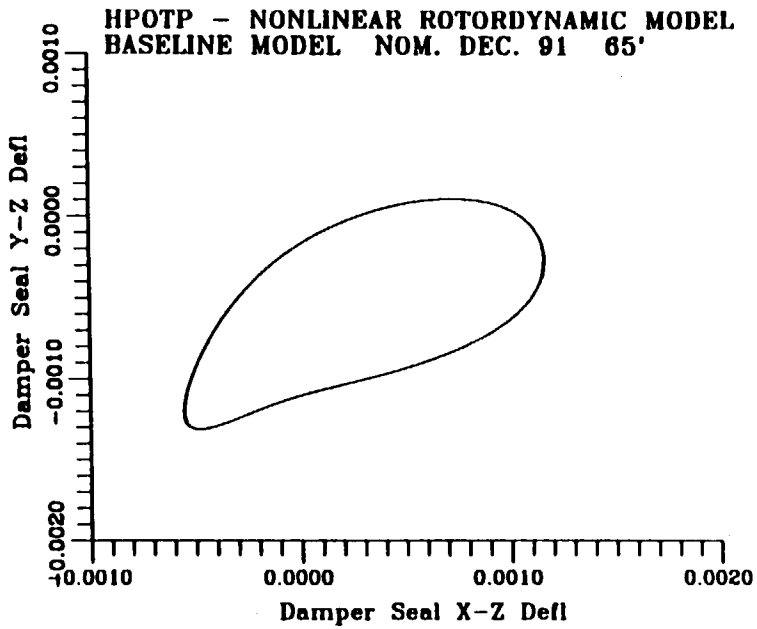

HPOTP† - NONLINEAR ROTORDYNAMIC MODEL
BASELINE MODEL NOM. DEC. 91 65'
Turbine End Bearing X-Z Defl
0.0000
0.0002
0.0004
0.00
0.10
Time (Seconds)

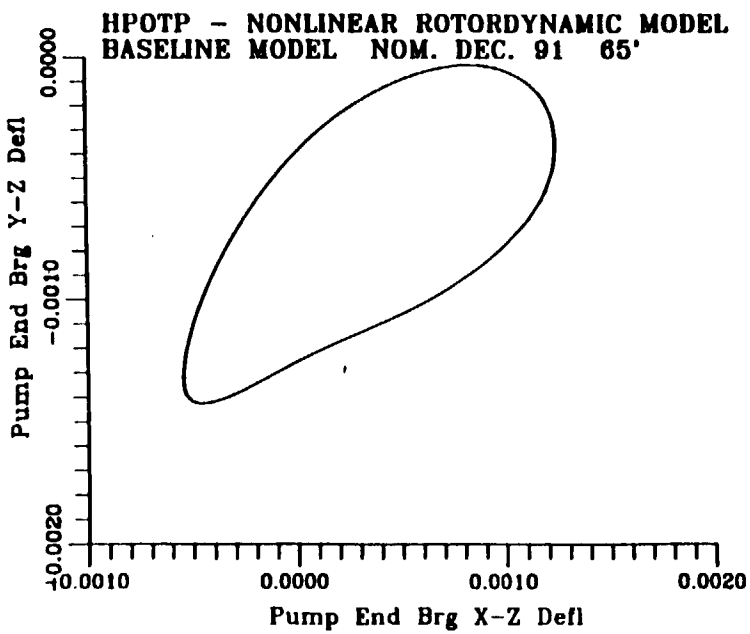

HPOTP - NONLINEAR ROTORDYNAMIC MODEL
BASELINE MODEL NOM. DEC. 91 65'
Turbine End Bearing Y-Z Defl
-0.0010
-0.0009
-0.0008
-0.0007
0.00
0.10
Time (Seconds)

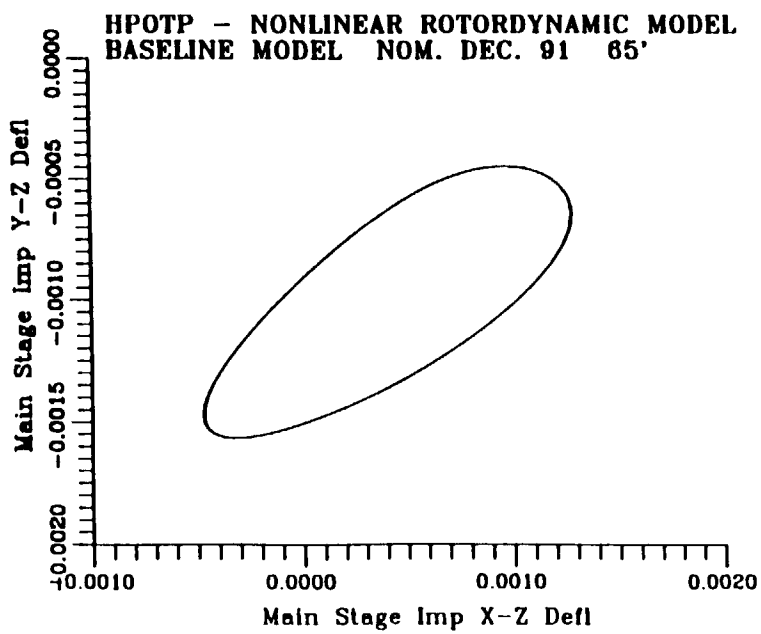

HPOTP - NONLINEAR ROTORDYNAMIC MODEL
BASELINE MODEL NOM. DEC. 91 65'
Turbine CG X-Z Defl
0.0000
0.0001
0.0002
0.0003
0.00
0.10
Time (Seconds)

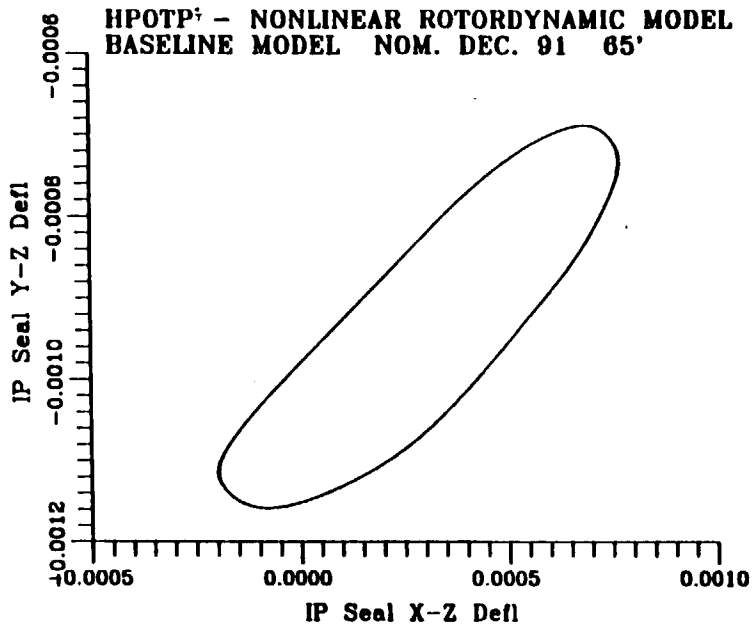

HPOTP - NONLINEAR ROTORDYNAMIC MODEL
BASELINE MODEL NOM. DEC. 91 65'
Turbine CG Y-Z Defl
-0.0010
-0.0009
-0.0008
-0.0007
-0.0006
0.00
0.10
Time (Seconds)

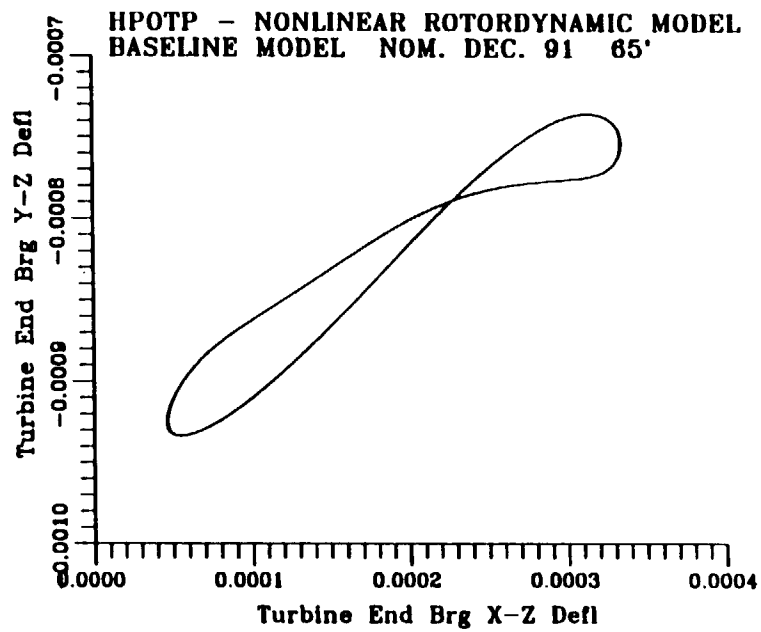

HPOTP - NONLINEAR ROTORDYNAMIC MODEL
BASELINE MODEL NOM. DEC. 91 65'
Preburner Imp Y-Z Defl
0.0010
0.0000
-0.0010
-0.0020
-0.0010
0.0000
0.0010
0.0020
Preburner Imp X-Z Defl

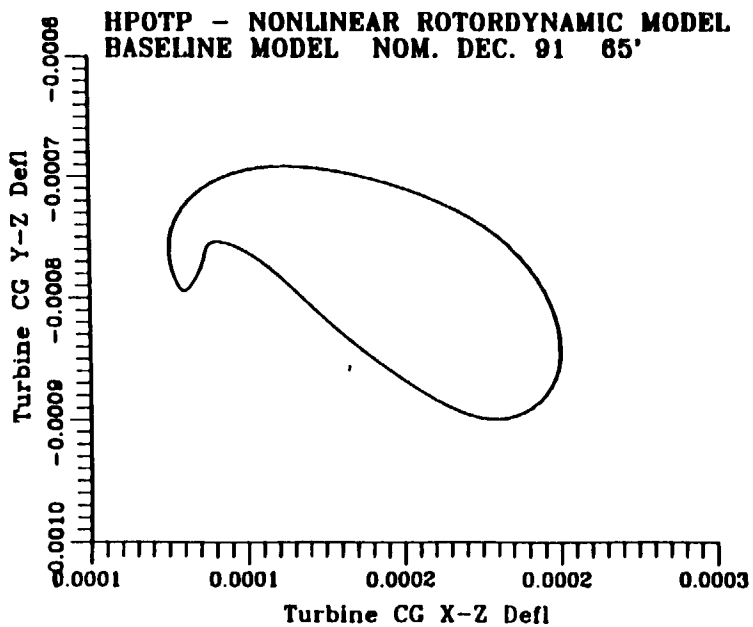

HPOTP - NONLINEAR ROTORDYNAMIC MODEL
BASELINE MODEL NOM. DEC. 91 65'
Damper Seal Y-Z Defl
0.0010
0.0000
-0.0010
-0.0020
-0.0010
0.0000
0.0010
0.0020
Damper Seal X-Z Defl

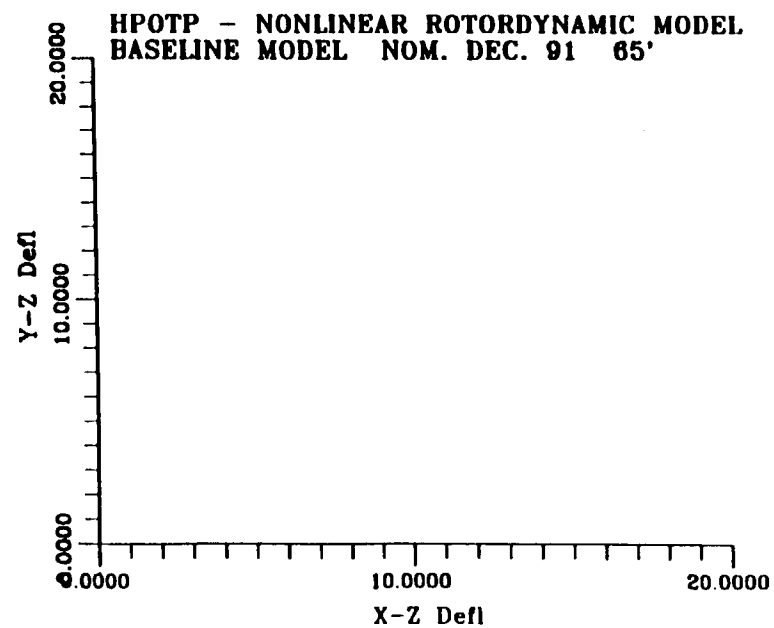

HPOTP - NONLINEAR ROTORDYNAMIC MODEL
BASELINE MODEL NOM. DEC. 91 65'
Pump End Brg Y-Z Defl
0.0000
-0.0010
-0.0020
-0.0010
0.0000
0.0010
0.0020
Pump End Brg X-Z Defl

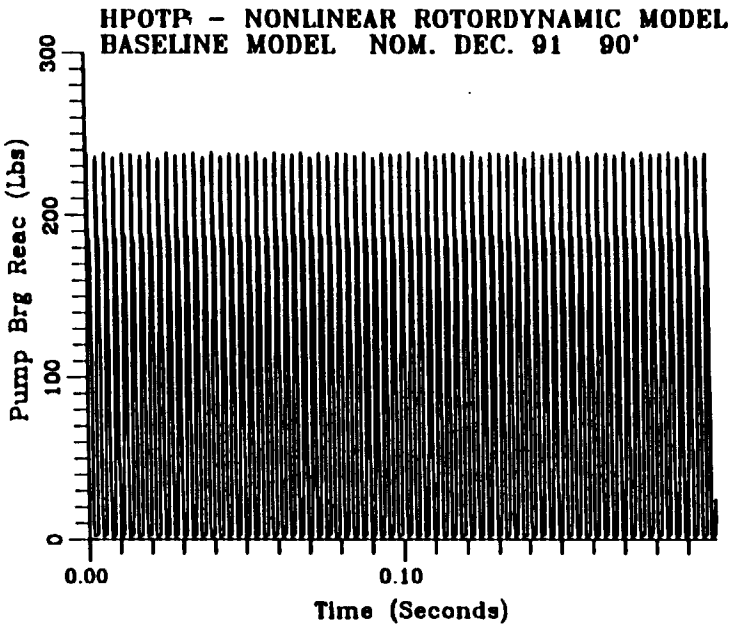

HPOTP - NONLINEAR ROTORDYNAMIC MODEL
BASELINE MODEL NOM. DEC. 91 65'
Main Stage Imp Y-Z Defl
0.0000
-0.0005
-0.0010
-0.0015
-0.0020
-0.0010
0.0000
0.0010
0.0020
Main Stage Imp X-Z Defl

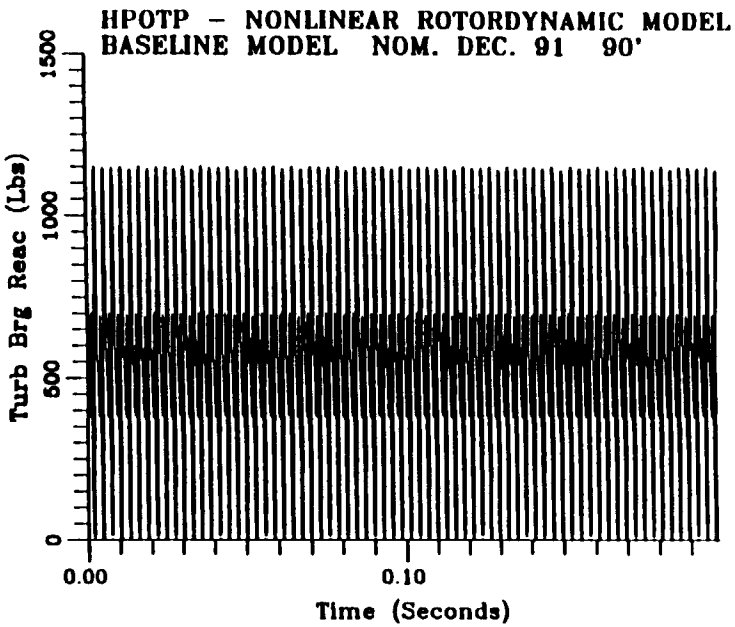

HPOTP - NONLINEAR ROTORDYNAMIC MODEL
BASELINE MODEL NOM. DEC. 91 65'
IP Seal Y-Z Defl
-0.0006
-0.0008
-0.0010
-0.0012
-0.0005
0.0000
0.0005
0.0010
IP Seal X-Z Defl

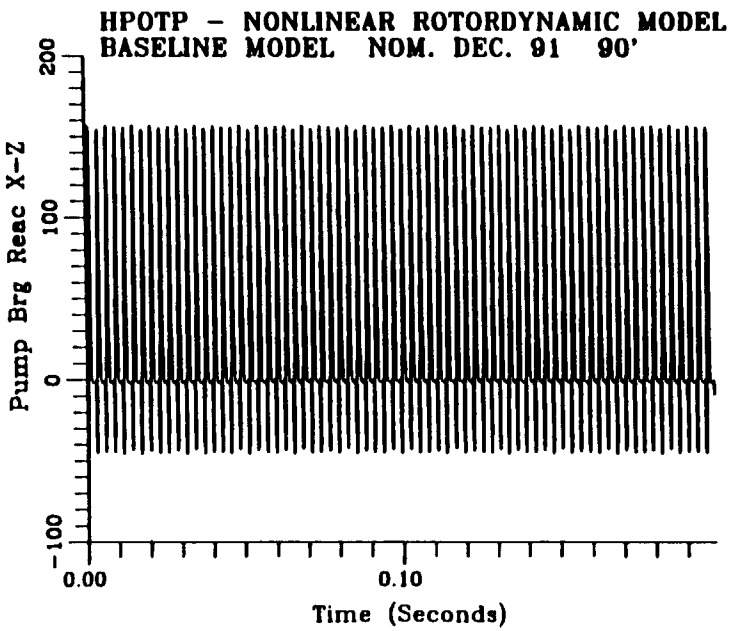

HPOTP - NONLINEAR ROTORDYNAMIC MODEL
BASELINE MODEL NOM. DEC. 91 65'
Turbine End Brg Y-Z Defl
-0.0007
-0.0008
-0.0009
-0.0010
0.0000
0.0001
0.0002
0.0003
0.0004
Turbine End Brg X-Z Defl

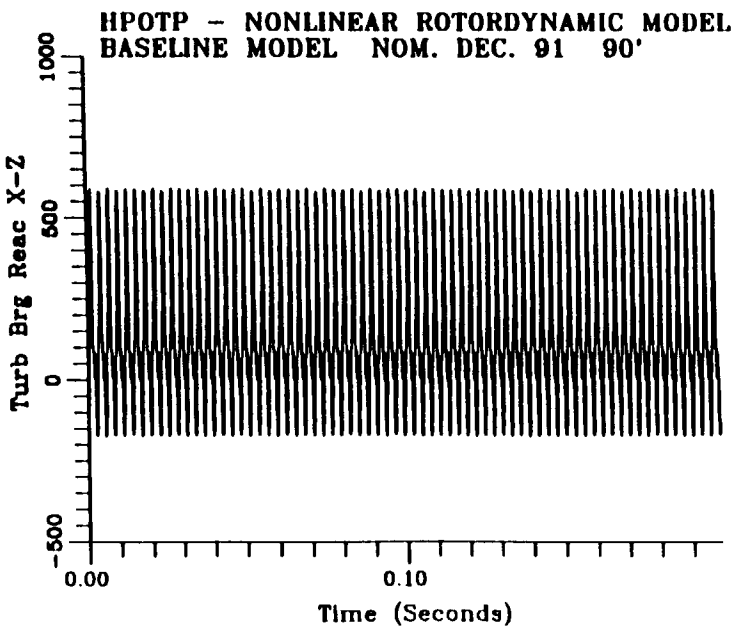

HPOTP - NONLINEAR ROTORDYNAMIC MODEL
BASELINE MODEL NOM. DEC. 91 65'
Turbine CG Y-Z Defl
-0.0006
-0.0007
-0.0008
-0.0009
-0.0010
0.0001
0.0001
0.0002
0.0002
0.0003
Turbine CG X-Z Defl

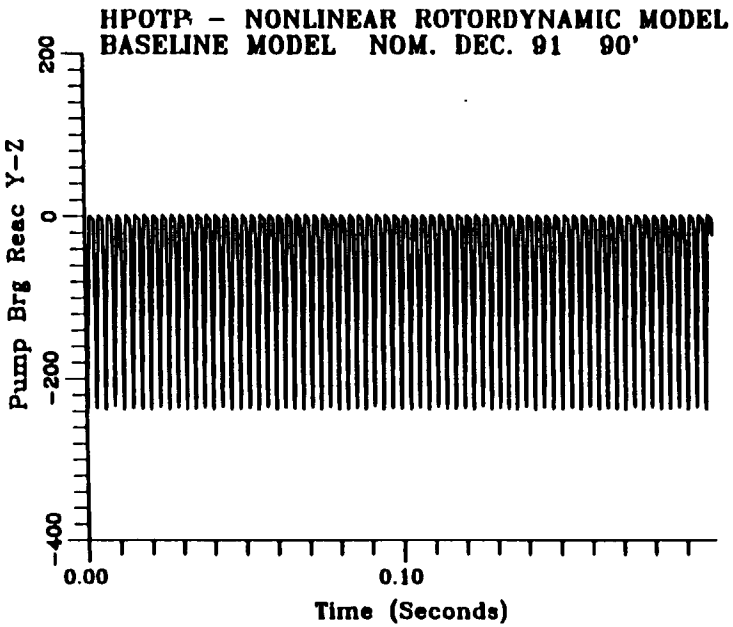

HPOTP - NONLINEAR ROTORDYNAMIC MODEL
BASELINE MODEL NOM. DEC. 91 65'
Y-Z Defl
20.0000
10.0000
0.0000
0.0000
10.0000
20.0000
X-Z Defl

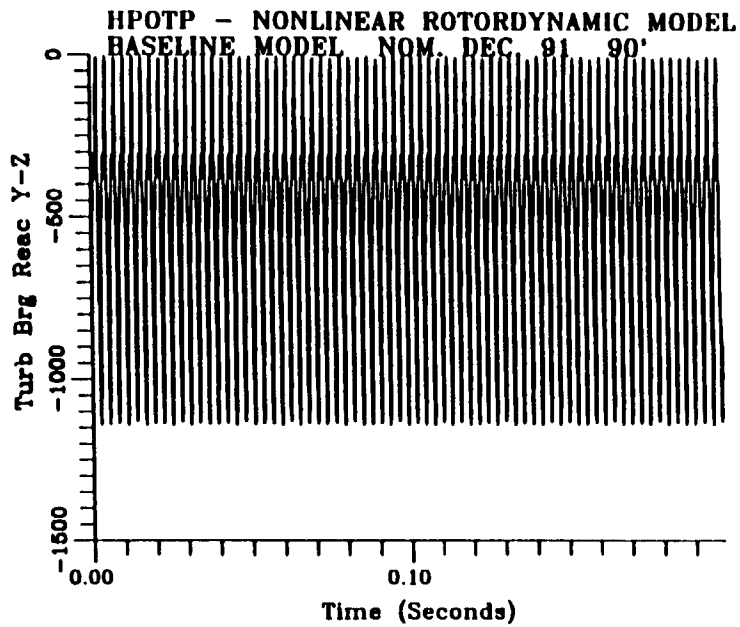

HPOTP - NONLINEAR ROTORDYNAMIC MODEL
BASELINE MODEL NOM. DEC. 91 90'
Pump Brg Reac (Lbs)
300
200
100
0
0.00
0.10
Time (Seconds)

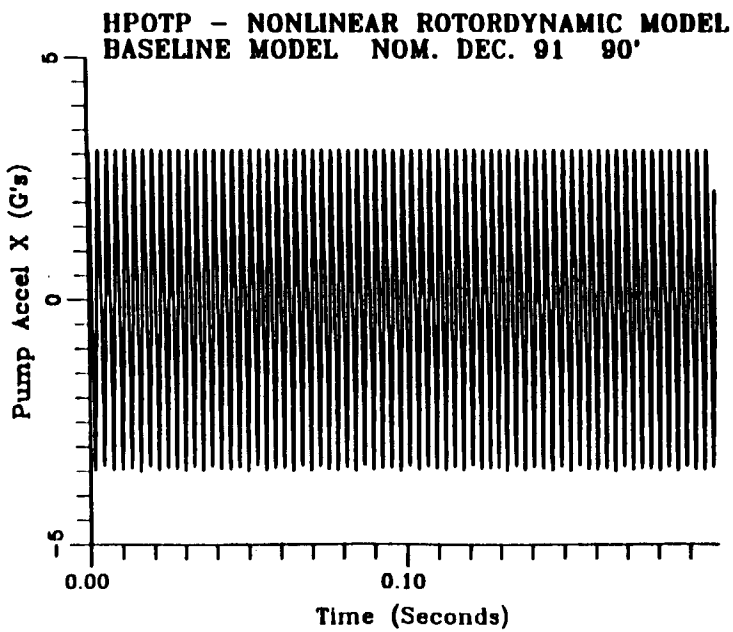

HPOTP - NONLINEAR ROTORDYNAMIC MODEL
BASELINE MODEL NOM. DEC. 91 90'
Turb Brg Reac (Lbs)
1500
1000
500
0
0.00
0.10
Time (Seconds)

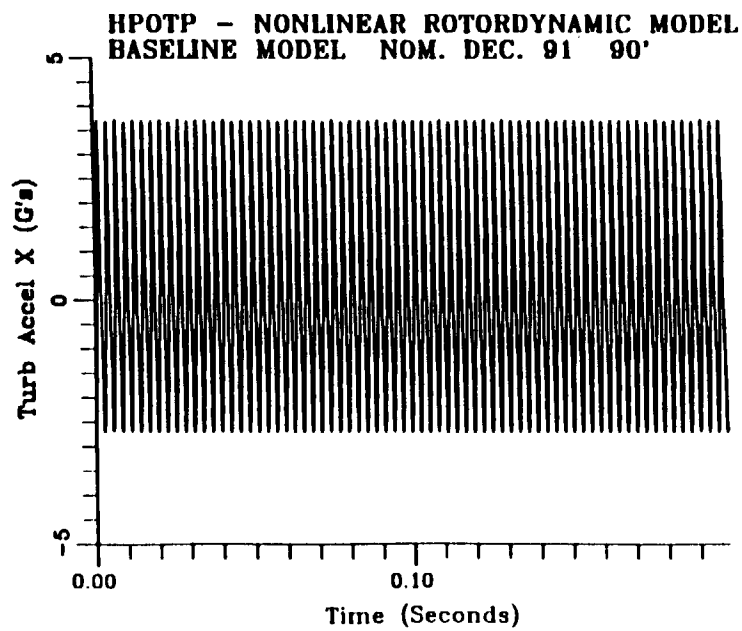

HPOTP - NONLINEAR ROTORDYNAMIC MODEL
BASELINE MODEL NOM. DEC. 91 90'
Pump Brg Reac X-Z
200
100
0
-100
0.00
0.10
Time (Seconds)


HPOTP - NONLINEAR ROTORDYNAMIC MODEL
BASELINE MODEL NOM. DEC. 91 90'
Turb Brg Reac X-Z
1000
500
0
-500
0.00
0.10
Time (Seconds)

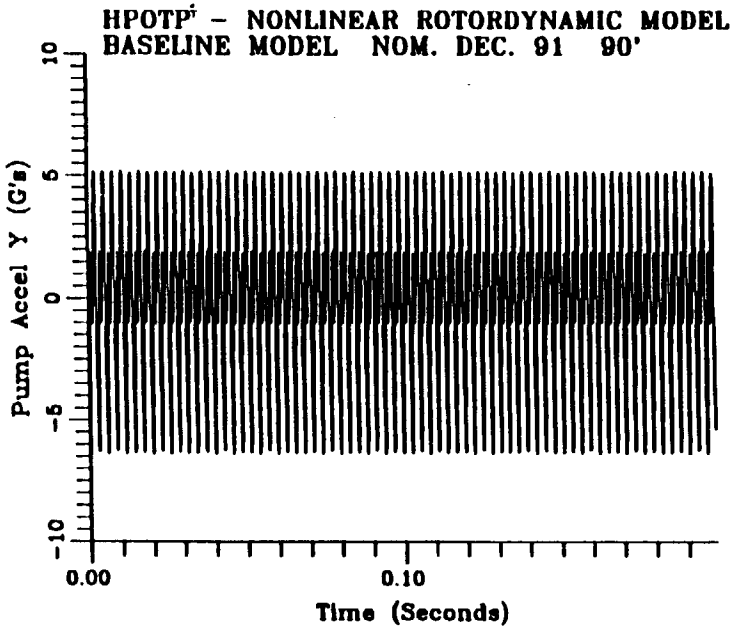

HPOTP - NONLINEAR ROTORDYNAMIC MODEL
BASELINE MODEL NOM. DEC. 91 90'
Pump Brg Reac Y-Z
200
0
-200
-400
0.00
0.10
Time (Seconds)

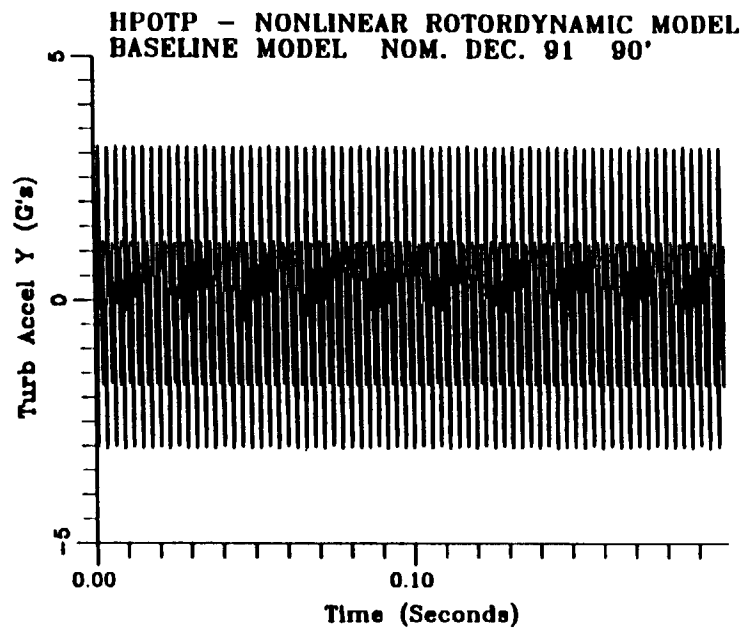

HPOTP - NONLINEAR ROTORDYNAMIC MODEL
BASELINE MODEL NOM. DEC. 91 90'
Turb Brg Reac Y-Z
0
-500
-1000
-1500
0.00
0.10
Time (Seconds)

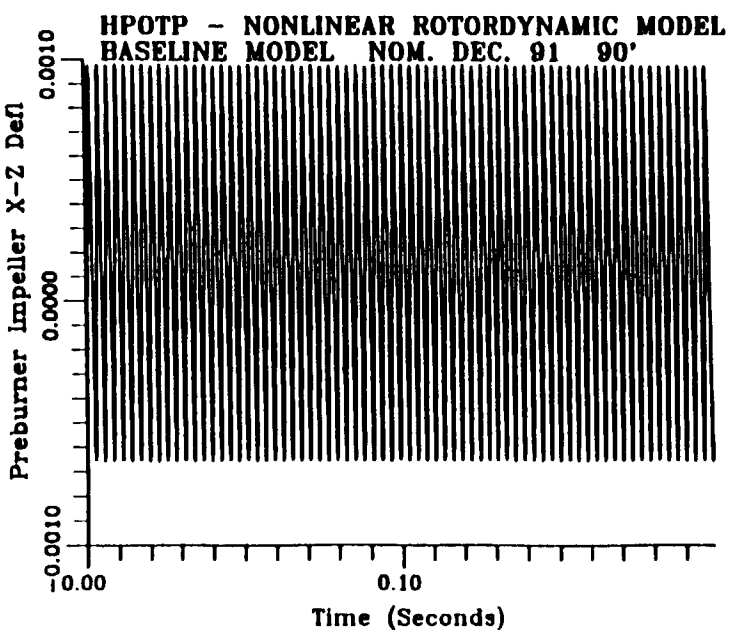

HPOTP - NONLINEAR ROTORDYNAMIC MODEL
BASELINE MODEL NOM. DEC. 91 90'
Pump Accel X (G's)
5
0
-5
0.00
0.10
Time (Seconds)

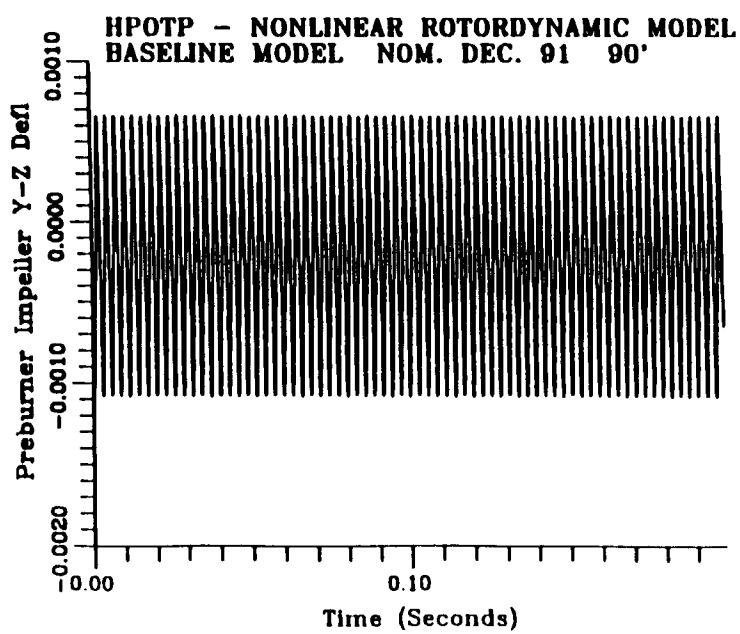

HPOTP - NONLINEAR ROTORDYNAMIC MODEL
BASELINE MODEL NOM. DEC. 91 90'
Turb Accel X (G's)
5
0
-5
0.00
0.10
Time (Seconds)

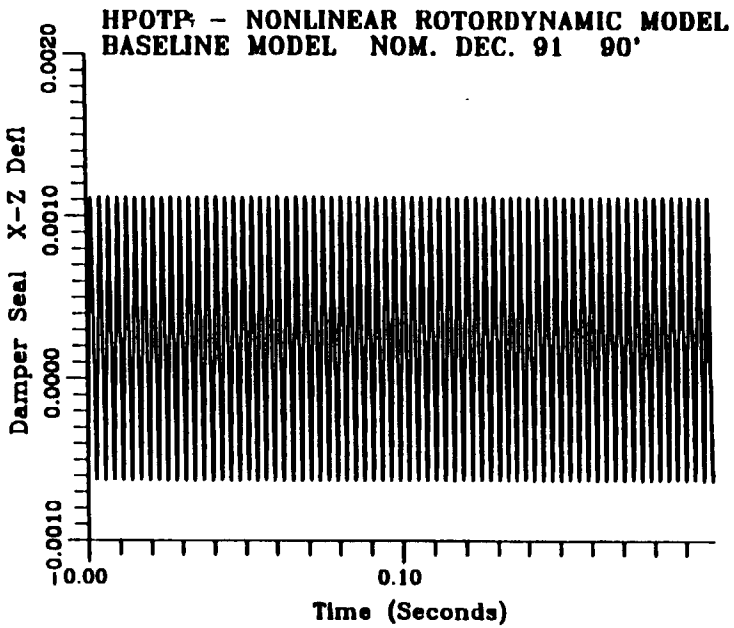
250

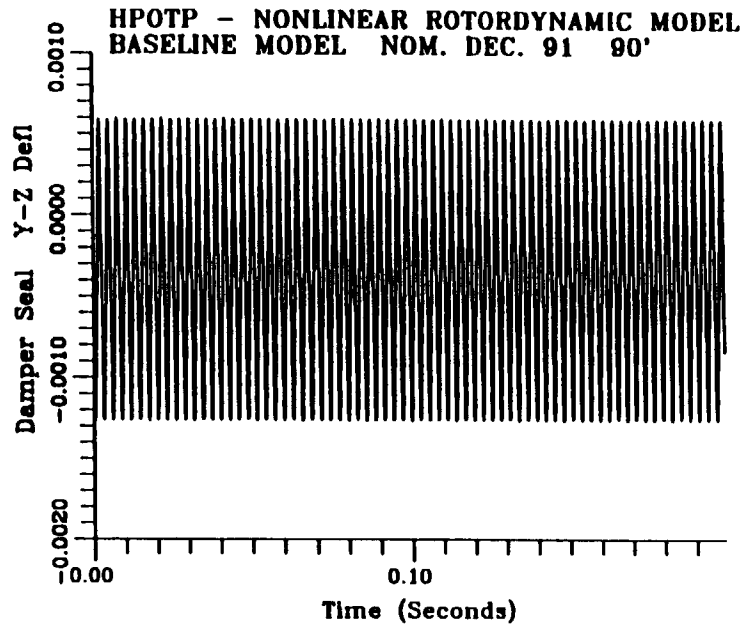

HPOTP - NONLINEAR ROTORDYNAMIC MODEL
BASELINE MODEL NOM. DEC. 91 90'
Pump Accel Y (G's)
10
5
0
-5
-10
0.00
0.10
Time (Seconds)

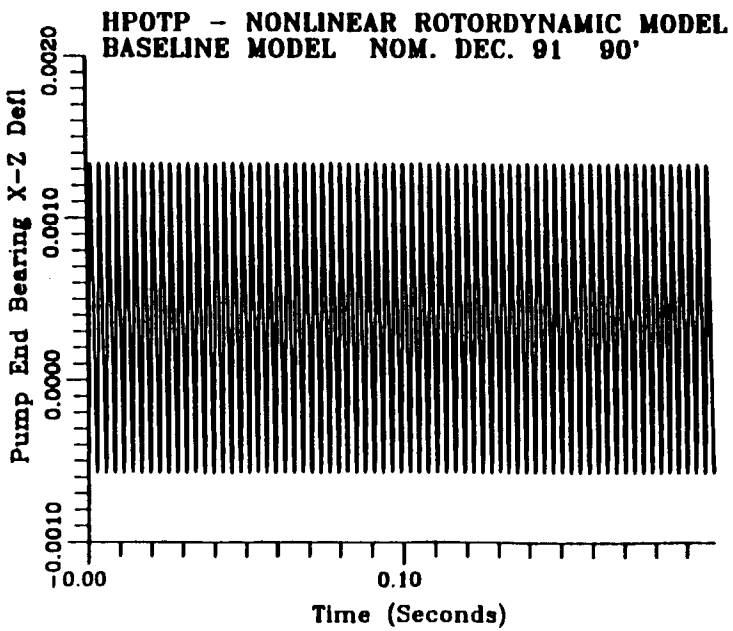

HPOTP - NONLINEAR ROTORDYNAMIC MODEL
BASELINE MODEL NOM. DEC. 91 90'
Turb Accel Y (G's)
5
0
-5
0.00
0.10
Time (Seconds)

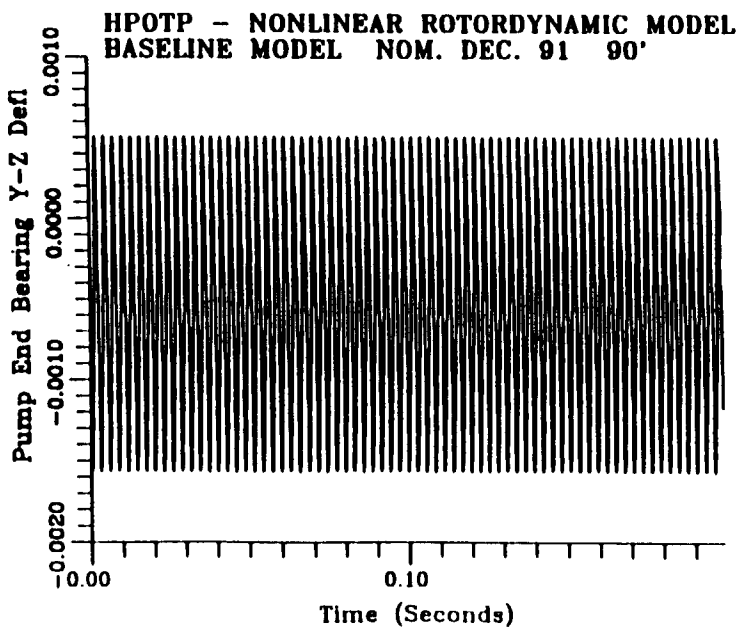

HPOTP - NONLINEAR ROTORDYNAMIC MODEL
BASELINE MODEL NOM. DEC. 91 90'
Preburner Impeller X-Z Defl
0.0010
0.0000
-0.0010
0.00
0.10
Time (Seconds)

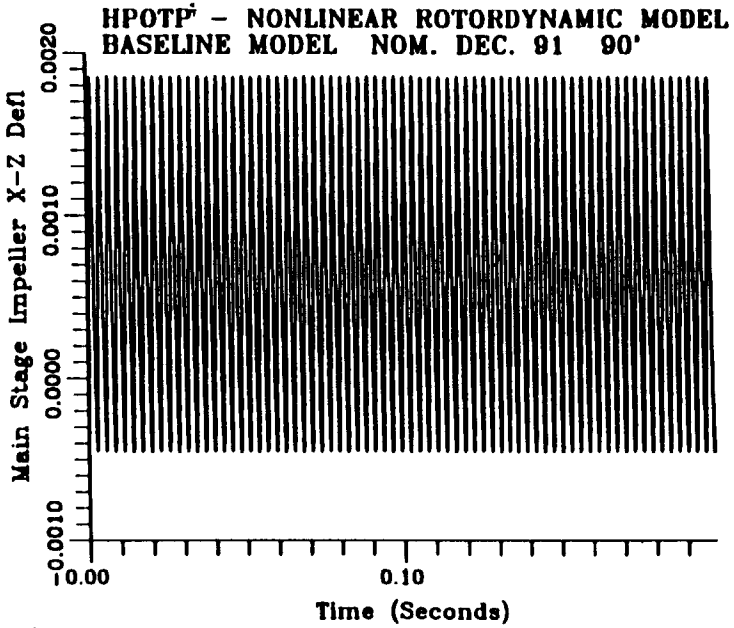

HPOTP - NONLINEAR ROTORDYNAMIC MODEL
BASELINE MODEL NOM. DEC. 91 90'
Preburner Impeller Y-Z Defl
0.0010
0.0000
-0.0010
-0.0020
0.00
0.10
Time (Seconds)

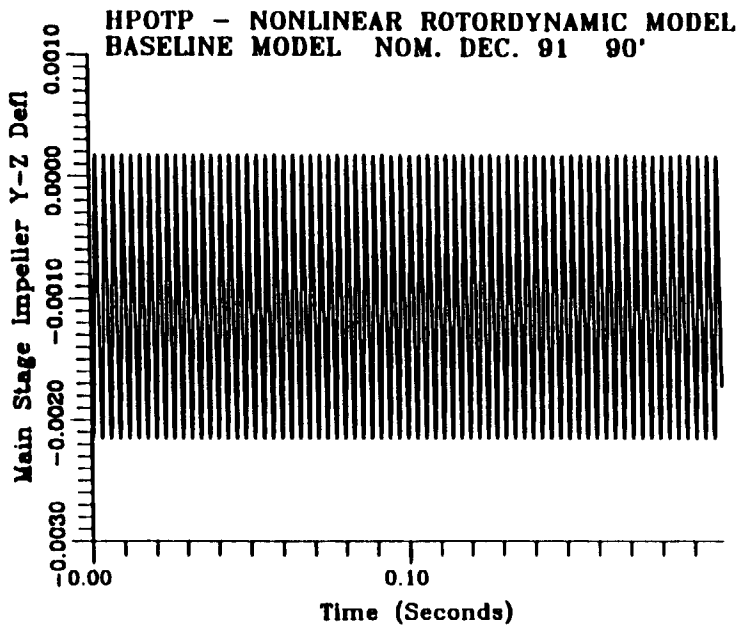

HPOTP - NONLINEAR ROTORDYNAMIC MODEL
BASELINE MODEL NOM. DEC. 91 90'
Damper Seal X-Z Defl
0.0020
0.0010
0.0000
-0.0010
0.00
0.10
Time (Seconds)

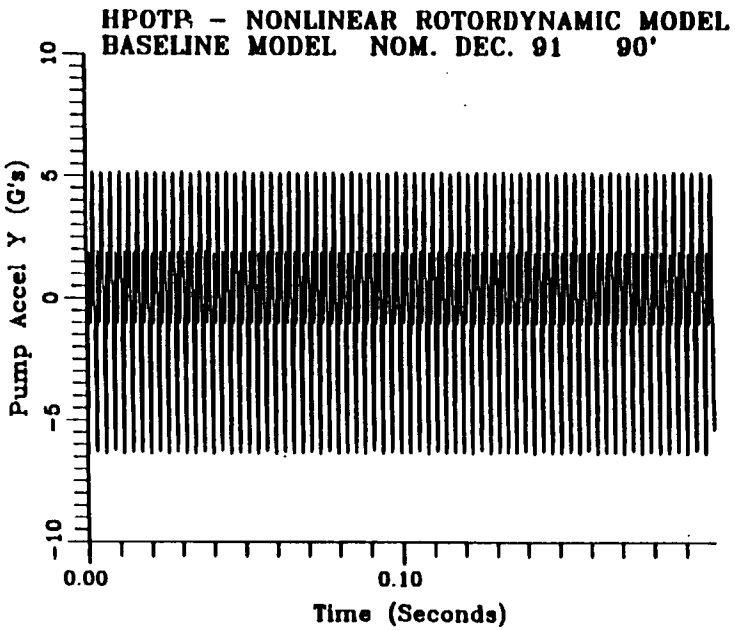

HPOTP - NONLINEAR ROTORDYNAMIC MODEL
BASELINE MODEL NOM. DEC. 91 90'
Damper Seal Y-Z Defl
0.0010
0.0000
-0.0010
-0.0020
0.00
0.10
Time (Seconds)

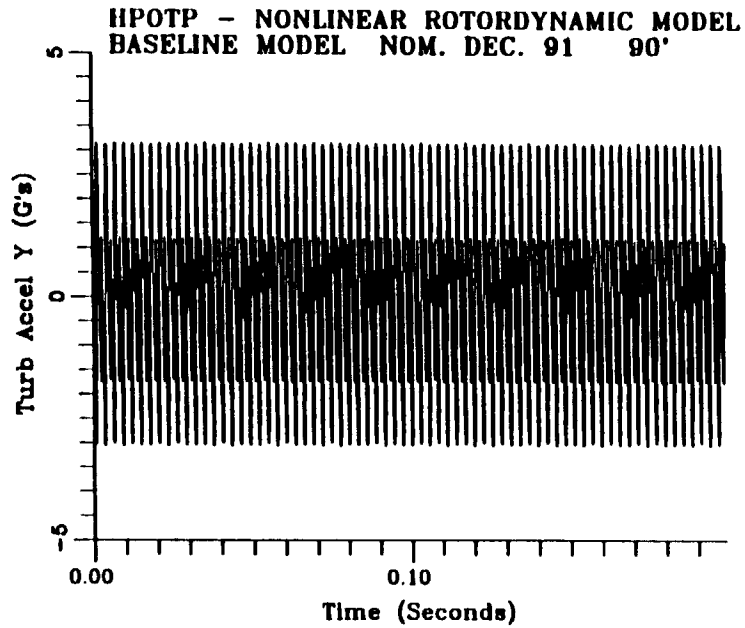

HPOTP - NONLINEAR ROTORDYNAMIC MODEL
BASELINE MODEL NOM. DEC. 91 90'
Pump End Bearing X-Z Defl
0.0020
0.0010
0.0000
-0.0010
0.00
0.10
Time (Seconds)

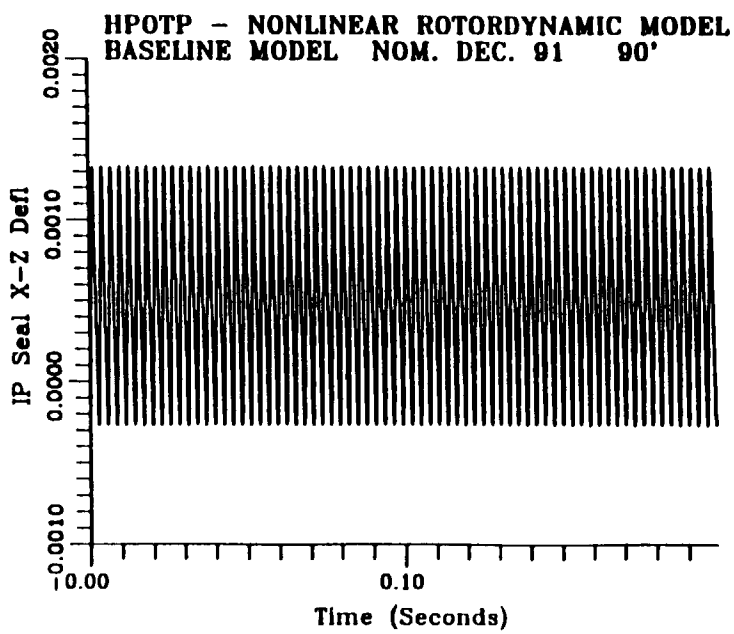

HPOTP - NONLINEAR ROTORDYNAMIC MODEL
BASELINE MODEL NOM. DEC. 91 90'
Pump End Bearing Y-Z Defl
0.0010
0.0000
-0.0010
-0.0020
0.00
0.10
Time (Seconds)

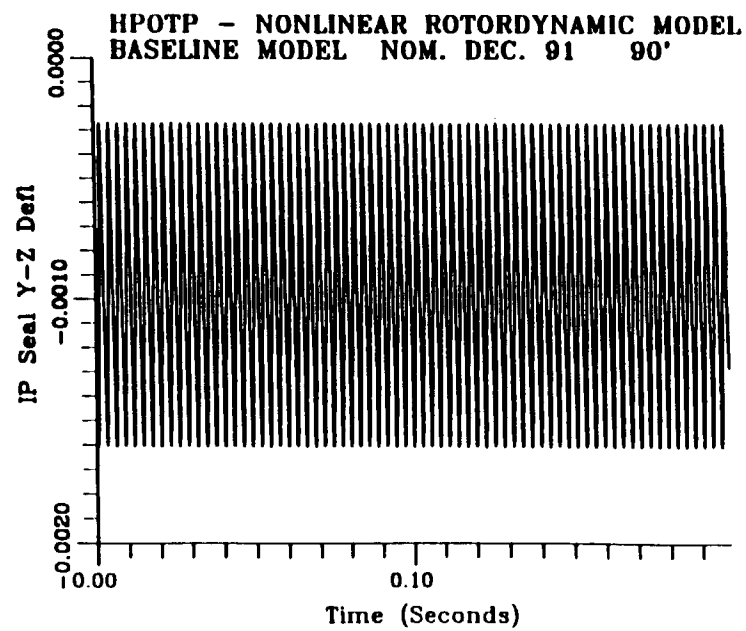

HPOTP - NONLINEAR ROTORDYNAMIC MODEL
BASELINE MODEL NOM. DEC. 91 90'
Main Stage Impeller X-Z Defl
0.0020
0.0010
0.0000
-0.0010
0.00
0.10
Time (Seconds)

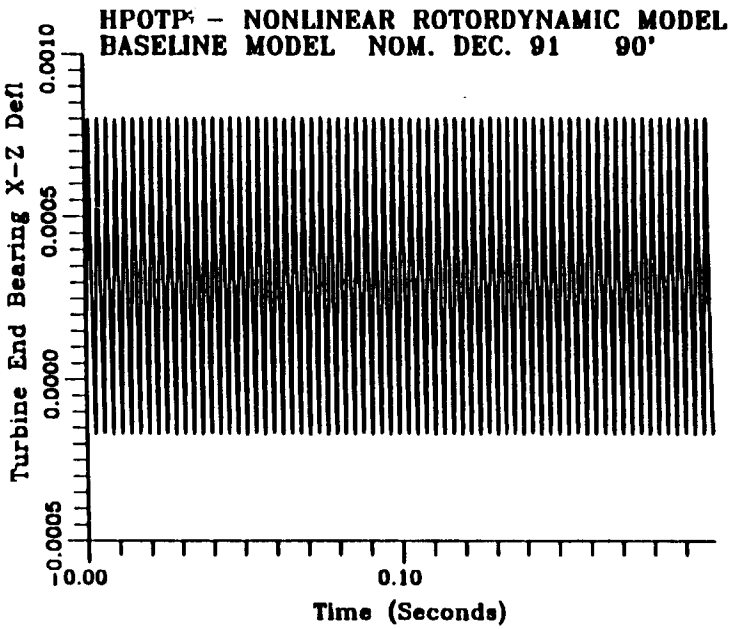

HPOTP - NONLINEAR ROTORDYNAMIC MODEL
BASELINE MODEL NOM. DEC. 91 90'
Main Stage Impeller Y-Z Defl
0.0010
0.0000
-0.0010
-0.0020
-0.0030
0.00
0.10
Time (Seconds)

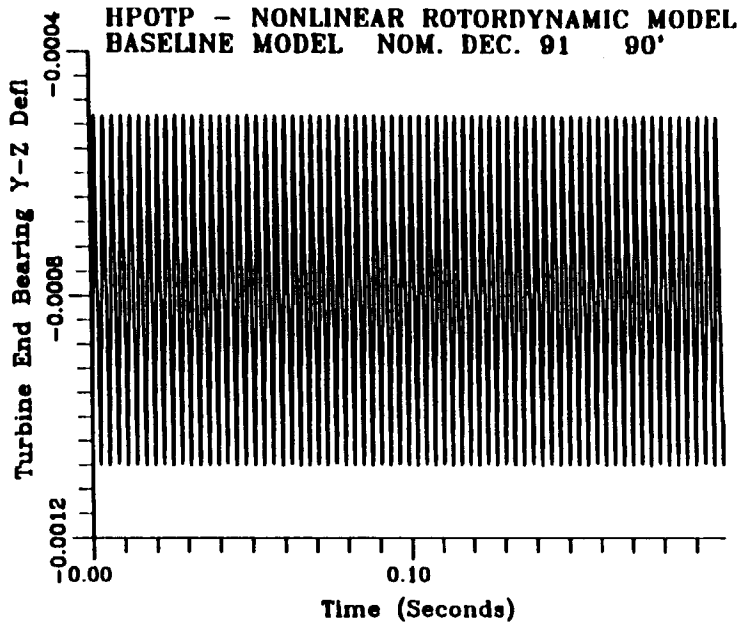

HPOTP - NONLINEAR ROTORDYNAMIC MODEL
BASELINE MODEL NOM. DEC. 91 90'
Pump Accel Y (G's)
10
5
0
-5
-10
0.00
0.10
Time (Seconds)

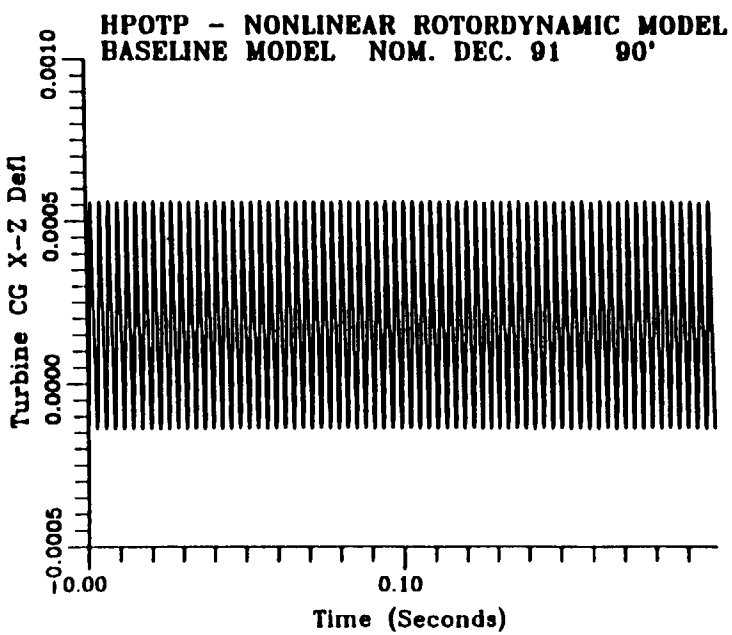

HPOTP - NONLINEAR ROTORDYNAMIC MODEL
BASELINE MODEL NOM. DEC. 91 90'
Turb Accel Y (G's)
5
0
-5
0.00
0.10
Time (Seconds)

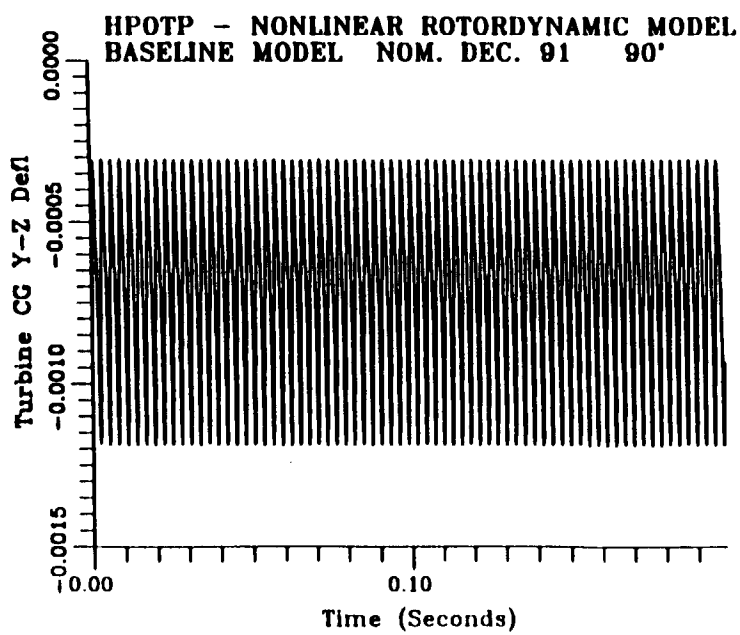

HPOTP - NONLINEAR ROTORDYNAMIC MODEL
BASELINE MODEL NOM. DEC. 91 90'
IP Seal X-Z Defl
0.0020
0.0010
0.0000
-0.0010
0.00
0.10
Time (Seconds)

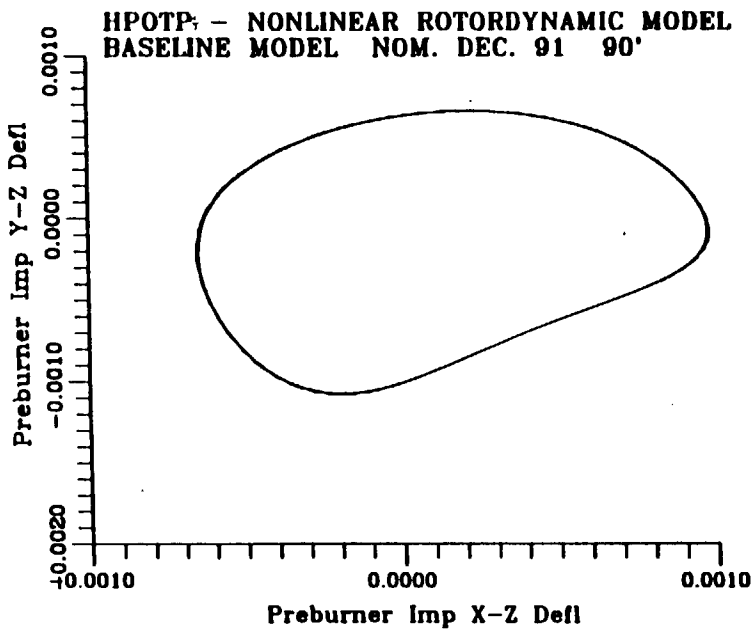

HPOTP - NONLINEAR ROTORDYNAMIC MODEL
BASELINE MODEL NOM. DEC. 91 90'
IP Seal Y-Z Defl
0.0000
-0.0010
-0.0020
0.00
0.10
Time (Seconds)

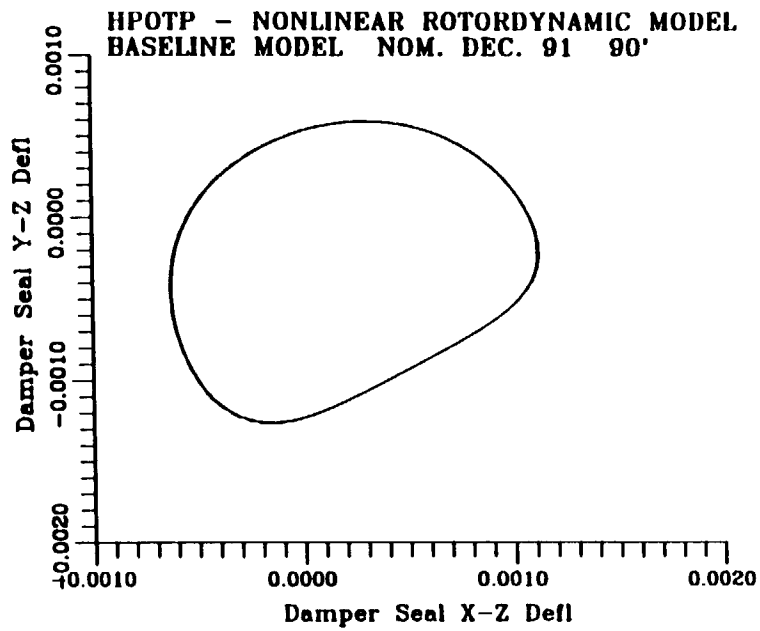

HPOTP - NONLINEAR ROTORDYNAMIC MODEL
BASELINE MODEL NOM. DEC. 91 90'
Turbine End Bearing X-Z Defl
0.0010
0.0005
0.0000
-0.0005
0.00
0.10
Time (Seconds)

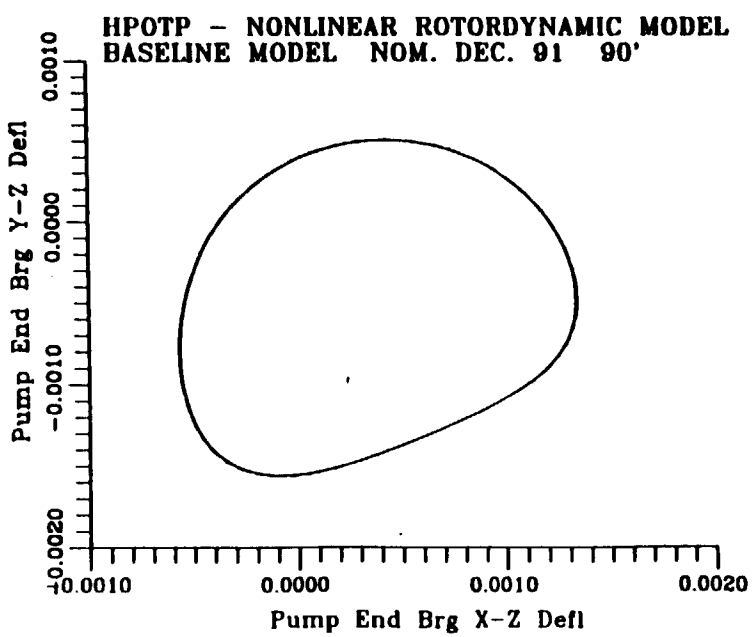

HPOTP - NONLINEAR ROTORDYNAMIC MODEL
BASELINE MODEL NOM. DEC. 91 90'
Turbine End Bearing Y-Z Defl
-0.0004
-0.0008
-0.0012
0.00
0.10
Time (Seconds)

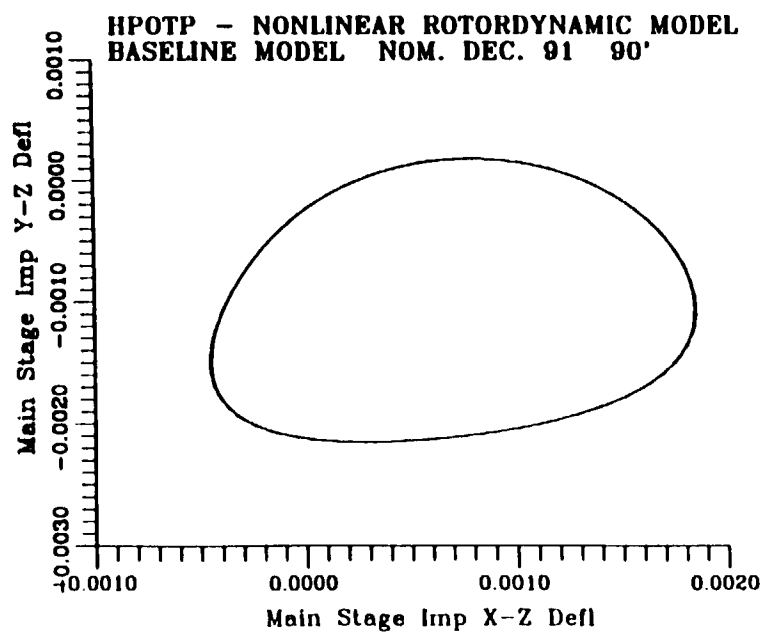

HPOTP - NONLINEAR ROTORDYNAMIC MODEL
BASELINE MODEL NOM. DEC. 91 90'
Turbine CG X-Z Defl
0.0010
0.0005
0.0000
-0.0005
0.00
0.10
Time (Seconds)

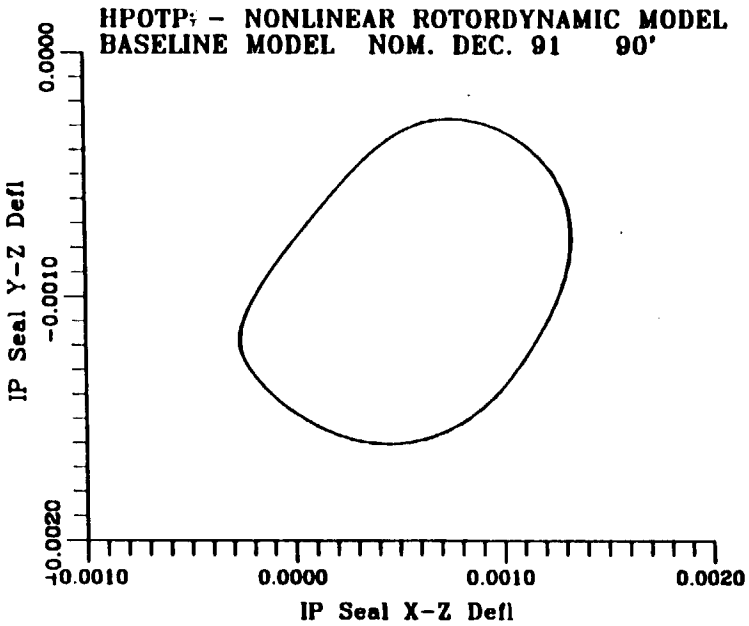

HPOTP - NONLINEAR ROTORDYNAMIC MODEL
BASELINE MODEL NOM. DEC. 91 90'
Turbine CG Y-Z Defl
0.0000
-0.0005
-0.0010
-0.0015
0.00
0.10
Time (Seconds)

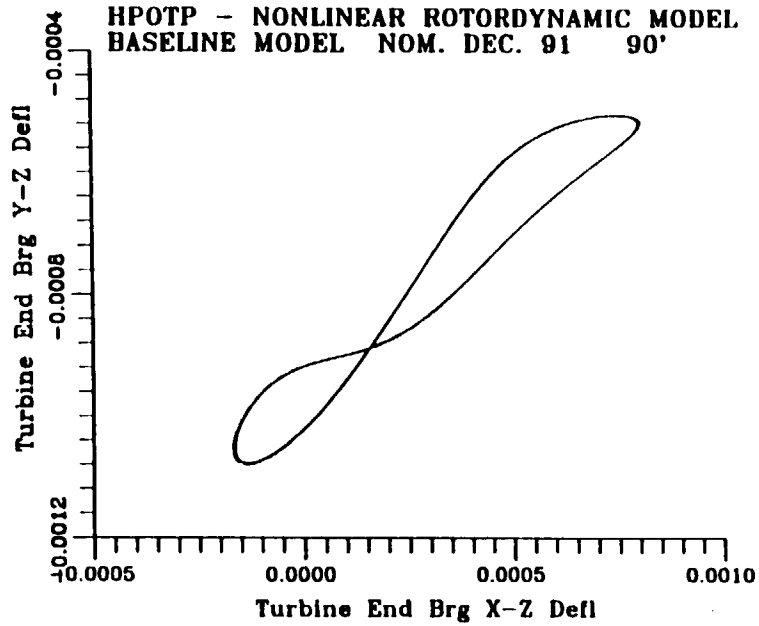

HPOTP - NONLINEAR ROTORDYNAMIC MODEL
BASELINE MODEL NOM. DEC. 91 90'
Preburner Imp Y-Z Defl
0.0010
0.0000
-0.0010
-0.0020
-0.0010
0.0000
0.0010
Preburner Imp X-Z Defl

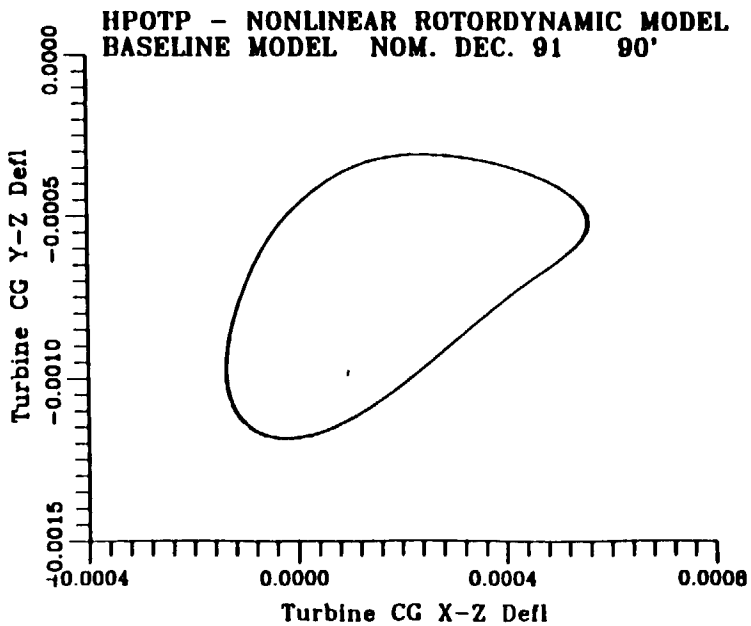

HPOTP - NONLINEAR ROTORDYNAMIC MODEL
BASELINE MODEL NOM. DEC. 91 90'
Damper Seal Y-Z Defl
0.0010
0.0000
-0.0010
-0.0020
-0.0010
0.0000
0.0010
0.0020
Damper Seal X-Z Defl

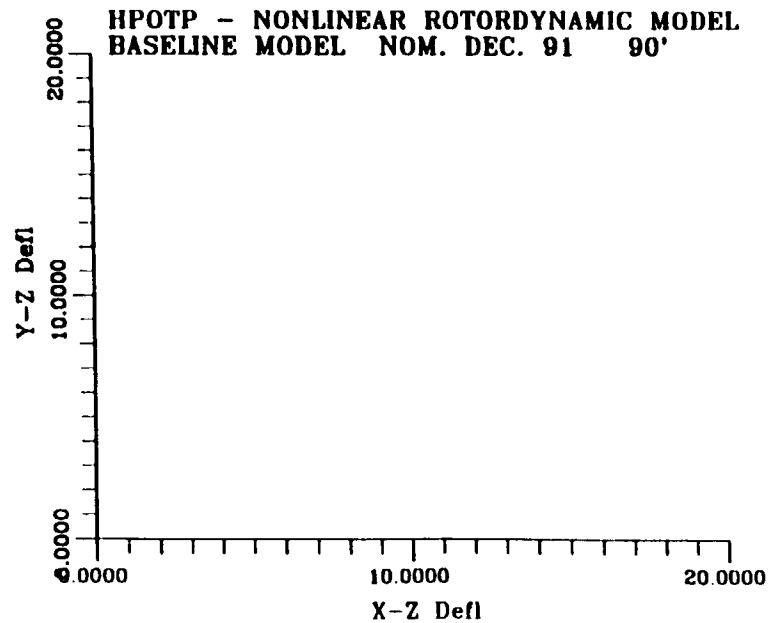

HPOTP - NONLINEAR ROTORDYNAMIC MODEL
BASELINE MODEL NOM. DEC. 91 90'
Pump End Brg Y-Z Defl
0.0010
0.0000
-0.0010
-0.0020
-0.0010
0.0000
0.0010
0.0020
Pump End Brg X-Z Defl


HPOTP - NONLINEAR ROTORDYNAMIC MODEL
BASELINE MODEL NOM. DEC. 91 90'
Main Stage Imp Y-Z Defl
0.0010
0.0000
-0.0010
-0.0020
-0.0030
-0.0010
0.0000
0.0010
0.0020
Main Stage Imp X-Z Defl

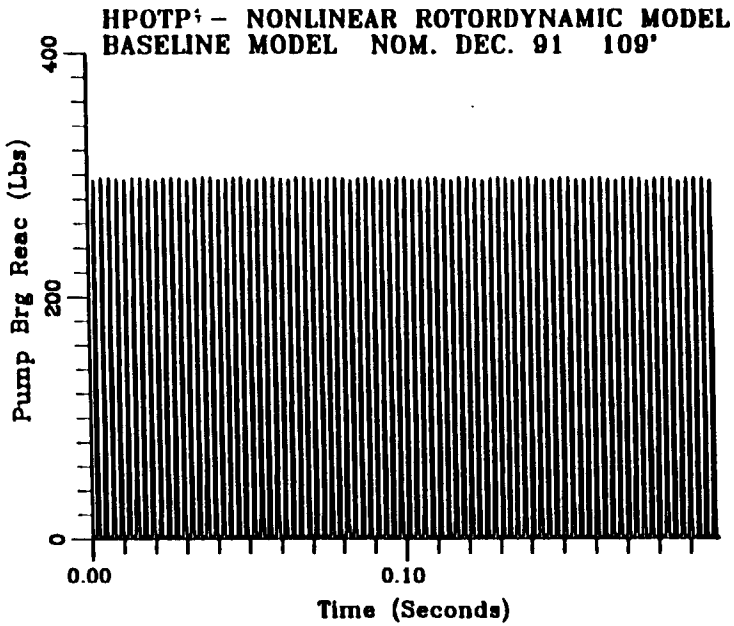

HPOTP - NONLINEAR ROTORDYNAMIC MODEL
BASELINE MODEL NOM. DEC. 91 90'
IP Seal Y-Z Defl
0.0000
-0.0010
-0.0020
-0.0010
0.0000
0.0010
0.0020
IP Seal X-Z Defl

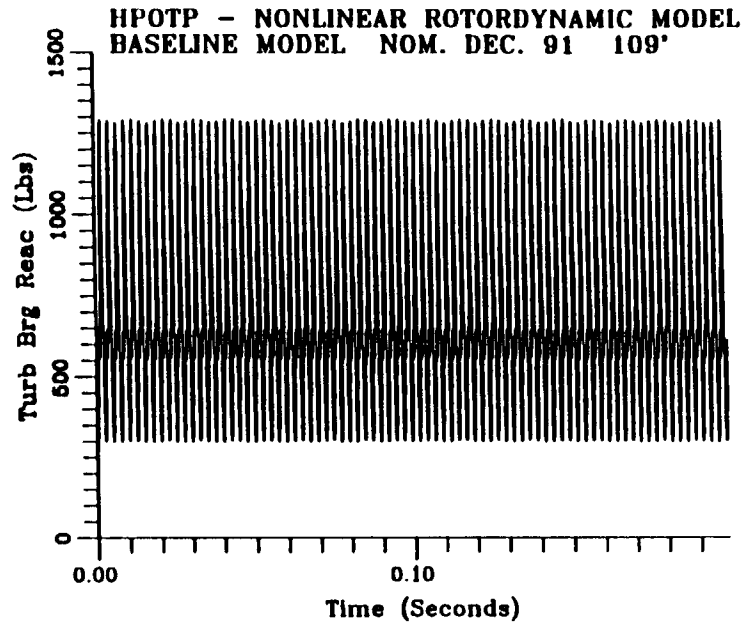

HPOTP - NONLINEAR ROTORDYNAMIC MODEL
BASELINE MODEL NOM. DEC. 91 90'
Turbine End Brg Y-Z Defl
-0.0004
-0.0008
-0.0012
-0.0005
0.0000
0.0005
0.0010
Turbine End Brg X-Z Defl

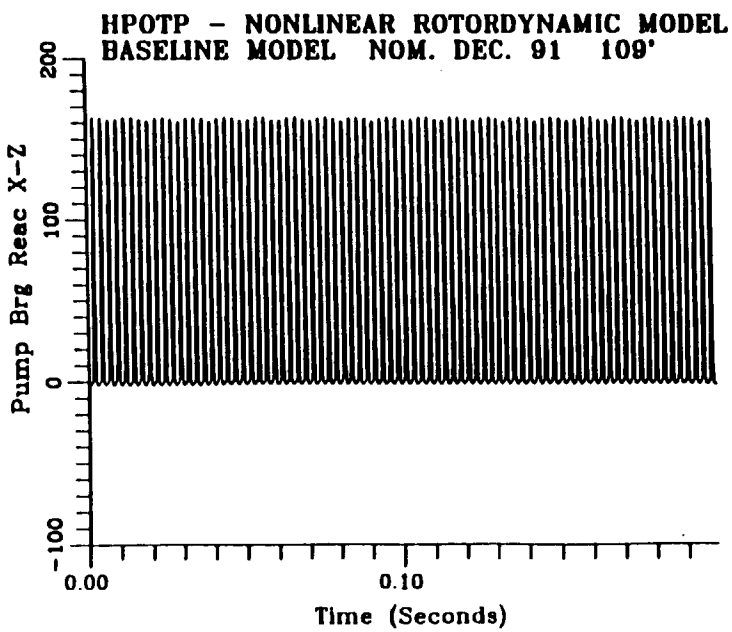

HPOTP - NONLINEAR ROTORDYNAMIC MODEL
BASELINE MODEL NOM. DEC. 91 90'
Turbine CG Y-Z Defl
0.0000
-0.0005
-0.0010
-0.0015
-0.0004
0.0000
0.0004
0.0008
Turbine CG X-Z Defl

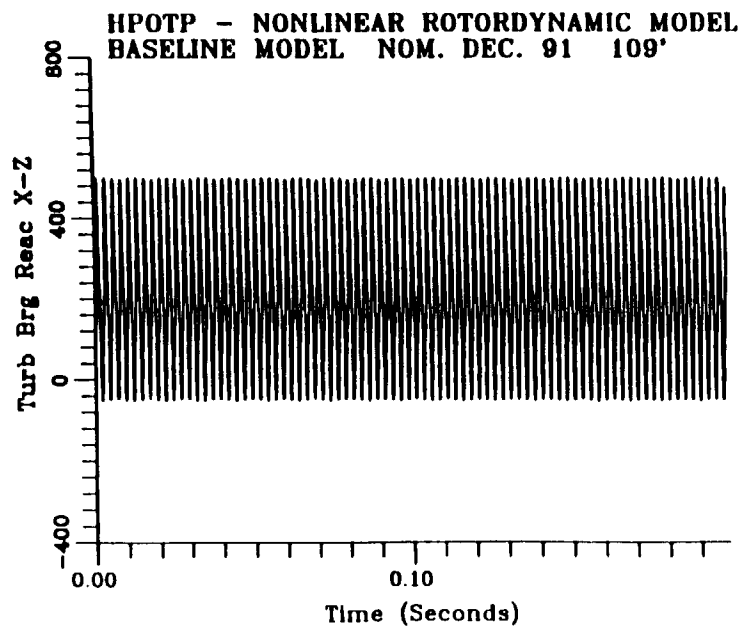

HPOTP - NONLINEAR ROTORDYNAMIC MODEL
BASELINE MODEL NOM. DEC. 91 90'
Y-Z Defl
20.0000
10.0000
0.0000
0.0000
10.0000
20.0000
X-Z Defl

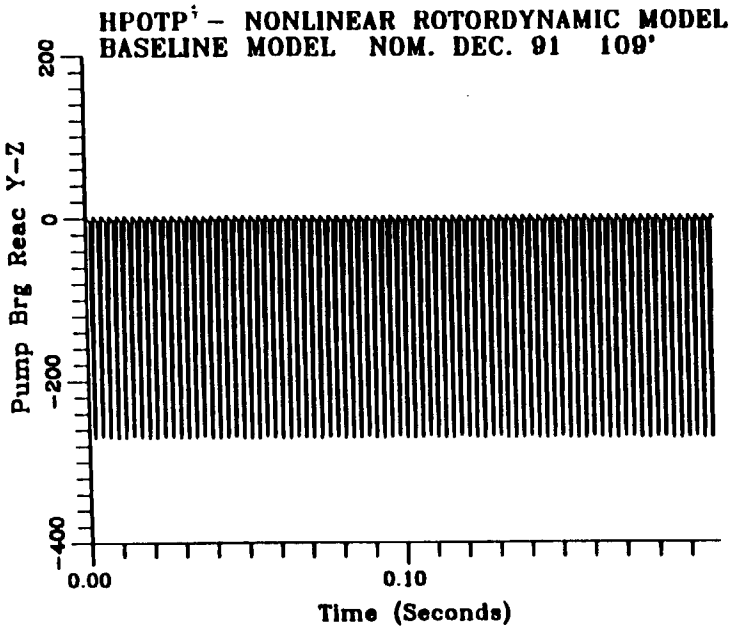
257

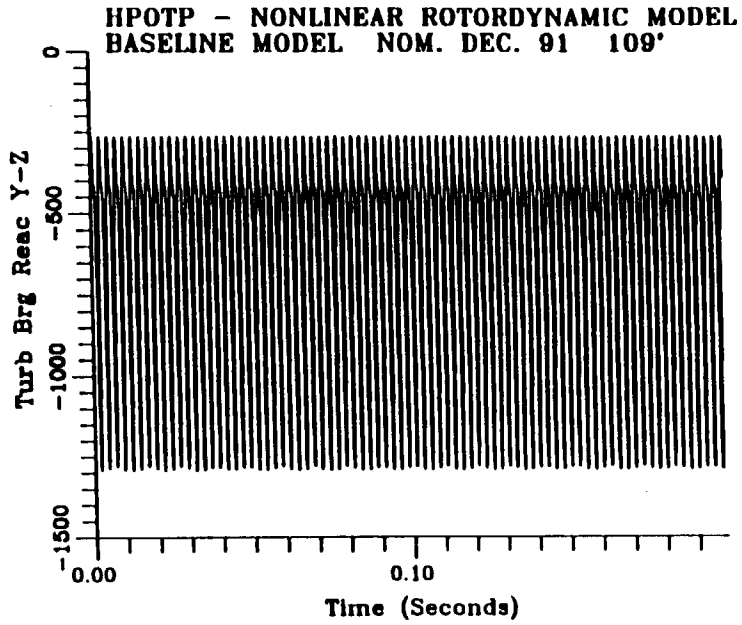

HPOTP - NONLINEAR ROTORDYNAMIC MODEL
BASELINE MODEL NOM. DEC. 91 109'
Pump Brg Reac (Lbs)
400
200
0
0.00
0.10
Time (Seconds)

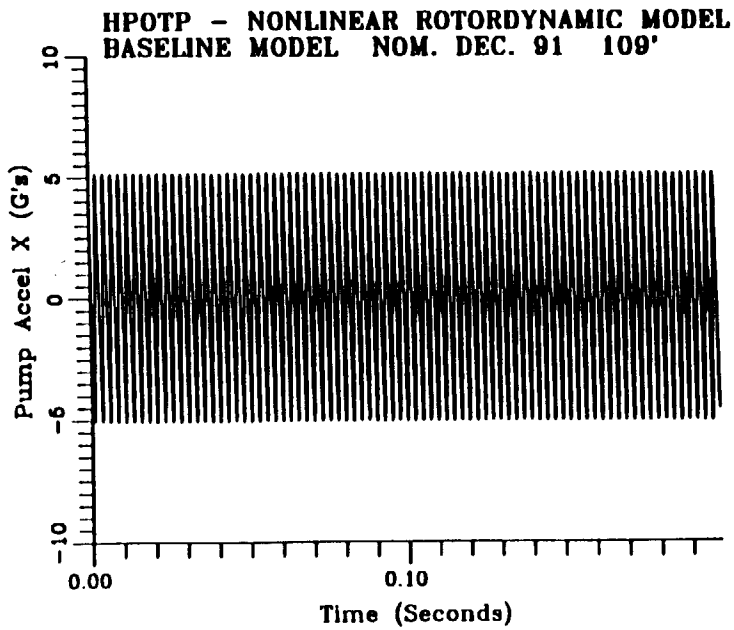

HPOTP - NONLINEAR ROTORDYNAMIC MODEL
BASELINE MODEL NOM. DEC. 91 109'
Turb Brg Reac (Lbs)
1500
1000
500
0
0.00
0.10
Time (Seconds)

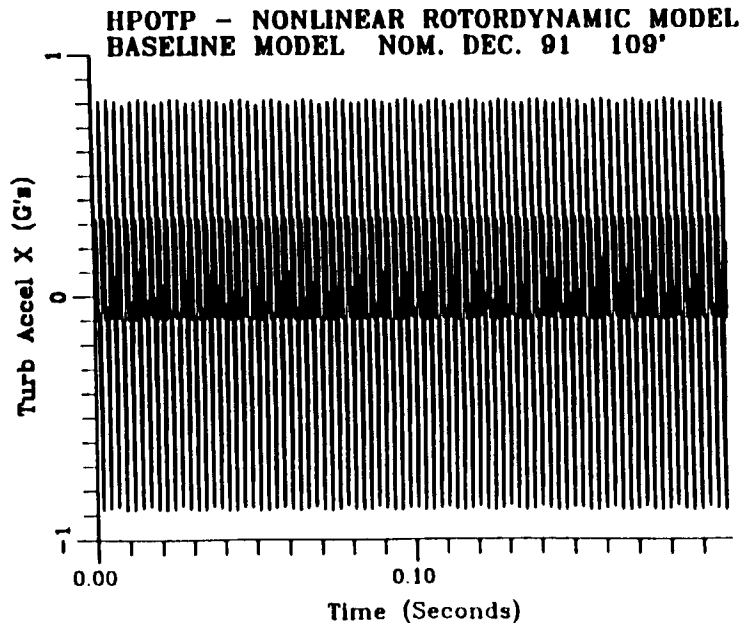

HPOTP - NONLINEAR ROTORDYNAMIC MODEL
BASELINE MODEL NOM. DEC. 91 109'
Pump Brg Reac X-Z
200
100
0
-100
0.00
0.10
Time (Seconds)

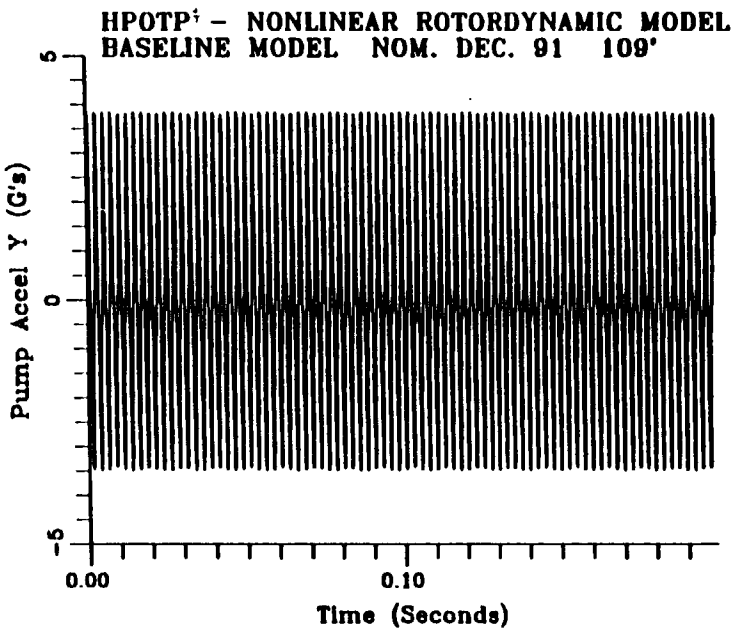

HPOTP - NONLINEAR ROTORDYNAMIC MODEL
BASELINE MODEL NOM. DEC. 91 109'
Turb Brg Reac X-Z
800
400
0
-400
0.00
0.10
Time (Seconds)

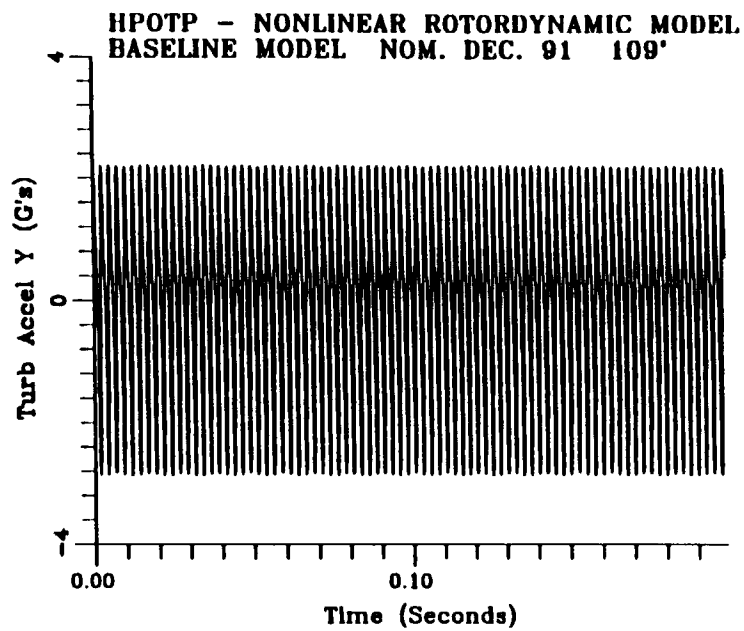

HPOTP - NONLINEAR ROTORDYNAMIC MODEL
BASELINE MODEL NOM. DEC. 91 109'
Pump Brg Reac Y-Z
200
0
-200
-400
0.00
0.10
Time (Seconds)

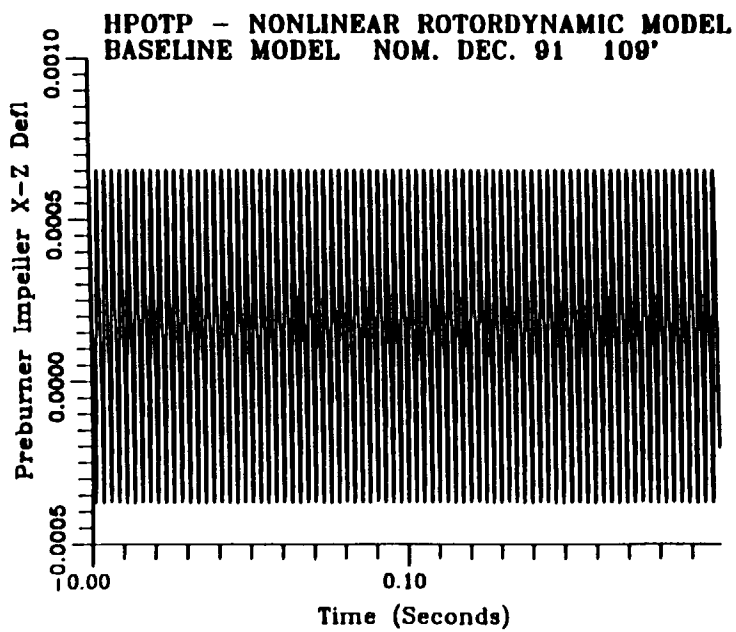

HPOTP - NONLINEAR ROTORDYNAMIC MODEL
BASELINE MODEL NOM. DEC. 91 109'
Turb Brg Reac Y-Z
0
-500
-1000
-1500
0.00
0.10
Time (Seconds)

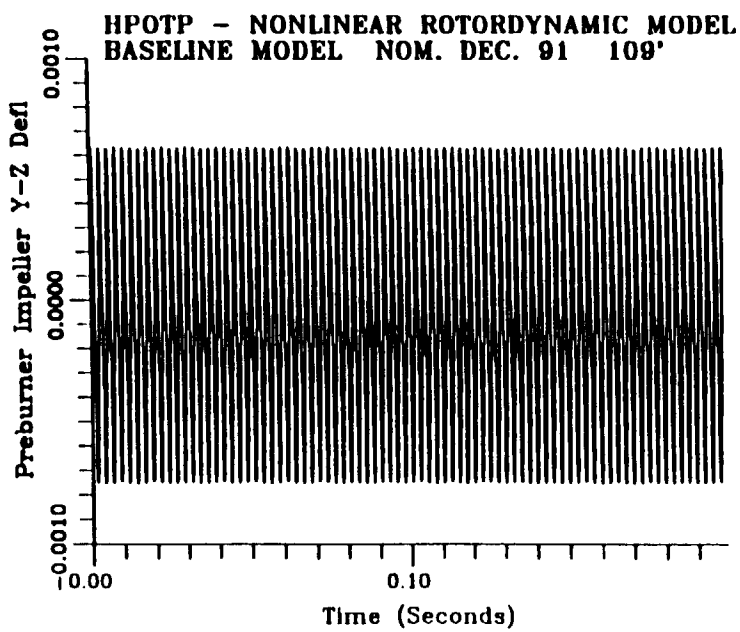

HPOTP - NONLINEAR ROTORDYNAMIC MODEL
BASELINE MODEL NOM. DEC. 91 109'
Pump Accel X (G's)
10
5
0
-5
-10
0.00
0.10
Time (Seconds)

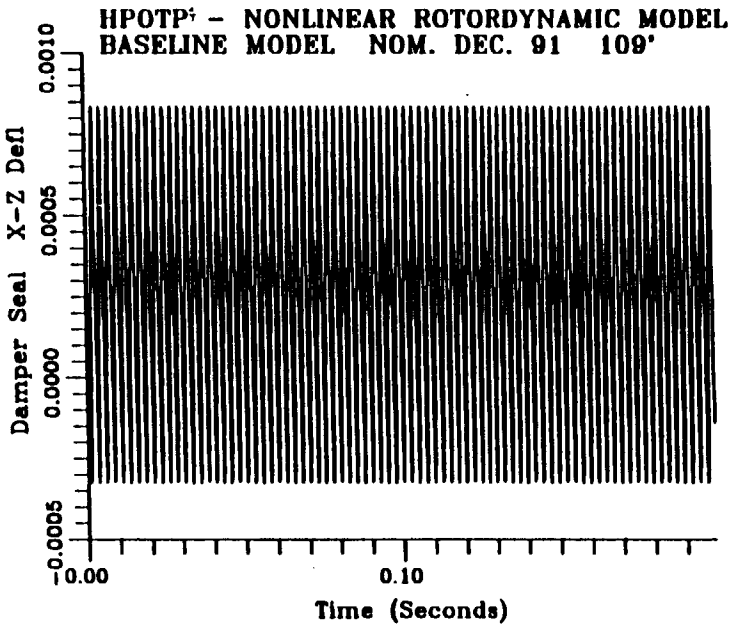

HPOTP - NONLINEAR ROTORDYNAMIC MODEL
BASELINE MODEL NOM. DEC. 91 109'
Turb Accel X (G's)
1
0
-1
0.00
0.10
Time (Seconds)

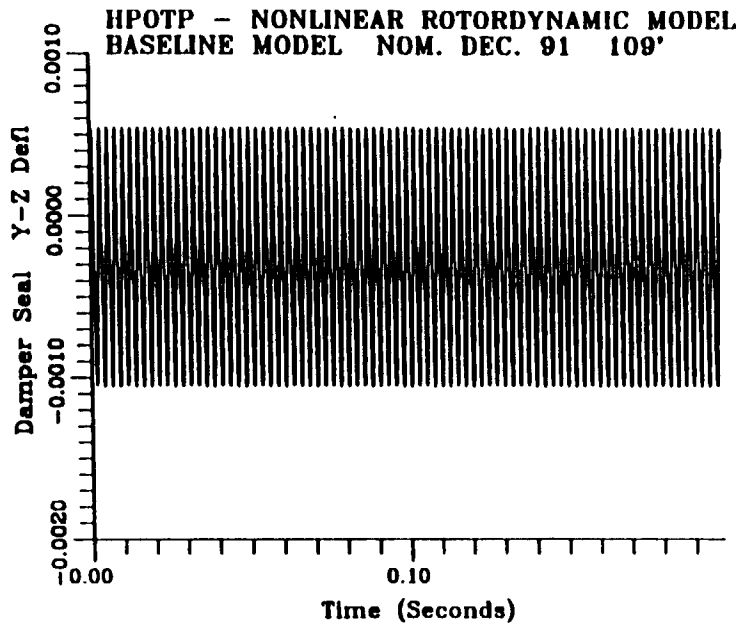

HPOTP - NONLINEAR ROTORDYNAMIC MODEL
BASELINE MODEL NOM. DEC. 91 109'
Pump Accel Y (G's)
5
0
-5
0.00
0.10
Time (Seconds)

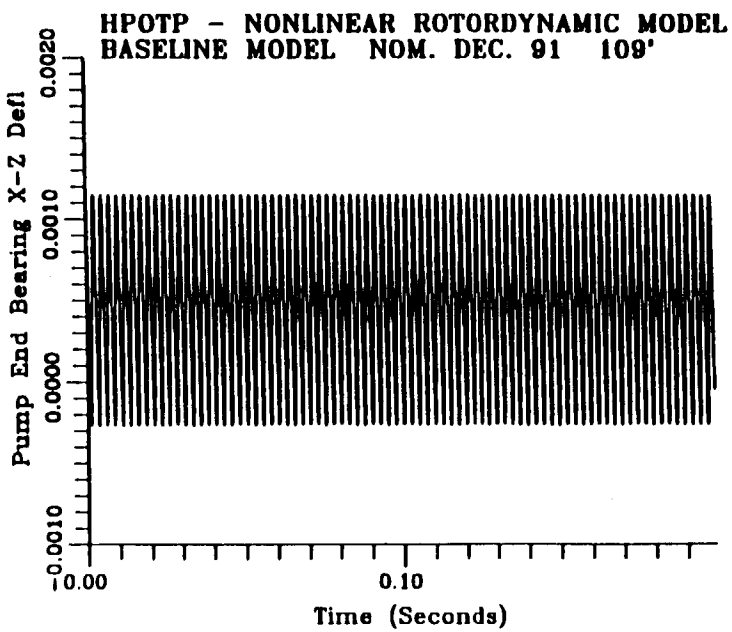

HPOTP - NONLINEAR ROTORDYNAMIC MODEL
BASELINE MODEL NOM. DEC. 91 109'
Turb Accel Y (G's)
4
0
-4
0.00
0.10
Time (Seconds)

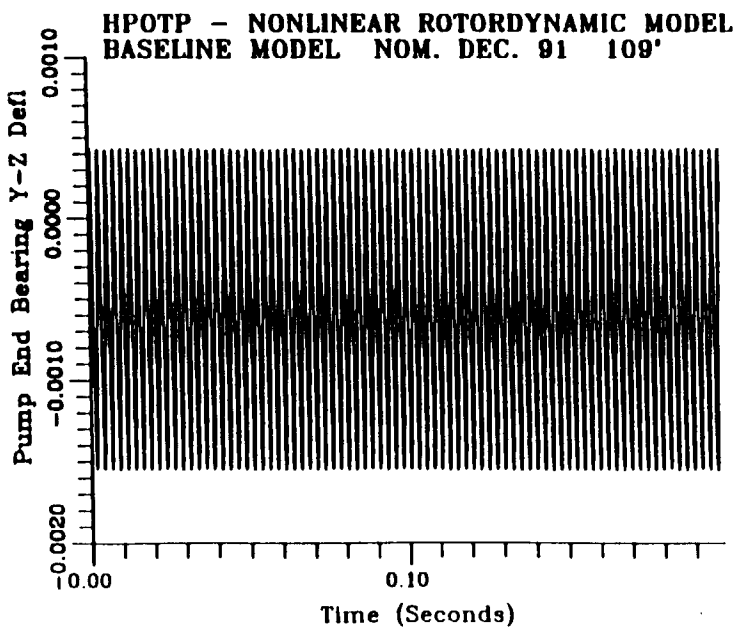

HPOTP - NONLINEAR ROTORDYNAMIC MODEL
BASELINE MODEL NOM. DEC. 91 109'
Preburner Impeller X-Z Defl
0.0010
0.0005
0.0000
-0.0005
-0.00
0.10
Time (Seconds)

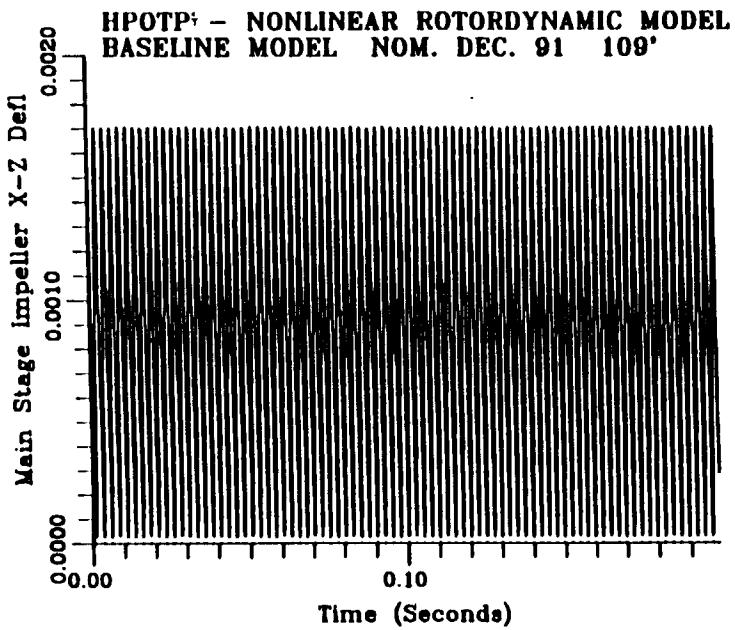

HPOTP - NONLINEAR ROTORDYNAMIC MODEL
BASELINE MODEL NOM. DEC. 91 109'
Preburner Impeller Y-Z Defl
0.0010
0.0000
-0.0010
-0.00
0.10
Time (Seconds)

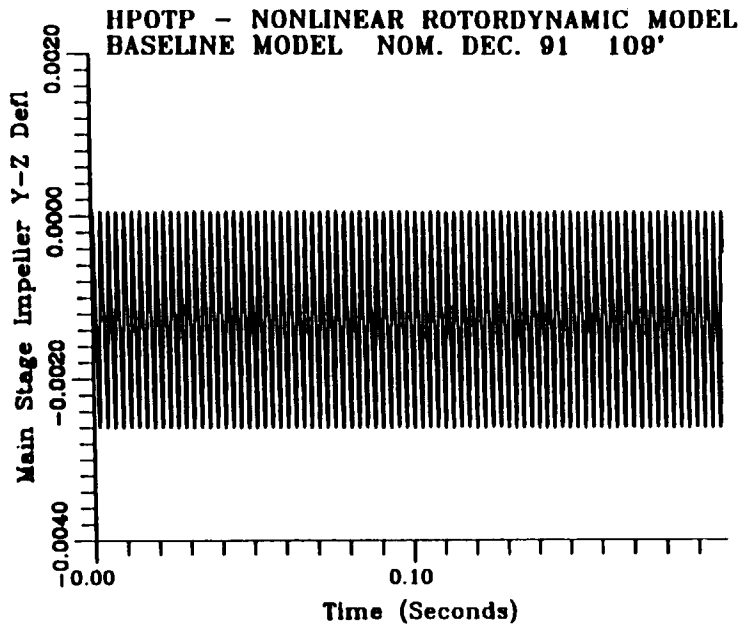

HPOTP - NONLINEAR ROTORDYNAMIC MODEL
BASELINE MODEL NOM. DEC. 91 109'
Damper Seal X-Z Defl
0.0010
0.0005
0.0000
-0.0005
0.00
0.10
Time (Seconds)


HPOTP - NONLINEAR ROTORDYNAMIC MODEL
BASELINE MODEL NOM. DEC. 91 109'
Damper Seal Y-Z Defl
0.0010
0.0000
-0.0010
-0.0020
0.00
0.10
Time (Seconds)

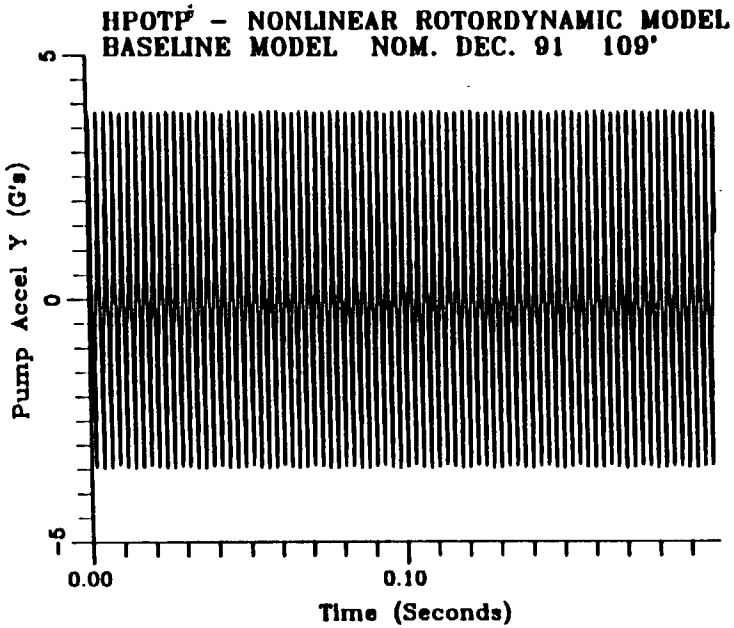

HPOTP - NONLINEAR ROTORDYNAMIC MODEL
BASELINE MODEL NOM. DEC. 91 109'
Pump End Bearing X-Z Defl
0.0020
0.0010
0.0000
-0.0010
0.00
0.10
Time (Seconds)

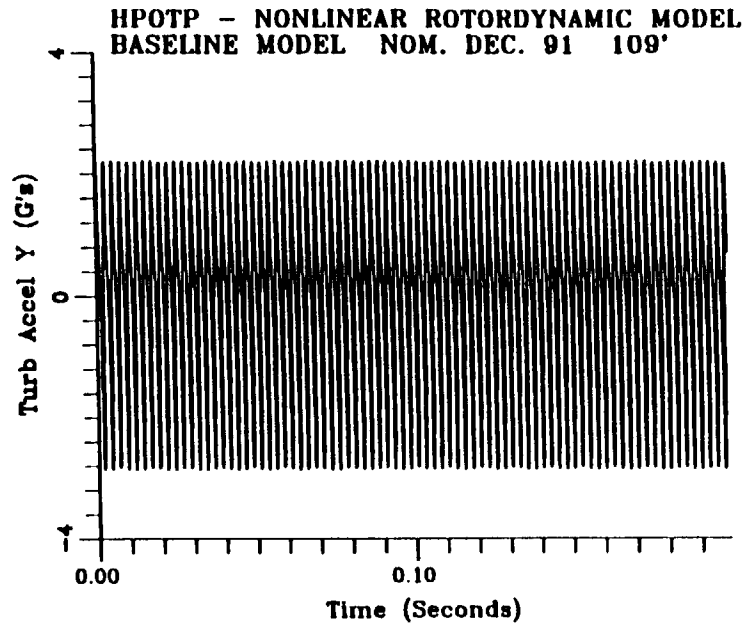

HPOTP - NONLINEAR ROTORDYNAMIC MODEL
BASELINE MODEL NOM. DEC. 91 109'
Pump End Bearing Y-Z Defl
0.0010
0.0000
-0.0010
-0.0020
0.00
0.10
Time (Seconds)

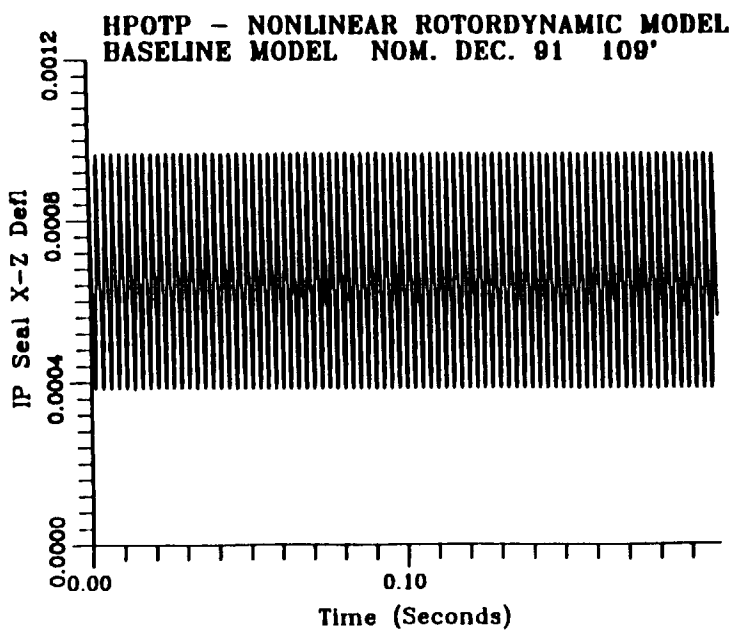

HPOTP - NONLINEAR ROTORDYNAMIC MODEL
BASELINE MODEL NOM. DEC. 91 109'
Main Stage Impeller X-Z Defl
0.0020
0.0010
0.0000
0.00
0.10
Time (Seconds)

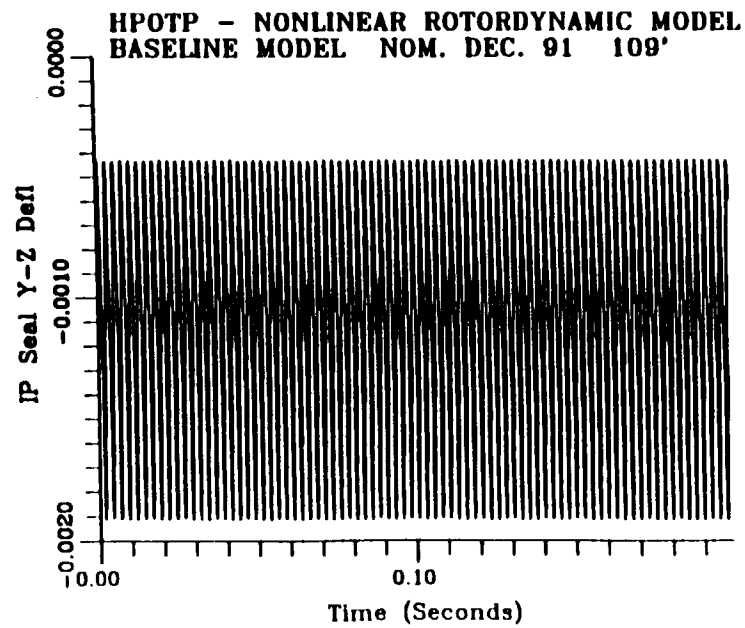

HPOTP - NONLINEAR ROTORDYNAMIC MODEL
BASELINE MODEL NOM. DEC. 91 109'
Main Stage Impeller Y-Z Defl
0.0020
0.0000
-0.0020
-0.0040
0.00
0.10
Time (Seconds)

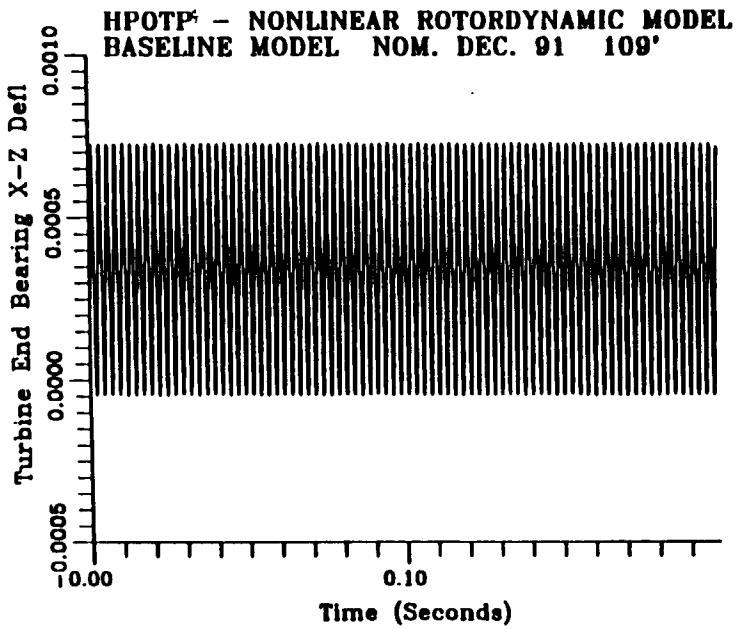
292

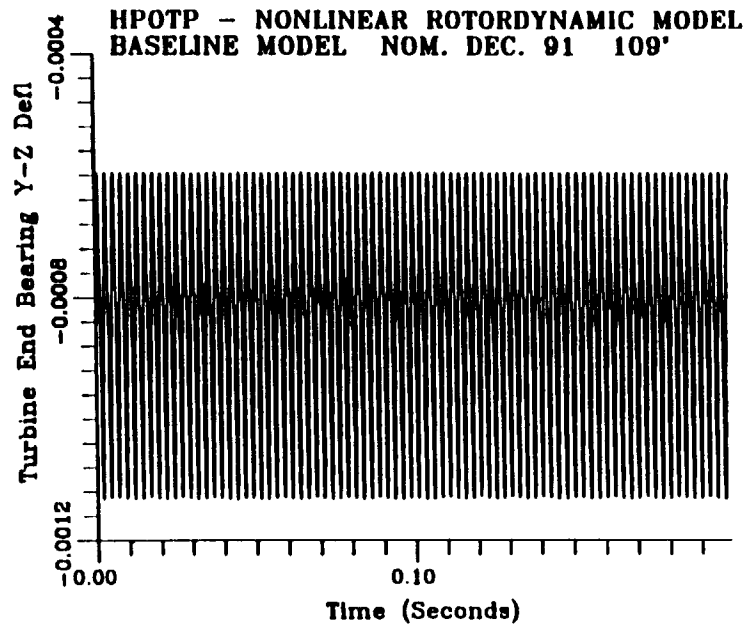

HPOTP - NONLINEAR ROTORDYNAMIC MODEL
BASELINE MODEL NOM. DEC. 91 109'
Pump Accel Y (G's)
5
0
-5
0.00
0.10
Time (Seconds)

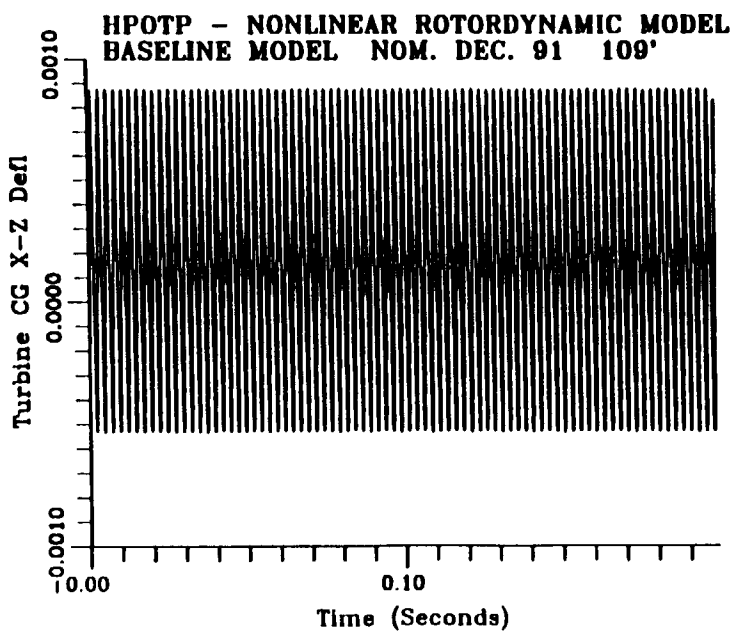

HPOTP - NONLINEAR ROTORDYNAMIC MODEL
BASELINE MODEL NOM. DEC. 91 109'
Turb Accel Y (G's)
4
0
-4
0.00
0.10
Time (Seconds)

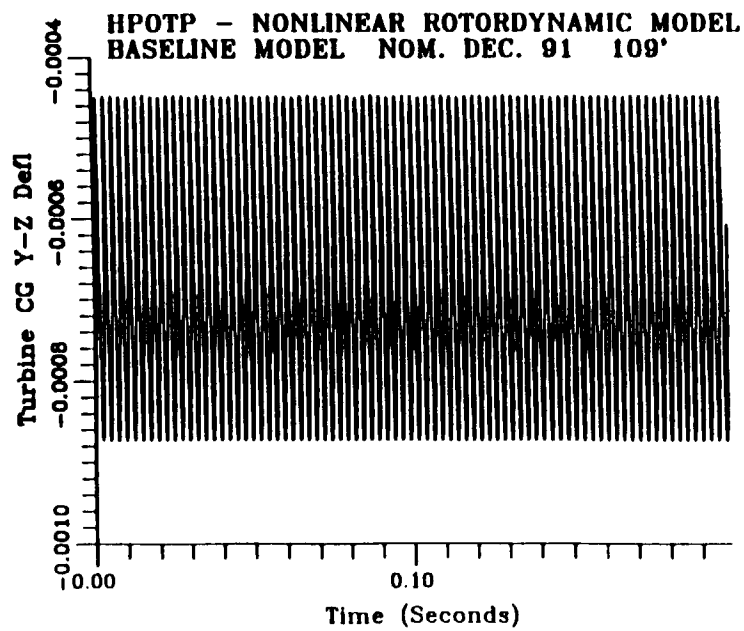

HPOTP - NONLINEAR ROTORDYNAMIC MODEL
BASELINE MODEL NOM. DEC. 91 109'
IP Seal X-Z Defl
0.0012
0.0008
0.0004
0.0000
0.00
0.10
Time (Seconds)

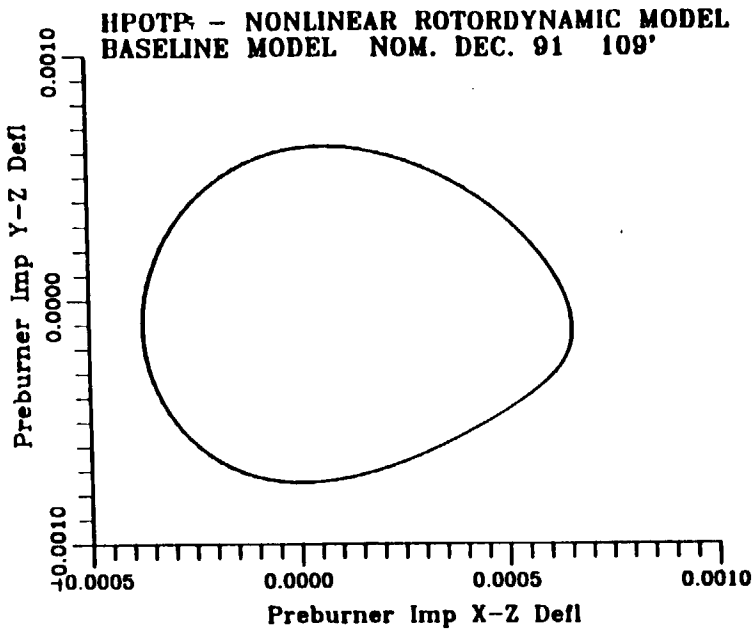

HPOTP - NONLINEAR ROTORDYNAMIC MODEL
BASELINE MODEL NOM. DEC. 91 109'
IP Seal Y-Z Defl
0.0000
-0.0010
-0.0020
0.00
0.10
Time (Seconds)

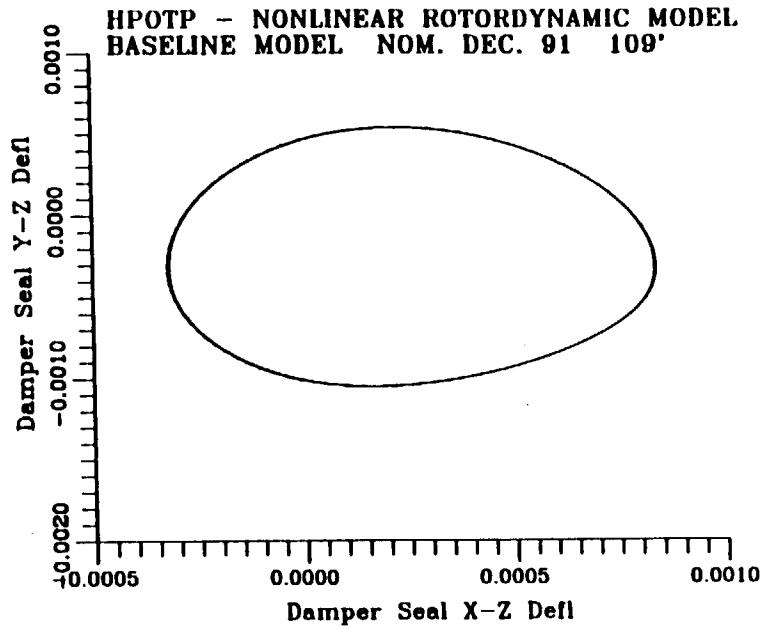

HPOTP - NONLINEAR ROTORDYNAMIC MODEL
BASELINE MODEL NOM. DEC. 91 109'
Turbine End Bearing X-Z Defl
0.0010
0.0005
0.0000
-0.0005
0.00
0.10
Time (Seconds)

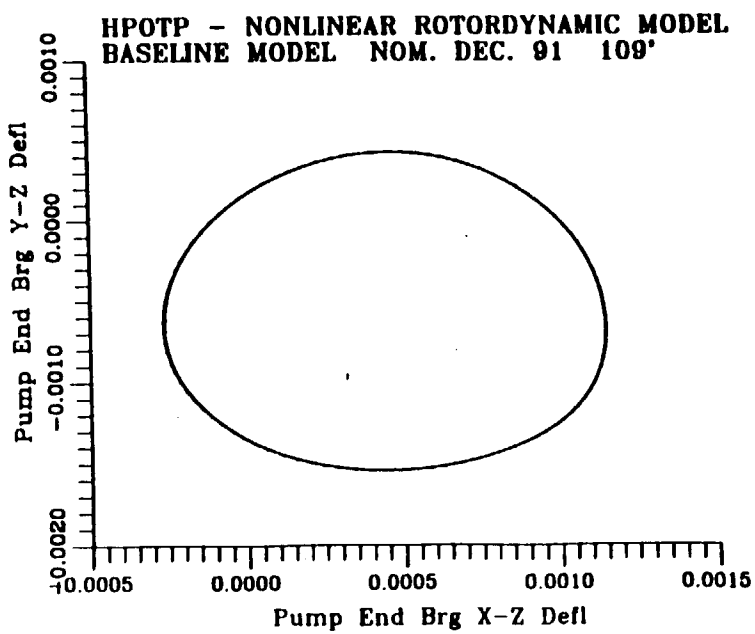

HPOTP - NONLINEAR ROTORDYNAMIC MODEL
BASELINE MODEL NOM. DEC. 91 109'
Turbine End Bearing Y-Z Defl
-0.0004
-0.0008
-0.0012
0.00
0.10
Time (Seconds)

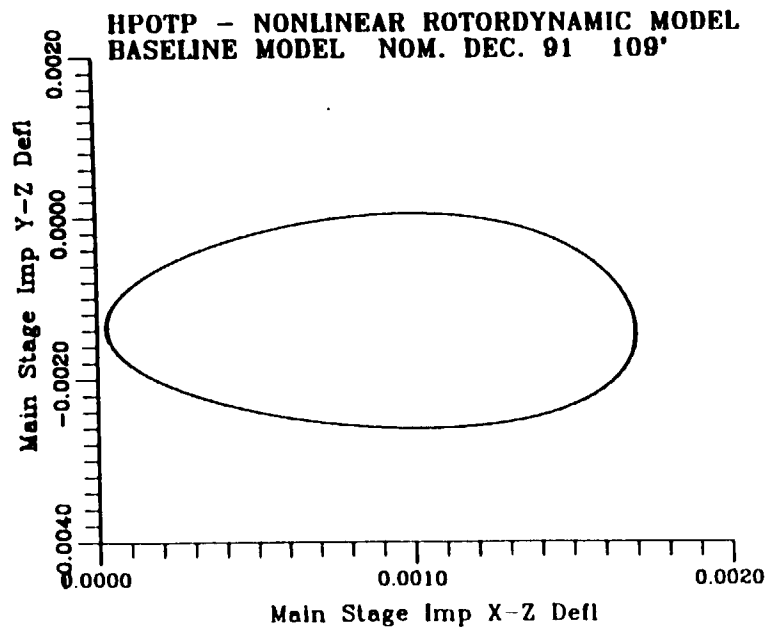

HPOTP - NONLINEAR ROTORDYNAMIC MODEL
BASELINE MODEL NOM. DEC. 91 109'
Turbine CG X-Z Defl
0.0010
0.0000
-0.0010
0.00
0.10
Time (Seconds)


HPOTP - NONLINEAR ROTORDYNAMIC MODEL
BASELINE MODEL NOM. DEC. 91 109'
Turbine CG Y-Z Defl
-0.0004
-0.0006
-0.0008
-0.0010
0.00
0.10
Time (Seconds)


HPOTP - NONLINEAR ROTORDYNAMIC MODEL
BASELINE MODEL NOM. DEC. 91 109'
Preburner Imp Y-Z Defl
0.0010
0.0000
-0.0010
-0.0005
0.0000
0.0005
0.0010
Preburner Imp X-Z Defl


HPOTP - NONLINEAR ROTORDYNAMIC MODEL
BASELINE MODEL NOM. DEC. 91 109'
Damper Seal Y-Z Defl
0.0010
0.0000
-0.0010
-0.0020
-0.0005
0.0000
0.0005
0.0010
Damper Seal X-Z Defl


HPOTP - NONLINEAR ROTORDYNAMIC MODEL
BASELINE MODEL NOM. DEC. 91 109'
Pump End Brg Y-Z Defl
0.0010
0.0000
-0.0010
-0.0020
-0.0005
0.0000
0.0005
0.0010
0.0015
Pump End Brg X-Z Defl


HPOTP - NONLINEAR ROTORDYNAMIC MODEL
BASELINE MODEL NOM. DEC. 91 109'
Main Stage Imp Y-Z Defl
0.0020
0.0000
-0.0020
-0.0040
0.0000
0.0010
0.0020
Main Stage Imp X-Z Defl

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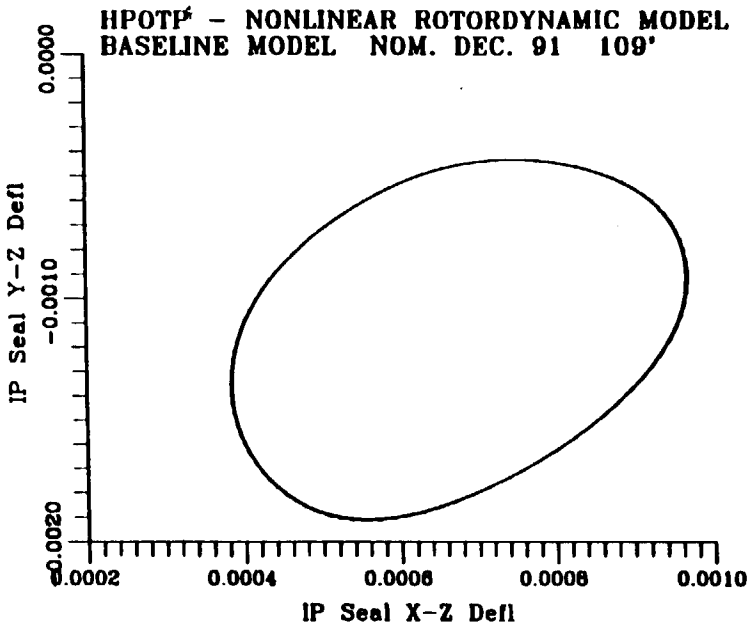
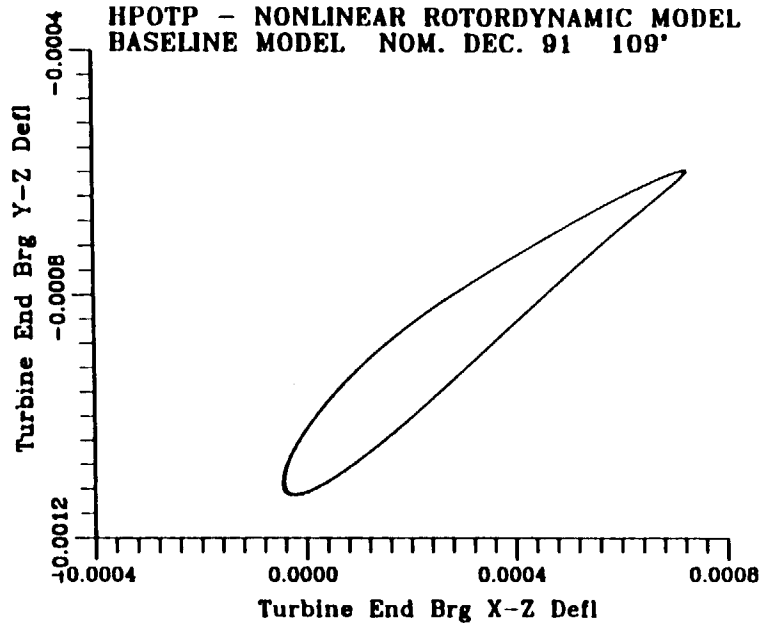
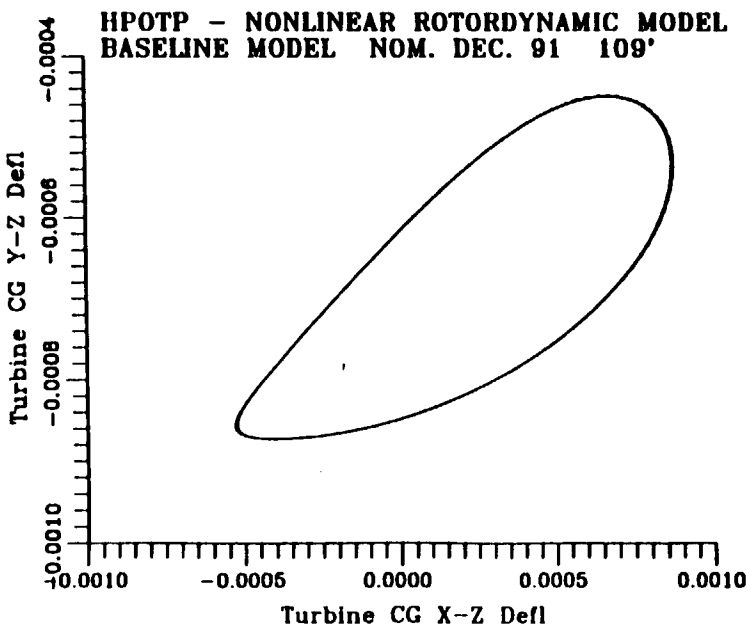
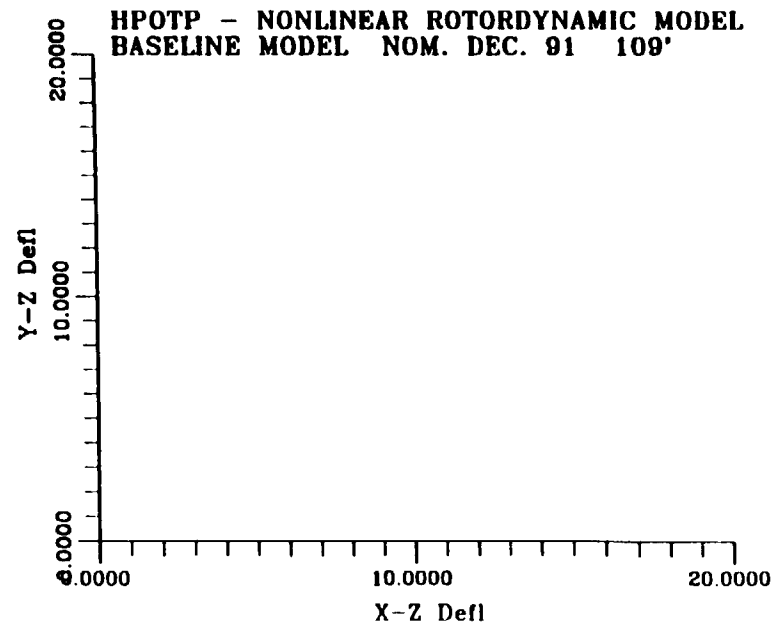
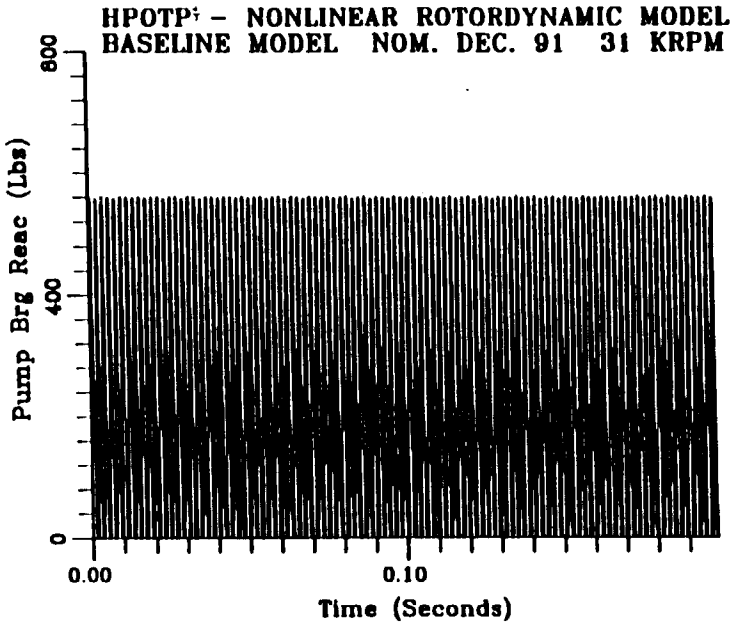

HPOTP - NONLINEAR ROTORDYNAMIC MODEL
BASELINE MODEL NOM. DEC. 91 109'
IP Seal Y-Z Defl
0.0000
-0.0010
-0.0020
0.0002
0.0004
0.0006
0.0008
0.0010
IP Seal X-Z Defl

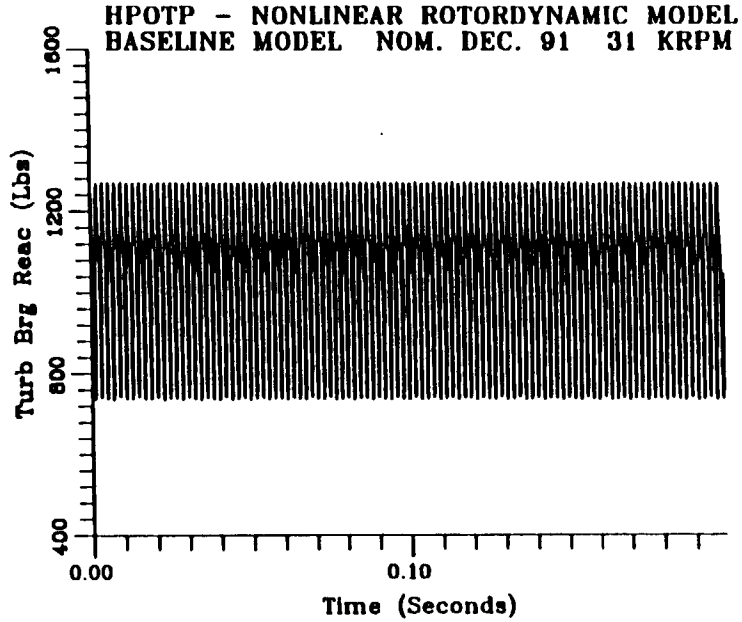

HPOTP - NONLINEAR ROTORDYNAMIC MODEL
BASELINE MODEL NOM. DEC. 91 109'
Turbine End Brg Y-Z Defl
-0.0004
-0.0008
-0.0012
-0.0004
0.0000
0.0004
0.0008
Turbine End Brg X-Z Defl

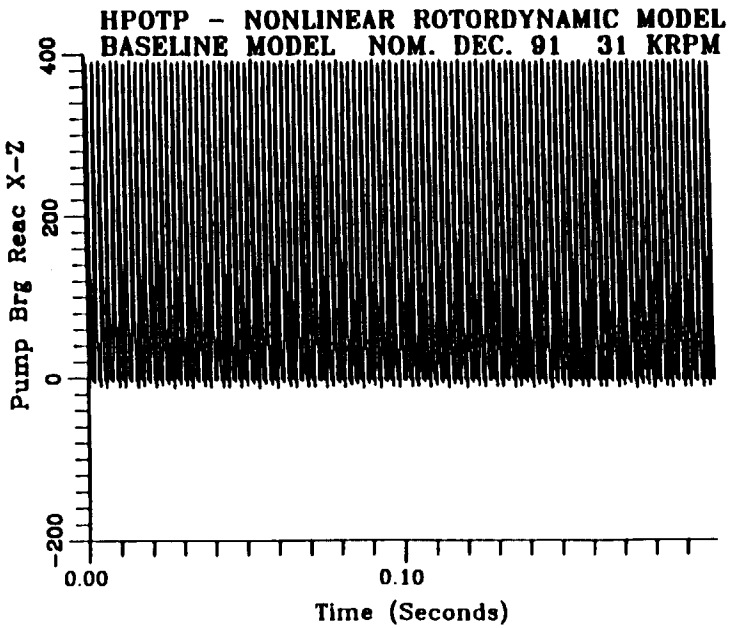

HPOTP - NONLINEAR ROTORDYNAMIC MODEL
BASELINE MODEL NOM. DEC. 91 109'
Turbine CG Y-Z Defl
-0.0004
-0.0006
-0.0008
-0.0010
-0.0010
-0.0005
0.0000
0.0005
0.0010
Turbine CG X-Z Defl

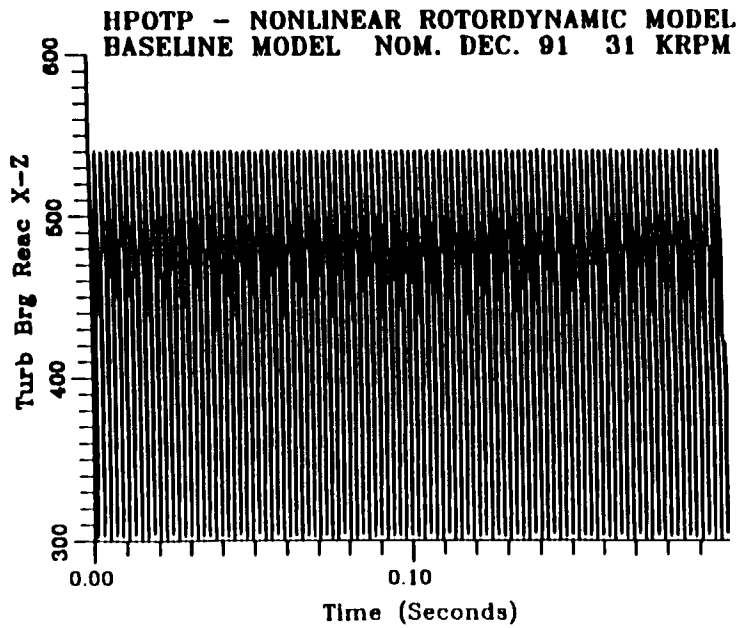

HPOTP - NONLINEAR ROTORDYNAMIC MODEL
BASELINE MODEL NOM. DEC. 91 109'
Y-Z Defl
20.0000
10.0000
0.0000
0.0000
10.0000
20.0000
X-Z Defl

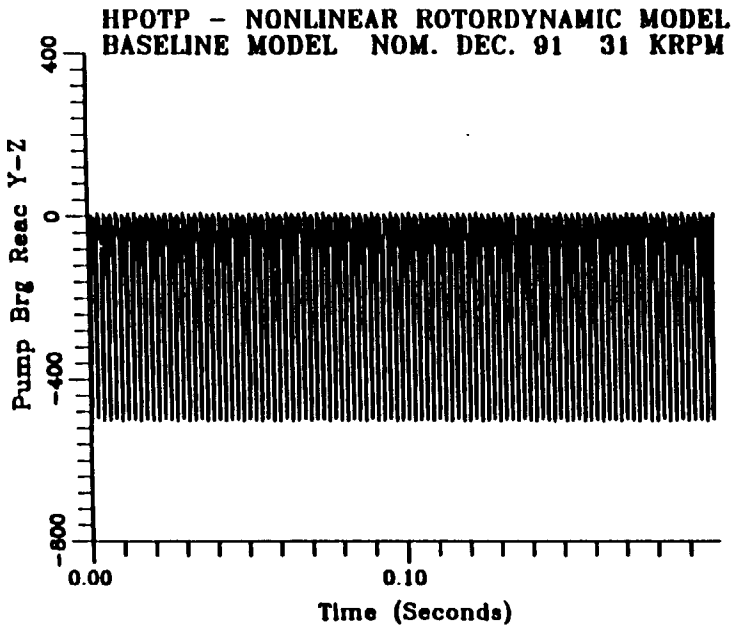
266

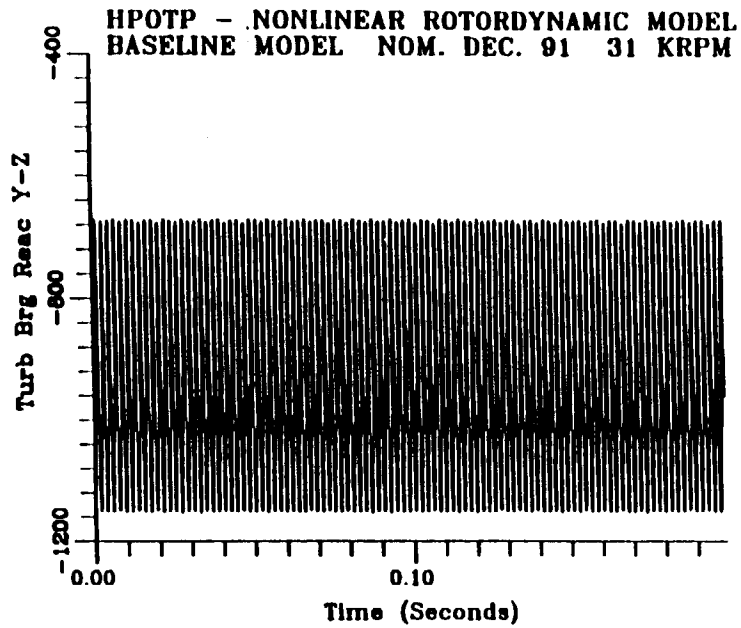

HPOTP - NONLINEAR ROTORDYNAMIC MODEL
BASELINE MODEL NOM. DEC. 91 31 KRPM
Pump Brg Reac (Lbs)
600
400
0
0.00
0.10
Time (Seconds)

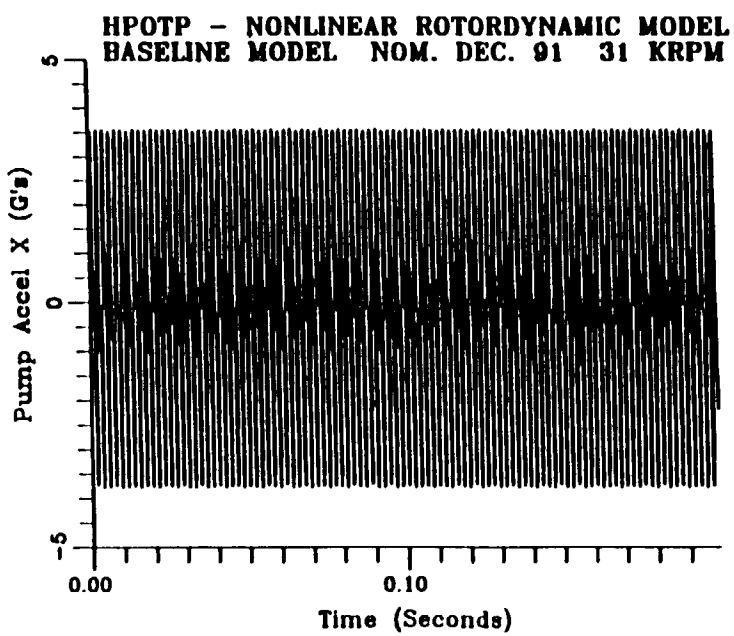

HPOTP - NONLINEAR ROTORDYNAMIC MODEL
BASELINE MODEL NOM. DEC. 91 31 KRPM
Turb Brg Reac (Lbs)
1600
1200
800
400
0.00
0.10
Time (Seconds)

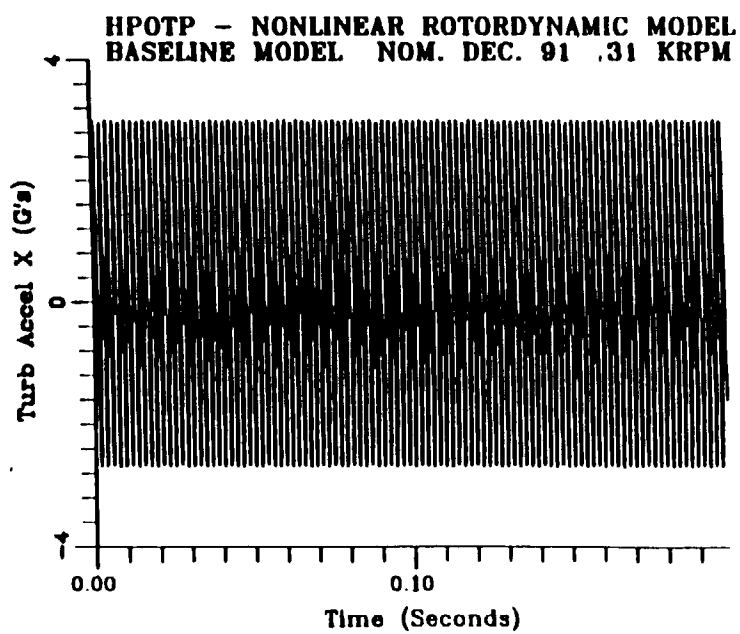

HPOTP - NONLINEAR ROTORDYNAMIC MODEL
BASELINE MODEL NOM. DEC. 91 31 KRPM
Pump Brg Reac X-Z
400
200
0
-200
0.00
0.10
Time (Seconds)

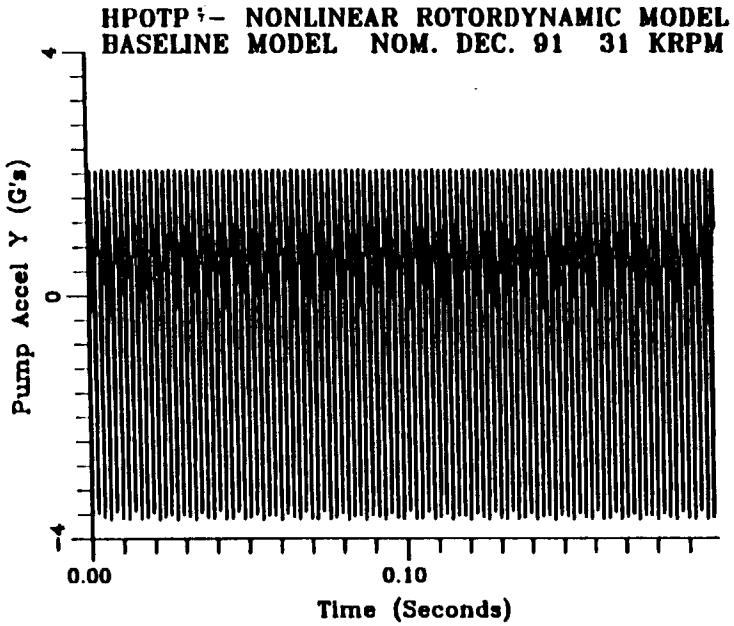

HPOTP - NONLINEAR ROTORDYNAMIC MODEL
BASELINE MODEL NOM. DEC. 91 31 KRPM
Turb Brg Reac X-Z
600
500
400
300
0.00
0.10
Time (Seconds)

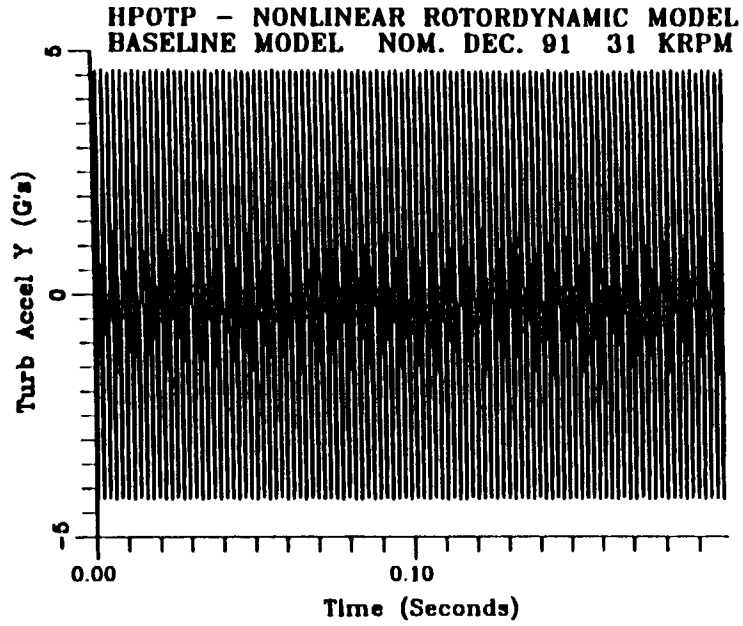

HPOTP - NONLINEAR ROTORDYNAMIC MODEL
BASELINE MODEL NOM. DEC. 91 31 KRPM
Pump Brg Reac Y-Z
400
0
-400
-800
0.00
0.10
Time (Seconds)

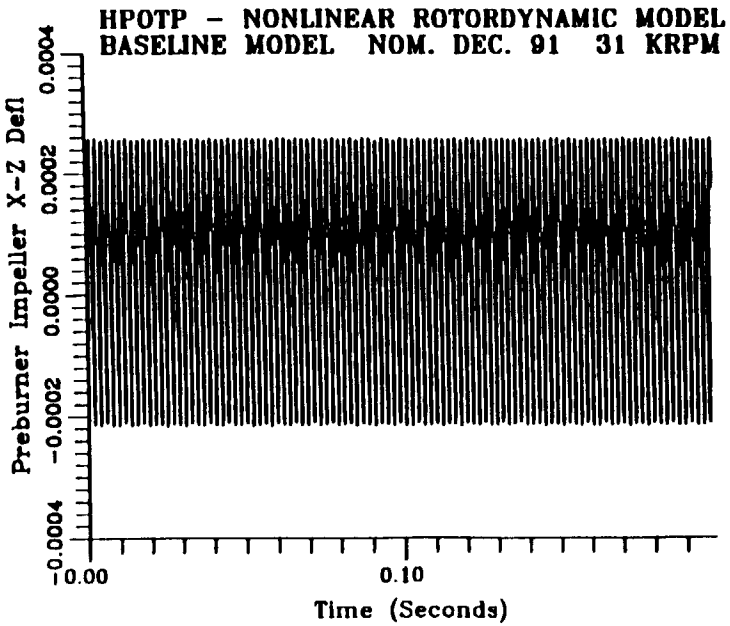

HPOTP - NONLINEAR ROTORDYNAMIC MODEL
BASELINE MODEL NOM. DEC. 91 31 KRPM
Turb Brg Reac Y-Z
-400
-800
-1200
0.00
0.10
Time (Seconds)

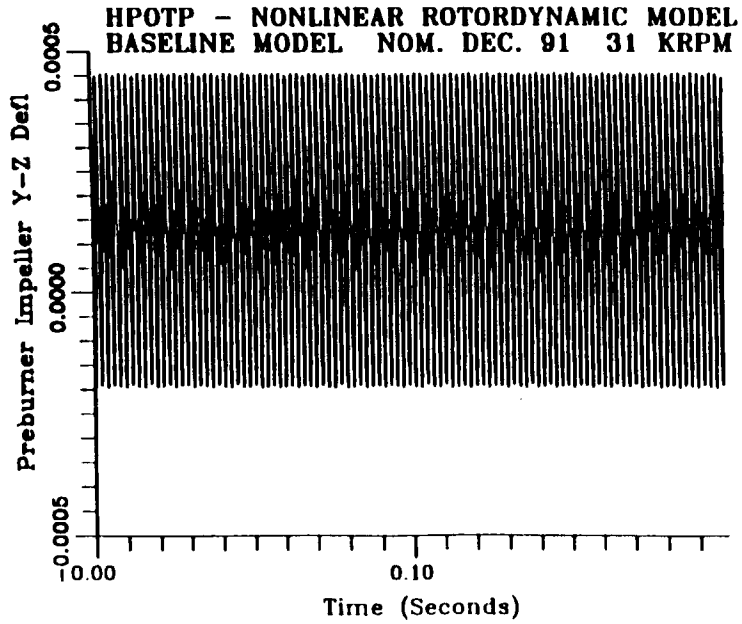

HPOTP - NONLINEAR ROTORDYNAMIC MODEL
BASELINE MODEL NOM. DEC. 91 31 KRPM
Pump Accel X (G's)
5
0
-5
0.00
0.10
Time (Seconds)

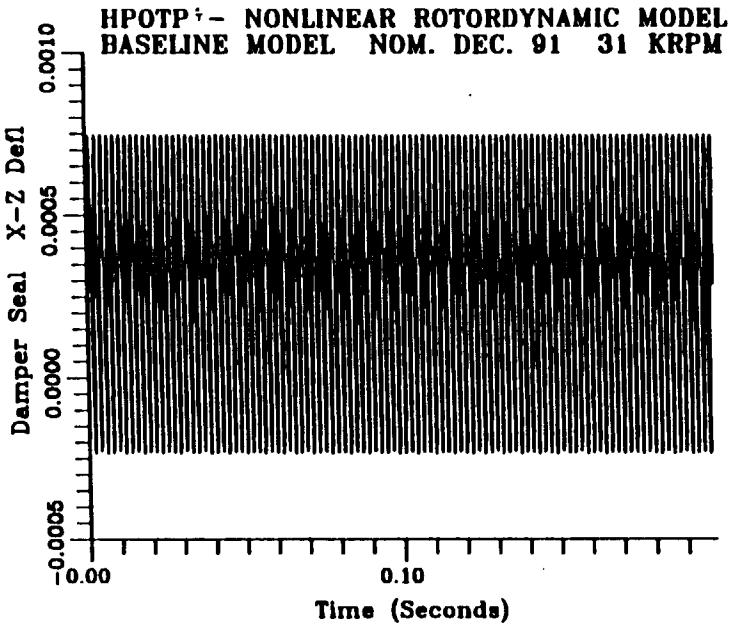

HPOTP - NONLINEAR ROTORDYNAMIC MODEL
BASELINE MODEL NOM. DEC. 91 31 KRPM
Turb Accel X (G's)
4
0
-4
0.00
0.10
Time (Seconds)

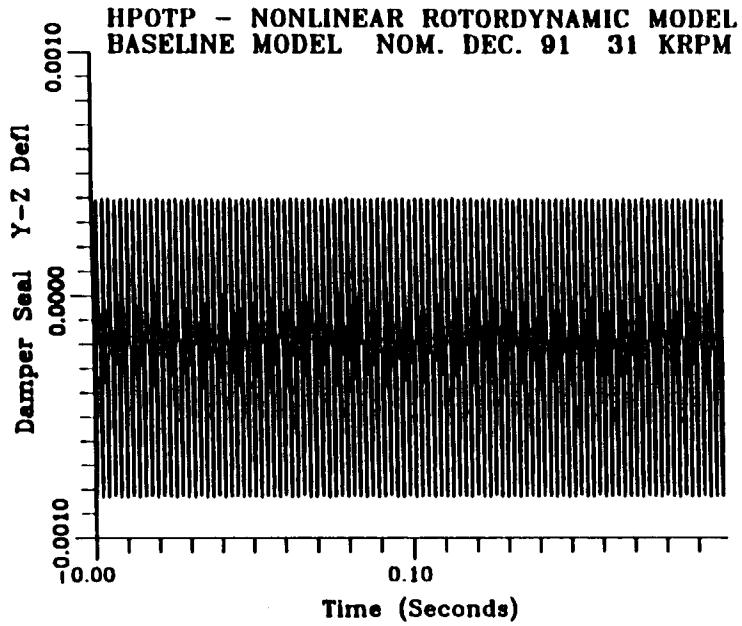

HPOTP - NONLINEAR ROTORDYNAMIC MODEL
BASELINE MODEL NOM. DEC. 91 31 KRPM
Pump Accel Y (G's)
4
0
-4
0.00
0.10
Time (Seconds)

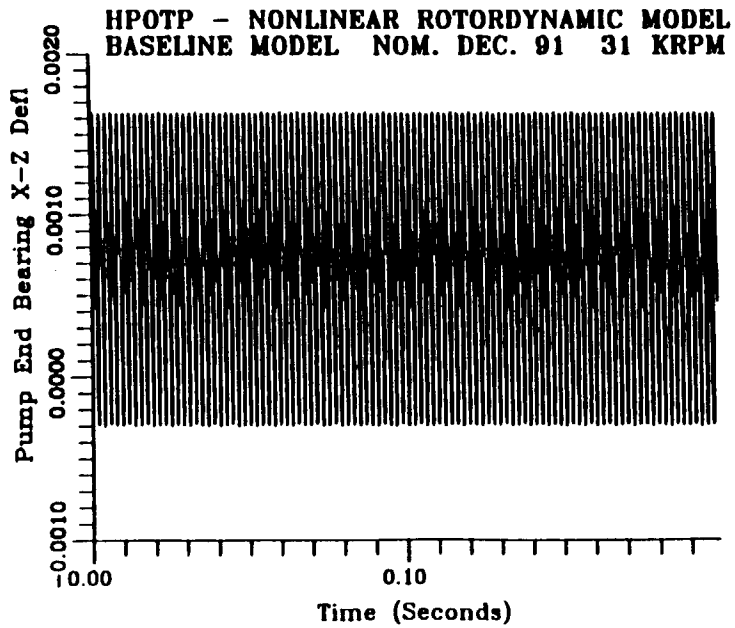

HPOTP - NONLINEAR ROTORDYNAMIC MODEL
BASELINE MODEL NOM. DEC. 91 31 KRPM
Turb Accel Y (G's)
5
0
-5
0.00
0.10
Time (Seconds)

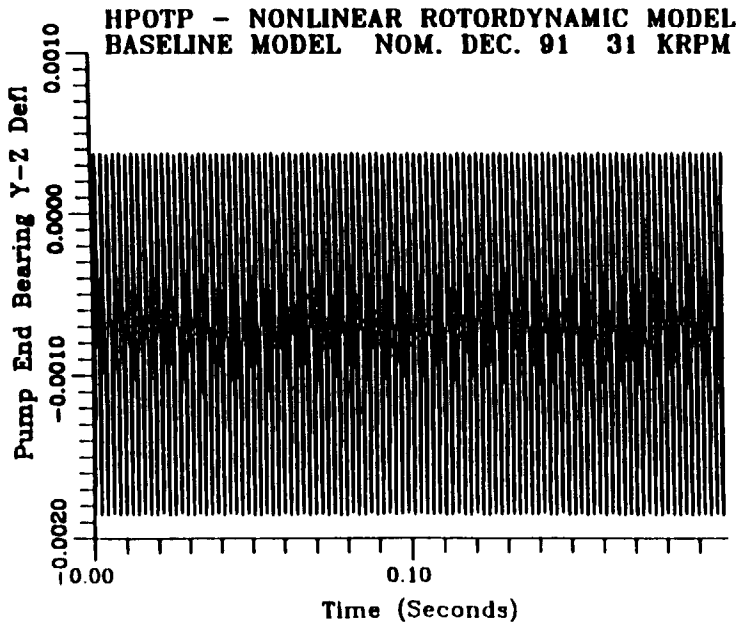

HPOTP - NONLINEAR ROTORDYNAMIC MODEL
BASELINE MODEL NOM. DEC. 91 31 KRPM
Preburner Impeller X-Z Defl
0.0004
0.0002
0.0000
-0.0002
-0.0004
0.00
0.10
Time (Seconds)

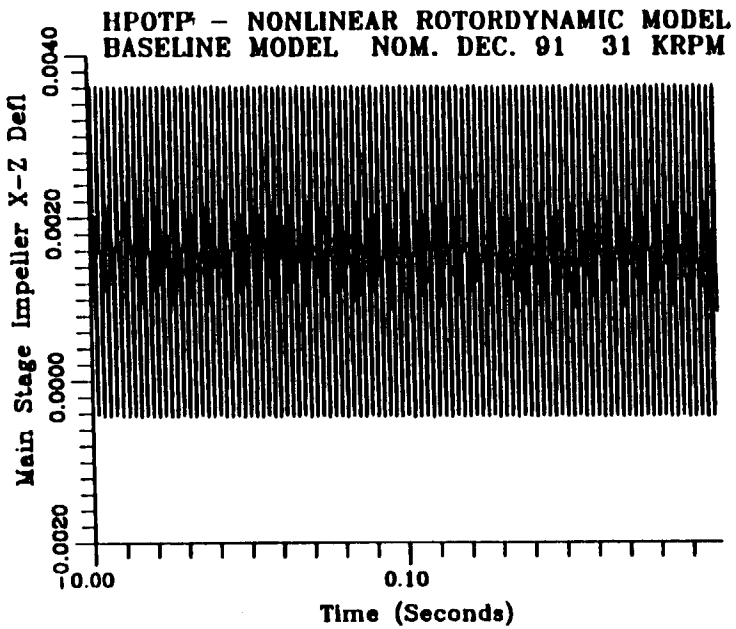

HPOTP - NONLINEAR ROTORDYNAMIC MODEL
BASELINE MODEL NOM. DEC. 91 31 KRPM
Preburner Impeller Y-Z Defl
0.0005
0.0000
-0.0005
0.00
0.10
Time (Seconds)

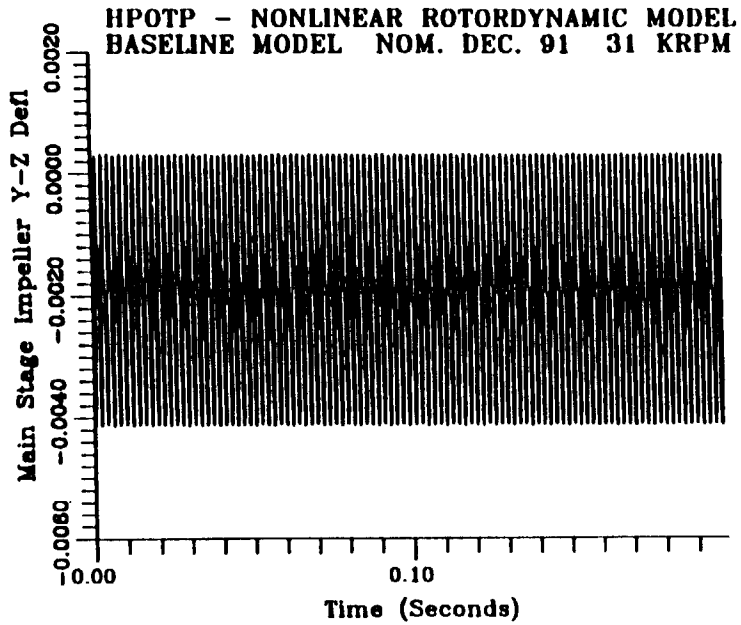

HPOTP - NONLINEAR ROTORDYNAMIC MODEL
BASELINE MODEL NOM. DEC. 91 31 KRPM
Damper Seal X-Z Defl
0.0010
0.0005
0.0000
-0.0005
0.00
0.10
Time (Seconds)

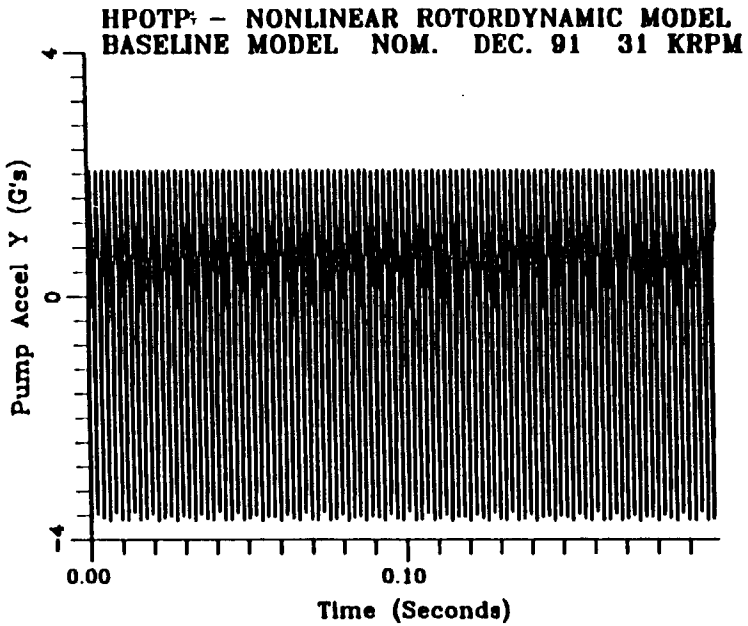

HPOTP - NONLINEAR ROTORDYNAMIC MODEL
BASELINE MODEL NOM. DEC. 91 31 KRPM
Damper Seal Y-Z Defl
0.0010
0.0000
-0.0010
0.00
0.10
Time (Seconds)

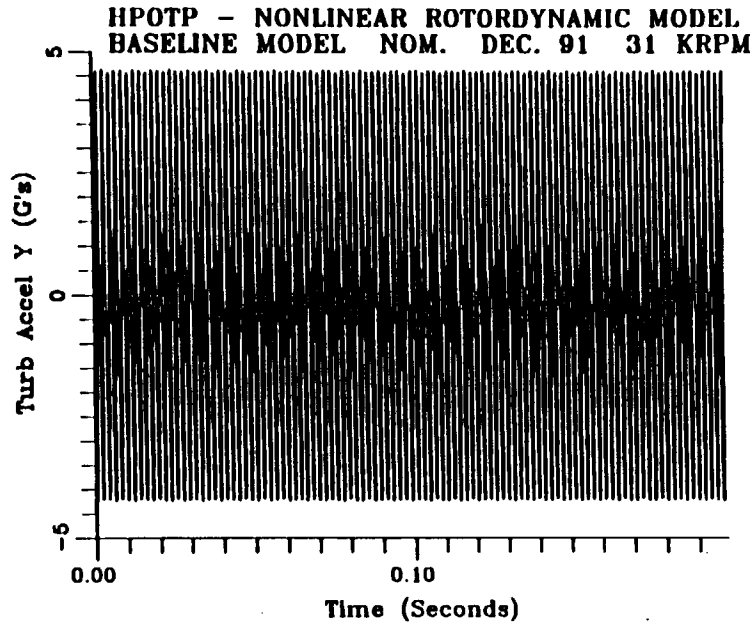

HPOTP - NONLINEAR ROTORDYNAMIC MODEL
BASELINE MODEL NOM. DEC. 91 31 KRPM
Pump End Bearing X-Z Defl
0.0020
0.0010
0.0000
-0.0010
0.00
0.10
Time (Seconds)

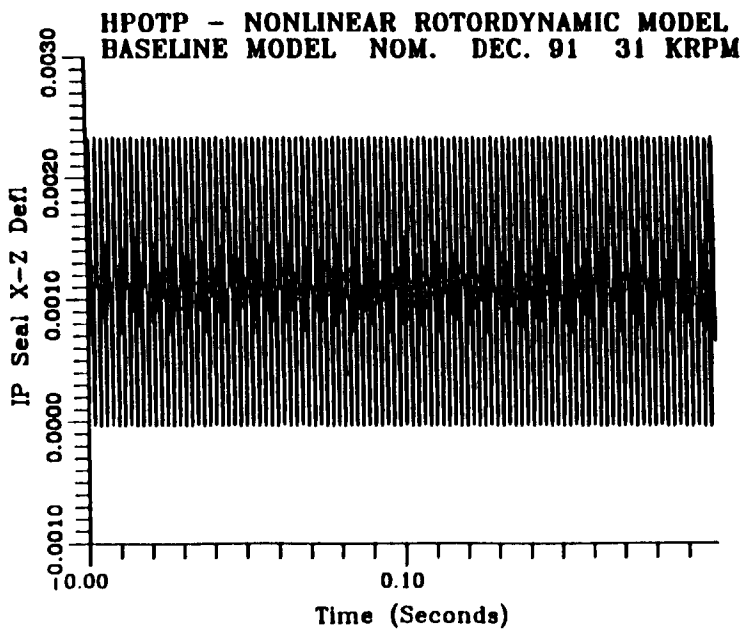

HPOTP - NONLINEAR ROTORDYNAMIC MODEL
BASELINE MODEL NOM. DEC. 91 31 KRPM
Pump End Bearing Y-Z Defl
0.0010
0.0000
-0.0010
-0.0020
0.00
0.10
Time (Seconds)

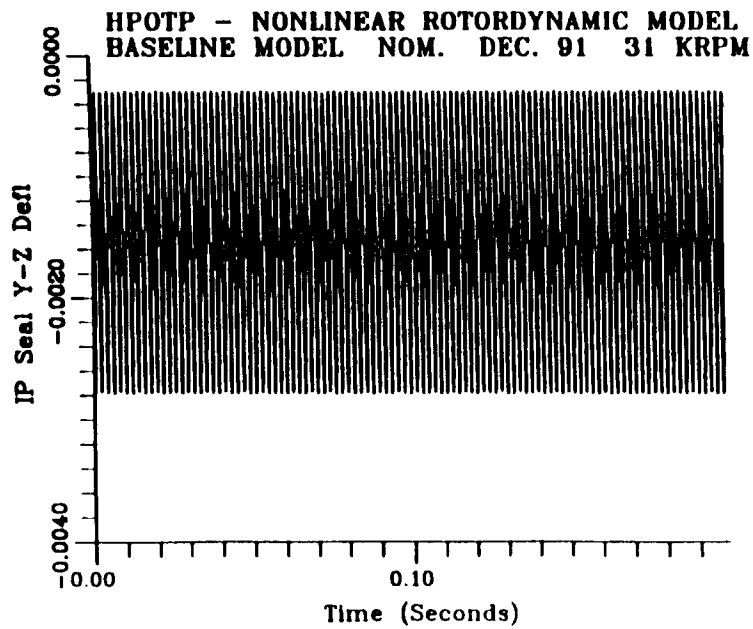

HPOTP - NONLINEAR ROTORDYNAMIC MODEL
BASELINE MODEL NOM. DEC. 91 31 KRPM
Main Stage Impeller X-Z Defl
0.0040
0.0020
0.0000
-0.0020
0.00
0.10
Time (Seconds)

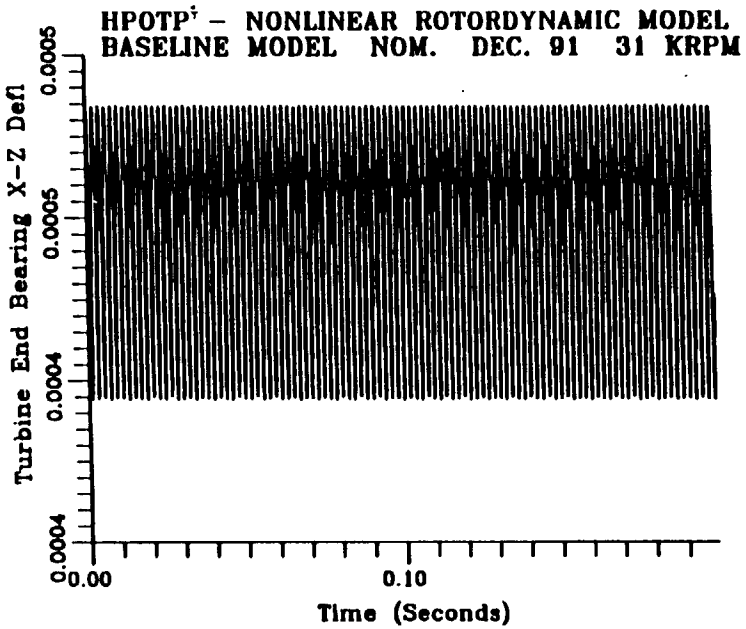

HPOTP - NONLINEAR ROTORDYNAMIC MODEL
BASELINE MODEL NOM. DEC. 91 31 KRPM
Main Stage Impeller Y-Z Defl
0.0020
0.0000
-0.0020
-0.0040
-0.0060
0.00
0.10
Time (Seconds)

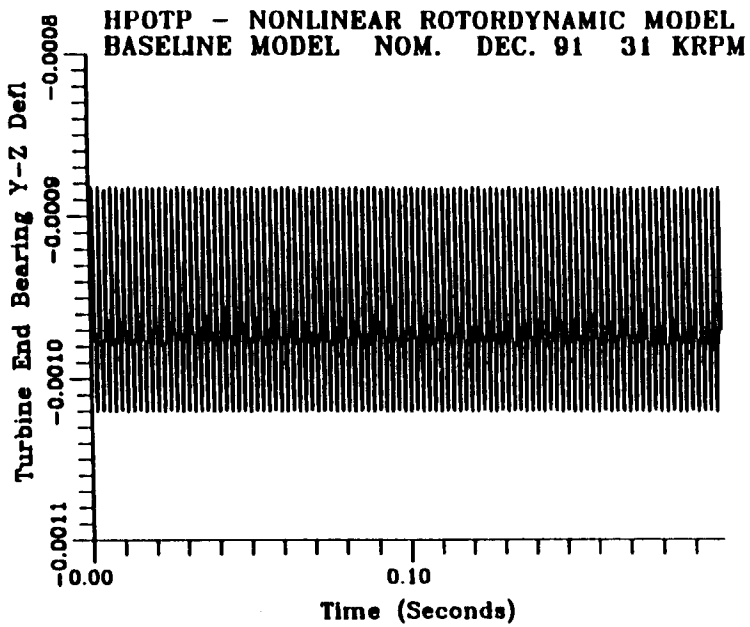

HPOTP - NONLINEAR ROTORDYNAMIC MODEL
BASELINE MODEL NOM. DEC. 91 31 KRPM
Pump Accel Y (G's)
4
0
-4
0.00
0.10
Time (Seconds)

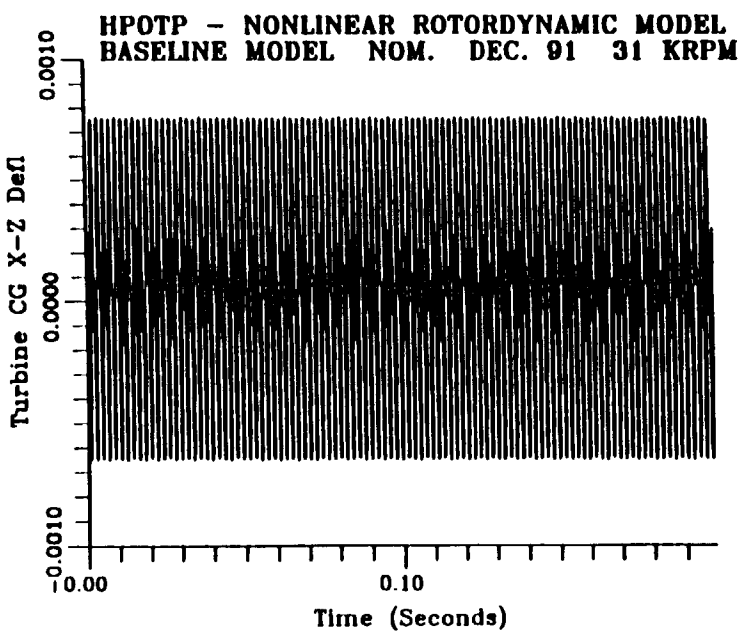

HPOTP - NONLINEAR ROTORDYNAMIC MODEL
BASELINE MODEL NOM. DEC. 91 31 KRPM
Turb Accel Y (G's)
5
0
-5
0.00
0.10
Time (Seconds)

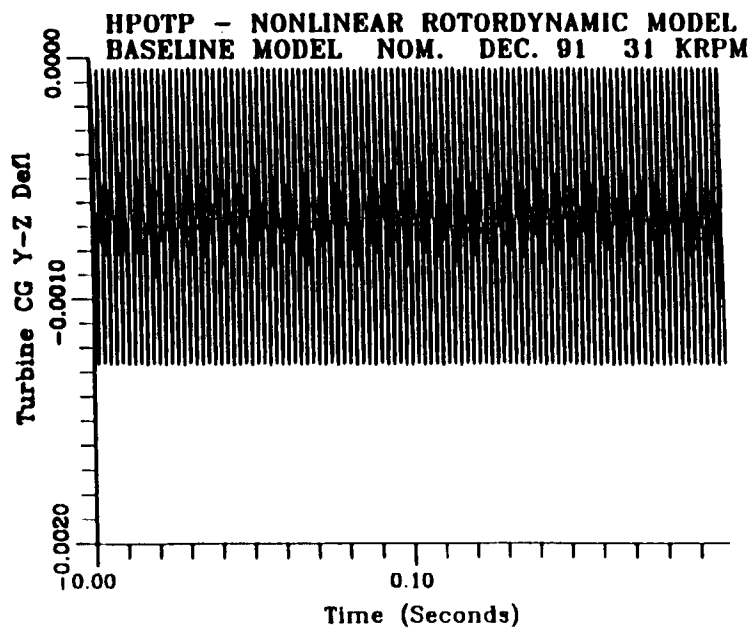

HPOTP - NONLINEAR ROTORDYNAMIC MODEL
BASELINE MODEL NOM. DEC. 91 31 KRPM
IP Seal X-Z Defl
0.0030
0.0020
0.0010
0.0000
-0.0010
0.00
0.10
Time (Seconds)

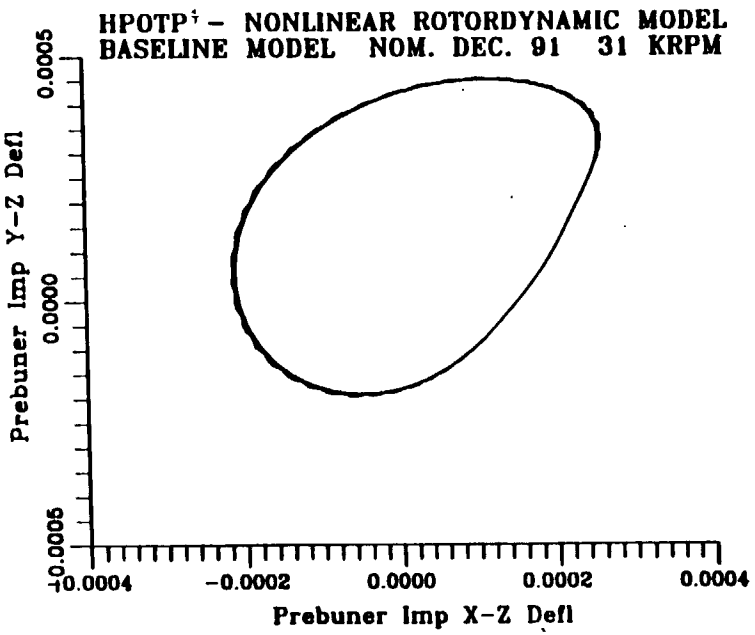

HPOTP - NONLINEAR ROTORDYNAMIC MODEL
BASELINE MODEL NOM. DEC. 91 31 KRPM
IP Seal Y-Z Defl
0.0000
-0.0020
-0.0040
0.00
0.10
Time (Seconds)

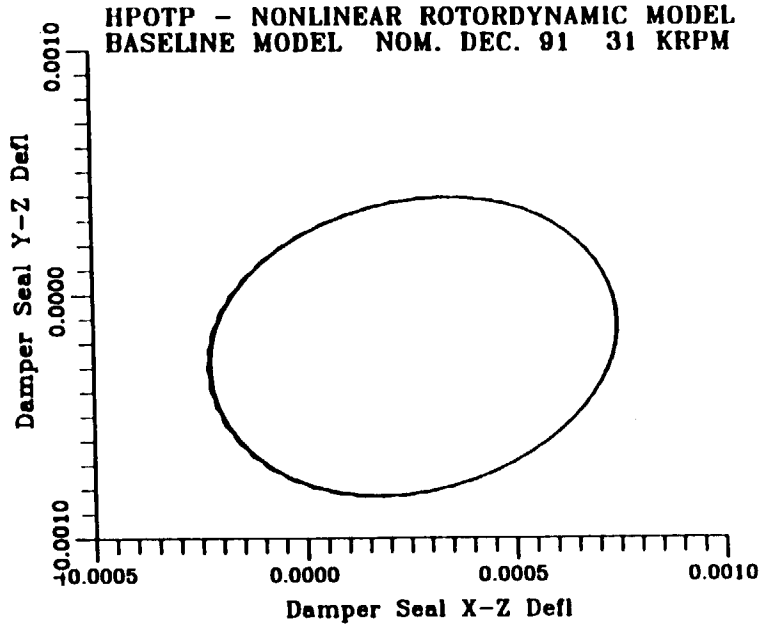

HPOTP - NONLINEAR ROTORDYNAMIC MODEL
BASELINE MODEL NOM. DEC. 91 31 KRPM
Turbine End Bearing X-Z Defl
0.0006
0.0005
0.0004
0.0004
0.00
0.10
Time (Seconds)

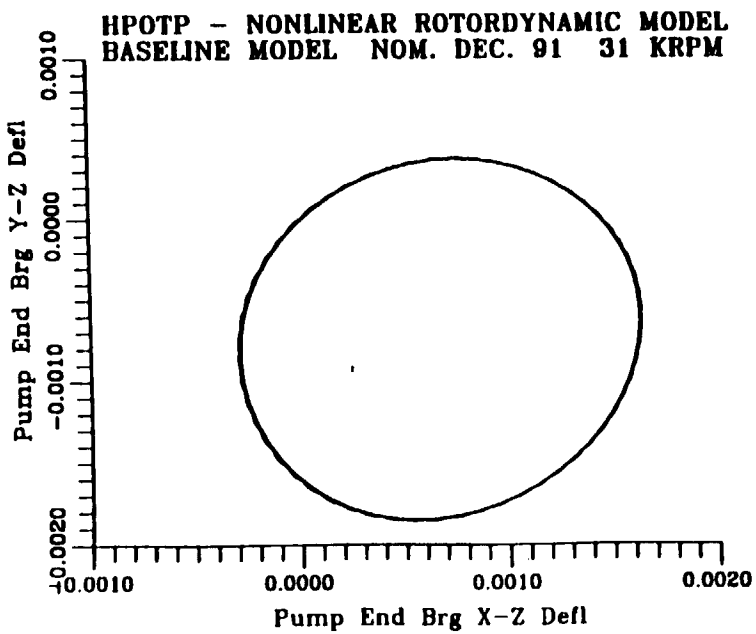

HPOTP - NONLINEAR ROTORDYNAMIC MODEL
BASELINE MODEL NOM. DEC. 91 31 KRPM
Turbine End Bearing Y-Z Defl
-0.0008
-0.0009
-0.0010
-0.0011
0.00
0.10
Time (Seconds)

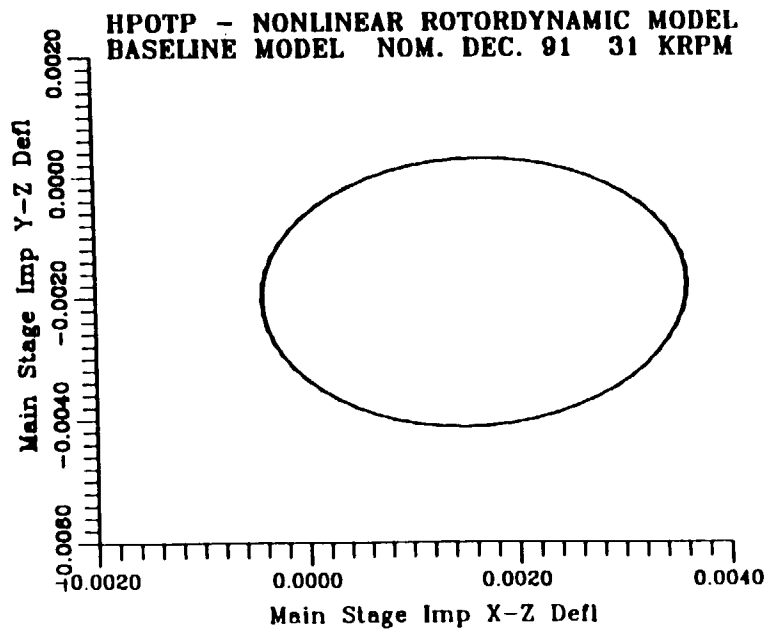

HPOTP - NONLINEAR ROTORDYNAMIC MODEL
BASELINE MODEL NOM. DEC. 91 31 KRPM
Turbine CG X-Z Defl
0.0010
0.0000
-0.0010
0.00
0.10
Time (Seconds)

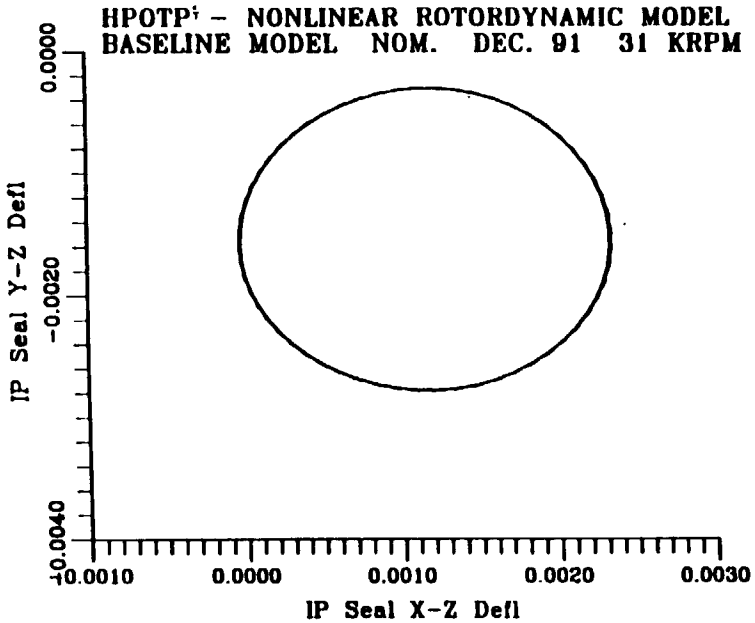

HPOTP - NONLINEAR ROTORDYNAMIC MODEL
BASELINE MODEL NOM. DEC. 91 31 KRPM
Turbine CG Y-Z Defl
0.0000
-0.0010
-0.0020
0.00
0.10
Time (Seconds)

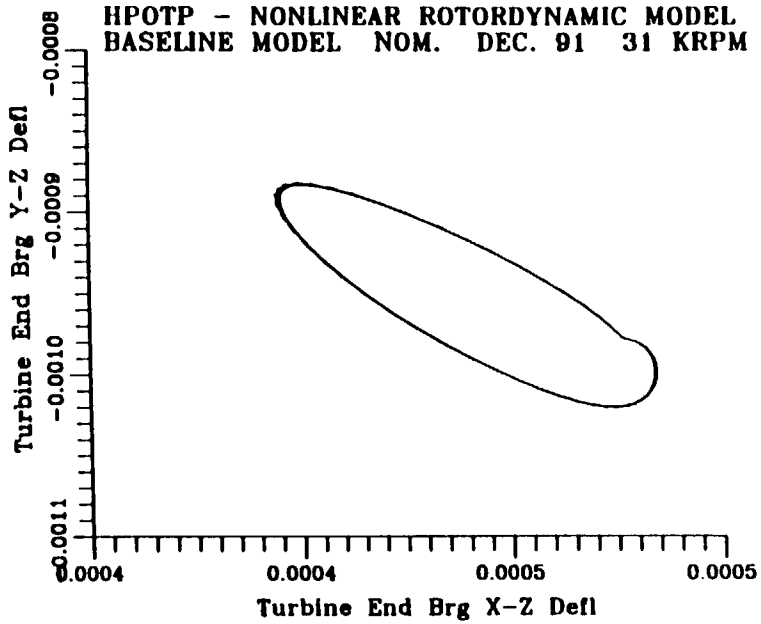

HPOTP - NONLINEAR ROTORDYNAMIC MODEL
BASELINE MODEL NOM. DEC. 91 31 KRPM
Prebuner Imp Y-Z Defl
0.0005
0.0000
-0.0005
-0.0004
-0.0002
0.0000
0.0002
0.0004
Prebuner Imp X-Z Defl

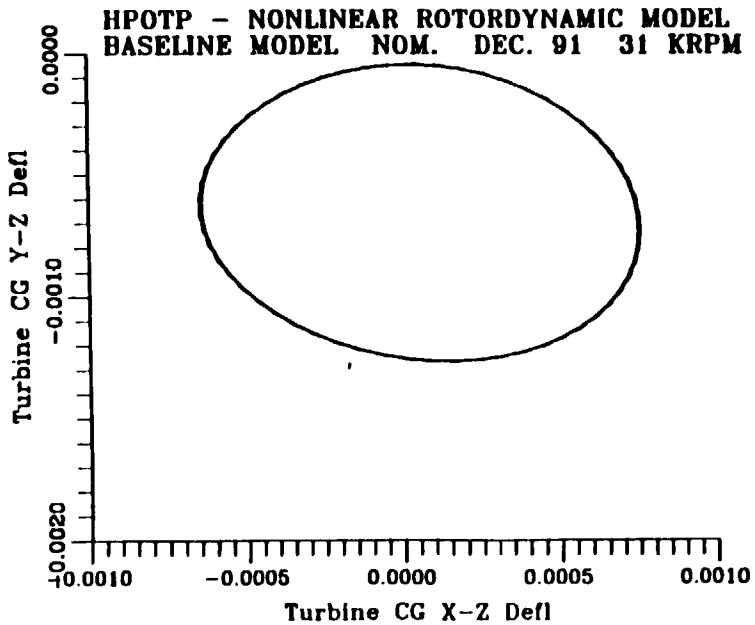

HPOTP - NONLINEAR ROTORDYNAMIC MODEL
BASELINE MODEL NOM. DEC. 91 31 KRPM
Damper Seal Y-Z Defl
0.0010
0.0000
-0.0010
-0.0005
0.0000
0.0005
0.0010
Damper Seal X-Z Defl

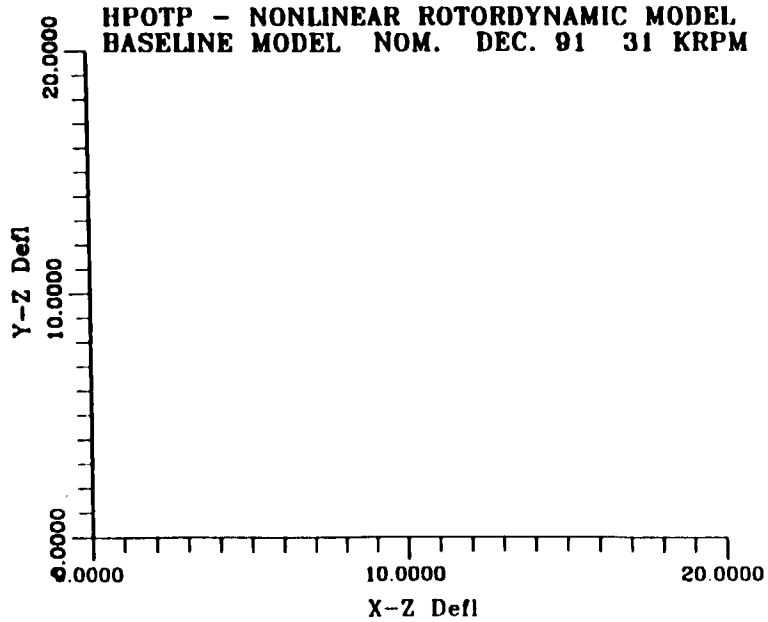

HPOTP - NONLINEAR ROTORDYNAMIC MODEL
BASELINE MODEL NOM. DEC. 91 31 KRPM
Pump End Brg Y-Z Defl
0.0010
0.0000
-0.0010
-0.0020
-0.0010
0.0000
0.0010
0.0020
Pump End Brg X-Z Defl


HPOTP - NONLINEAR ROTORDYNAMIC MODEL
BASELINE MODEL NOM. DEC. 91 31 KRPM
Main Stage Imp Y-Z Defl
0.0020
0.0000
-0.0020
-0.0040
-0.0060
-0.0020
0.0000
0.0020
0.0040
Main Stage Imp X-Z Defl


HPOTP - NONLINEAR ROTORDYNAMIC MODEL
BASELINE MODEL NOM. DEC. 91 31 KRPM
IP Seal Y-Z Defl
0.0000
-0.0020
-0.0040
-0.0010
0.0000
0.0010
0.0020
0.0030
IP Seal X-Z Defl


HPOTP - NONLINEAR ROTORDYNAMIC MODEL
BASELINE MODEL NOM. DEC. 91 31 KRPM
Turbine End Brg Y-Z Defl
-0.0008
-0.0009
-0.0010
-0.0011
-0.0004
0.0004
0.0005
0.0005
Turbine End Brg X-Z Defl


HPOTP - NONLINEAR ROTORDYNAMIC MODEL
BASELINE MODEL NOM. DEC. 91 31 KRPM
Turbine CG Y-Z Defl
0.0000
-0.0010
-0.0020
-0.0010
-0.0005
0.0000
0.0005
0.0010
Turbine CG X-Z Defl


HPOTP - NONLINEAR ROTORDYNAMIC MODEL
BASELINE MODEL NOM. DEC. 91 31 KRPM
Y-Z Defl
20.0000
10.0000
0.0000
0.0000
10.0000
20.0000
X-Z Defl

Appendix H. 'Design of Experiments' Response Tables

DAMPER SEAL
@ 65% RPL

PARAM VALUES

	CLEAR(A)	TAPER(B)	PRESS(C)	TVR (D)
MIN (1)	0.0058	0.0023	1,300	0.100
NOM (2)	0.0068	0.0038	1,500	0.300
MAX (3)	0.0078	0.0053	1,700	0.500

TEST MATRIX / OUTPUT DATA

TEST NO.	CLEAR(A)	TAPER(B)	PRESS(C)	TVR (D)	DIRECT K	CROSS K	DIRECT C	CROSS C	DIRECT M	MDOT
# 1	0.0058	0.0023	1,300	0.100	150,540	10,887	58.909	1.561	0.88449	6.2686
# 2	0.0058	0.0038	1,500	0.300	203,320	31,033	65.204	2.219	0.90376	6.4758
# 3	0.0058	0.0053	1,700	0.500	279,740	53,916	71.695	3.3818	0.97298	6.3232
# 4	0.0068	0.0023	1,500	0.500	143,940	42,232	53.453	2.3118	0.73484	8.4063
# 5	0.0068	0.0038	1,700	0.100	195,280	10,415	58.965	1.2208	0.74941	8.8353
# 6	0.0068	0.0053	1,300	0.300	176,280	25,246	52.57	1.976	0.7915	7.118
# 7	0.0078	0.0023	1,700	0.300	145,740	24,340	49.844	1.5158	0.6295	11.108
# 8	0.0078	0.0038	1,300	0.500	123,850	35,337	44.101	2.0882	0.63577	9.2712
# 9	0.0078	0.0053	1,500	0.100	141,820	7,496.3	45.168	0.96287	0.59567	10.96

RESPONSE TABLE

	DIRECT K	DELTA	CROSS K	DELTA	DIRECT C	DELTA	CROSS C	DELTA	DIRECT M	DELTA	MDOT	DELTA
A1	2.11E+05		3.19E+04		6.53E+01		2.39E+00		9.20E-01		6.36E+00	
A2	1.72E+05		2.60E+04		5.50E+01		1.84E+00		7.59E-01		8.12E+00	
A3	1.37E+05	7.41E+04	2.24E+04	9.55E+03	4.64E+01	1.89E+01	1.52E+00	8.65E-01	6.20E-01	3.00E-01	1.04E+01	4.09E+00
B1	1.47E+05		2.58E+04		5.41E+01		1.80E+00		7.50E-01		8.59E+00	
B2	1.74E+05		2.56E+04		5.61E+01		1.84E+00		7.63E-01		8.19E+00	
B3	1.99E+05	5.25E+04	2.89E+04	3.29E+03	5.65E+01	2.41E+00	2.11E+00	3.11E-01	7.87E-01	3.71E-02	8.13E+00	4.61E-01
C1	1.50E+05		2.38E+04		5.19E+01		1.88E+00		7.71E-01		7.55E+00	
C2	1.63E+05		2.69E+04		5.46E+01		1.83E+00		7.45E-01		8.61E+00	
C3	2.07E+05	5.67E+04	2.96E+04	5.73E+03	6.02E+01	8.31E+00	2.04E+00	2.08E-01	7.84E-01	3.92E-02	8.76E+00	1.20E+00
D1	1.63E+05		9.60E+03		5.43E+01		1.25E+00		7.43E-01		8.69E+00	
D2	1.75E+05		2.69E+04		5.59E+01		1.90E+00		7.75E-01		8.23E+00	
D3	1.83E+05	2.00E+04	4.38E+04	3.42E+04	5.64E+01	2.07E+00	2.59E+00	1.35E+00	7.81E-01	3.80E-02	8.00E+00	6.88E-01

DAMPER SEAL
@ 90% RPL

PARAM VALUES

	GAP(A)	TAPER(B)	PRESS(C)	TVR (D)
MIN (1)	0.0053	0.0023	2,700	0.100
NOM (2)	0.0063	0.0038	2,900	0.300
MAX (3)	0.0073	0.0053	3,100	0.500

TEST MATRIX / OUTPUT DATA

TEST NO.	GAP(A)	TAPER(B)	PRESS(C)	TVR (D)	DIRECT K	CROSS K	DIRECT C	CROSS C	DIRECT M	MDOT
# 1	0.0053	0.0023	2,700	0.100	346,940	22,529	94.032	2.0732	0.96502	8.02
# 2	0.0053	0.0038	2,900	0.300	442,390	59,566	100.2	3.0328	0.99589	7.9186
# 3	0.0053	0.0053	3,100	0.500	580,540	99,318	106.82	4.7542	1.0892	7.3854
# 4	0.0063	0.0023	2,900	0.500	304,470	79,377	80.721	3.0826	0.79088	10.679
# 5	0.0063	0.0038	3,100	0.100	391,440	19,638	86.287	1.6314	0.81097	10.715
# 6	0.0063	0.0053	2,700	0.300	409,240	49,571	82.486	2.6805	0.8654	9.194
# 7	0.0073	0.0023	3,100	0.300	285,970	44,060	72	2.0042	0.67055	13.739
# 8	0.0073	0.0038	2,700	0.500	281,270	68,458	68.393	2.7689	0.67883	12.291
# 9	0.0073	0.0053	2,900	0.100	370,370	16,317	73.385	1.3405	0.71552	12.083

RESPONSE TABLE

	DIRECT K	DELTA	CROSS K	DELTA	DIRECT C	DELTA	CROSS C	DELTA	DIRECT M	DELTA	MDOT	DELTA
A1	4.57E+05		6.05E+04		1.00E+02		3.29E+00		1.02E+00		7.77E+00	
A2	3.68E+05		4.95E+04		8.32E+01		2.46E+00		8.22E-01		1.02E+01	
A3	3.13E+05	1.44E+05	4.29E+04	1.75E+04	7.13E+01	2.91E+01	2.04E+00	1.25E+00	6.88E-01	3.28E-01	1.27E+01	4.93E+00
B1	3.12E+05		4.87E+04		8.23E+01		2.39E+00		8.09E-01		1.08E+01	
B2	3.72E+05		4.92E+04		8.50E+01		2.48E+00		8.29E-01		1.03E+01	
B3	4.53E+05	1.41E+05	5.51E+04	6.41E+03	8.76E+01	5.31E+00	2.93E+00	5.38E-01	8.90E-01	8.12E-02	9.55E+00	1.26E+00
C1	3.46E+05		4.69E+04		8.16E+01		2.51E+00		8.36E-01		9.84E+00	
C2	3.72E+05		5.18E+04		8.48E+01		2.49E+00		8.34E-01		1.02E+01	
C3	4.19E+05	7.35E+04	5.43E+04	7.49E+03	8.84E+01	6.73E+00	2.80E+00	3.11E-01	8.57E-01	2.28E-02	1.06E+01	7.78E-01
D1	3.70E+05		1.95E+04		8.46E+01		1.68E+00		8.31E-01		1.03E+01	
D2	3.79E+05		5.11E+04		8.49E+01		2.57E+00		8.44E-01		1.03E+01	
D3	3.89E+05	1.92E+04	8.24E+04	6.29E+04	8.53E+01	7.43E-01	3.54E+00	1.85E+00	8.53E-01	2.25E-02	1.01E+01	1.65E-01

DAMPER SEAL
@ 109% RPL

PARAM VALUES

	GAP(A)	TAPER(B)	PRESS(C)	TVR (D)
MIN (1)	0.0048	0.0023	4,200	0.100
NOM (2)	0.0058	0.0038	4,400	0.300
MAX (3)	0.0068	0.0053	4,600	0.500

TEST MATRIX / OUTPUT DATA

TEST NO.	GAP(A)	TAPER(B)	PRESS(C)	TVR (D)	DIRECT K	CROSS K	DIRECT C	CROSS C	DIRECT M	MDOT
# 1	0.0048	0.0023	4,200	0.100	604,120	37,693	131.08	2.5957	1.0713	8.6953
# 2	0.0048	0.0038	4,400	0.300	762,120	93,481	137.89	3.8868	1.1178	8.4046
# 3	0.0048	0.0053	4,600	0.500	991,360	151,940	145.35	6.2477	1.245	7.6012
# 4	0.0058	0.0023	4,400	0.500	506,990	121,130	108.75	3.831	0.86291	11.743
# 5	0.0058	0.0038	4,600	0.100	642,870	30,943	114.93	2.0255	0.88937	11.579
# 6	0.0058	0.0053	4,200	0.300	713,300	77,369	112.69	3.3997	0.96073	10.085
# 7	0.0068	0.0023	4,600	0.300	458,220	66,078	94.421	2.4608	0.7225	15.202
# 8	0.0068	0.0038	4,200	0.500	478,050	104,810	92.071	3.4155	0.73393	13.916
# 9	0.0068	0.0053	4,400	0.100	617,350	25,448	97.498	1.6566	0.77972	13.393

RESPONSE TABLE

	DIRECT K	DELTA	CROSS K	DELTA	DIRECT C	DELTA	CROSS C	DELTA	DIRECT M	DELTA	MDOT	DELTA
A1	7.86E+05		9.44E+04		1.38E+02		4.24E+00		1.14E+00		8.23E+00	
A2	6.21E+05		7.65E+04		1.12E+02		3.09E+00		9.04E-01		1.11E+01	
A3	5.18E+05	2.68E+05	6.54E+04	2.89E+04	9.47E+01	4.34E+01	2.51E+00	1.73E+00	7.45E-01	3.99E-01	1.42E+01	5.94E+00
B1	5.23E+05		7.50E+04		1.11E+02		2.96E+00		8.86E-01		1.19E+01	
B2	6.28E+05		7.64E+04		1.15E+02		3.11E+00		9.14E-01		1.13E+01	
B3	7.74E+05	2.51E+05	8.49E+04	9.95E+03	1.19E+02	7.10E+00	3.77E+00	8.06E-01	9.95E-01	1.10E-01	1.04E+01	1.52E+00
C1	5.98E+05		7.33E+04		1.12E+02		3.14E+00		9.22E-01		1.09E+01	
C2	6.29E+05		8.00E+04		1.15E+02		3.12E+00		9.20E-01		1.12E+01	
C3	6.97E+05	9.90E+04	8.30E+04	9.70E+03	1.18E+02	6.29E+00	3.58E+00	4.53E-01	9.52E-01	3.21E-02	1.15E+01	5.62E-01
D1	6.21E+05		3.14E+04		1.15E+02		2.09E+00		9.13E-01		1.12E+01	
D2	6.45E+05		7.90E+04		1.15E+02		3.25E+00		9.34E-01		1.12E+01	
D3	6.59E+05	3.74E+04	1.26E+05	9.46E+04	1.15E+02	8.88E-01	4.50E+00	2.41E+00	9.47E-01	3.38E-02	1.11E+01	1.44E-01

C-4

TURBINE SEAL
1-2 STAGE
@ 65% RPL

PARAM VALUES

	GAP(A)	TEMP(B)	PRESS(C)	PRESS(C)	PRESS(C)	TVR (D)
MIN (1)	0.0190	575	2,453	2,358	95	0.50
NOM (2)	0.0230	639	2,461	2,354	107	0.75
MAX (3)	0.0270	703	2,469	2,350	119	1.00

TEST MATRIX / OUTPUT DATA

TEST NO.	GAP(A)	TEMP(B)	Pr PRESS(C)	Ps PRESS(C)	Pd PRESS(C)	TVR (D)	||	DIRECT K	CROSS K	DIRECT C	CROSS C	DIRECT M	CROSS M
# 1	0.0190	575	2,453.00	2,358.00	95.00	0.50	||	123.2	1,320.6	1.60	-0.018		
# 2	0.0190	639	2,461.00	2,354.00	107.00	0.75	||	199.9	2,064.3	1.64	-0.025		
# 3	0.0190	703	2,469.00	2,350.00	119.00	1.00	||	268.7	2,780.6	1.69	-0.029		
# 4	0.0230	575	2,461.00	2,354.00	107.00	1.00	||	213.3	2,254.6	1.40	-0.223		
# 5	0.0230	639	2,469.00	2,350.00	119.00	0.50	||	102.7	1,163.2	1.40	-0.014		
# 6	0.0230	703	2,453.00	2,358.00	95.00	0.75	||	140.2	1,540.0	1.24	-0.017		
# 7	0.0270	575	2,469.00	2,350.00	119.00	0.75	||	172.8	1,831.0	1.44	-0.025		
# 8	0.0270	639	2,453.00	2,358.00	95.00	1.00	||	191.3	2,054.2	1.28	-0.020		
# 9	0.0270	703	2,461.00	2,354.00	107.00	0.50	||	92.0	1,074.3	1.28	-0.013		

RESPONSE TABLE

	DIRECT K	DELTA	CROSS K	DELTA	DIRECT C	DELTA	CROSS C	DELTA	DIRECT M	DELTA	CROSS M	DELTA
A1	1.97E+02		2.06E+03		1.64E+00		-2.4E-02		0.00E+00		0.00E+00	
A2	1.52E+02		1.65E+03		1.35E+00		-8.5E-02		0.00E+00		0.00E+00	
A3	1.52E+02	4.53E+01	1.65E+03	4.03E+02	1.33E+00	3.11E-01	-1.9E-02	6.54E-02	0.00E+00	0.00E+00	0.00E+00	0.00E+00
B1	1.70E+02		1.80E+03		1.48E+00		-8.9E-02		0.00E+00		0.00E+00	
B2	1.65E+02		1.76E+03		1.44E+00		-2.0E-02		0.00E+00		0.00E+00	
B3	1.67E+02	5.13E+00	1.80E+03	4.15E+01	1.40E+00	7.60E-02	-2.0E-02	6.89E-02	0.00E+00	0.00E+00	0.00E+00	0.00E+00
C1	1.52E+02		1.64E+03		1.37E+00		-1.8E-02		0.00E+00		0.00E+00	
C2	1.68E+02		1.80E+03		1.44E+00		-8.7E-02		0.00E+00		0.00E+00	
C3	1.81E+02	2.98E+01	1.92E+03	2.87E+02	1.51E+00	1.37E-01	-2.3E-02	6.86E-02	0.00E+00	0.00E+00	0.00E+00	0.00E+00
D1	1.06E+02		1.19E+03		1.43E+00		-1.5E-02		0.00E+00		0.00E+00	
D2	1.71E+02		1.81E+03		1.44E+00		-2.2E-02		0.00E+00		0.00E+00	
D3	2.24E+02	1.18E+02	2.36E+03	1.18E+03	1.46E+00	3.07E-02	-9.1E-02	7.54E-02	0.00E+00	0.00E+00	0.00E+00	0.00E+00

TURBINE SEAL
1-2 STAGE
@ 90% RPL

PARAM VALUES

	GAP(A)	TEMP(B)	PRESS(C)	PRESS(C)	PRESS(C)	TVR (D)
MIN (1)	0.0190	823	3,579	3,392	187	0.50
NOM (2)	0.0230	915	3,593	3,400	193	0.75
MAX (3)	0.0270	1,007	3,608	3,407	201	1.00

TEST MATRIX / OUTPUT DATA

TEST NO.	GAP(A)	TEMP(B)	Pr PRESS(C)	Ps PRESS(C)	Pd PRESS(C)	TVR (D)	||	DIRECT K	CROSS K	DIRECT C	CROSS C	DIRECT M	CROSS M
# 1	0.0190	823	3,579.00	3,392.00	187.00	0.50	||	293.2	2,656.3	2.56	-0.032		
# 2	0.0190	915	3,593.00	3,400.00	193.00	0.75	||	422.4	3,302.7	2.53	-0.041		
# 3	0.0190	1,007	3,608.00	3,407.00	201.00	1.00	||	527.8	5,081.1	2.51	-0.046		
# 4	0.0230	823	3,593.00	3,400.00	193.00	1.00	||	439.7	4,311.0	2.15	-0.037		
# 5	0.0230	915	3,608.00	3,407.00	201.00	0.50	||	219.8	2,168.6	2.10	-0.023		
# 6	0.0230	1,007	3,579.00	3,392.00	187.00	0.75	||	307.4	3,073.2	1.97	-0.029		
# 7	0.0270	823	3,608.00	3,407.00	201.00	0.75	||	284.1	2,862.6	1.84	-0.026		
# 8	0.0270	915	3,579.00	3,392.00	187.00	1.00	||	339.3	3,488.6	1.72	-0.028		
# 9	0.0270	1,007	3,593.00	3,400.00	193.00	0.50	||	159.8	1,717.8	1.68	-0.017		

RESPONSE TABLE

	DIRECT K	DELTA	CROSS K	DELTA	DIRECT C	DELTA	CROSS C	DELTA	DIRECT M	DELTA	CROSS M	DELTA
A1	4.14E+02		3.68E+03		2.54E+00		-4.0E-02		0.00E+00		0.00E+00	
A2	3.22E+02		3.18E+03		2.07E+00		-3.0E-02		0.00E+00		0.00E+00	
A3	2.61E+02	1.53E+02	2.69E+03	9.90E+02	1.75E+00	7.90E-01	-2.3E-02	1.61E-02	0.00E+00	0.00E+00	0.00E+00	0.00E+00
B1	3.39E+02		3.28E+03		2.18E+00		-3.2E-02		0.00E+00		0.00E+00	
B2	3.27E+02		2.99E+03		2.12E+00		-3.1E-02		0.00E+00		0.00E+00	
B3	3.32E+02	1.19E+01	3.29E+03	3.04E+02	2.05E+00	1.31E-01	-3.1E-02	9.95E-04	0.00E+00	0.00E+00	0.00E+00	0.00E+00
C1	3.13E+02		3.07E+03		2.08E+00		-2.9E-02		0.00E+00		0.00E+00	
C2	3.41E+02		3.11E+03		2.12E+00		-3.2E-02		0.00E+00		0.00E+00	
C3	3.44E+02	3.06E+01	3.37E+03	2.98E+02	2.15E+00	6.72E-02	-3.2E-02	2.53E-03	0.00E+00	0.00E+00	0.00E+00	0.00E+00
D1	2.24E+02		2.18E+03		2.11E+00		-2.4E-02		0.00E+00		0.00E+00	
D2	3.38E+02		3.08E+03		2.11E+00		-3.2E-02		0.00E+00		0.00E+00	
D3	4.36E+02	2.11E+02	4.29E+03	2.11E+03	2.13E+00	1.40E-02	-3.7E-02	1.30E-02	0.00E+00	0.00E+00	0.00E+00	0.00E+00

TURBINE SEAL
1-2 STAGE
@ 109% RPL

PARAM VALUES

	GAP(A)	TEMP(B)	PRESS(C)	PRESS(C)	PRESS(C)	TVR (D)
MIN (1)	0.0190	1,014	4,507	4,262	245	0.50
NOM (2)	0.0230	1,127	4,527	4,252	275	0.75
MAX (3)	0.0270	1,240	4,548	4,241	307	1.00

TEST MATRIX — OUTPUT DATA

TEST NO.	GAP(A)	TEMP(B)	Pr PRESS(C)	Ps PRESS(C)	Pd PRESS(C)	TVR (D)	||	DIRECT K	CROSS K	DIRECT C	CROSS C	DIRECT M	CROSS M
# 1	0.0190	1,014	4,507.00	4,262.00	245.00	0.50	||	443.9	3,727.0	3.16	-0,041		
# 2	0.0190	1,127	4,527.00	4,252.00	275.00	0.75	||	655.0	5,735.4	2.83	-0.055		
# 3	0.0190	1,240	4,548.00	4,241.00	307.00	1.00	||	851.3	7,710.4	3.32	-0.065		
# 4	0.0230	1,014	4,527.00	4,252.00	275.00	1.00	||	672.8	6,284.7	2.74	-0.050		
# 5	0.0230	1,127	4,548.00	4,241.00	307.00	0.50	||	367.7	3,290.8	2.77	-0.032		
# 6	0.0230	1,240	4,507.00	4,262.00	245.00	0.75	||	448.8	4,281.5	2.41	-0.037		
# 7	0.0270	1,014	4,548.00	4,241.00	307.00	0.75	||	461.1	4,356.3	2.44	-0.036		
# 8	0.0270	1,127	4,507.00	4,262.00	245.00	1.00	||	489.6	4,857.1	2.11	-0.035		
# 9	0.0270	1,240	4,527.00	4,252.00	275.00	0.50	||	251.8	2,506.2	2.14	-0.023		

RESPONSE TABLE

	DIRECT K	DELTA	CROSS K	DELTA	DIRECT C	DELTA	CROSS C	DELTA	DIRECT M	DELTA	CROSS M	DELTA
A1	6.50E+02		5.72E+03		3.10E+00		-5.3E-02		0.00E+00		0.00E+00	
A2	4.96E+02		4.62E+03		2.64E+00		-4.0E-02		0.00E+00		0.00E+00	
A3	4.01E+02	2.49E+02	3.91E+03	1.82E+03	2.23E+00	8.73E-01	-3.1E-02	2.22E-02	0.00E+00	0.00E+00	0.00E+00	0.00E+00
B1	5.26E+02		4.79E+03		2.78E+00		-4.2E-02		0.00E+00		0.00E+00	
B2	5.04E+02		4.63E+03		2.57E+00		-4.1E-02		0.00E+00		0.00E+00	
B3	5.17E+02	2.19E+01	4.83E+03	2.05E+02	2.62E+00	2.11E-01	-4.1E-02	1.54E-03	0.00E+00	0.00E+00	0.00E+00	0.00E+00
C1	4.61E+02		4.29E+03		2.56E+00		-3.8E-02		0.00E+00		0.00E+00	
C2	5.27E+02		4.84E+03		2.57E+00		-4.2E-02		0.00E+00		0.00E+00	
C3	5.60E+02	9.93E+01	5.12E+03	8.31E+02	2.84E+00	2.81E-01	-4.5E-02	7.00E-03	0.00E+00	0.00E+00	0.00E+00	0.00E+00
D1	3.54E+02		3.17E+03		2.69E+00		-3.2E-02		0.00E+00		0.00E+00	
D2	5.22E+02		4.79E+03		2.56E+00		-4.3E-02		0.00E+00		0.00E+00	
D3	6.71E+02	3.17E+02	6.28E+03	3.11E+03	2.72E+00	1.62E-01	-5.0E-02	1.80E-02	0.00E+00	0.00E+00	0.00E+00	0.00E+00

TURBINE SEAL
2-3 STAGE
@65% RPL

PARAM VALUES

	GAP(A)	TEMP(B)	PRESS(C)	PRESS(C)	PRESS(C)	TVR (D)
MIN (1)	0.0120	523	2,256	2,198	58	0.50
NOM (2)	0.0160	582	2,258	2,193	65	0.75
MAX (3)	0.0200	640	2,260	2,188	72	1.00

TEST MATRIX / OUTPUT DATA

TEST NO.	GAP(A)	TEMP(B)	Pr PRESS(C)	Ps PRESS(C)	Pd PRESS(C)	TVR (D)	||	DIRECT K	CROSS K	DIRECT C	CROSS C	DIRECT M	CROSS M
# 1	0.0120	523	2,256.00	2,198.00	58.00	0.50	||	161.4	1,624.5	2.07	-0.026		
# 2	0.0120	582	2,258.00	2,193.00	65.00	0.75	||	247.0	2,449.7	2.14	-0.036		
# 3	0.0120	640	2,260.00	2,188.00	72.00	1.00	||	320.8	3,237.0	2.19	-0.042		
# 4	0.0160	523	2,258.00	2,193.00	65.00	1.00	||	233.3	2,404.4	1.62	-0.028		
# 5	0.0160	582	2,260.00	2,188.00	72.00	0.50	||	127.3	1,334.4	1.63	-0.020		
# 6	0.0160	640	2,256.00	2,198.00	58.00	0.75	||	159.3	1,682.9	1.44	-0.022		
# 7	0.0200	523	2,260.00	2,188.00	72.00	0.75	||	153.2	1,604.0	1.33	-0.020		
# 8	0.0200	582	2,256.00	2,198.00	58.00	1.00	||	163.6	1,759.2	1.17	-0.019		
# 9	0.0200	640	2,258.00	2,193.00	65.00	0.50	||	85.0	965.9	1.18	-0.013		

RESPONSE TABLE

	DIRECT K	DELTA	CROSS K	DELTA	DIRECT C	DELTA	CROSS C	DELTA	DIRECT M	DELTA	CROSS M	DELTA
A1	2.43E+02		2.44E+03		2.13E+00		-3.5E-02		0.00E+00		0.00E+00	
A2	1.73E+02		1.81E+03		1.56E+00		-2.3E-02		0.00E+00		0.00E+00	
A3	1.34E+02	1.09E+02	1.44E+03	9.94E+02	1.23E+00	9.07E-01	-1.7E-02	1.76E-02	0.00E+00	0.00E+00	0.00E+00	0.00E+00
B1	1.83E+02		1.88E+03		1.68E+00		-2.5E-02		0.00E+00		0.00E+00	
B2	1.79E+02		1.85E+03		1.64E+00		-2.5E-02		0.00E+00		0.00E+00	
B3	1.88E+02	9.08E+00	1.96E+03	1.14E+02	1.61E+00	7.11E-02	-2.6E-02	9.89E-04	0.00E+00	0.00E+00	0.00E+00	0.00E+00
C1	1.61E+02		1.69E+03		1.56E+00		-2.2E-02		0.00E+00		0.00E+00	
C2	1.88E+02		1.94E+03		1.65E+00		-2.6E-02		0.00E+00		0.00E+00	
C3	2.00E+02	3.90E+01	2.06E+03	3.70E+02	1.72E+00	1.62E-01	-2.7E-02	4.80E-03	0.00E+00	0.00E+00	0.00E+00	0.00E+00
D1	1.25E+02		1.31E+03		1.63E+00		-2.0E-02		0.00E+00		0.00E+00	
D2	1.86E+02		1.91E+03		1.64E+00		-2.6E-02		0.00E+00		0.00E+00	
D3	2.39E+02	1.15E+02	2.47E+03	1.16E+03	1.66E+00	3.20E-02	-3.0E-02	1.00E-02	0.00E+00	0.00E+00	0.00E+00	0.00E+00

TURBINE SEAL
2-3 STAGE
@ 90% RPL

PARAM VALUES

	GAP(A)	TEMP(B)	PRESS(C)	PRESS(C)	PRESS(C)	TVR (D)
MIN (1)	0.0120	750	3,223	3,112	111	0.50
NOM (2)	0.0160	834	3,227	3,104	123	0.75
MAX (3)	0.0200	917	3,230	3,094	136	1.00

TEST MATRIX / OUTPUT DATA

TEST NO.	GAP(A)	TEMP(B)	Pr PRESS(C)	Ps PRESS(C)	Pd PRESS(C)	TVR (D)	||	DIRECT K	CROSS K	DIRECT C	CROSS C	DIRECT M	CROSS M
# 1	0.0120	750	3,223.00	3,112.00	111.00	0.50	||	380.5	3,141.0	3.20	-0.044		
# 2	0.0120	834	3,227.00	3,104.00	123.00	0.75	||	542.3	4,679.9	3.26	-0.059		
# 3	0.0120	917	3,230.00	3,094.00	136.00	1.00	||	686.3	6,177.8	3.35	-0.070		
# 4	0.0160	750	3,227.00	3,104.00	123.00	1.00	||	488.1	4,603.4	2.49	-0.047		
# 5	0.0160	834	3,230.00	3,094.00	136.00	0.50	||	284.9	2,547.7	2.49	-0.032		
# 6	0.0160	917	3,223.00	3,112.00	111.00	0.75	||	340.1	3,245.1	2.21	-0.036		
# 7	0.0200	750	3,230.00	3,094.00	136.00	0.75	||	323.4	3,070.2	2.04	-0.032		
# 8	0.0200	834	3,223.00	3,112.00	111.00	1.00	||	339.4	3,403.2	1.80	-0.031		
# 9	0.0200	917	3,227.00	3,104.00	123.00	0.50	||	185.8	1,852.4	1.81	-0.021		

RESPONSE TABLE

	DIRECT K	DELTA	CROSS K	DELTA	DIRECT C	DELTA	CROSS C	DELTA	DIRECT M	DELTA	CROSS M	DELTA
A1	5.36E+02		4.67E+03		3.27E+00		-5.8E-02		0.00E+00		0.00E+00	
A2	3.71E+02		3.47E+03		2.40E+00		-3.8E-02		0.00E+00		0.00E+00	
A3	2.83E+02	2.54E+02	2.78E+03	1.89E+03	1.88E+00	1.39E+00	-2.8E-02	2.97E-02	0.00E+00	0.00E+00	0.00E+00	0.00E+00
B1	3.97E+02		3.60E+03		2.58E+00		-4.1E-02		0.00E+00		0.00E+00	
B2	3.89E+02		3.54E+03		2.52E+00		-4.1E-02		0.00E+00		0.00E+00	
B3	4.04E+02	1.52E+01	3.76E+03	2.15E+02	2.46E+00	1.20E-01	-4.2E-02	1.67E-03	0.00E+00	0.00E+00	0.00E+00	0.00E+00
C1	3.53E+02		3.26E+03		2.40E+00		-3.7E-02		0.00E+00		0.00E+00	
C2	4.05E+02		3.71E+03		2.52E+00		-4.2E-02		0.00E+00		0.00E+00	
C3	4.32E+02	7.82E+01	3.93E+03	6.69E+02	2.63E+00	2.23E-01	-4.5E-02	7.67E-03	0.00E+00	0.00E+00	0.00E+00	0.00E+00
D1	2.84E+02		2.51E+03		2.50E+00		-3.2E-02		0.00E+00		0.00E+00	
D2	4.02E+02		3.67E+03		2.50E+00		-4.2E-02		0.00E+00		0.00E+00	
D3	5.05E+02	2.21E+02	4.73E+03	2.21E+03	2.55E+00	4.67E-02	-4.9E-02	1.70E-02	0.00E+00	0.00E+00	0.00E+00	0.00E+00

TURBINE SEAL
2-3 STAGE
@ 109% RPL

PARAM VALUES

	GAP(A)	TEMP(B)	PRESS(C)	PRESS(C)	PRESS(C)	TVR (D)
MIN (1)	0.0120	930	3,999	3,839	160	0.50
NOM (2)	0.0160	1,034	4,005	3,827	178	0.75
MAX (3)	0.0200	1,138	4,009	3,812	197	1.00

TEST MATRIX / OUTPUT DATA

TEST NO.	GAP(A)	TEMP(B)	Pr PRESS(C)	Ps PRESS(C)	Pd PRESS(C)	TVR (D)	DIRECT K	CROSS K	DIRECT C	CROSS C	DIRECT M	CROSS M
# 1	0.0120	930	3,999.00	3,839.00	160.00	0.50	625.0	4,583.0	4.08	-0.059		
# 2	0.0120	1,034	4,005.00	3,827.00	178.00	0.75	870.4	6,860.6	4.19	-0.080		
# 3	0.0120	1,138	4,009.00	3,812.00	197.00	1.00	1,075.1	8,990.9	4.26	-0.095		
# 4	0.0160	930	4,005.00	3,827.00	178.00	1.00	758.4	6,725.2	3.18	-0.063		
# 5	0.0160	1,034	4,009.00	3,812.00	197.00	0.50	463.3	3,741.1	3.19	-0.043		
# 6	0.0160	1,138	3,999.00	3,839.00	160.00	0.75	527.4	4,712.8	2.81	-0.048		
# 7	0.0200	930	4,009.00	3,812.00	197.00	0.75	508.1	4,512.9	2.62	-0.043		
# 8	0.0200	1,034	3,999.00	3,839.00	160.00	1.00	517.6	4,951.7	2.29	-0.041		
# 9	0.0200	1,138	4,005.00	3,827.00	178.00	0.50	294.2	2,700.0	2.31	-0.028		

RESPONSE TABLE

	DIRECT K	DELTA	CROSS K	DELTA	DIRECT C	DELTA	CROSS C	DELTA	DIRECT M	DELTA	CROSS M	DELTA
A1	8.57E+02		6.81E+03		4.18E+00		-7.8E-02		0.00E+00		0.00E+00	
A2	5.83E+02		5.06E+03		3.06E+00		-5.1E-02		0.00E+00		0.00E+00	
A3	4.40E+02	4.17E+02	4.05E+03	2.76E+03	2.41E+00	1.77E+00	-3.7E-02	4.06E-02	0.00E+00	0.00E+00	0.00E+00	0.00E+00
B1	6.30E+02		5.27E+03		3.30E+00		-5.5E-02		0.00E+00		0.00E+00	
B2	6.17E+02		5.18E+03		3.22E+00		-5.5E-02		0.00E+00		0.00E+00	
B3	6.32E+02	1.51E+01	5.47E+03	2.83E+02	3.13E+00	1.71E-01	-5.7E-02	2.00E-03	0.00E+00	0.00E+00	0.00E+00	0.00E+00
C1	5.57E+02		4.75E+03		3.06E+00		-4.9E-02		0.00E+00		0.00E+00	
C2	6.41E+02		5.43E+03		3.23E+00		-5.7E-02		0.00E+00		0.00E+00	
C3	6.82E+02	1.26E+02	5.75E+03	9.99E+02	3.36E+00	2.98E-01	-6.0E-02	1.12E-02	0.00E+00	0.00E+00	0.00E+00	0.00E+00
D1	4.61E+02		3.67E+03		3.19E+00		-4.4E-02		0.00E+00		0.00E+00	
D2	6.35E+02		5.36E+03		3.21E+00		-5.7E-02		0.00E+00		0.00E+00	
D3	7.84E+02	3.23E+02	6.89E+03	3.21E+03	3.25E+00	5.14E-02	-6.6E-02	2.29E-02	0.00E+00	0.00E+00	0.00E+00	0.00E+00

LINEAR ANALYSIS

STABILITY ANALYSIS

PARAM VALUES

ANALYSIS PARAMETER	CASE	Kxx	Kxy	Cxx	Cxy	Mxx	Mxy
(A) DAMPER SEAL	MIN (1)	4.190E+06	2.200E+04	9.000E+01	1.750E+00	7.200E-01	0.000E+00
	MAX (2)	9.880E+06	1.530E+05	1.460E+02	6.200E+00	1.250E+00	0.000E+00
(B) T LABY SEAL	MIN (1)	5.680E+02	5.251E+03	4.540E+00	-5.30E-02	0.000E+00	0.000E+00
	MAX (2)	1.926E+03	1.670E+04	7.580E+00	-1.60E-01	0.000E+00	0.000E+00
(C) TURBINE	MIN (1)	---	6.075E+03	---	---	---	---
	MAX (2)	---	1.520E+04	---	---	---	---
(D) IMPELLERS	MIN (1)	-5.50E+04	4.428E+04	4.250E+01	6.610E+01	2.000E-02	2.000E-03
	MAX (2)	-9.17E+04	4.428E+04	2.580E+01	1.101E+02	3.000E-02	4.000E-03
(E) BALL BEARING	MIN (1)	5.000E+05	---	---	---	---	---
	MAX (2)	1.000E+06	---	---	---	---	---
(F) ROLL BEARING	MIN (1)	2.500E+06	---	---	---	---	---
	MAX (2)	4.500E+06	---	---	---	---	---
(G) STR DAMPING	MIN (1)	---	---	5.000E-03	---	---	---
	MAX (2)	---	---	6.000E-02	---	---	---

TEST MATRIX

ANALYSIS PARAMETER	TEST #1	TEST #2	TEST #3	TEST #4	TEST #5	TEST #6	TEST #7	TEST #8
(A) DMP SEAL - Kxx	4.190E+06	4.190E+06	4.190E+06	4.190E+06	9.880E+06	9.880E+06	9.880E+06	9.880E+06
(A) DMP SEAL - Kxy	2.200E+04	2.200E+04	2.200E+04	2.200E+04	1.530E+05	1.530E+05	1.530E+05	1.530E+05
(A) DMP SEAL - Cxx	9.000E+01	9.000E+01	9.000E+01	9.000E+01	1.460E+02	1.460E+02	1.460E+02	1.460E+02
(A) DMP SEAL - Cxy	1.750E+00	1.750E+00	1.750E+00	1.750E+00	6.200E+00	6.200E+00	6.200E+00	6.200E+00
(A) DMP SEAL - Mxx	7.200E-01	7.200E-01	7.200E-01	7.200E-01	1.250E+00	1.250E+00	1.250E+00	1.250E+00
(A) DMP SEAL - Mxy	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00
(B) TLABSEAL - Kxx	5.680E+02	5.680E+02	1.926E+03	1.926E+03	5.680E+02	5.680E+02	1.926E+03	1.926E+03
(B) TLABSEAL - Kxy	5.251E+03	5.251E+03	1.670E+04	1.670E+04	5.251E+03	5.251E+03	1.670E+04	1.670E+04
(B) TLABSEAL - Cxx	4.540E+00	4.540E+00	7.580E+00	7.580E+00	4.540E+00	4.540E+00	7.580E+00	7.580E+00
(B) TLABSEAL - Cxy	-5.30E-02	-5.30E-02	-1.60E-01	-1.60E-01	-5.30E-02	-5.30E-02	-1.60E-01	-1.60E-01
(B) TLABSEAL - Mxx	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00
(B) TLABSEAL - Mxy	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00
(C) TURBINE - Kxy	6.075E+03	6.075E+03	1.520E+04	1.520E+04	1.520E+04	1.520E+04	6.075E+03	6.075E+03
(D) IMPELLER - Kxx	-5.50E+04	-9.17E+04	-5.50E+04	-9.17E+04	-5.50E+04	-9.17E+04	-5.50E+04	-9.17E+04
(D) IMPELLER - Kxy	4.428E+04	4.428E+04	4.428E+04	4.428E+04	4.428E+04	4.428E+04	4.428E+04	4.428E+04
(D) IMPELLER - Cxx	4.250E+01	2.580E+01	4.250E+01	2.580E+01	4.250E+01	2.580E+01	4.250E+01	2.580E+01
(D) IMPELLER - Cxy	6.610E+01	1.101E+02	6.610E+01	1.101E+02	6.610E+01	1.101E+02	6.610E+01	1.101E+02
(D) IMPELLER - Mxx	2.000E-02	3.000E-02	2.000E-02	3.000E-02	2.000E-02	3.000E-02	2.000E-02	3.000E-02
(D) IMPELLER - Mxy	2.000E-03	4.000E-03	2.000E-03	4.000E-03	2.000E-03	4.000E-03	2.000E-03	4.000E-03
(E) BALL BRG - Kxx	5.000E+05	1.000E+06	5.000E+05	1.000E+06	1.000E+06	5.000E+05	1.000E+06	5.000E+05
(F) ROLL BRG - Kxx	2.500E+06	4.500E+06	4.500E+06	2.500E+06	2.500E+06	4.500E+06	4.500E+06	2.500E+06
(G) STR DAMP - Cxx	5.000E-03	6.000E-02	6.000E-02	5.000E-03	6.000E-02	5.000E-03	5.000E-03	6.000E-02

STABILITY ANALYSIS

ROTOR PUMP MODE

OUTPUT DATA

OUTPUT DESCRIPTION	TEST #1	TEST #2	TEST #3	TEST #4	TEST #5	TEST #6	TEST #7	TEST #8
LOG-DEC O.S.I.	0.43	0.19	0.51	0.04	0.16	0.17	0.27	0.13

RESPONSE TABLE

	LOG-DEC	DELTA	O.S.I.	DELTA
A1	0.292		0.000E+00	
A2	0.184	0.109	0.000E+00	0.000E+00
B1	0.238		0.000E+00	
B2	0.238	0.000	0.000E+00	0.000E+00
C1	0.255		0.000E+00	
C2	0.221	0.035	0.000E+00	0.000E+00
D1	0.343		0.000E+00	
D2	0.133	0.211	0.000E+00	0.000E+00
E1	0.310		0.000E+00	
E2	0.166	0.145	0.000E+00	0.000E+00
F1	0.189		0.000E+00	
F2	0.287	0.097	0.000E+00	0.000E+00
G1	0.228		0.000E+00	
G2	0.248	0.019	0.000E+00	0.000E+00

STABILITY ANALYSIS

ROTOR TURBINE MODE

OUTPUT DATA

OUTPUT DESCRIPTION	TEST #1	TEST #2	TEST #3	TEST #4	TEST #5	TEST #6	TEST #7	TEST #8
LOG-DEC	0.18	0.18	0.29	0.19	0.29	0.11	0.11	0.21
O.S.I.								

RESPONSE TABLE

	LOG-DEC	DELTA	O.S.I.	DELTA
A1	0.208		0.000E+00	
A2	0.179	0.029	0.000E+00	0.000E+00
B1	0.188		0.000E+00	
B2	0.199	0.011	0.000E+00	0.000E+00
C1	0.170		0.000E+00	
C2	0.218	0.048	0.000E+00	0.000E+00
D1	0.215		0.000E+00	
D2	0.172	0.043	0.000E+00	0.000E+00
E1	0.194		0.000E+00	
E2	0.193	0.001	0.000E+00	0.000E+00
F1	0.216		0.000E+00	
F2	0.172	0.044	0.000E+00	0.000E+00
G1	0.146		0.000E+00	
G2	0.241	0.095	0.000E+00	0.000E+00

STABILITY ANALYSIS

OUTPUT DATA

OUTPUT DESCRIPTION	TEST #1	TEST #2	TEST #3	TEST #4	TEST #5	TEST #6	TEST #7	TEST #8
LOG-DEC	1.55	1.47	1.54	1.44	1.81	1.83	1.82	1.82
O.S.I.								

ROTOR 1ST BENDING MODE

RESPONSE TABLE

	LOG-DEC	DELTA	O.S.I.	DELTA
A1	1.499		0.000E+00	
A2	1.820	0.321	0.000E+00	0.000E+00
B1	1.664		0.000E+00	
B2	1.655	0.009	0.000E+00	0.000E+00
C1	1.665		0.000E+00	
C2	1.654	0.011	0.000E+00	0.000E+00
D1	1.677		0.000E+00	
D2	1.642	0.035	0.000E+00	0.000E+00
E1	1.684		0.000E+00	
E2	1.634	0.050	0.000E+00	0.000E+00
F1	1.655		0.000E+00	
F2	1.664	0.009	0.000E+00	0.000E+00
G1	1.658		0.000E+00	
G2	1.660	0.002	0.000E+00	0.000E+00

NONLINEAR FORCED RESPONSE

IN-PHASE IMBALANCE

PARAM VALUES

ANALYSIS PARAMETER	CASE	Kxx	Kxy	Cxx	CLEARANCE	SIDELOAD
(A) DAMPER SEAL	MIN (1)	4.190E+05	2.200E+04	9.000E+01	---	---
	MAX (2)	1.950E+06	2.800E+05	2.350E+02	---	---
(B) T LABY SEAL	MIN (1)	5.680E+02	5.251E+03	4.540E+00	---	---
	MAX (2)	1.926E+03	1.670E+04	7.580E+00	---	---
(C) IMPELLER	MIN (1)	-5.50E+04	4.428E+04	4.250E+01	---	---
	MAX (2)	-9.17E+04	4.428E+04	2.580E+01	---	---
(D) BALL BEARING	MIN (1)	5.000E+05	---	---	---	---
	MAX (2)	1.000E+06	---	---	---	---
(E) ROLL BEARING	MIN (1)	2.500E+06	---	---	---	---
	MAX (2)	4.500E+06	---	---	---	---
(F) STR DAMPING	MIN (1)	---	---	5.000E-01	---	---
	MAX (2)	---	---	6.000E+00	---	---
(G) BALL BRG DBD	MIN (1)	---	---	---	5.000E-04	---
	MAX (2)	---	---	---	2.000E-03	---
(H) ROLL BRG DBD	MIN (1)	---	---	---	5.000E-04	---
	MAX (2)	---	---	---	1.000E-03	---
(I) STAT SIDELOAD	MIN (1)	---	---	---	---	2.203E+02
	MAX (2)	---	---	---	---	3.671E+02

TEST MATRIX

ANALYSIS PARAMETER	TEST #1	TEST #2	TEST #3	TEST #4	TEST #5	TEST #6	TEST #7	TEST #8	TEST #9	TEST #10	TEST #11	TEST #12
(A) DMP SEAL - Kxx	4.190E+05	4.190E+05	4.190E+05	4.190E+05	4.190E+05	4.190E+05	1.950E+06	1.950E+06	1.950E+06	1.950E+06	1.950E+06	1.950E+06
(A) DMP SEAL - Kxy	2.200E+04	2.200E+04	2.200E+04	2.200E+04	2.200E+04	2.200E+04	2.800E+05	2.800E+05	2.800E+05	2.800E+05	2.800E+05	2.800E+05
(A) DMP SEAL - Cxx	9.000E+01	9.000E+01	9.000E+01	9.000E+01	9.000E+01	9.000E+01	2.350E+02	2.350E+02	2.350E+02	2.350E+02	2.350E+02	2.350E+02
(B) TLABSEAL - Kxx	5.680E+02	5.680E+02	5.680E+02	1.926E+03	1.926E+03	1.926E+03	5.680E+02	5.680E+02	5.680E+02	1.926E+03	1.926E+03	1.926E+03
(B) TLABSEAL - Kxy	5.251E+03	5.251E+03	5.251E+03	1.670E+04	1.670E+04	1.670E+04	5.251E+03	5.251E+03	5.251E+03	1.670E+04	1.670E+04	1.670E+04
(B) TLABSEAL - Cxx	4.540E+00	4.540E+00	4.540E+00	7.580E+00	7.580E+00	7.580E+00	4.540E+00	4.540E+00	4.540E+00	7.580E+00	7.580E+00	7.580E+00
(C) IMPELLER - Kxx	-5.50E+04	-5.50E+04	-9.17E+04	-5.50E+04	-9.17E+04	-9.17E+04	-9.17E+04	-9.17E+04	-5.50E+04	-9.17E+04	-5.50E+04	-5.50E+04
(C) IMPELLER - Kxy	4.428E+04	4.428E+04	4.428E+04	4.428E+04	4.428E+04	4.428E+04	4.428E+04	4.428E+04	4.428E+04	4.428E+04	4.428E+04	4.428E+04
(C) IMPELLER - Cxx	4.250E+01	4.250E+01	2.580E+01	4.250E+01	2.580E+01	2.580E+01	2.580E+01	2.580E+01	4.250E+01	2.580E+01	4.250E+01	4.250E+01
(D) BALL BRG - Kxx	5.000E+05	5.000E+05	1.000E+06	1.000E+06	5.000E+05	1.000E+06	1.000E+06	5.000E+05	1.000E+06	5.000E+05	1.000E+06	5.000E+05
(E) ROLL BRG - Kxx	2.500E+06	2.500E+06	4.500E+06	4.500E+06	4.500E+06	2.500E+06	2.500E+06	4.500E+06	4.500E+06	2.500E+06	2.500E+06	4.500E+06
(F) STR DAMP - Cxx	5.000E-01	6.000E+00	5.000E-01	5.000E-01	6.000E+00	6.000E+00	5.000E-01	6.000E+00	6.000E+00	5.000E-01	6.000E+00	5.000E-01
(G) BALL BRG - DBD	5.000E-04	2.000E-03	5.000E-04	2.000E-03	5.000E-04	2.000E-03	2.000E-03	2.000E-03	5.000E-04	5.000E-04	5.000E-04	2.000E-03
(H) ROLL BRG - DBD	5.000E-04	1.000E-03	5.000E-04	1.000E-03	1.000E-03	5.000E-04	1.000E-03	5.000E-04	1.000E-03	1.000E-03	5.000E-04	5.000E-04
(I) SIDELOAD - F	2.203E+02	3.671E+02	3.671E+02	2.203E+02	2.203E+02	3.671E+02	2.203E+02	2.203E+02	3.671E+02	3.671E+02	2.203E+02	3.671E+02

OUTPUT DATA

OUTPUT DESCRIPTION	TEST #1	TEST #2	TEST #3	TEST #4	TEST #5	TEST #6	TEST #7	TEST #8	TEST #9	TEST #10	TEST #11	TEST #12
ROLL BEARING LOAD	4.800E+02	8.000E+02	9.000E+02	0.000E+00	5.500E+02	1.900E+02	0.000E+00	9.500E+01	5.000E+02	8.500E+02	4.750E+02	3.000E+00
BALL BEARING LOAD	2.175E+03	1.075E+03	1.300E+03	9.000E+02	1.100E+03	1.350E+03	3.600E+03	1.900E+03	1.400E+03	3.500E+03	2.300E+03	1.375E+03
PREBURN IMP DEFL	6.500E-01	1.100E+00	7.000E-01	1.100E+00	8.000E-01	1.300E+00	5.000E-01	8.500E-01	3.000E-01	4.500E-01	2.800E-01	7.000E-01
MAINSTG IMP DEFL	2.600E+00	2.900E+00	2.500E+00	2.300E+00	2.600E+00	3.000E+00	3.250E+00	3.600E+00	2.300E+00	5.000E+00	2.200E+00	3.000E+00
DAMPER SEAL DEFL	9.300E-01	1.500E+00	8.000E-01	1.300E+00	1.000E+00	1.600E+00	9.000E-01	1.300E+00	3.600E-01	1.000E+00	4.200E-01	1.000E+00
BALL BEARING DEFL	1.500E+00	2.000E+00	1.400E+00	1.600E+00	1.400E+00	2.100E+00	1.600E+00	2.100E+00	9.000E-01	2.000E+00	9.000E-01	1.700E+00
ROLL BEARING DEFL	1.300E+00	1.420E+00	7.500E-01	1.200E+00	1.240E+00	1.050E+00	2.400E+00	9.500E-01	1.320E+00	2.500E+00	1.400E+00	8.000E-01
TURBINE CG DEFL	1.000E+00	1.120E+00	5.500E-01	1.150E+00	1.150E+00	7.000E-01	2.200E+00	3.500E-01	1.060E+00	2.000E+00	1.200E+00	5.500E-01
PUMP HSG ACCEL	4.000E+00	3.100E+00	5.000E+00	6.000E+00	6.200E+00	2.800E+00	5.500E+00	6.500E+00	4.000E+00	8.000E+00	4.000E+00	4.800E+00
TURB HSG ACCEL	5.100E+00	1.300E+00	3.000E+00	2.000E+00	3.000E+00	1.600E+00	6.200E+00	4.500E+00	2.500E+00	8.000E+00	3.750E+00	3.000E+00

NONLINEAR FORCED RESPONSE

IN-PHASE IMBALANCE

RESPONSE TABLE #1

	BBRG LOAD	DELTA	RBRG LOAD	DELTA	PBI DEFL	DELTA	MSI DEFL	DELTA	DS DEFL	DELTA
A1	4.867E+02		1.317E+03		9.417E-01		2.650E+00		1.188E+00	
A2	3.205E+02	1.662E+02	2.346E+03	1.029E+03	5.133E-01	4.283E-01	3.225E+00	5.750E-01	8.300E-01	3.583E-01
B1	4.625E+02		1.908E+03		6.833E-01		2.858E+00		9.650E-01	
B2	3.447E+02	1.178E+02	1.754E+03	1.542E+02	7.717E-01	8.833E-02	3.017E+00	1.583E-01	1.053E+00	8.833E-02
C1	3.763E+02		1.538E+03		6.883E-01		2.550E+00		9.183E-01	
C2	4.308E+02	5.450E+01	2.125E+03	5.875E+02	7.667E-01	7.833E-02	3.325E+00	7.750E-01	1.100E+00	1.817E-01
D1	4.630E+02		1.854E+03		7.583E-01		3.283E+00		1.122E+00	
D2	3.442E+02	1.188E+02	1.808E+03	4.583E+01	6.967E-01	6.167E-02	2.592E+00	6.917E-01	8.967E-01	2.250E-01
E1	4.658E+02		2.333E+03		7.133E-01		3.158E+00		1.058E+00	
E2	3.413E+02	1.245E+02	1.329E+03	1.004E+03	7.417E-01	2.833E-02	2.717E+00	4.417E-01	9.600E-01	9.833E-02
F1	3.722E+02		2.142E+03		6.833E-01		3.108E+00		9.883E-01	
F2	4.350E+02	6.283E+01	1.521E+03	6.208E+02	7.717E-01	8.833E-02	2.767E+00	3.417E-01	1.030E+00	4.167E-02
G1	6.258E+02		1.963E+03		5.300E-01		2.867E+00		7.517E-01	
G2	1.813E+02	4.445E+02	1.700E+03	2.625E+02	9.250E-01	3.950E-01	3.008E+00	1.417E-01	1.267E+00	5.150E-01
H1	3.572E+02		1.733E+03		7.467E-01		2.817E+00		1.008E+00	
H2	4.500E+02	9.283E+01	1.929E+03	1.958E+02	7.083E-01	3.833E-02	3.058E+00	2.417E-01	1.010E+00	1.667E-03
I1	2.667E+02		1.996E+03		6.967E-01		2.758E+00		9.750E-01	
I2	5.405E+02	2.738E+02	1.667E+03	3.292E+02	7.583E-01	6.167E-02	3.117E+00	3.583E-01	1.043E+00	6.833E-02

RESPONSE TABLE #2

	BBRG DEFL	DELTA	RBRG DEFL	DELTA	TCG DEFL	DELTA	~~MSI DEFL~~ PHA	DELTA	~~DS DEFL~~ THA	DELTA
A1	1.667E+00		1.160E+00		9.450E-01		4.517E+00		2.667E+00	
A2	1.533E+00	1.333E-01	1.562E+00	4.017E-01	1.227E+00	2.817E-01	5.467E+00	9.500E-01	4.658E+00	1.992E+00
B1	1.583E+00		1.357E+00		1.047E+00		4.683E+00		3.767E+00	
B2	1.617E+00	3.333E-02	1.365E+00	8.333E-03	1.125E+00	7.833E-02	5.300E+00	6.167E-01	3.558E+00	2.083E-01
C1	1.433E+00		1.240E+00		1.013E+00		4.317E+00		2.942E+00	
C2	1.767E+00	3.333E-01	1.482E+00	2.417E-01	1.158E+00	1.450E-01	5.667E+00	1.350E+00	4.383E+00	1.442E+00
D1	1.783E+00		1.368E+00		1.028E+00		5.433E+00		4.150E+00	
D2	1.417E+00	3.667E-01	1.353E+00	1.500E-02	1.143E+00	1.150E-01	4.550E+00	8.833E-01	3.175E+00	9.750E-01
E1	1.683E+00		1.678E+00		1.370E+00		4.567E+00		4.325E+00	
E2	1.517E+00	1.667E-01	1.043E+00	6.350E-01	8.017E-01	5.683E-01	5.417E+00	8.500E-01	3.000E+00	1.325E+00
F1	1.633E+00		1.492E+00		1.242E+00		5.550E+00		4.550E+00	
F2	1.567E+00	6.667E-02	1.230E+00	2.617E-01	9.300E-01	3.117E-01	4.433E+00	1.117E+00	2.775E+00	1.775E+00
G1	1.350E+00		1.418E+00		1.160E+00		5.200E+00		4.225E+00	
G2	1.850E+00	5.000E-01	1.303E+00	1.150E-01	1.012E+00	1.483E-01	4.783E+00	4.167E-01	3.100E+00	1.125E+00
H1	1.617E+00		1.042E+00		7.250E-01		4.517E+00		3.492E+00	
H2	1.583E+00	3.333E-02	1.680E+00	6.383E-01	1.447E+00	7.217E-01	5.467E+00	9.500E-01	3.833E+00	3.417E-01
I1	1.517E+00		1.415E+00		1.175E+00		5.367E+00		4.092E+00	
I2	1.683E+00	1.667E-01	1.307E+00	1.083E-01	9.967E-01	1.783E-01	4.617E+00	7.500E-01	3.233E+00	8.583E-01

NONLINEAR FORCED RESPONSE

OUT-OF-PHASE IMBALANCE

PARAM VALUES

ANALYSIS PARAMETER	CASE	Kxx	Kxy	Cxx	CLEARANCE	SIDELOAD
(A) DAMPER SEAL	MIN (1)	4.190E+05	2.200E+04	9.000E+01	---	---
	MAX (2)	1.950E+06	2.800E+05	2.350E+02	---	---
(B) T LABY SEAL	MIN (1)	5.680E+02	5.251E+03	4.540E+00	---	---
	MAX (2)	1.926E+03	1.670E+04	7.580E+00	---	---
(C) IMPELLER	MIN (1)	-5.50E+04	4.428E+04	4.250E+01	---	---
	MAX (2)	-9.17E+04	4.428E+04	2.580E+01	---	---
(D) BALL BEARING	MIN (1)	5.000E+05	---	---	---	---
	MAX (2)	1.000E+06	---	---	---	---
(E) ROLL BEARING	MIN (1)	2.500E+06	---	---	---	---
	MAX (2)	4.500E+06	---	---	---	---
(F) STR DAMPING	MIN (1)	---	---	5.000E-01	---	---
	MAX (2)	---	---	6.000E+00	---	---
(G) BALL BRG DBD	MIN (1)	---	---	---	5.000E-04	---
	MAX (2)	---	---	---	2.000E-03	---
(H) ROLL BRG DBD	MIN (1)	---	---	---	5.000E-04	---
	MAX (2)	---	---	---	1.000E-03	---
(I) STAT SIDELOAD	MIN (1)	---	---	---	---	2.203E+02
	MAX (2)	---	---	---	---	3.671E+02

TEST MATRIX

ANALYSIS PARAMETER	TEST #1	TEST #2	TEST #3	TEST #4	TEST #5	TEST #6	TEST #7	TEST #8	TEST #9	TEST #10	TEST #11	TEST #12
(A) DMP SEAL - Kxx	4.190E+05	4.190E+05	4.190E+05	4.190E+05	4.190E+05	4.190E+05	1.950E+06	1.950E+06	1.950E+06	1.950E+06	1.950E+06	1.950E+06
(A) DMP SEAL - Kxy	2.200E+04	2.200E+04	2.200E+04	2.200E+04	2.200E+04	2.200E+04	2.800E+05	2.800E+05	2.800E+05	2.800E+05	2.800E+05	2.800E+05
(A) DMP SEAL - Cxx	9.000E+01	9.000E+01	9.000E+01	9.000E+01	9.000E+01	9.000E+01	2.350E+02	2.350E+02	2.350E+02	2.350E+02	2.350E+02	2.350E+02
(B) TLABSEAL - Kxx	5.680E+02	5.680E+02	5.680E+02	1.926E+03	1.926E+03	1.926E+03	5.680E+02	5.680E+02	5.680E+02	1.926E+03	1.926E+03	1.926E+03
(B) TLABSEAL - Kxy	5.251E+03	5.251E+03	5.251E+03	1.670E+04	1.670E+04	1.670E+04	5.251E+03	5.251E+03	5.251E+03	1.670E+04	1.670E+04	1.670E+04
(B) TLABSEAL - Cxx	4.540E+00	4.540E+00	4.540E+00	7.580E+00	7.580E+00	7.580E+00	4.540E+00	4.540E+00	4.540E+00	7.580E+00	7.580E+00	7.580E+00
(C) IMPELLER - Kxx	-5.50E+04	-5.50E+04	-9.17E+04	-5.50E+04	-9.17E+04	-9.17E+04	-9.17E+04	-9.17E+04	-5.50E+04	-9.17E+04	-5.50E+04	-5.50E+04
(C) IMPELLER - Kxy	4.428E+04	4.428E+04	4.428E+04	4.428E+04	4.428E+04	4.428E+04	4.428E+04	4.428E+04	4.428E+04	4.428E+04	4.428E+04	4.428E+04
(C) IMPELLER - Cxx	4.250E+01	4.250E+01	2.580E+01	4.250E+01	2.580E+01	2.580E+01	2.580E+01	2.580E+01	4.250E+01	2.580E+01	4.250E+01	4.250E+01
(D) BALL BRG - Kxx	5.000E+05	5.000E+05	1.000E+06	1.000E+06	5.000E+05	1.000E+06	1.000E+06	5.000E+05	1.000E+06	5.000E+05	1.000E+06	5.000E+05
(E) ROLL BRG - Kxx	2.500E+06	2.500E+06	4.500E+06	4.500E+06	4.500E+06	2.500E+06	2.500E+06	4.500E+06	4.500E+06	2.500E+06	2.500E+06	4.500E+06
(F) STR DAMP - Cxx	5.000E-01	6.000E+00	5.000E-01	5.000E-01	6.000E+00	6.000E+00	5.000E-01	6.000E+00	6.000E+00	5.000E-01	6.000E+00	5.000E-01
(G) BALL BRG - DBD	5.000E-04	2.000E-03	5.000E-04	2.000E-03	5.000E-04	2.000E-03	2.000E-03	2.000E-03	5.000E-04	5.000E-04	5.000E-04	2.000E-03
(H) ROLL BRG - DBD	5.000E-04	1.000E-03	5.000E-04	1.000E-03	1.000E-03	5.000E-04	1.000E-03	5.000E-04	1.000E-03	1.000E-03	5.000E-04	5.000E-04
(I) SIDELOAD - F	2.203E+02	3.671E+02	3.671E+02	2.203E+02	2.203E+02	3.671E+02	2.203E+02	2.203E+02	3.671E+02	3.671E+02	2.203E+02	3.671E+02

OUTPUT DATA

OUTPUT DESCRIPTION	TEST #1	TEST #2	TEST #3	TEST #4	TEST #5	TEST #6	TEST #7	TEST #8	TEST #9	TEST #10	TEST #11	TEST #12
ROLL BEARING LOAD	4.500E+02	1.150E+02	9.000E+02	0.000E+00	5.750E+02	2.600E+02	0.000E+00	8.500E+01	5.000E+02	7.000E+02	4.250E+02	4.000E+00
BALL BEARING LOAD	1.800E+03	1.100E+03	1.200E+03	1.000E+03	9.750E+02	1.400E+03	1.750E+03	1.900E+03	1.100E+03	3.680E+03	1.250E+03	1.400E+03
PREBURN IMP DEFL	7.000E-01	1.200E+00	7.500E-01	1.200E+00	8.000E-01	1.300E+00	7.000E-02	8.700E-01	3.000E-01	4.000E-01	3.500E-01	7.000E-01
MAINSTG IMP DEFL	2.400E+00	3.000E+00	2.500E+00	2.400E+00	2.500E+00	3.100E+00	2.650E+00	3.750E+00	2.200E+00	4.000E+00	2.000E+00	3.100E+00
DAMPER SEAL DEFL	9.500E-01	1.500E+00	8.000E-01	1.300E+00	1.100E+00	1.700E+00	1.000E+00	1.300E+00	4.000E-01	8.500E-01	4.250E-01	1.050E+00
BALL BEARING DEFL	1.350E+00	2.000E+00	1.400E+00	1.600E+00	1.600E+00	2.200E+00	1.500E+00	2.100E+00	9.000E-01	1.900E+00	8.500E-01	1.700E+00
ROLL BEARING DEFL	1.200E+00	1.400E+00	7.200E-01	1.220E+00	1.200E+00	1.070E+00	1.500E+00	9.500E-01	1.250E+00	2.400E+00	1.000E+00	6.000E-01
TURBINE CG DEFL	1.100E+00	1.120E+00	7.000E-01	1.220E+00	1.300E+00	6.250E-01	1.750E+00	3.500E-01	1.120E+00	2.100E+00	7.500E-01	7.500E-01
PUMP HSG ACCEL	5.000E+00	3.500E+00	4.500E+00	6.500E+00	6.900E+00	3.000E+00	1.100E+01	6.100E+00	4.400E+00	6.000E+00	4.750E+00	5.000E+00
TURB HSG ACCEL	4.900E+00	1.500E+00	3.000E+00	2.400E+00	2.750E+00	1.750E+00	4.000E+00	4.500E+00	2.000E+00	7.500E+00	2.750E+00	3.400E+00

RESPONSE TABLE #1

	BBRG LOAD	DELTA	RBRG LOAD	DELTA	PBI DEFL	DELTA	MSI DEFL	DELTA	DS DEFL	DELTA
A1	3.833E+02		1.246E+03		9.917E-01		2.650E+00		1.225E+00	
A2	2.857E+02	9.767E+01	1.847E+03	6.008E+02	4.483E-01	5.433E-01	2.950E+00	3.000E-01	8.375E-01	3.875E-01
B1	3.417E+02		1.475E+03		6.483E-01		2.750E+00		9.917E-01	
B2	3.273E+02	1.433E+01	1.618E+03	1.425E+02	7.917E-01	1.433E-01	2.850E+00	1.000E-01	1.071E+00	7.917E-02
C1	2.490E+02		1.275E+03		7.417E-01		2.517E+00		9.375E-01	
C2	4.200E+02	1.710E+02	1.818E+03	5.425E+02	6.983E-01	4.333E-02	3.083E+00	5.667E-01	1.125E+00	1.875E-01
D1	3.215E+02		1.809E+03		7.783E-01		3.125E+00		1.125E+00	
D2	3.475E+02	2.600E+01	1.283E+03	5.258E+02	6.617E-01	1.167E-01	2.475E+00	6.500E-01	9.375E-01	1.875E-01
E1	3.250E+02		1.830E+03		6.700E-01		2.858E+00		1.071E+00	
E2	3.440E+02	1.900E+01	1.263E+03	5.675E+02	7.700E-01	1.000E-01	2.742E+00	1.167E-01	9.917E-01	7.917E-02
F1	3.423E+02		1.805E+03		6.367E-01		2.842E+00		9.917E-01	
F2	3.267E+02	1.567E+01	1.288E+03	5.175E+02	8.033E-01	1.667E-01	2.758E+00	8.333E-02	1.071E+00	7.917E-02
G1	5.917E+02		1.668E+03		5.500E-01		2.600E+00		7.542E-01	
G2	7.733E+01	5.143E+02	1.425E+03	2.425E+02	8.900E-01	3.400E-01	3.000E+00	4.000E-01	1.308E+00	5.542E-01
H1	3.540E+02		1.492E+03		7.783E-01		2.808E+00		1.038E+00	
H2	3.150E+02	3.900E+01	1.601E+03	1.092E+02	6.617E-01	1.167E-01	2.792E+00	1.667E-02	1.025E+00	1.250E-02
I1	2.558E+02		1.446E+03		6.650E-01		2.617E+00		1.013E+00	
I2	4.132E+02	1.573E+02	1.647E+03	2.008E+02	7.750E-01	1.100E-01	2.983E+00	3.667E-01	1.050E+00	3.750E-02

NONLINEAR FORCED RESPONSE

OUT-OF-PHASE IMBALANCE

RESPONSE TABLE #2

	BBRG DEFL	DELTA	RBRG DEFL	DELTA	TCG DEFL	DELTA	PHA ~~MSI DEFL~~	DELTA	THA ~~DS DEFL~~	DELTA
A1	1.692E+00		1.135E+00		1.011E+00		4.900E+00		2.717E+00	
A2	1.492E+00	2.000E-01	1.283E+00	1.483E-01	1.137E+00	1.258E-01	6.208E+00	1.308E+00	4.025E+00	1.308E+00
B1	1.542E+00		1.170E+00		1.023E+00		5.750E+00		3.317E+00	
B2	1.642E+00	1.000E-01	1.248E+00	7.833E-02	1.124E+00	1.008E-01	5.358E+00	3.917E-01	3.425E+00	1.083E-01
C1	1.400E+00		1.112E+00		1.010E+00		4.858E+00		2.825E+00	
C2	1.783E+00	3.833E-01	1.307E+00	1.950E-01	1.138E+00	1.275E-01	6.250E+00	1.392E+00	3.917E+00	1.092E+00
D1	1.775E+00		1.292E+00		1.120E+00		5.417E+00		4.092E+00	
D2	1.408E+00	3.667E-01	1.127E+00	1.650E-01	1.028E+00	9.250E-02	5.692E+00	2.750E-01	2.650E+00	1.442E+00
E1	1.633E+00		1.428E+00		1.241E+00		5.542E+00		3.733E+00	
E2	1.550E+00	8.333E-02	9.900E-01	4.383E-01	9.067E-01	3.342E-01	5.567E+00	2.500E-02	3.008E+00	7.250E-01
F1	1.575E+00		1.273E+00		1.270E+00		6.333E+00		4.200E+00	
F2	1.608E+00	3.333E-02	1.145E+00	1.283E-01	8.775E-01	3.925E-01	4.775E+00	1.558E+00	2.542E+00	1.658E+00
G1	1.333E+00		1.295E+00		1.178E+00		5.258E+00		3.817E+00	
G2	1.850E+00	5.167E-01	1.123E+00	1.717E-01	9.692E-01	2.092E-01	5.850E+00	5.917E-01	2.925E+00	8.917E-01
H1	1.600E+00		9.233E-01		7.125E-01		4.725E+00		3.383E+00	
H2	1.583E+00	1.667E-02	1.495E+00	5.717E-01	1.435E+00	7.225E-01	6.383E+00	1.658E+00	3.358E+00	2.500E-02
I1	1.500E+00		1.178E+00		1.078E+00		6.708E+00		3.550E+00	
I2	1.683E+00	1.833E-01	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

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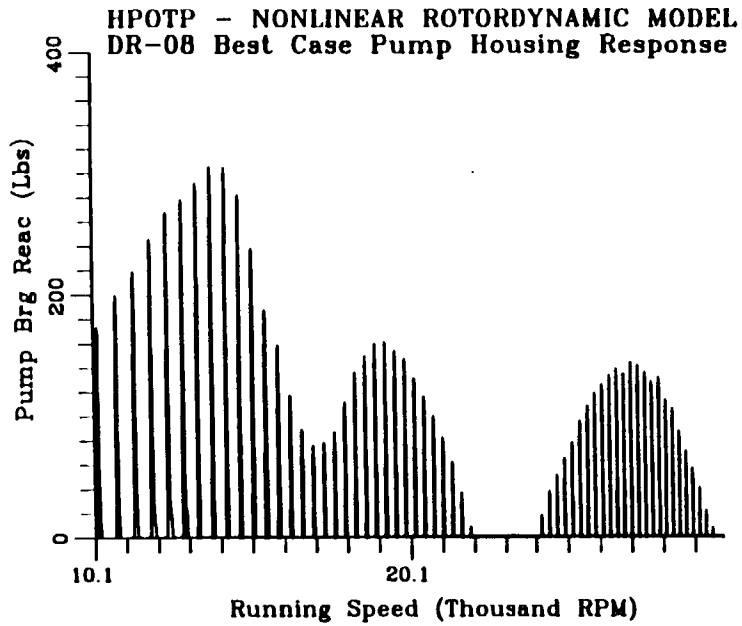
Appendix I. 'Design of Experiments' Nonlinear Response Plots

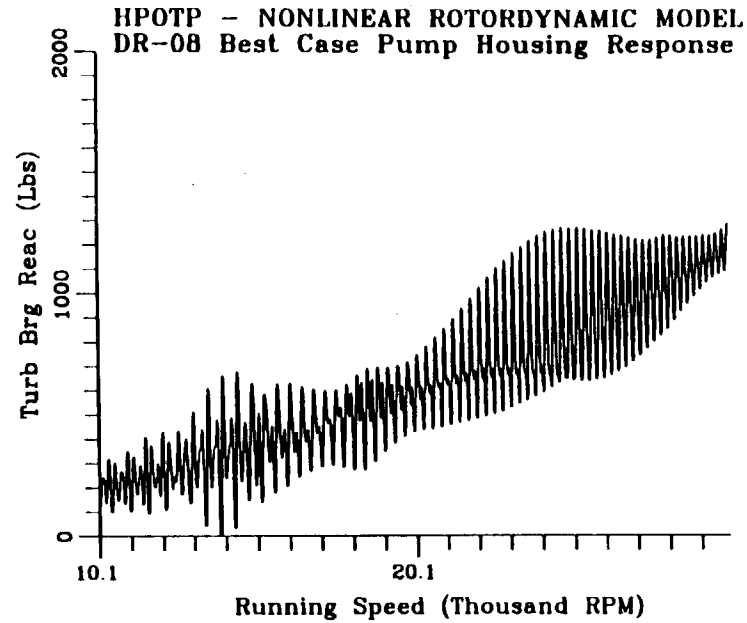
"Best Case" Pump Flange Response, In-Phase Imbalance; pp.295-301

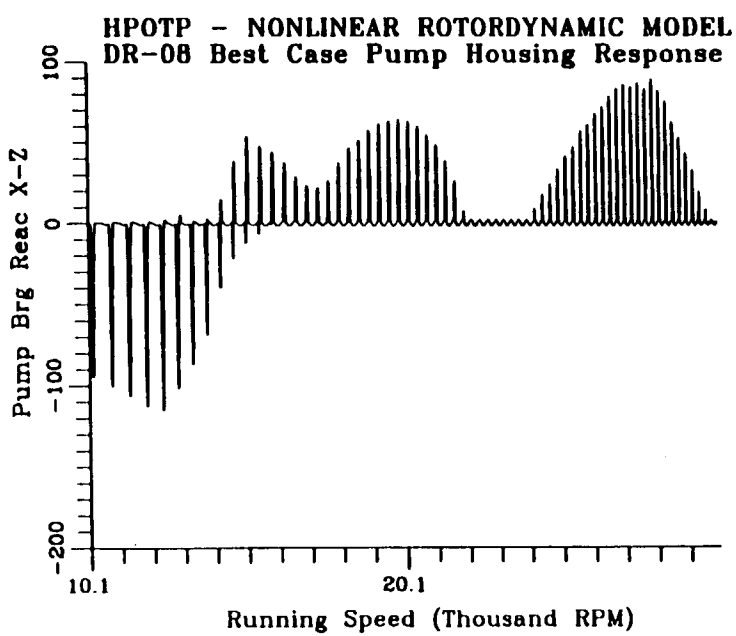
"Worst Case" Pump Flange Response, In-Phase Imbalance; pp.302-308

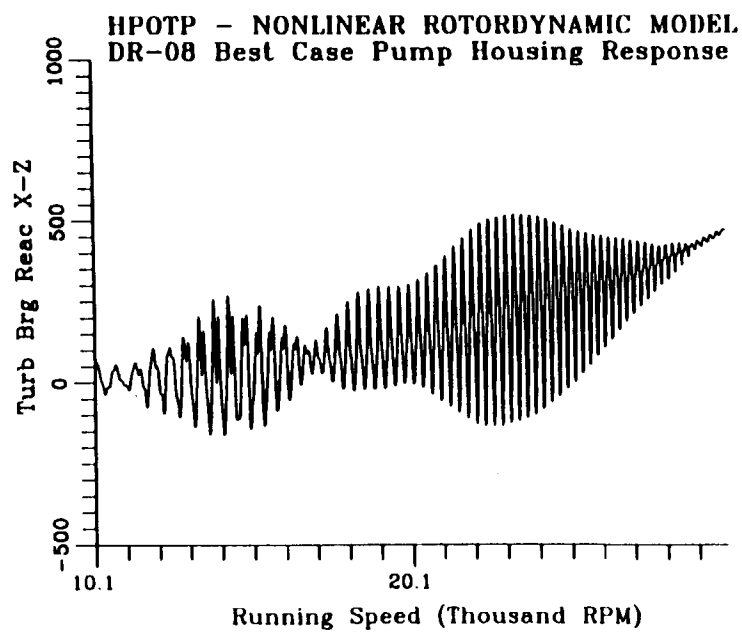
"Best Case" Pump Flange Response, Out-of-Phase Imbalance; pp.309-315

"Worst Case" Pump Flange Response, Out-of-Phase Imbalance; pp.316-322

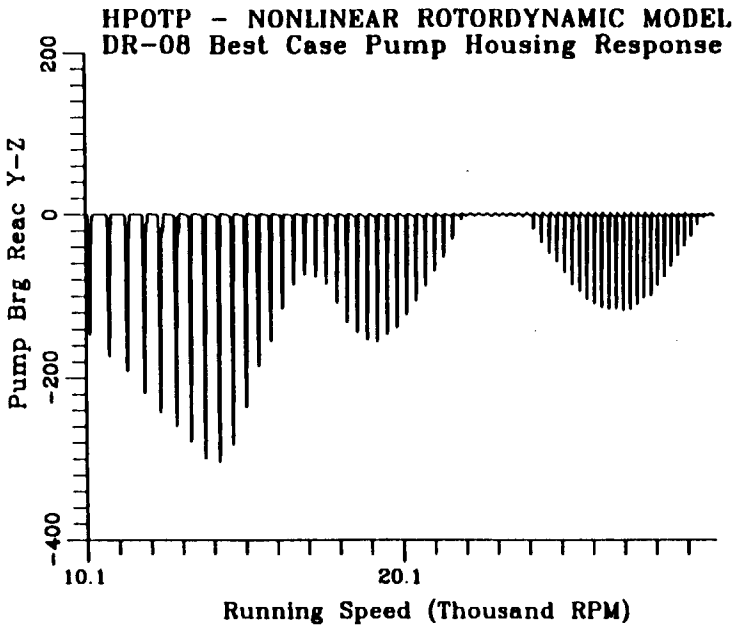

HPOTP - NONLINEAR ROTORDYNAMIC MODEL
DR-08 Best Case Pump Housing Response
Pump Brg Reac (Lbs)
400
200
0
10.1
20.1
Running Speed (Thousand RPM)

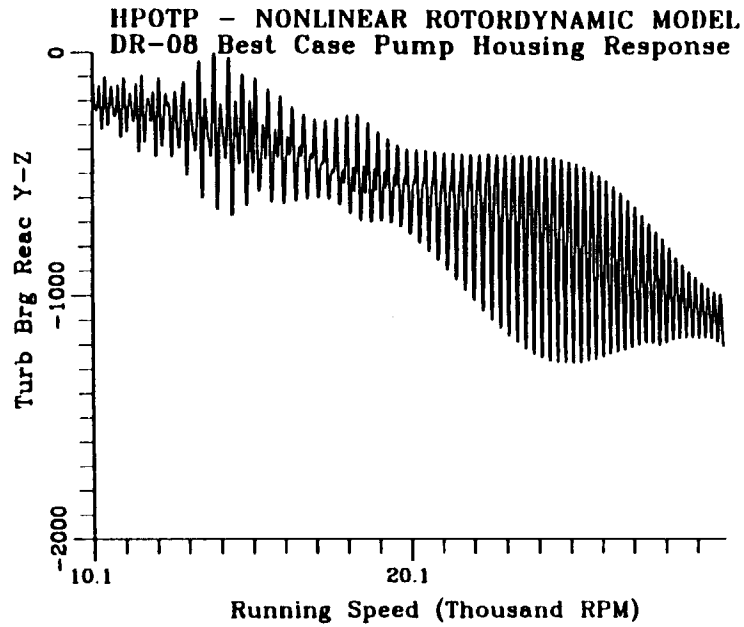

HPOTP - NONLINEAR ROTORDYNAMIC MODEL
DR-08 Best Case Pump Housing Response
Turb Brg Reac (Lbs)
2000
1000
0
10.1
20.1
Running Speed (Thousand RPM)

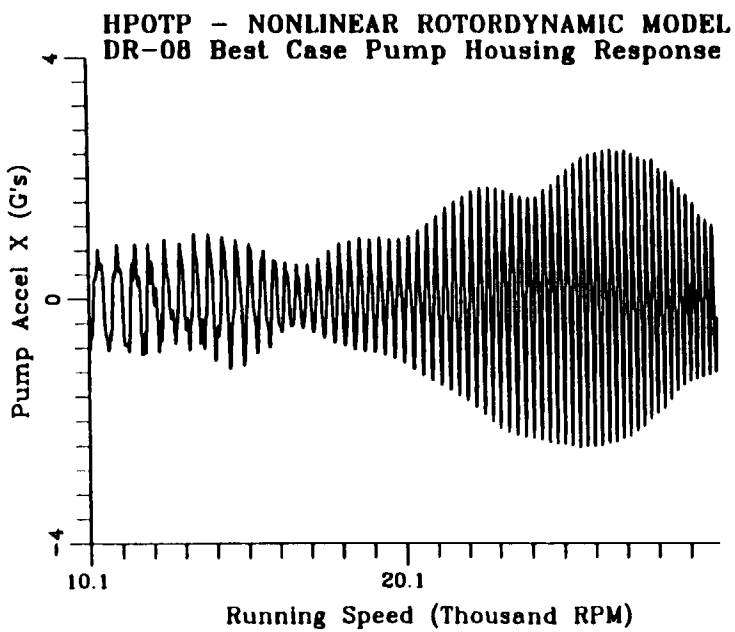

HPOTP - NONLINEAR ROTORDYNAMIC MODEL
DR-08 Best Case Pump Housing Response
Pump Brg Reac X-Z
100
0
-100
-200
10.1
20.1
Running Speed (Thousand RPM)

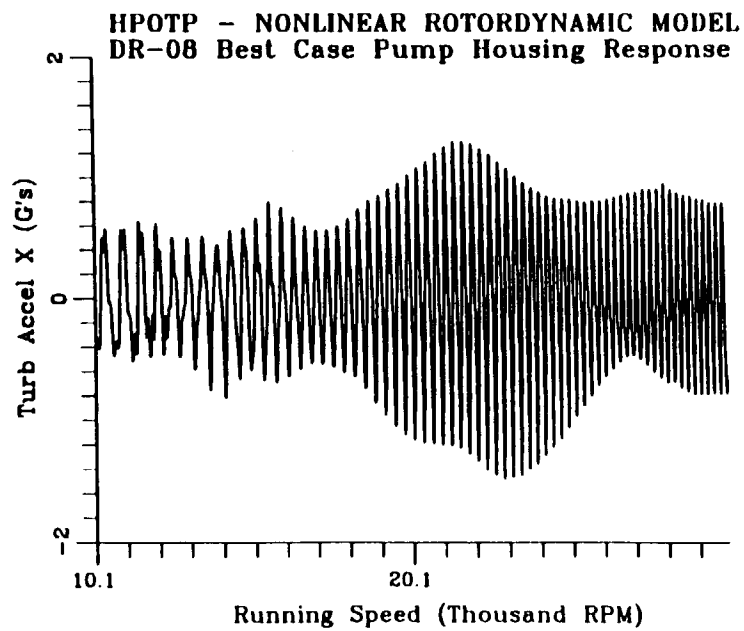

HPOTP - NONLINEAR ROTORDYNAMIC MODEL
DR-08 Best Case Pump Housing Response
Turb Brg Reac X-Z
1000
500
0
-500
10.1
20.1
Running Speed (Thousand RPM)

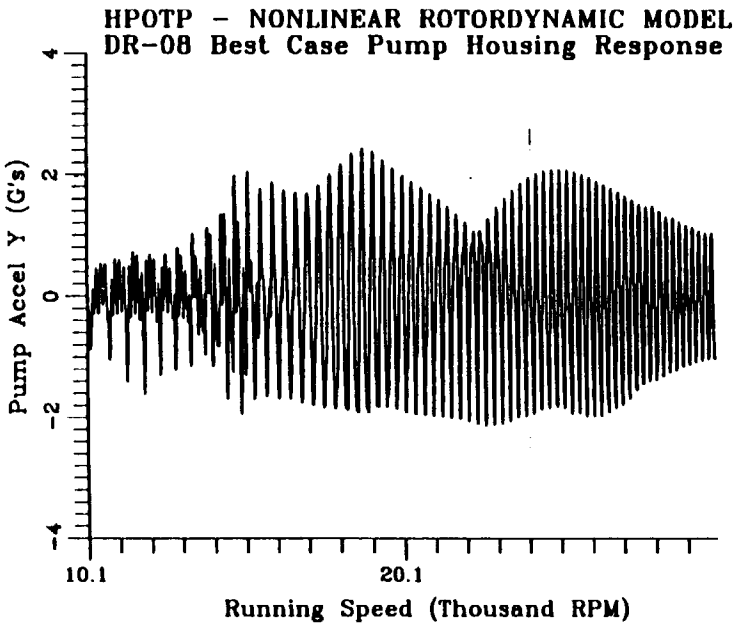
295

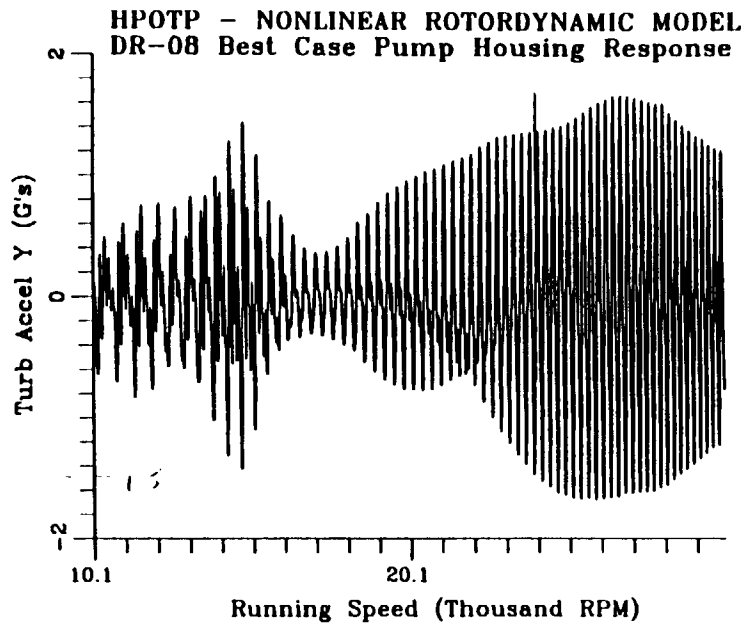

HPOTP - NONLINEAR ROTORDYNAMIC MODEL
DR-08 Best Case Pump Housing Response
Pump Brg Reac Y-Z
200
0
-200
-400
10.1
20.1
Running Speed (Thousand RPM)

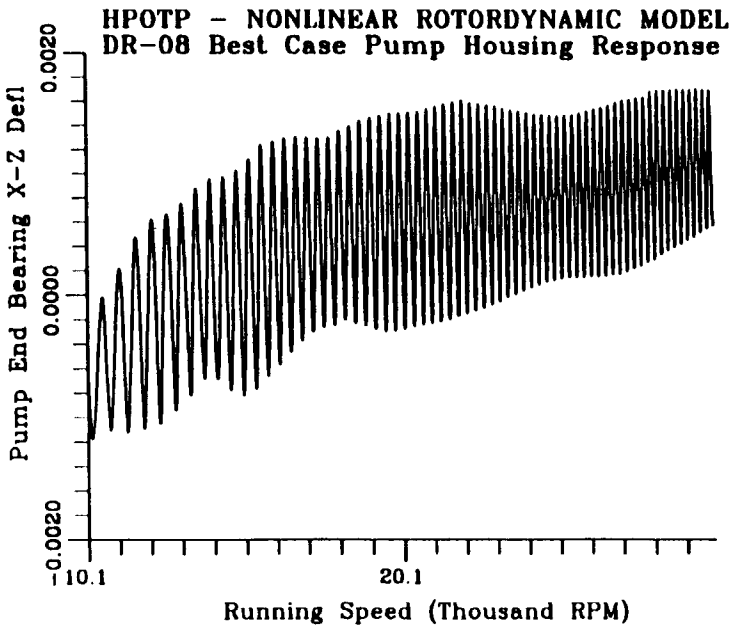

HPOTP - NONLINEAR ROTORDYNAMIC MODEL
DR-08 Best Case Pump Housing Response
Turb Brg Reac Y-Z
0
-1000
-2000
10.1
20.1
Running Speed (Thousand RPM)

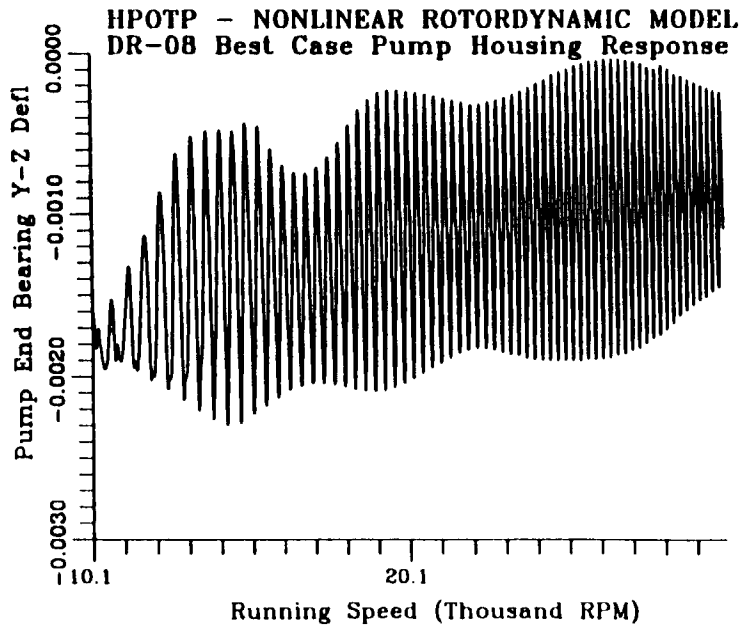

HPOTP - NONLINEAR ROTORDYNAMIC MODEL
DR-08 Best Case Pump Housing Response
Pump Accel X (G's)
4
0
-4
10.1
20.1
Running Speed (Thousand RPM)

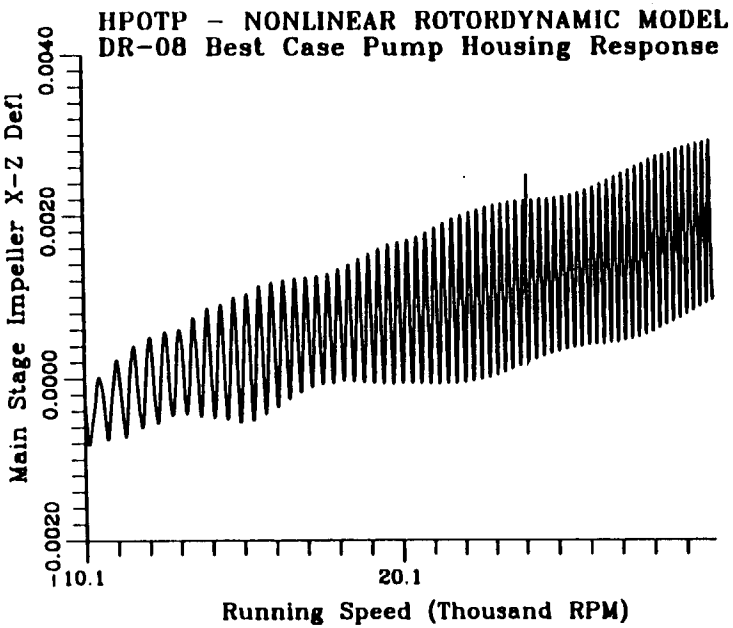

HPOTP - NONLINEAR ROTORDYNAMIC MODEL
DR-08 Best Case Pump Housing Response
Turb Accel X (G's)
2
0
-2
10.1
20.1
Running Speed (Thousand RPM)

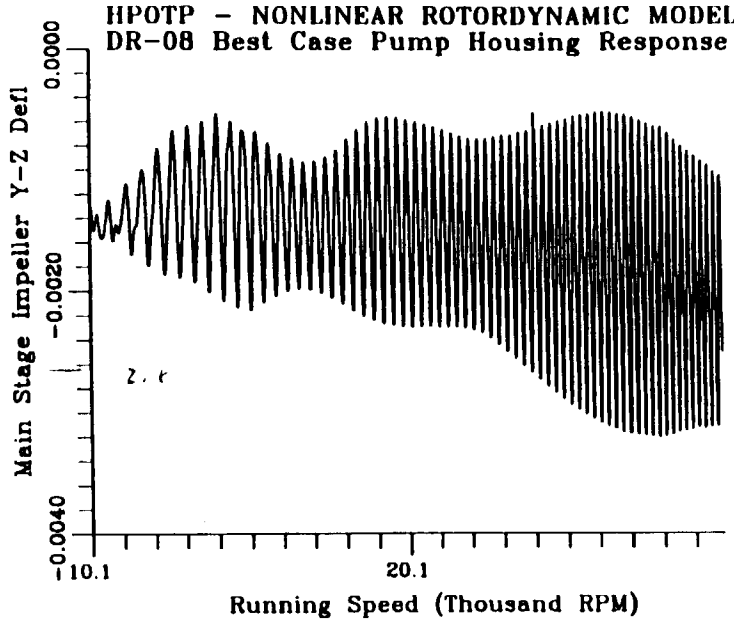

HPOTP - NONLINEAR ROTORDYNAMIC MODEL
DR-08 Best Case Pump Housing Response
Pump Accel Y (G's)
4
2
0
-2
-4
10.1
20.1
Running Speed (Thousand RPM)

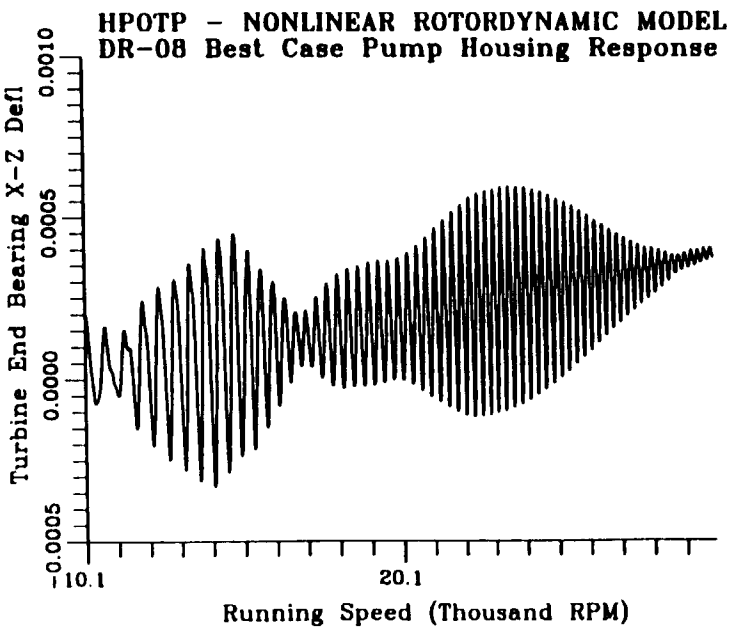

HPOTP - NONLINEAR ROTORDYNAMIC MODEL
DR-08 Best Case Pump Housing Response
Turb Accel Y (G's)
2
0
-2
10.1
20.1
Running Speed (Thousand RPM)

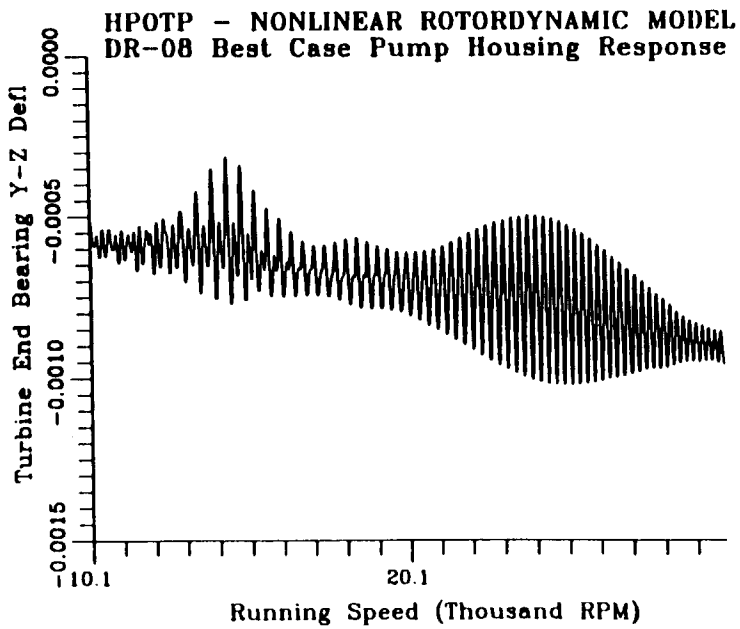

HPOTP - NONLINEAR ROTORDYNAMIC MODEL
DR-08 Best Case Pump Housing Response
Pump End Bearing X-Z Defl
0.0020
0.0000
-0.0020
-10.1
20.1
Running Speed (Thousand RPM)

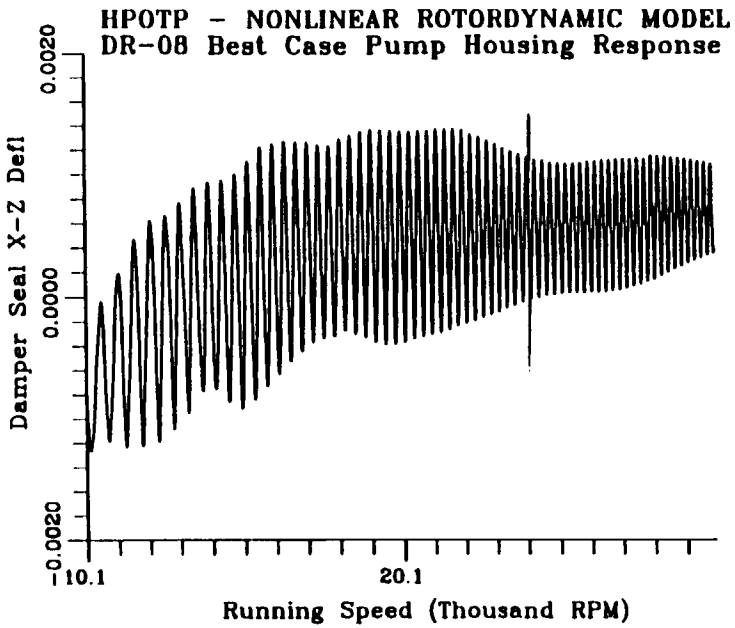

HPOTP - NONLINEAR ROTORDYNAMIC MODEL
DR-08 Best Case Pump Housing Response
Pump End Bearing Y-Z Defl
0.0000
-0.0010
-0.0020
-0.0030
-10.1
20.1
Running Speed (Thousand RPM)

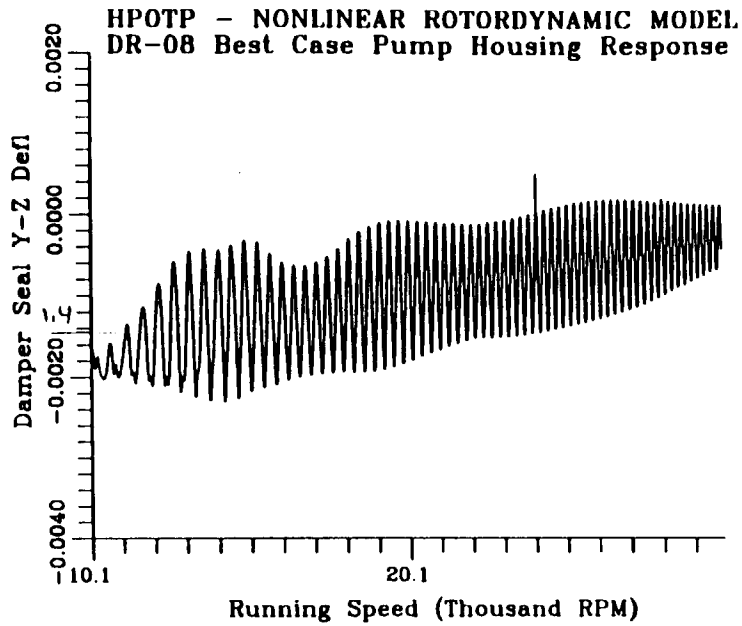

HPOTP - NONLINEAR ROTORDYNAMIC MODEL
DR-08 Best Case Pump Housing Response
Main Stage Impeller X-Z Defl
0.0040
0.0020
0.0000
-0.0020
-10.1
20.1
Running Speed (Thousand RPM)

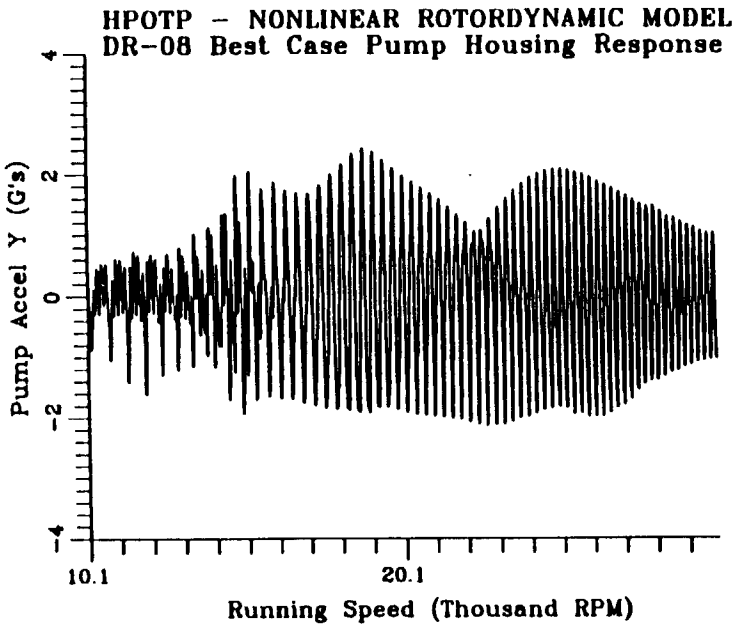

HPOTP - NONLINEAR ROTORDYNAMIC MODEL
DR-08 Best Case Pump Housing Response
Main Stage Impeller Y-Z Defl
0.0000
-0.0020
-0.0040
-10.1
20.1
Running Speed (Thousand RPM)

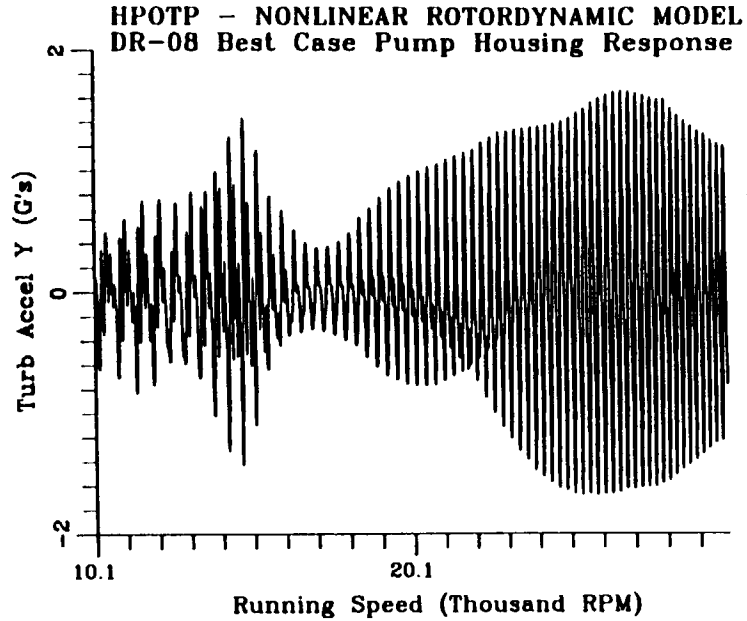

HPOTP - NONLINEAR ROTORDYNAMIC MODEL
DR-08 Best Case Pump Housing Response
Turbine End Bearing X-Z Defl
0.0010
0.0005
0.0000
-0.0005
-10.1
20.1
Running Speed (Thousand RPM)

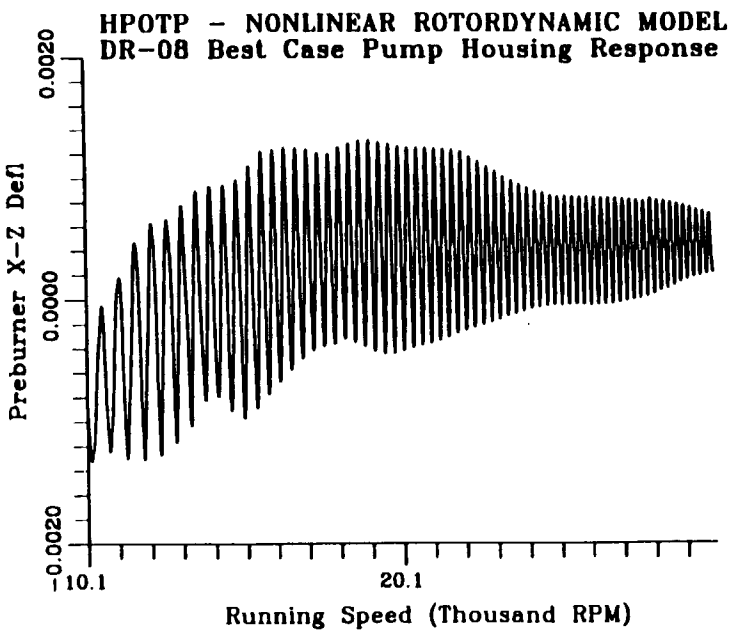

HPOTP - NONLINEAR ROTORDYNAMIC MODEL
DR-08 Best Case Pump Housing Response
Turbine End Bearing Y-Z Defl
0.0000
-0.0005
-0.0010
-0.0015
-10.1
20.1
Running Speed (Thousand RPM)

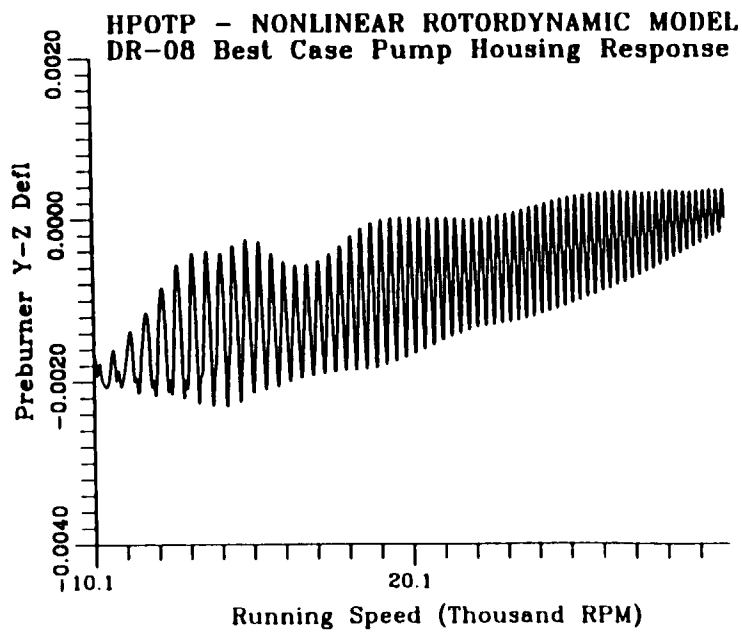

HPOTP - NONLINEAR ROTORDYNAMIC MODEL
DR-08 Best Case Pump Housing Response
Damper Seal X-Z Defl
0.0020
0.0000
-0.0020
-10.1
20.1
Running Speed (Thousand RPM)

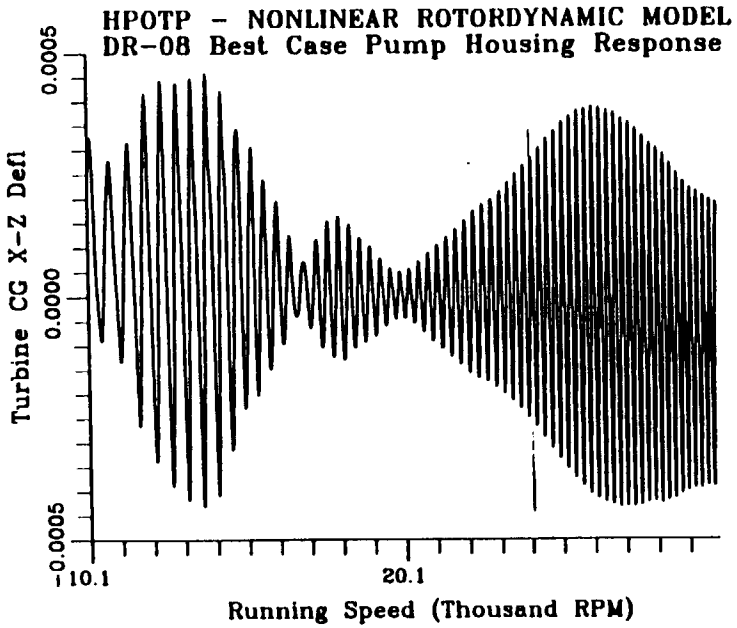

HPOTP - NONLINEAR ROTORDYNAMIC MODEL
DR-08 Best Case Pump Housing Response
Damper Seal Y-Z Defl
0.0020
0.0000
-0.0020
-0.0040
-10.1
20.1
Running Speed (Thousand RPM)

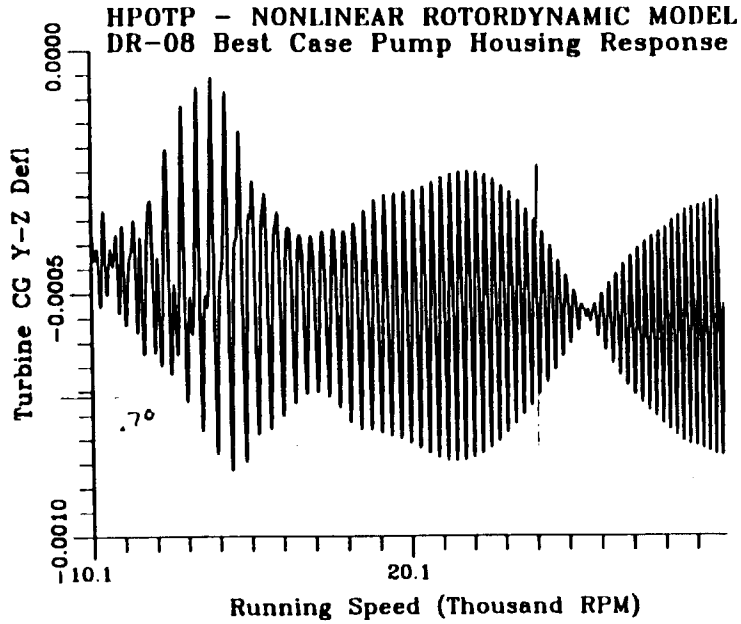

HPOTP - NONLINEAR ROTORDYNAMIC MODEL
DR-08 Best Case Pump Housing Response
Pump Accel Y (G's)
4
2
0
-2
-4
10.1
20.1
Running Speed (Thousand RPM)

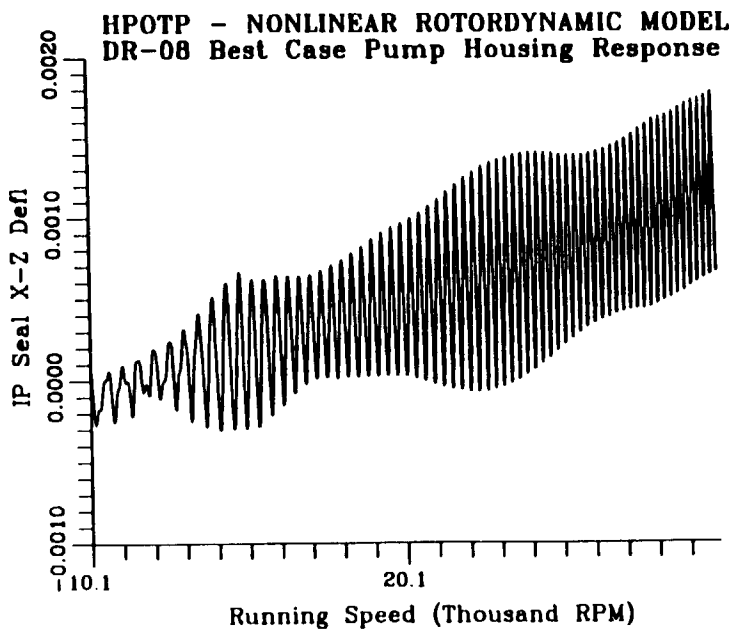

HPOTP - NONLINEAR ROTORDYNAMIC MODEL
DR-08 Best Case Pump Housing Response
Turb Accel Y (G's)
2
0
-2
10.1
20.1
Running Speed (Thousand RPM)

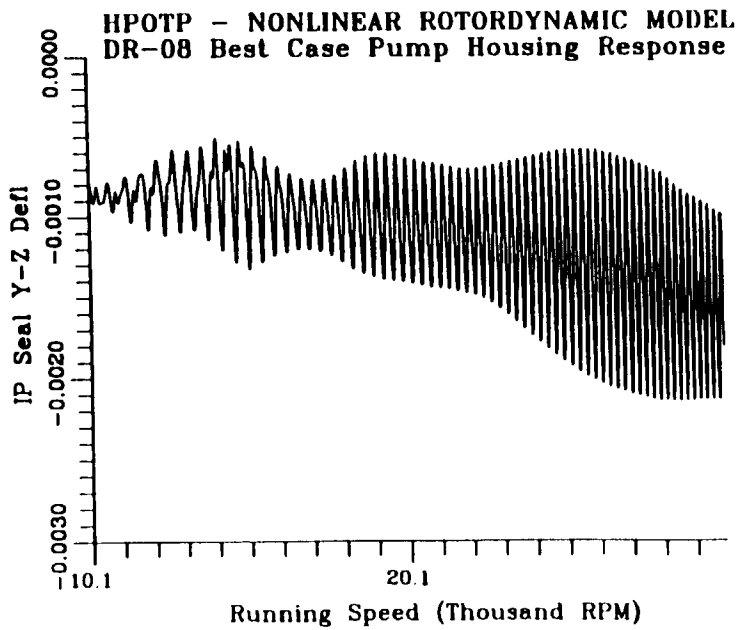

HPOTP - NONLINEAR ROTORDYNAMIC MODEL
DR-08 Best Case Pump Housing Response
Preburner X-Z Defl
0.0020
0.0000
-0.0020
10.1
20.1
Running Speed (Thousand RPM)

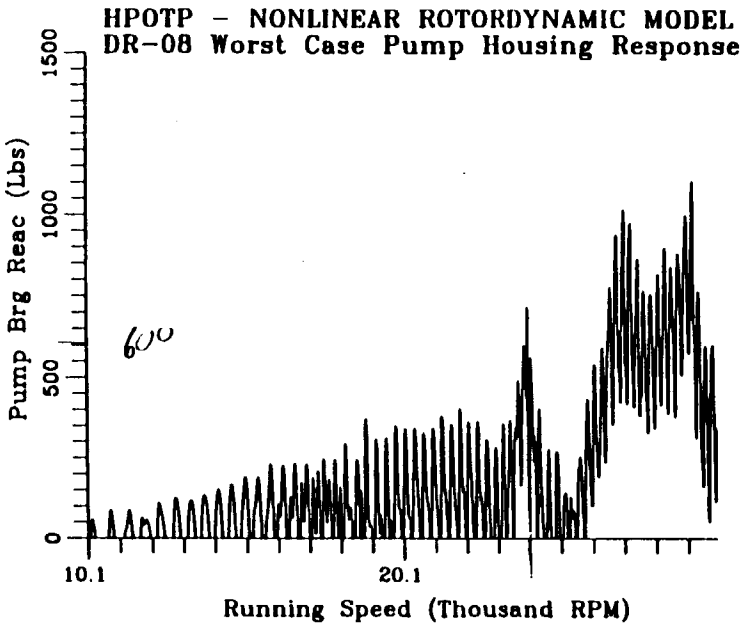

HPOTP - NONLINEAR ROTORDYNAMIC MODEL
DR-08 Best Case Pump Housing Response
Preburner Y-Z Defl
0.0020
0.0000
-0.0020
-0.0040
10.1
20.1
Running Speed (Thousand RPM)

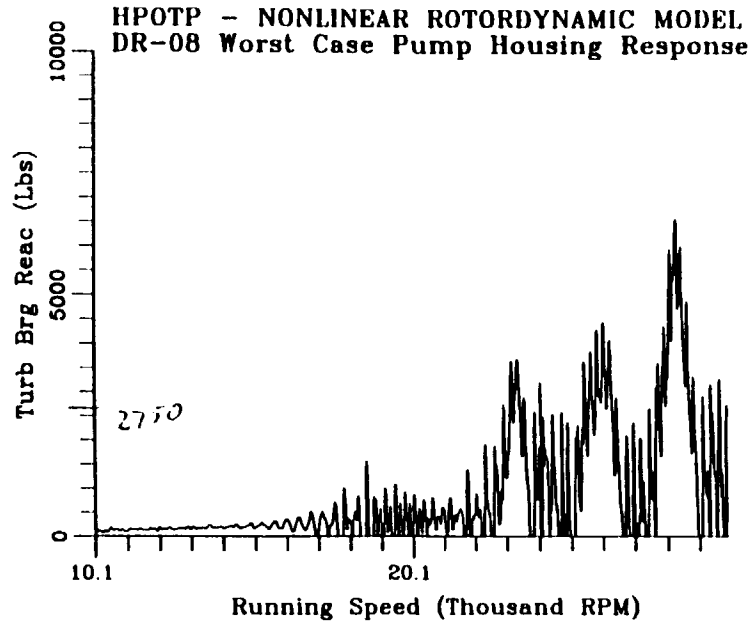

HPOTP - NONLINEAR ROTORDYNAMIC MODEL
DR-08 Best Case Pump Housing Response
Turbine CG X-Z Defl
0.0005
0.0000
-0.0005
-10.1
20.1
Running Speed (Thousand RPM)

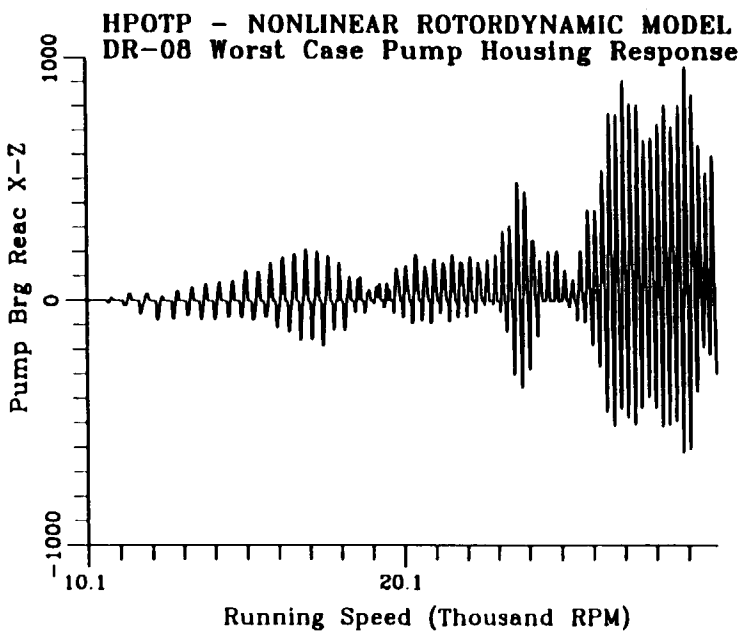

HPOTP - NONLINEAR ROTORDYNAMIC MODEL
DR-08 Best Case Pump Housing Response
Turbine CG Y-Z Defl
0.0000
-0.0005
-0.0010
.7°
-10.1
20.1
Running Speed (Thousand RPM)

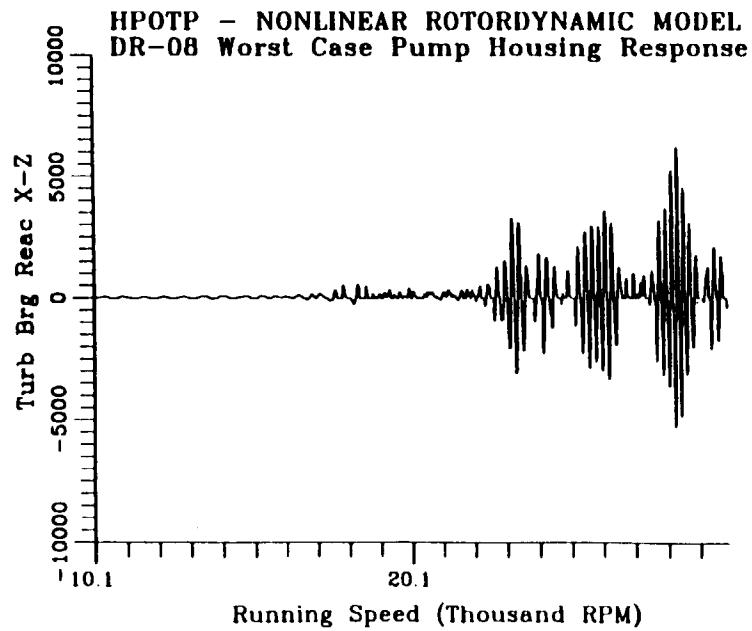

HPOTP - NONLINEAR ROTORDYNAMIC MODEL
DR-08 Best Case Pump Housing Response
IP Seal X-Z Defl
0.0020
0.0010
0.0000
-0.0010
-10.1
20.1
Running Speed (Thousand RPM)

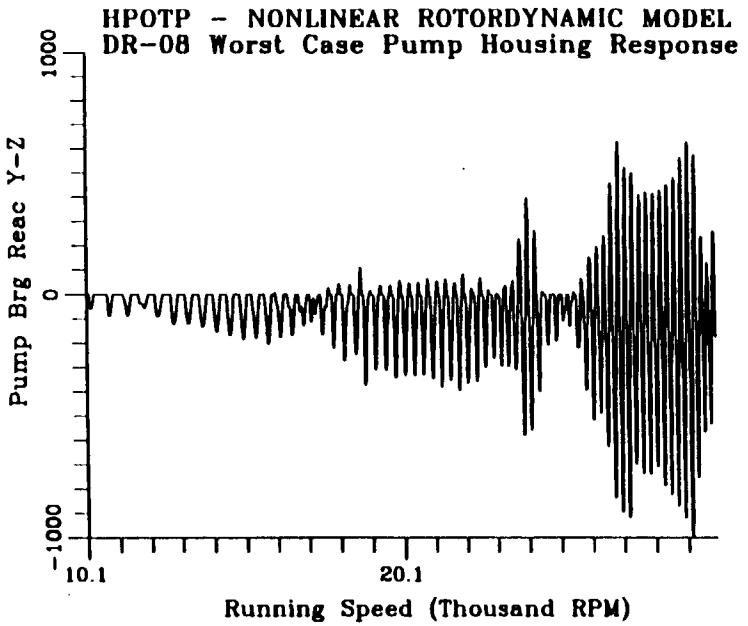

HPOTP - NONLINEAR ROTORDYNAMIC MODEL
DR-08 Best Case Pump Housing Response
IP Seal Y-Z Defl
0.0000
-0.0010
-0.0020
-0.0030
-10.1
20.1
Running Speed (Thousand RPM)

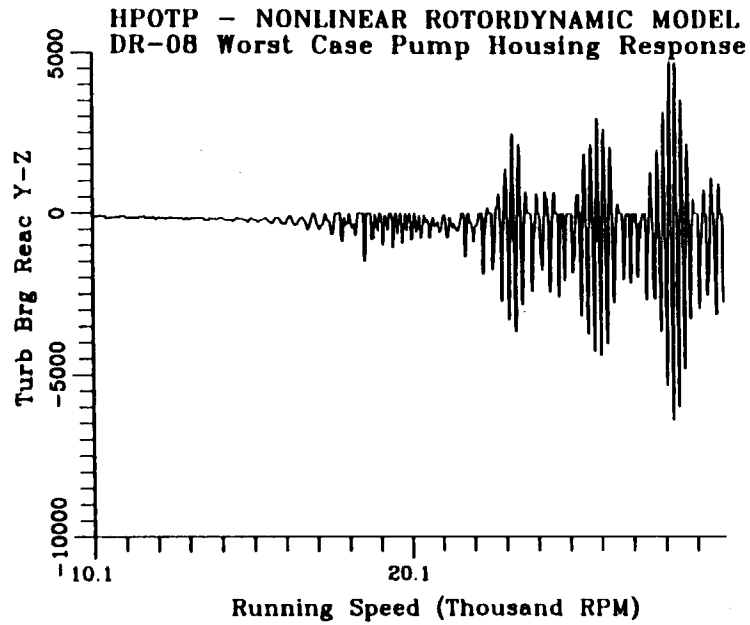

HPOTP - NONLINEAR ROTORDYNAMIC MODEL
DR-08 Worst Case Pump Housing Response
Pump Brg Reac (Lbs)
0
500
1000
1500
600
10.1
20.1
Running Speed (Thousand RPM)

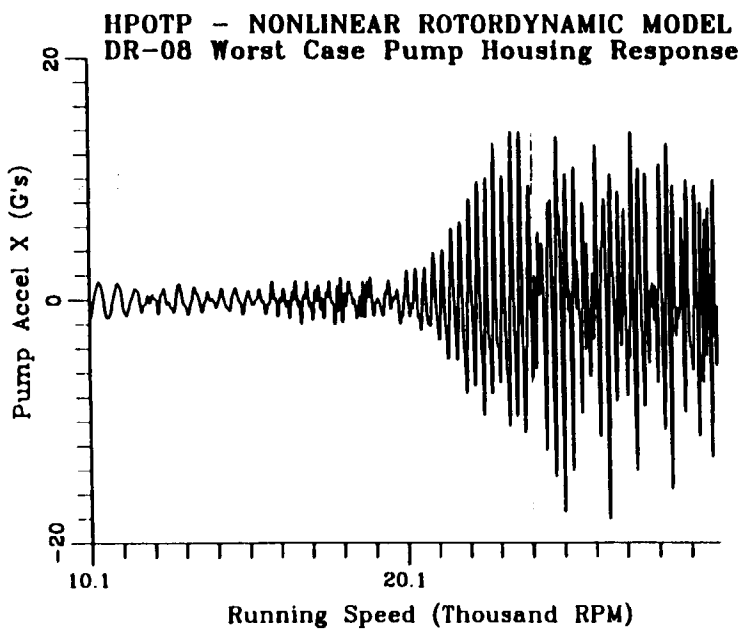

HPOTP - NONLINEAR ROTORDYNAMIC MODEL
DR-08 Worst Case Pump Housing Response
Turb Brg Reac (Lbs)
0
5000
10000
2750
10.1
20.1
Running Speed (Thousand RPM)

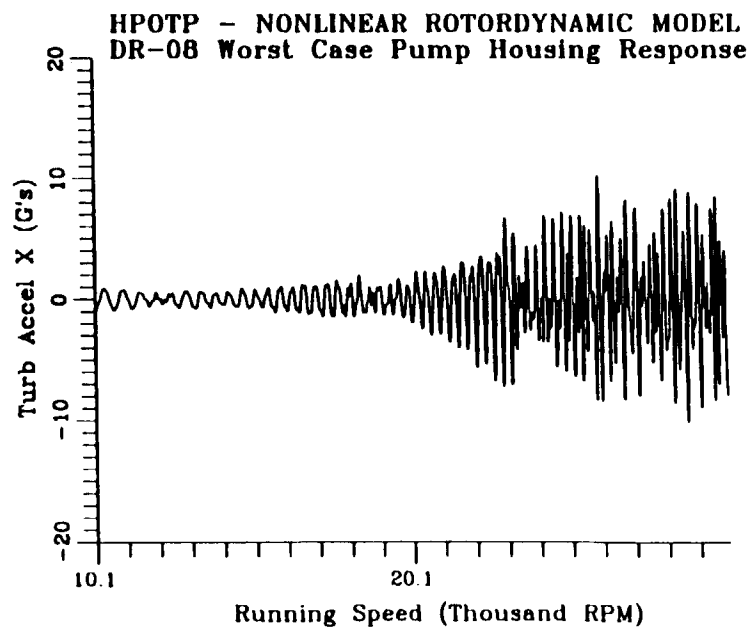

HPOTP - NONLINEAR ROTORDYNAMIC MODEL
DR-08 Worst Case Pump Housing Response
Pump Brg Reac X-Z
-1000
0
1000
10.1
20.1
Running Speed (Thousand RPM)

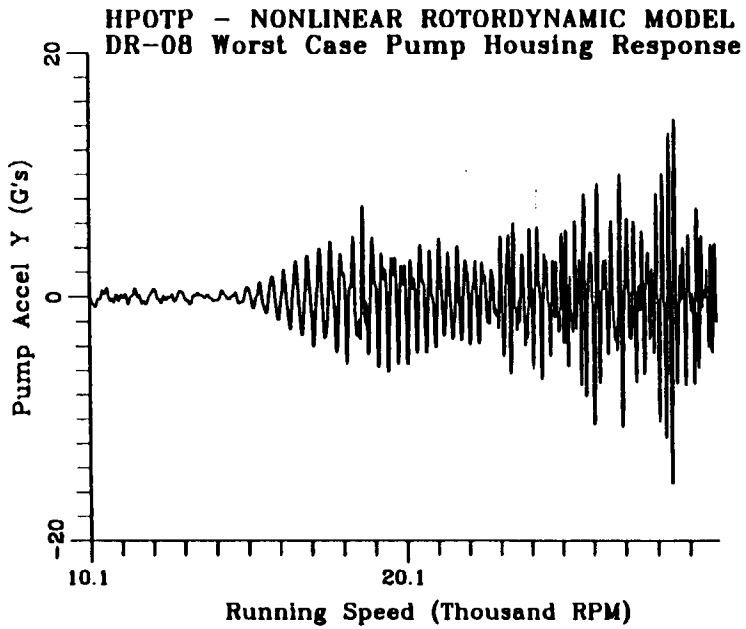

HPOTP - NONLINEAR ROTORDYNAMIC MODEL
DR-08 Worst Case Pump Housing Response
Turb Brg Reac X-Z
-10000
-5000
0
5000
10000
10.1
20.1
Running Speed (Thousand RPM)

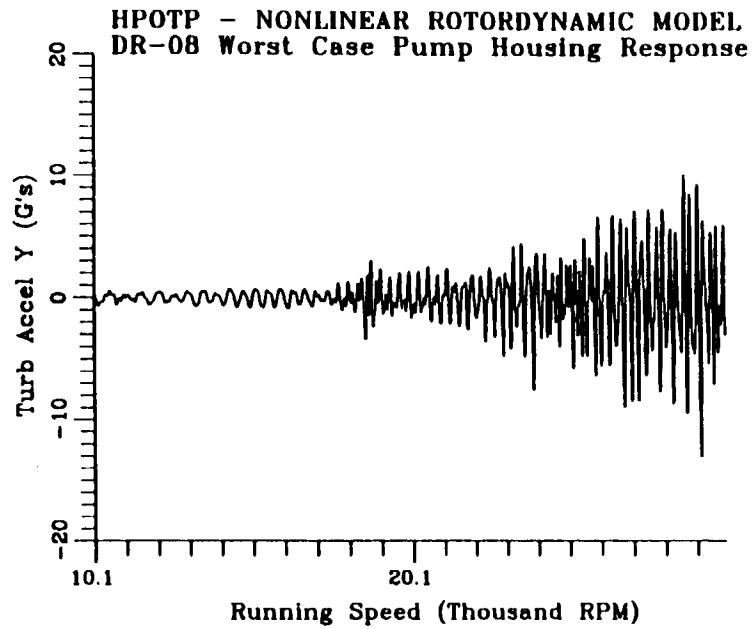

HPOTP - NONLINEAR ROTORDYNAMIC MODEL
DR-08 Worst Case Pump Housing Response
Pump Brg Reac Y-Z
1000
0
-1000
10.1
20.1
Running Speed (Thousand RPM)

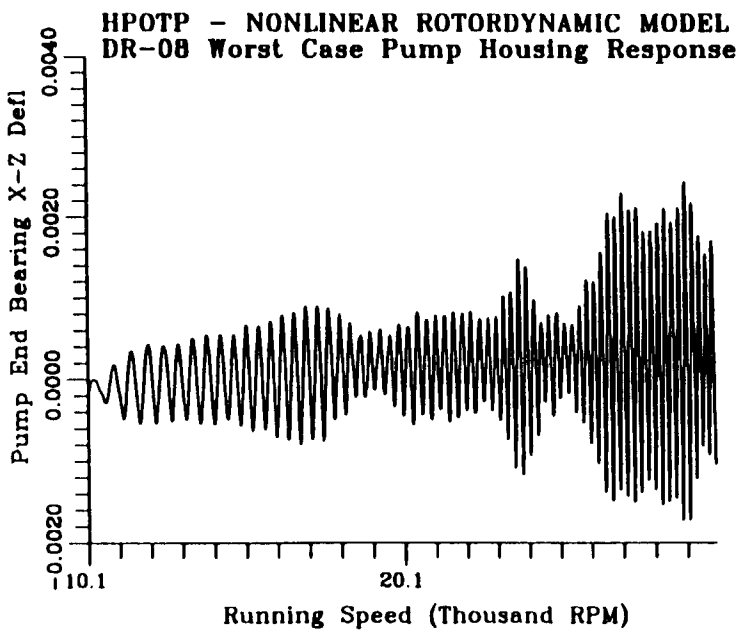

HPOTP - NONLINEAR ROTORDYNAMIC MODEL
DR-08 Worst Case Pump Housing Response
Turb Brg Reac Y-Z
5000
0
-5000
-10000
10.1
20.1
Running Speed (Thousand RPM)

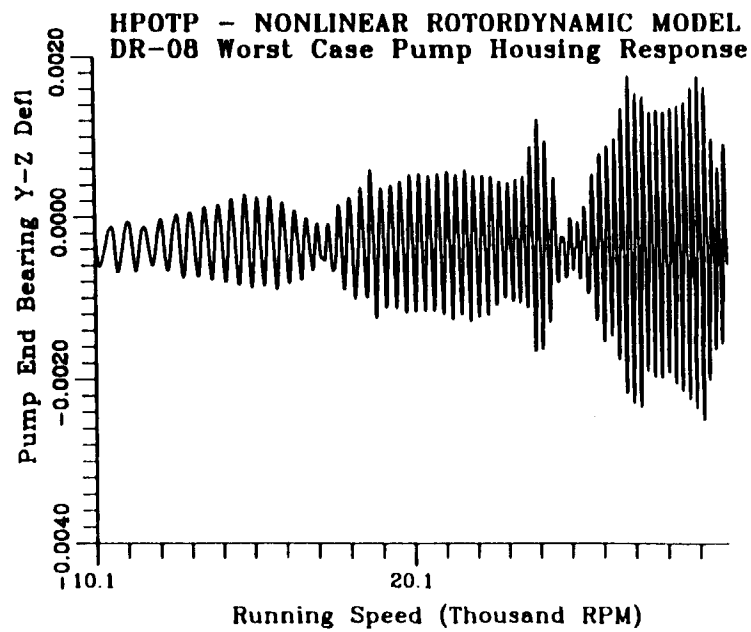

HPOTP - NONLINEAR ROTORDYNAMIC MODEL
DR-08 Worst Case Pump Housing Response
Pump Accel X (G's)
20
0
-20
10.1
20.1
Running Speed (Thousand RPM)

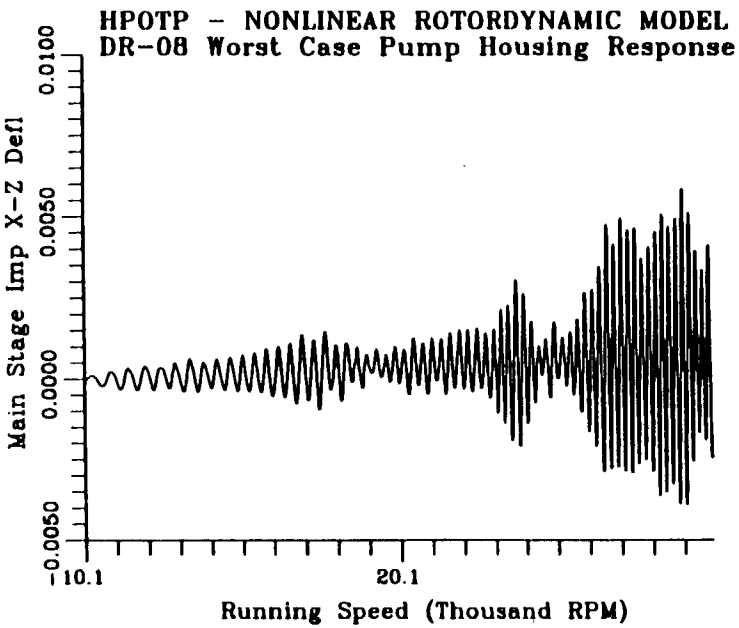

HPOTP - NONLINEAR ROTORDYNAMIC MODEL
DR-08 Worst Case Pump Housing Response
Turb Accel X (G's)
20
10
0
-10
-20
10.1
20.1
Running Speed (Thousand RPM)

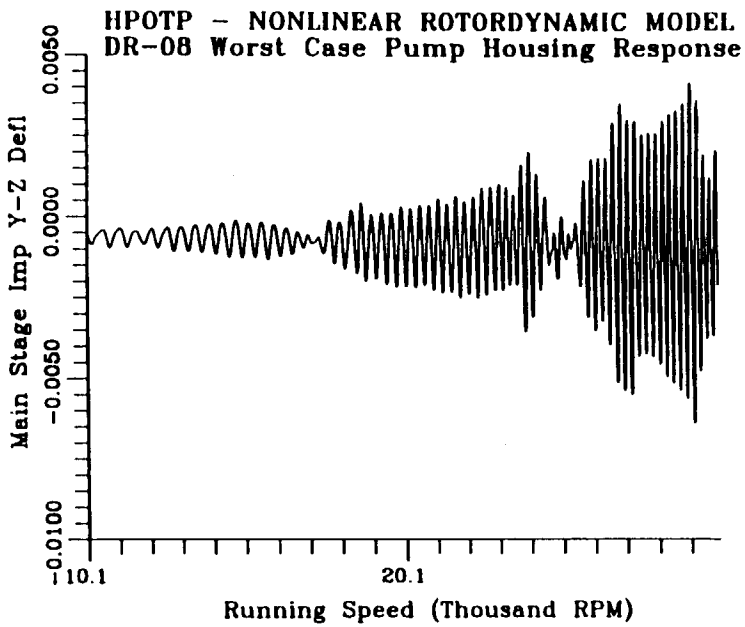

HPOTP - NONLINEAR ROTORDYNAMIC MODEL
DR-08 Worst Case Pump Housing Response
Pump Accel Y (G's)
20
0
-20
10.1
20.1
Running Speed (Thousand RPM)

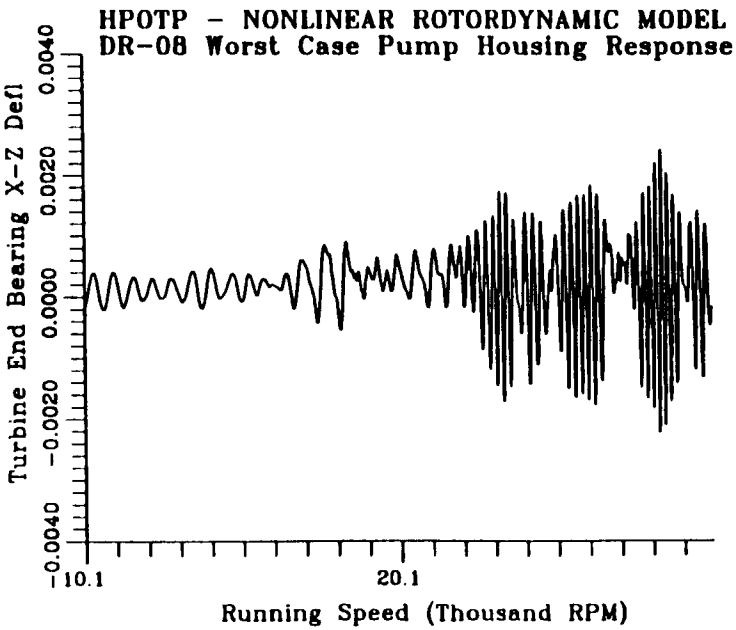

HPOTP - NONLINEAR ROTORDYNAMIC MODEL
DR-08 Worst Case Pump Housing Response
Turb Accel Y (G's)
20
10
0
-10
-20
10.1
20.1
Running Speed (Thousand RPM)

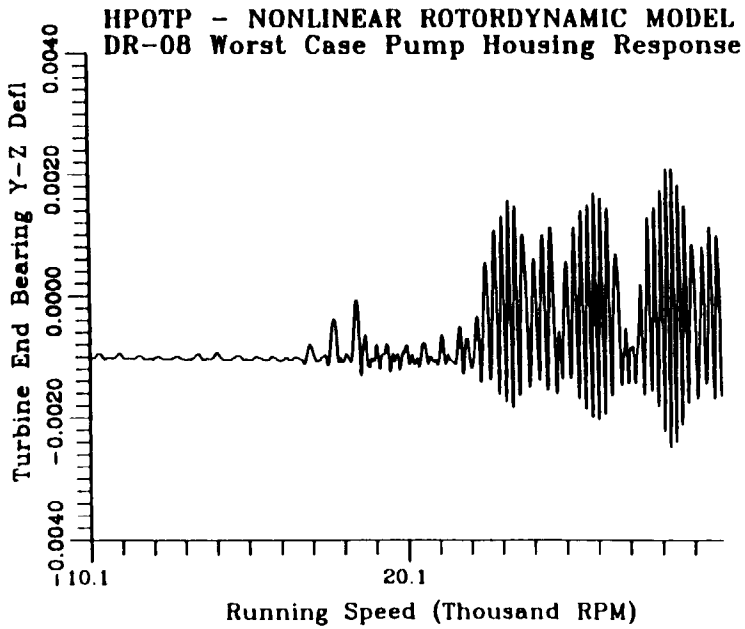

HPOTP - NONLINEAR ROTORDYNAMIC MODEL
DR-08 Worst Case Pump Housing Response
Pump End Bearing X-Z Defl
0.0040
0.0020
0.0000
-0.0020
10.1
20.1
Running Speed (Thousand RPM)

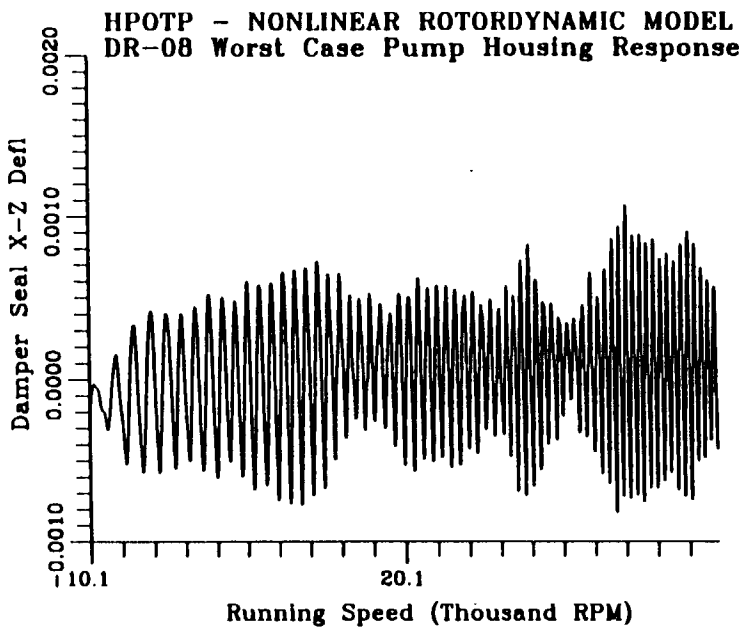

HPOTP - NONLINEAR ROTORDYNAMIC MODEL
DR-08 Worst Case Pump Housing Response
Pump End Bearing Y-Z Defl
0.0020
0.0000
-0.0020
-0.0040
10.1
20.1
Running Speed (Thousand RPM)

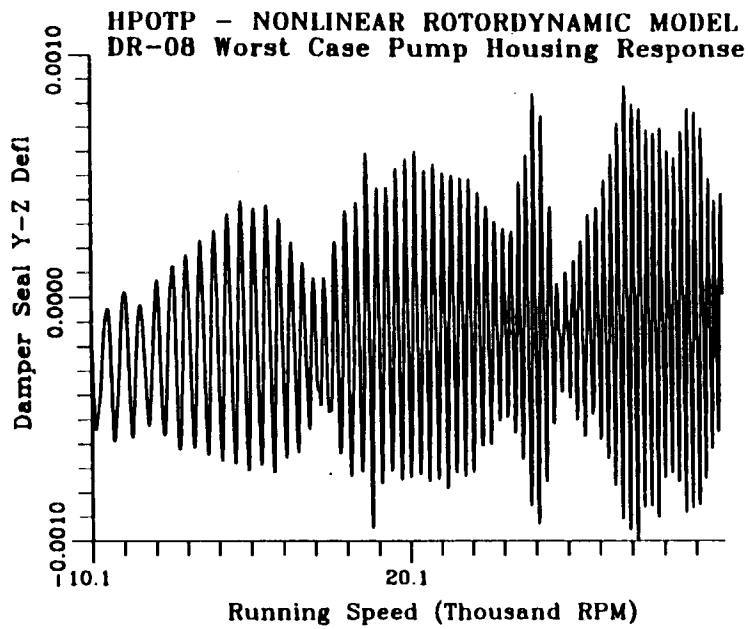

HPOTP - NONLINEAR ROTORDYNAMIC MODEL
DR-08 Worst Case Pump Housing Response
Main Stage Imp X-Z Defl
0.0100
0.0050
0.0000
-0.0050
-10.1
20.1
Running Speed (Thousand RPM)


HPOTP - NONLINEAR ROTORDYNAMIC MODEL
DR-08 Worst Case Pump Housing Response
Main Stage Imp Y-Z Defl
0.0050
0.0000
-0.0050
-0.0100
-10.1
20.1
Running Speed (Thousand RPM)

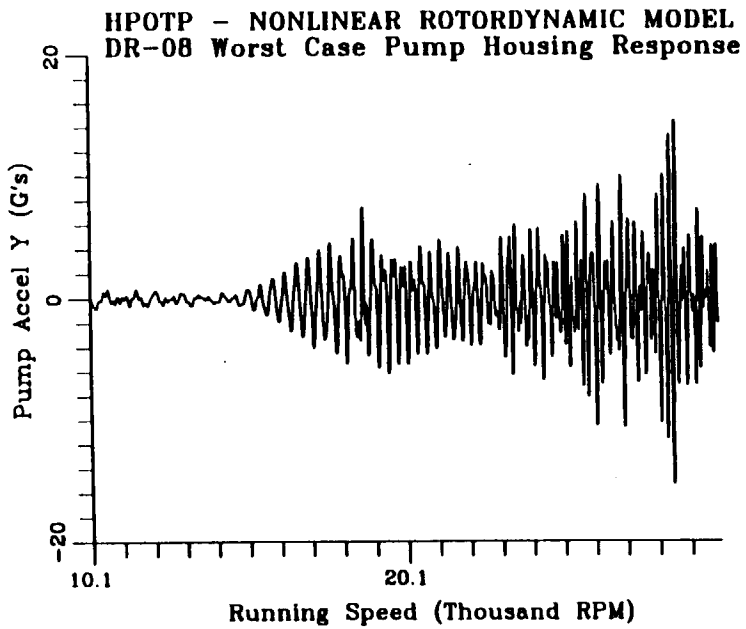

HPOTP - NONLINEAR ROTORDYNAMIC MODEL
DR-08 Worst Case Pump Housing Response
Turbine End Bearing X-Z Defl
0.0040
0.0020
0.0000
-0.0020
-0.0040
-10.1
20.1
Running Speed (Thousand RPM)

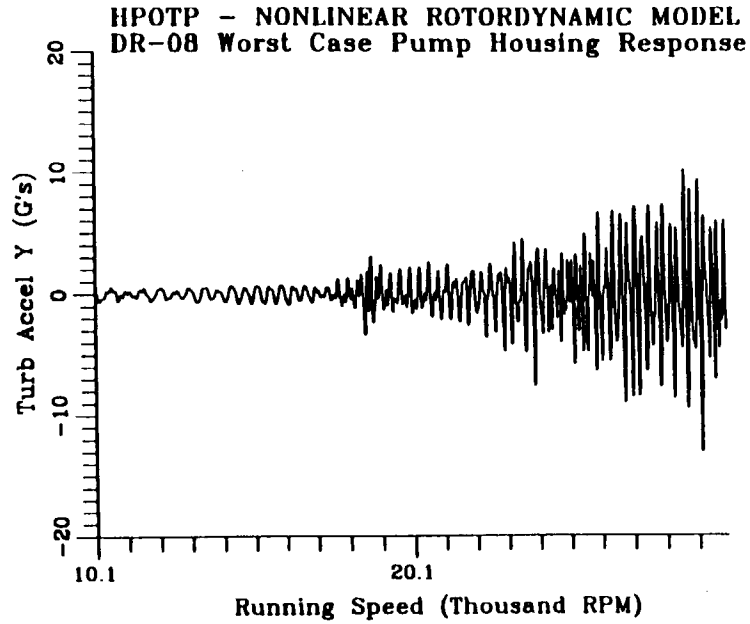

HPOTP - NONLINEAR ROTORDYNAMIC MODEL
DR-08 Worst Case Pump Housing Response
Turbine End Bearing Y-Z Defl
0.0040
0.0020
0.0000
-0.0020
-0.0040
-10.1
20.1
Running Speed (Thousand RPM)

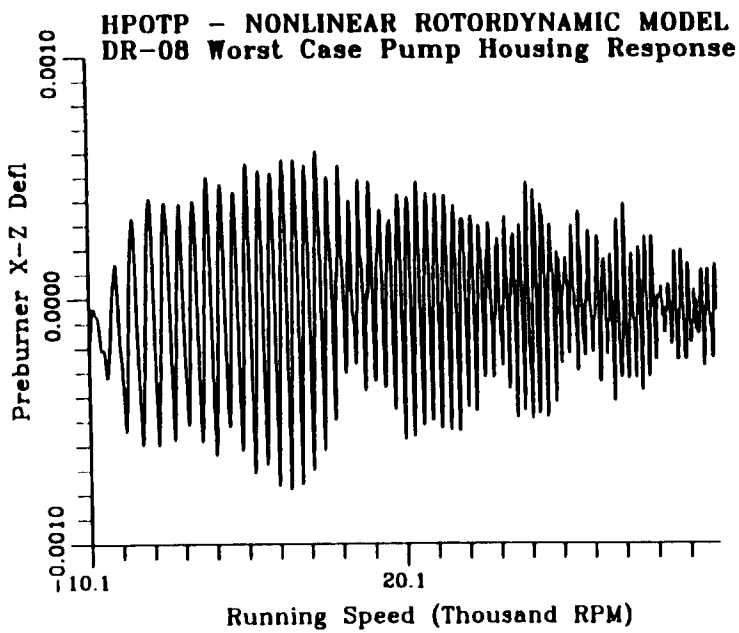

HPOTP - NONLINEAR ROTORDYNAMIC MODEL
DR-08 Worst Case Pump Housing Response
Damper Seal X-Z Defl
0.0020
0.0010
0.0000
-0.0010
-10.1
20.1
Running Speed (Thousand RPM)

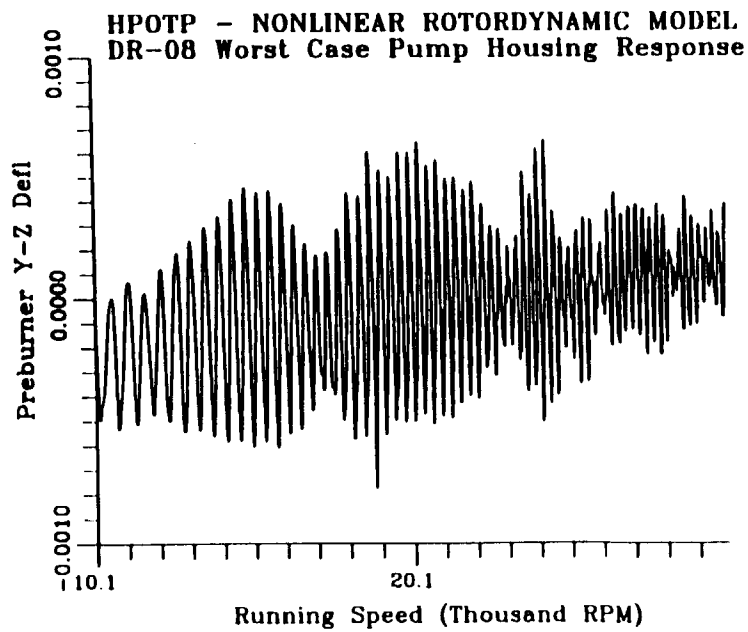

HPOTP - NONLINEAR ROTORDYNAMIC MODEL
DR-08 Worst Case Pump Housing Response
Damper Seal Y-Z Defl
0.0010
0.0000
-0.0010
-10.1
20.1
Running Speed (Thousand RPM)

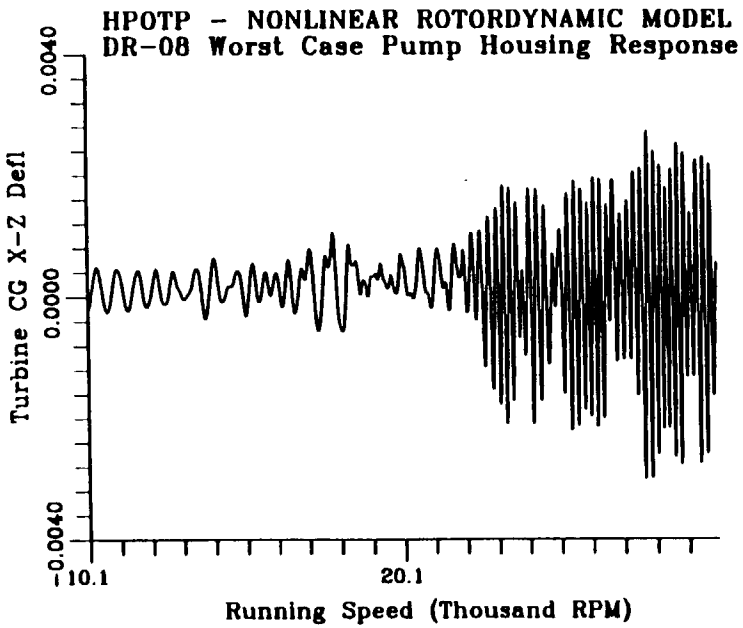
306

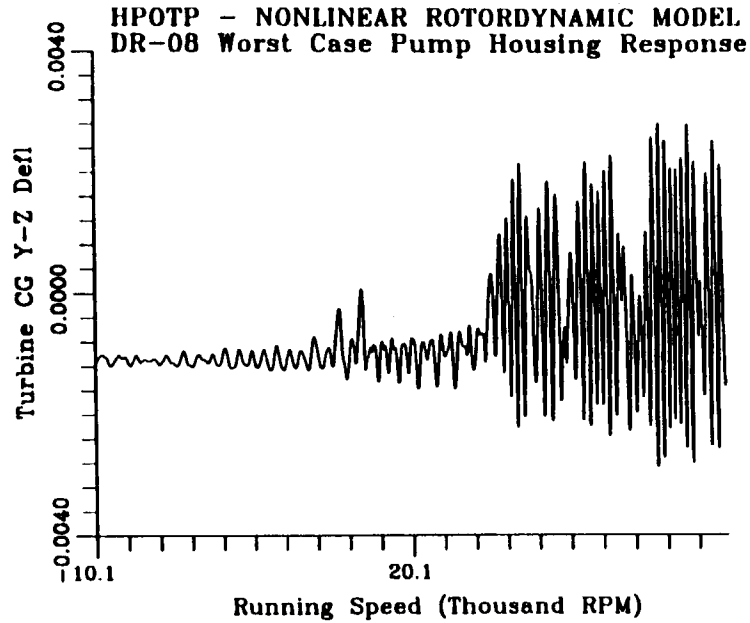

HPOTP - NONLINEAR ROTORDYNAMIC MODEL
DR-08 Worst Case Pump Housing Response
Pump Accel Y (G's)
20
0
-20
10.1
20.1
Running Speed (Thousand RPM)

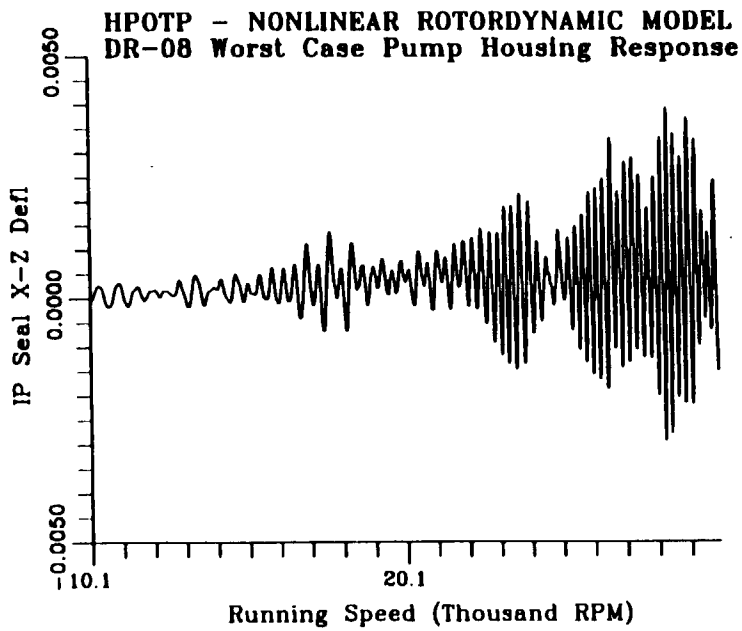

HPOTP - NONLINEAR ROTORDYNAMIC MODEL
DR-08 Worst Case Pump Housing Response
Turb Accel Y (G's)
20
10
0
-10
-20
10.1
20.1
Running Speed (Thousand RPM)

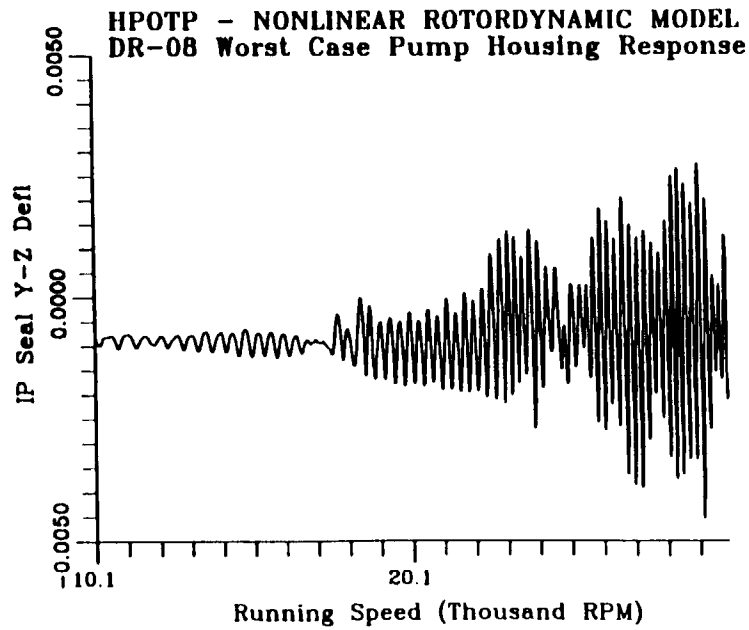

HPOTP - NONLINEAR ROTORDYNAMIC MODEL
DR-08 Worst Case Pump Housing Response
Preburner X-Z Defl
0.0010
0.0000
-0.0010
-10.1
20.1
Running Speed (Thousand RPM)

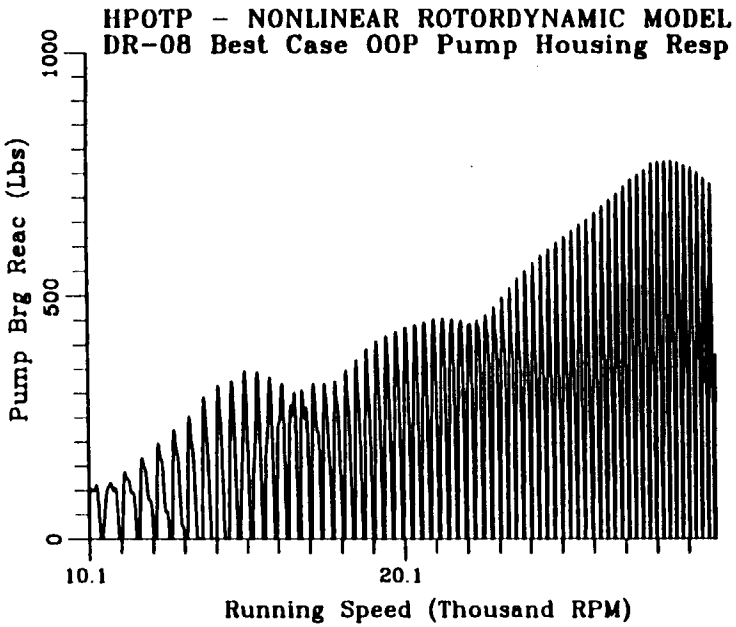

HPOTP - NONLINEAR ROTORDYNAMIC MODEL
DR-08 Worst Case Pump Housing Response
Preburner Y-Z Defl
0.0010
0.0000
-0.0010
-10.1
20.1
Running Speed (Thousand RPM)

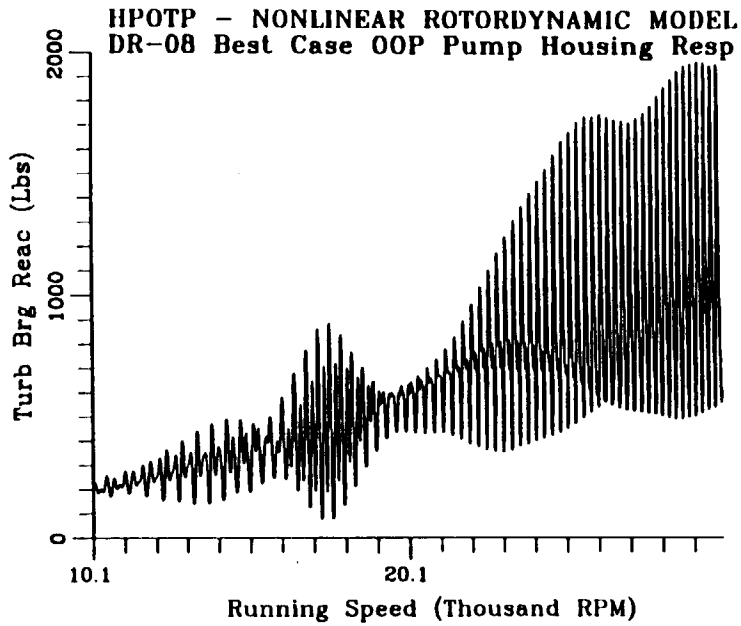

HPOTP - NONLINEAR ROTORDYNAMIC MODEL
DR-08 Worst Case Pump Housing Response
Turbine CG X-Z Defl
0.0040
0.0000
-0.0040
-10.1
20.1
Running Speed (Thousand RPM)

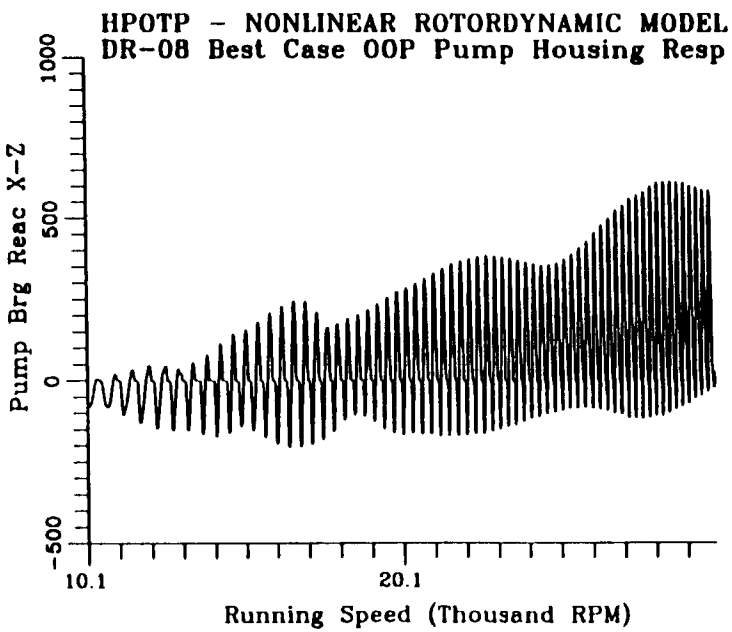

HPOTP - NONLINEAR ROTORDYNAMIC MODEL
DR-08 Worst Case Pump Housing Response
Turbine CG Y-Z Defl
0.0040
0.0000
-0.0040
-10.1
20.1
Running Speed (Thousand RPM)

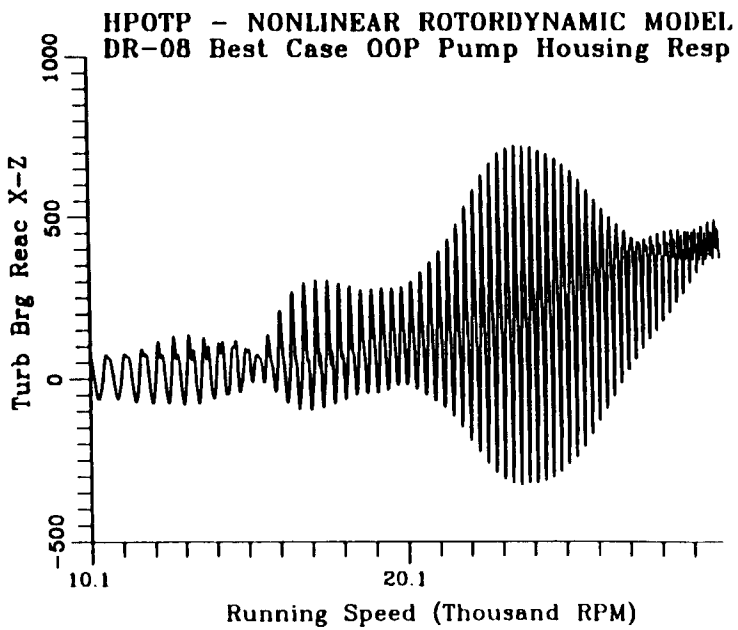

HPOTP - NONLINEAR ROTORDYNAMIC MODEL
DR-08 Worst Case Pump Housing Response
IP Seal X-Z Defl
0.0050
0.0000
-0.0050
-10.1
20.1
Running Speed (Thousand RPM)

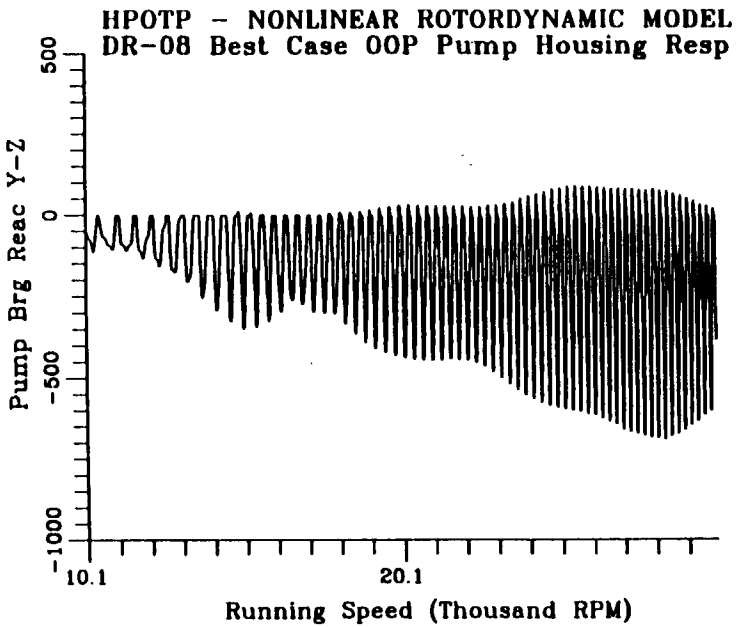

HPOTP - NONLINEAR ROTORDYNAMIC MODEL
DR-08 Worst Case Pump Housing Response
IP Seal Y-Z Defl
0.0050
0.0000
-0.0050
-10.1
20.1
Running Speed (Thousand RPM)

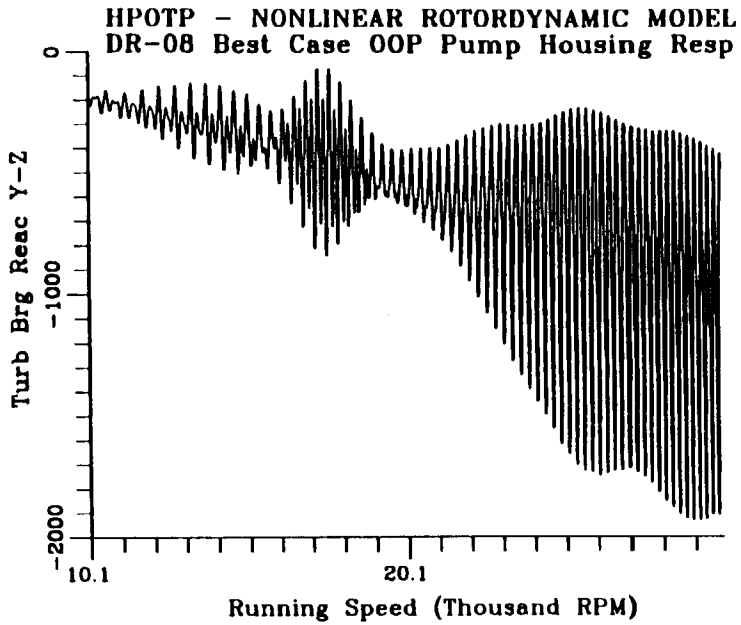

HPOTP - NONLINEAR ROTORDYNAMIC MODEL
DR-08 Best Case OOP Pump Housing Resp
Pump Brg Reac (Lbs)
0
500
1000
10.1
20.1
Running Speed (Thousand RPM)

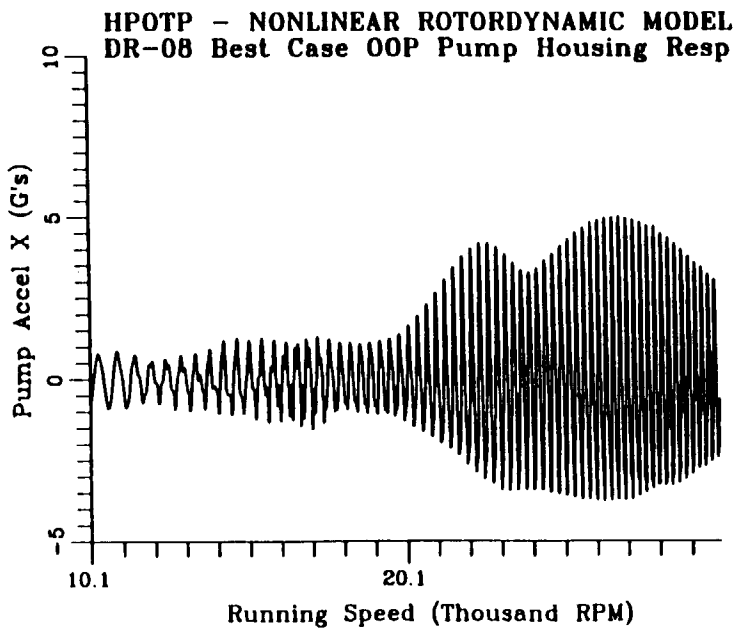

HPOTP - NONLINEAR ROTORDYNAMIC MODEL
DR-08 Best Case OOP Pump Housing Resp
Turb Brg Reac (Lbs)
0
1000
2000
10.1
20.1
Running Speed (Thousand RPM)

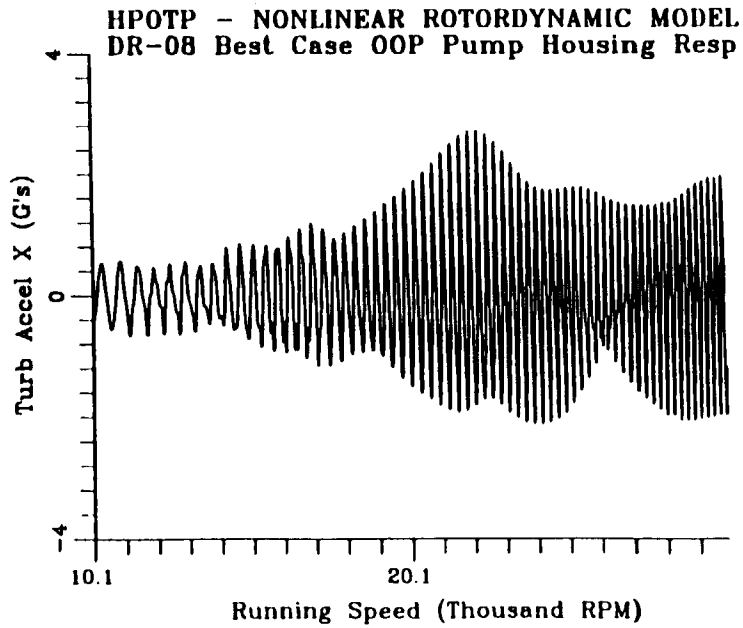

HPOTP - NONLINEAR ROTORDYNAMIC MODEL
DR-08 Best Case OOP Pump Housing Resp
Pump Brg Reac X-Z
-500
0
500
1000
10.1
20.1
Running Speed (Thousand RPM)

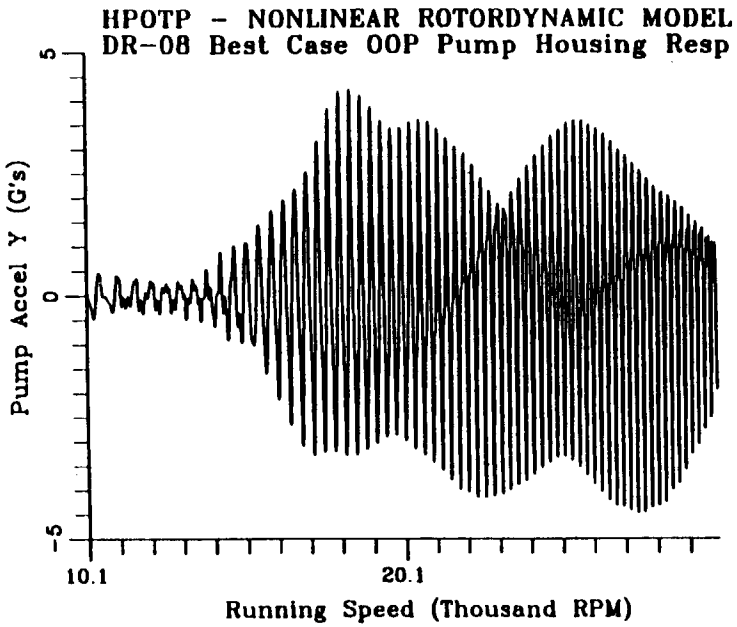

HPOTP - NONLINEAR ROTORDYNAMIC MODEL
DR-08 Best Case OOP Pump Housing Resp
Turb Brg Reac X-Z
-500
0
500
1000
10.1
20.1
Running Speed (Thousand RPM)

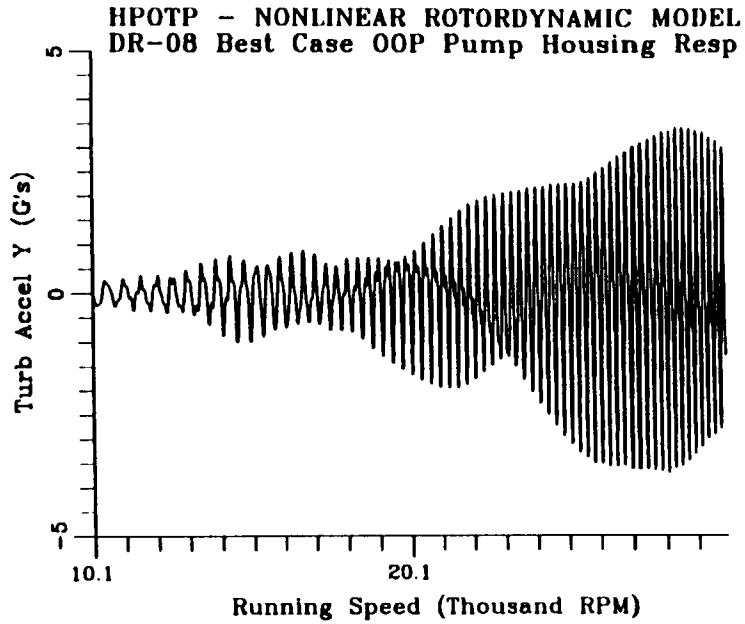

HPOTP - NONLINEAR ROTORDYNAMIC MODEL
DR-08 Best Case OOP Pump Housing Resp
Pump Brg Reac Y-Z
500
0
-500
-1000
10.1
20.1
Running Speed (Thousand RPM)

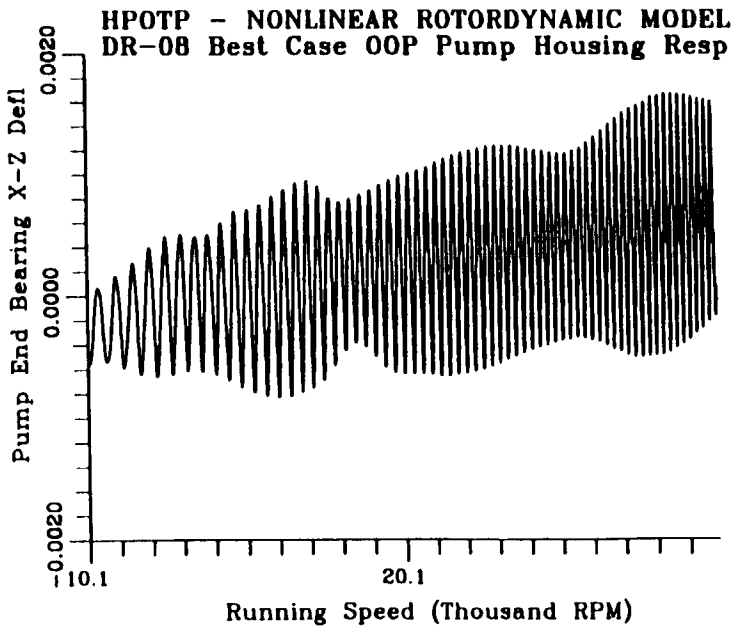

HPOTP - NONLINEAR ROTORDYNAMIC MODEL
DR-08 Best Case OOP Pump Housing Resp
Turb Brg Reac Y-Z
0
-1000
-2000
10.1
20.1
Running Speed (Thousand RPM)

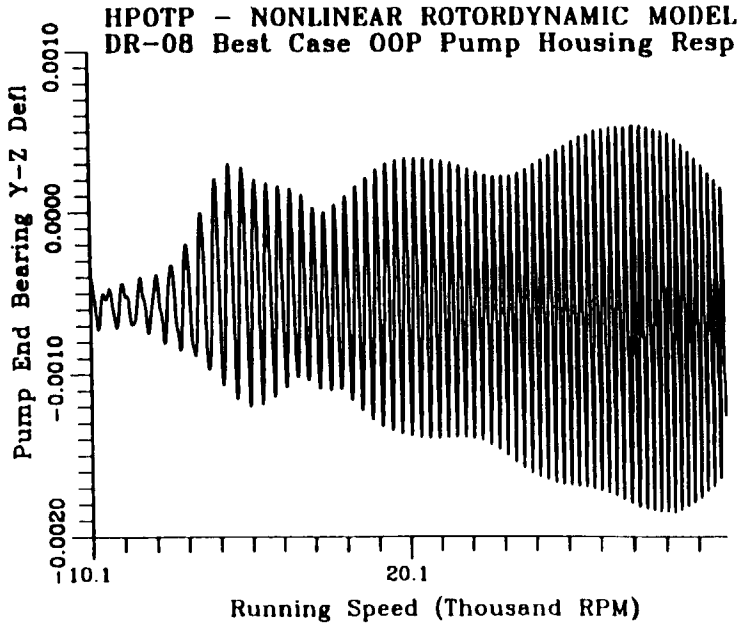

HPOTP - NONLINEAR ROTORDYNAMIC MODEL
DR-08 Best Case OOP Pump Housing Resp
Pump Accel X (G's)
10
5
0
-5
10.1
20.1
Running Speed (Thousand RPM)

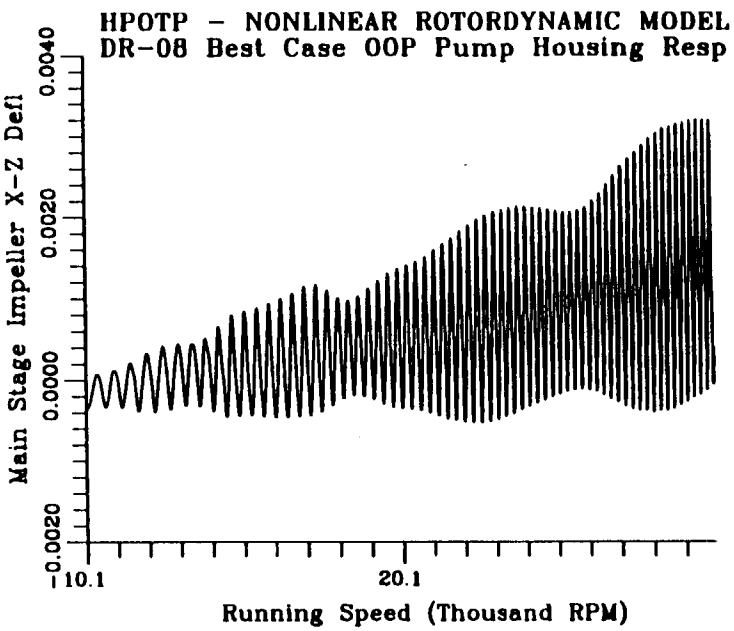

HPOTP - NONLINEAR ROTORDYNAMIC MODEL
DR-08 Best Case OOP Pump Housing Resp
Turb Accel X (G's)
4
0
-4
10.1
20.1
Running Speed (Thousand RPM)

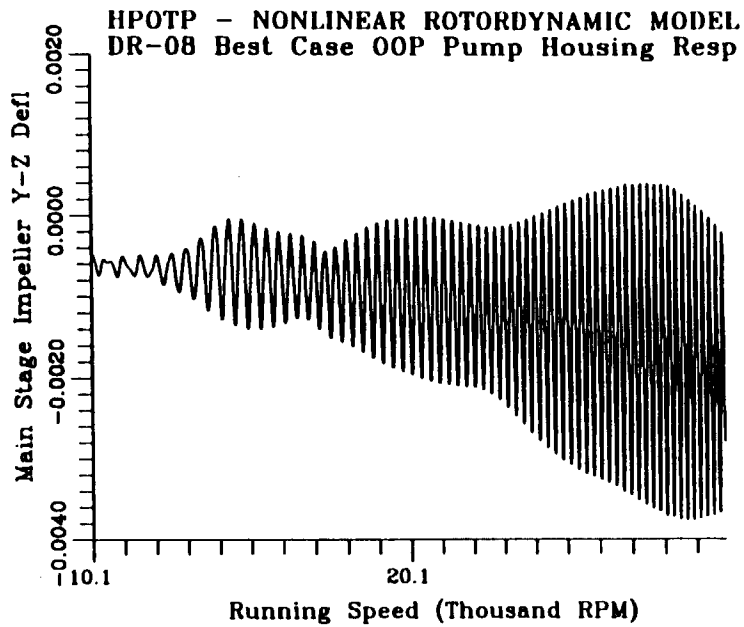

HPOTP - NONLINEAR ROTORDYNAMIC MODEL
DR-08 Best Case OOP Pump Housing Resp
Pump Accel Y (G's)
5
0
-5
10.1
20.1
Running Speed (Thousand RPM)

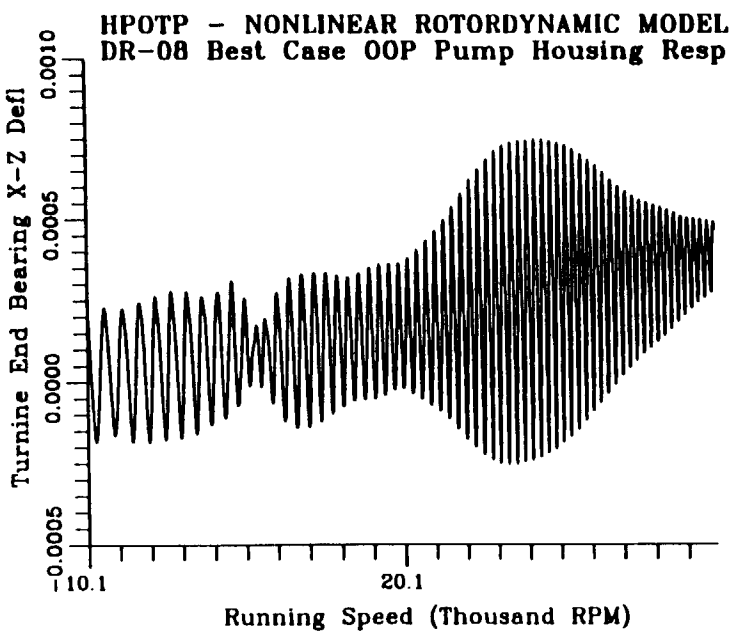

HPOTP - NONLINEAR ROTORDYNAMIC MODEL
DR-08 Best Case OOP Pump Housing Resp
Turb Accel Y (G's)
5
0
-5
10.1
20.1
Running Speed (Thousand RPM)

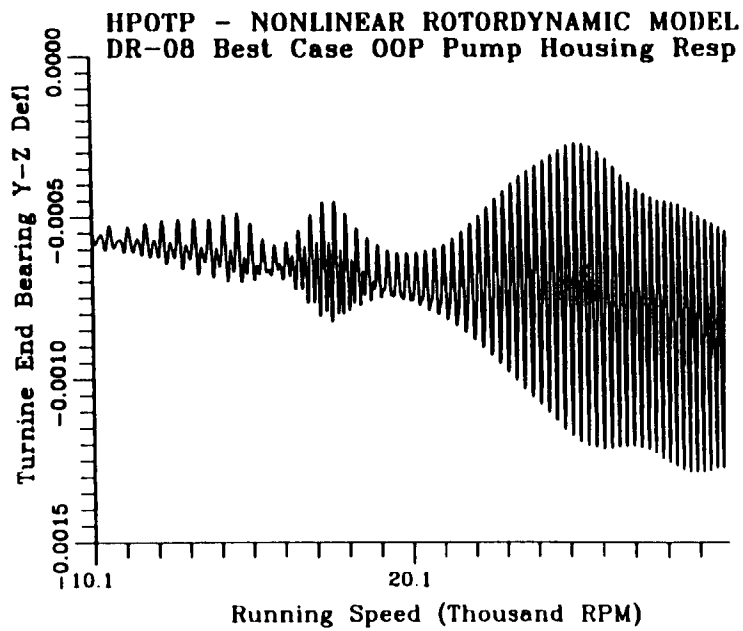

HPOTP - NONLINEAR ROTORDYNAMIC MODEL
DR-08 Best Case OOP Pump Housing Resp
Pump End Bearing X-Z Defl
0.0020
0.0000
-0.0020
10.1
20.1
Running Speed (Thousand RPM)

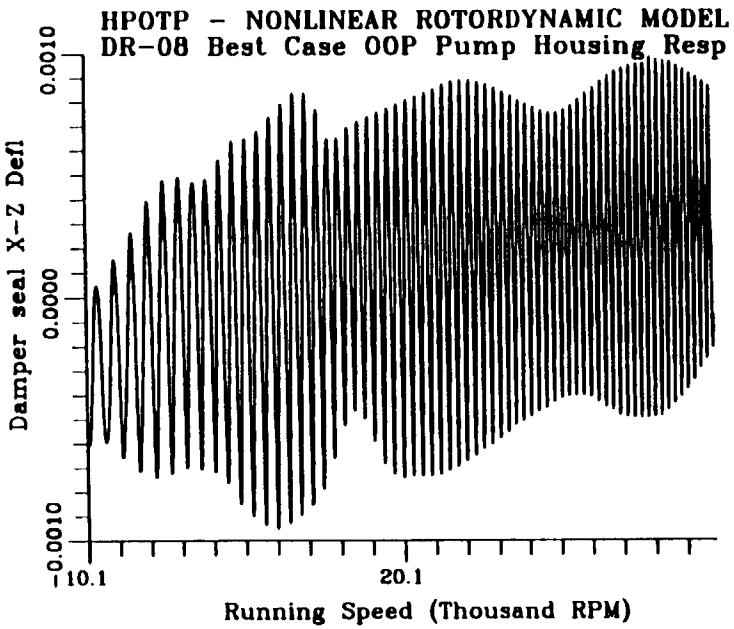

HPOTP - NONLINEAR ROTORDYNAMIC MODEL
DR-08 Best Case OOP Pump Housing Resp
Pump End Bearing Y-Z Defl
0.0010
0.0000
-0.0010
-0.0020
10.1
20.1
Running Speed (Thousand RPM)

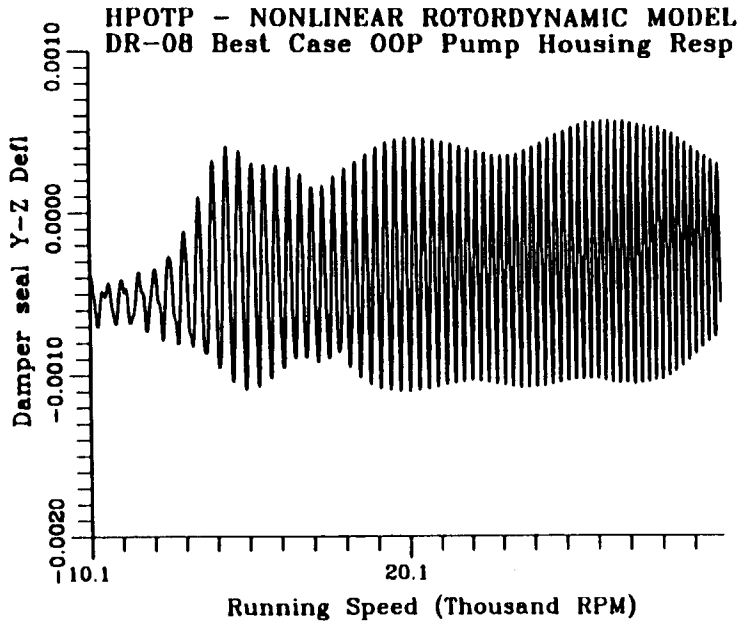

HPOTP - NONLINEAR ROTORDYNAMIC MODEL
DR-08 Best Case OOP Pump Housing Resp
Main Stage Impeller X-Z Defl
0.0040
0.0020
0.0000
-0.0020
-10.1
20.1
Running Speed (Thousand RPM)

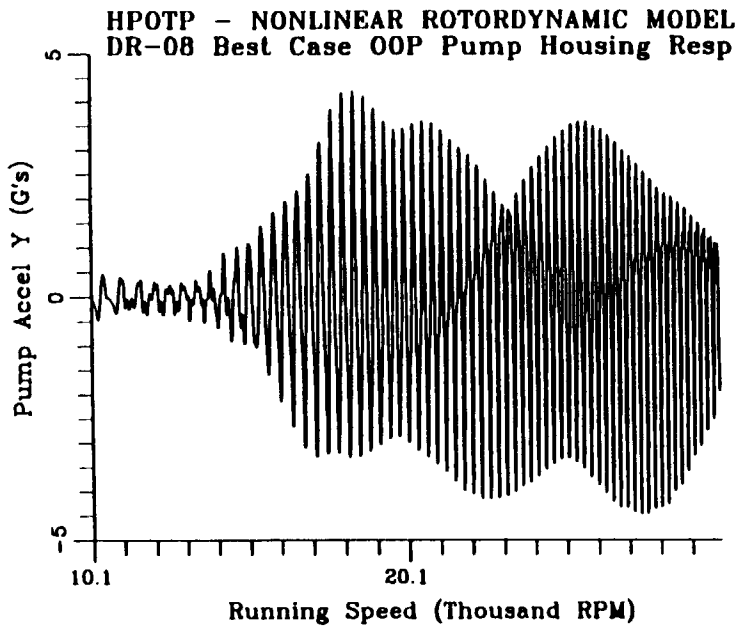

HPOTP - NONLINEAR ROTORDYNAMIC MODEL
DR-08 Best Case OOP Pump Housing Resp
Main Stage Impeller Y-Z Defl
0.0020
0.0000
-0.0020
-0.0040
-10.1
20.1
Running Speed (Thousand RPM)

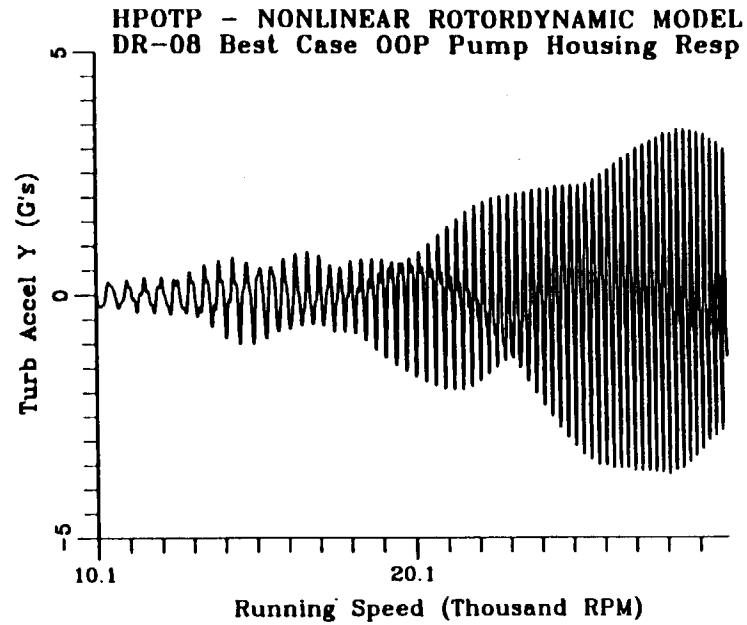

HPOTP - NONLINEAR ROTORDYNAMIC MODEL
DR-08 Best Case OOP Pump Housing Resp
Turnine End Bearing X-Z Defl
0.0010
0.0005
0.0000
-0.0005
-10.1
20.1
Running Speed (Thousand RPM)

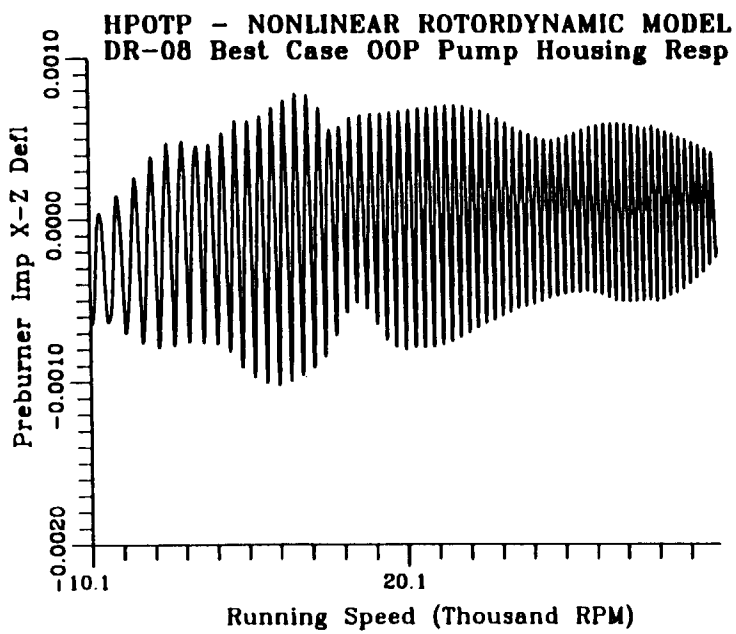

HPOTP - NONLINEAR ROTORDYNAMIC MODEL
DR-08 Best Case OOP Pump Housing Resp
Turnine End Bearing Y-Z Defl
0.0000
-0.0005
-0.0010
-0.0015
-10.1
20.1
Running Speed (Thousand RPM)

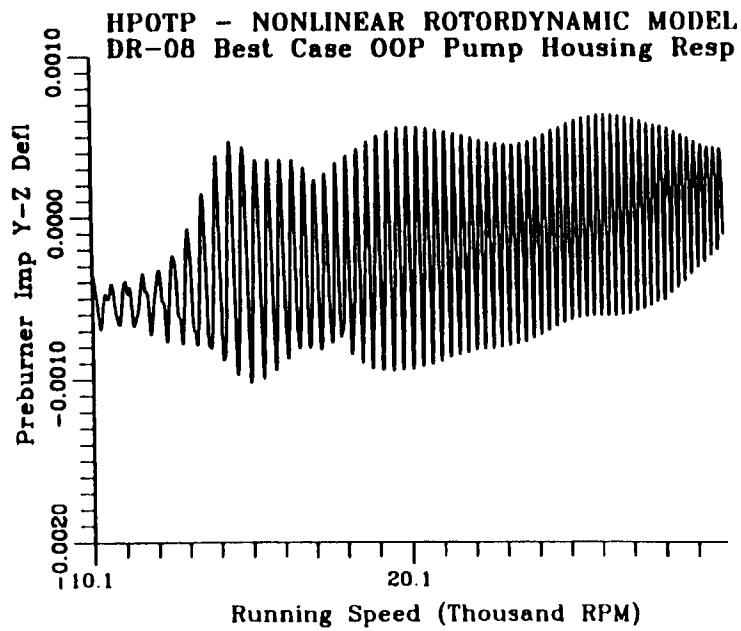

HPOTP - NONLINEAR ROTORDYNAMIC MODEL
DR-08 Best Case OOP Pump Housing Resp
Damper seal X-Z Defl
0.0010
0.0000
-0.0010
-10.1
20.1
Running Speed (Thousand RPM)

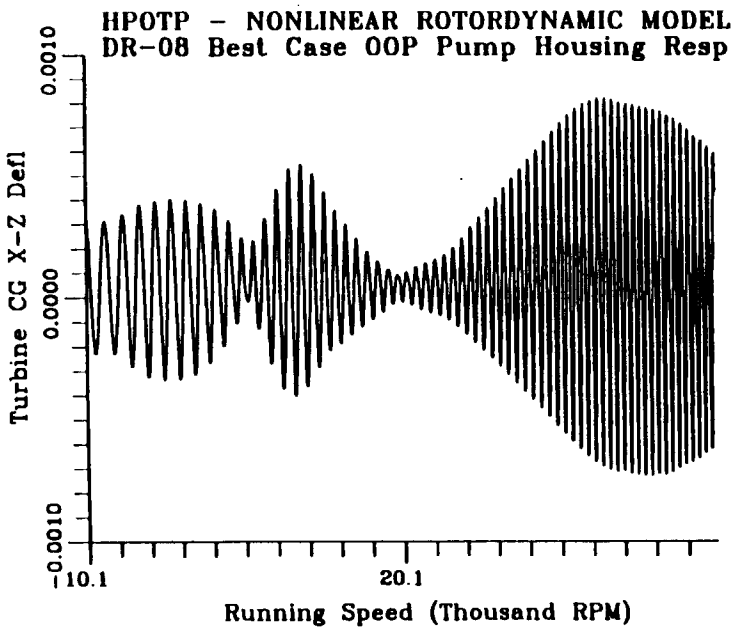

HPOTP - NONLINEAR ROTORDYNAMIC MODEL
DR-08 Best Case OOP Pump Housing Resp
Damper seal Y-Z Defl
0.0010
0.0000
-0.0010
-0.0020
-10.1
20.1
Running Speed (Thousand RPM)

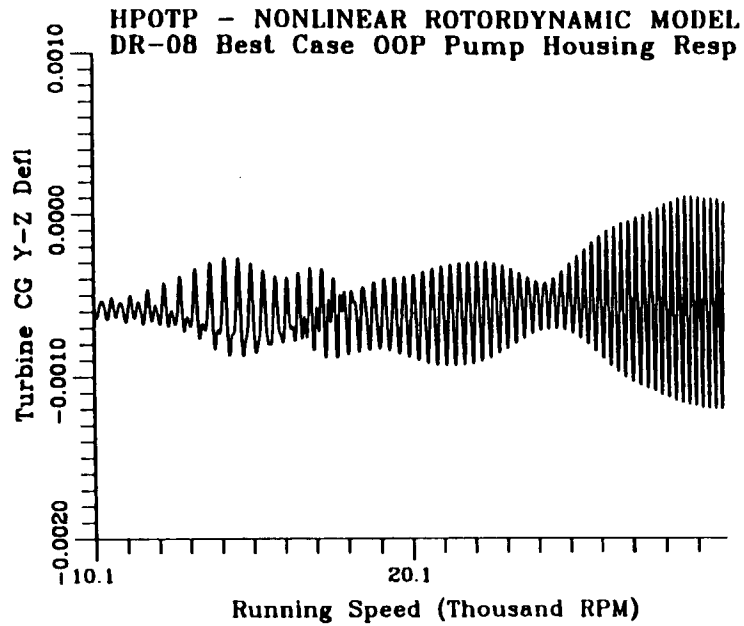

HPOTP - NONLINEAR ROTORDYNAMIC MODEL
DR-08 Best Case OOP Pump Housing Resp
Pump Accel Y (G's)
5
0
-5
10.1
20.1
Running Speed (Thousand RPM)

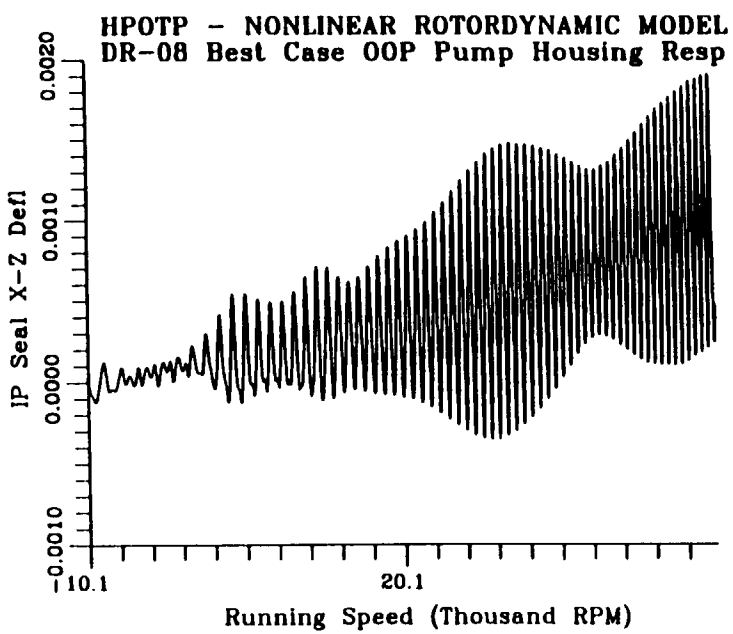

HPOTP - NONLINEAR ROTORDYNAMIC MODEL
DR-08 Best Case OOP Pump Housing Resp
Turb Accel Y (G's)
5
0
-5
10.1
20.1
Running Speed (Thousand RPM)

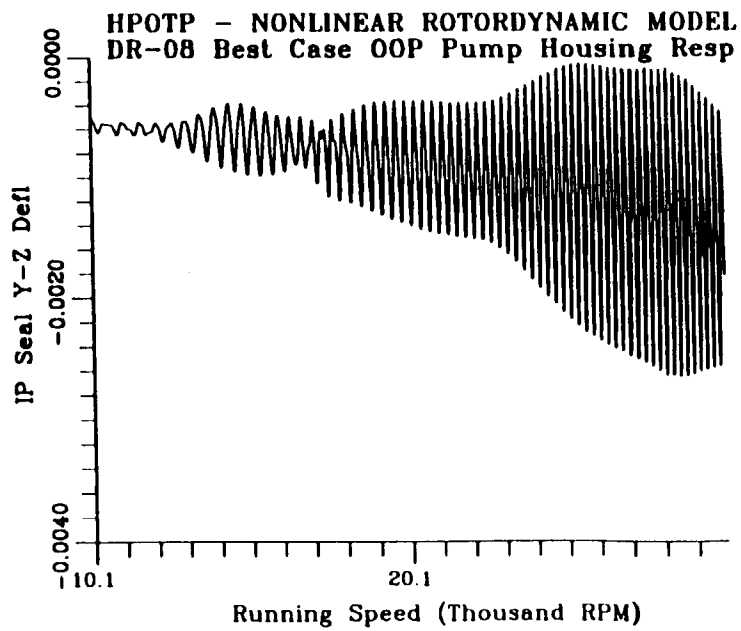

HPOTP - NONLINEAR ROTORDYNAMIC MODEL
DR-08 Best Case OOP Pump Housing Resp
Preburner Imp X-Z Defl
0.0010
0.0000
-0.0010
-0.0020
10.1
20.1
Running Speed (Thousand RPM)

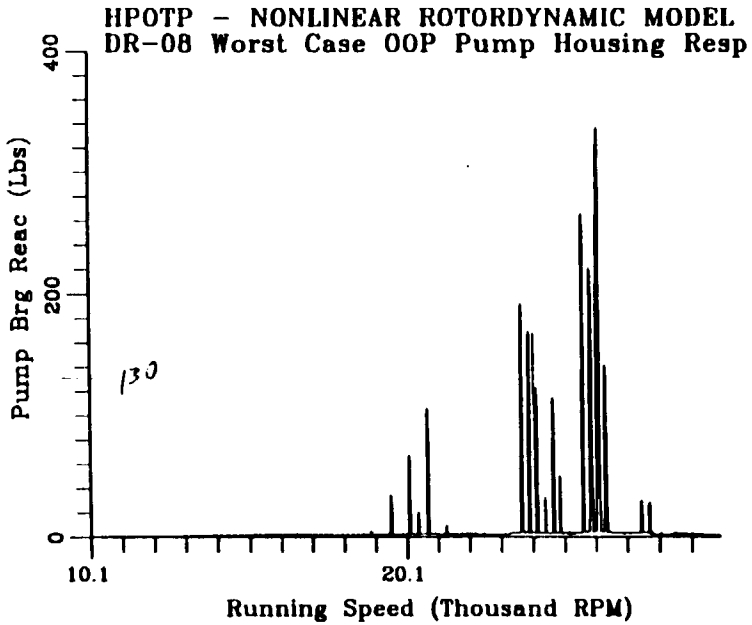

HPOTP - NONLINEAR ROTORDYNAMIC MODEL
DR-08 Best Case OOP Pump Housing Resp
Preburner Imp Y-Z Defl
0.0010
0.0000
-0.0010
-0.0020
10.1
20.1
Running Speed (Thousand RPM)

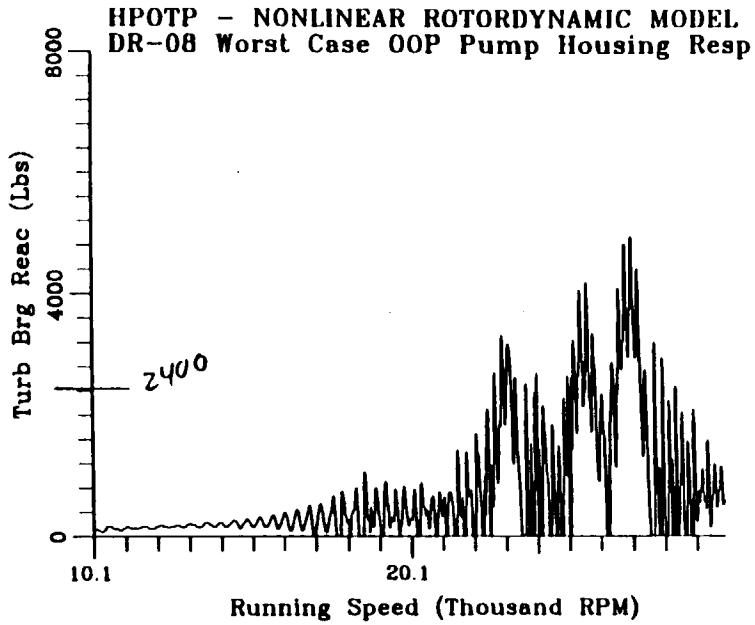

HPOTP - NONLINEAR ROTORDYNAMIC MODEL
DR-08 Best Case OOP Pump Housing Resp
Turbine CG X-Z Defl
0.0010
0.0000
-0.0010
-10.1
20.1
Running Speed (Thousand RPM)

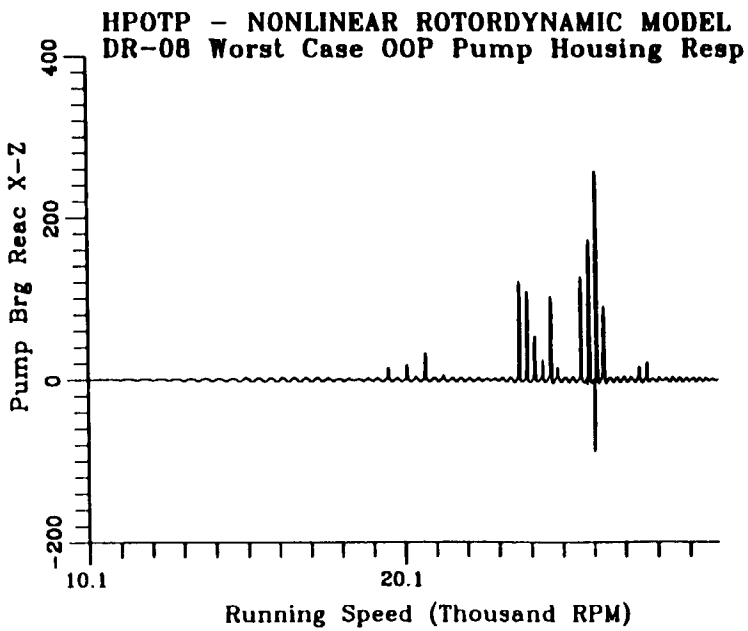

HPOTP - NONLINEAR ROTORDYNAMIC MODEL
DR-08 Best Case OOP Pump Housing Resp
Turbine CG Y-Z Defl
0.0010
0.0000
-0.0010
-0.0020
-10.1
20.1
Running Speed (Thousand RPM)

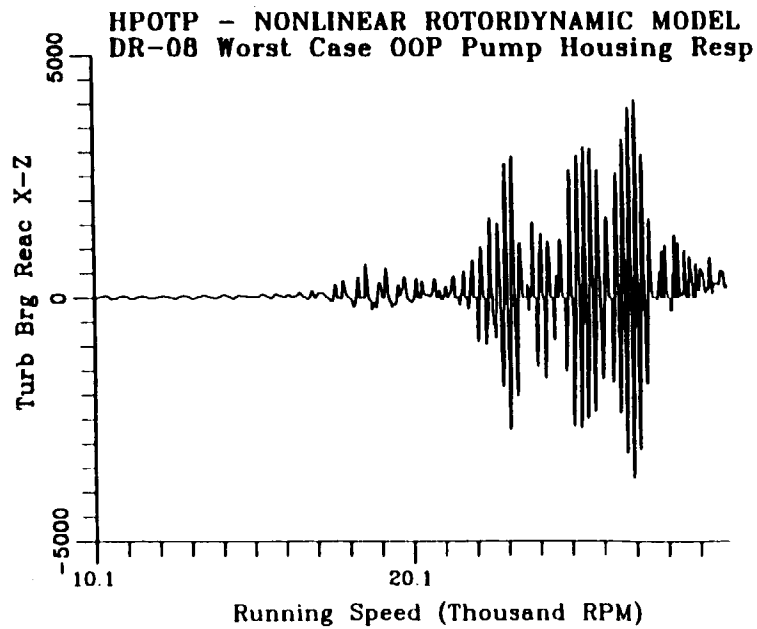

HPOTP - NONLINEAR ROTORDYNAMIC MODEL
DR-08 Best Case OOP Pump Housing Resp
IP Seal X-Z Defl
0.0020
0.0010
0.0000
-0.0010
-10.1
20.1
Running Speed (Thousand RPM)

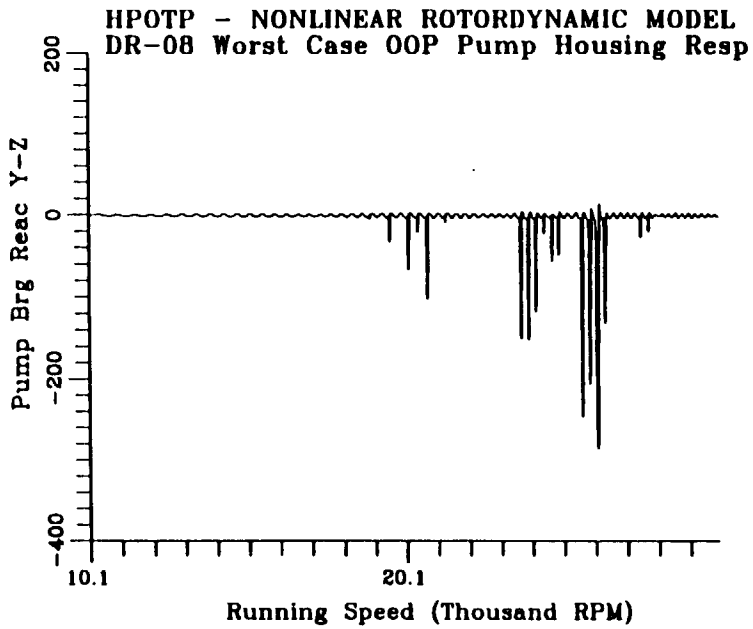

HPOTP - NONLINEAR ROTORDYNAMIC MODEL
DR-08 Best Case OOP Pump Housing Resp
IP Seal Y-Z Defl
0.0000
-0.0020
-0.0040
-10.1
20.1
Running Speed (Thousand RPM)

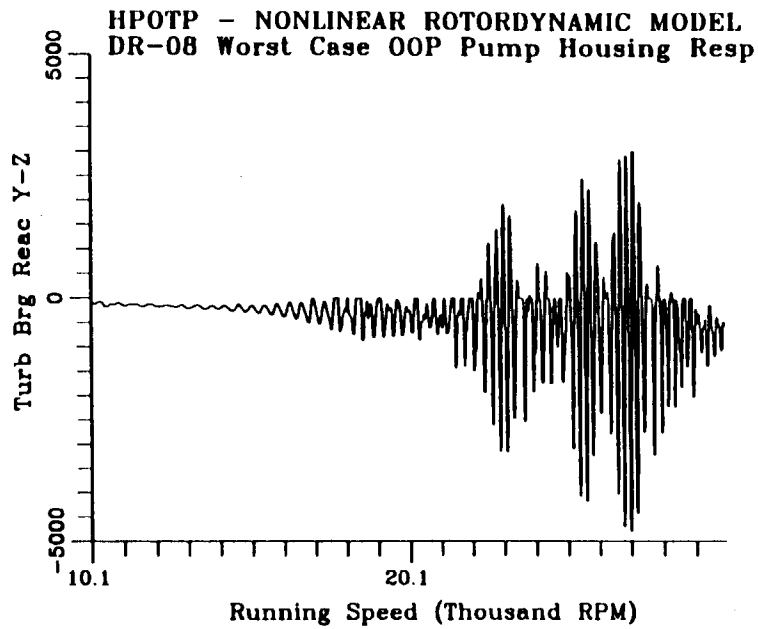

HPOTP - NONLINEAR ROTORDYNAMIC MODEL
DR-08 Worst Case OOP Pump Housing Resp
Pump Brg Reac (Lbs)
400
200
0
130
10.1
20.1
Running Speed (Thousand RPM)

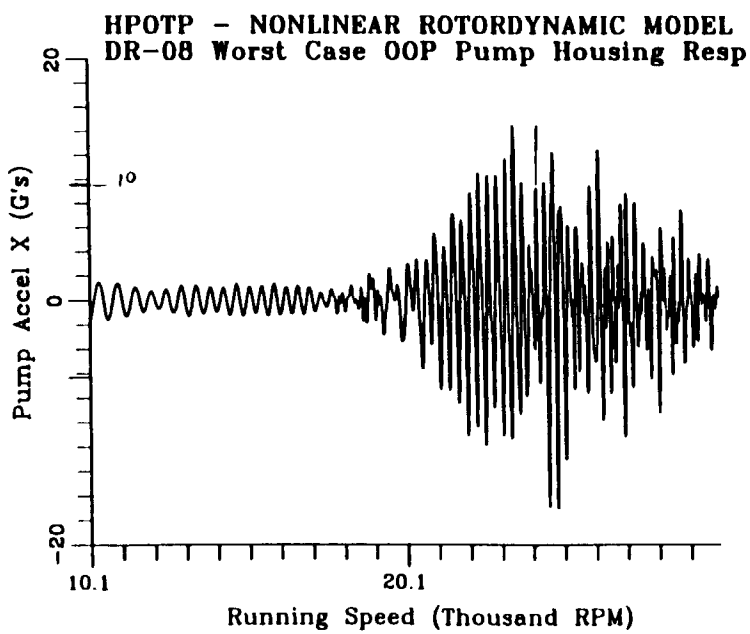

HPOTP - NONLINEAR ROTORDYNAMIC MODEL
DR-08 Worst Case OOP Pump Housing Resp
Turb Brg Reac (Lbs)
8000
4000
0
2400
10.1
20.1
Running Speed (Thousand RPM)

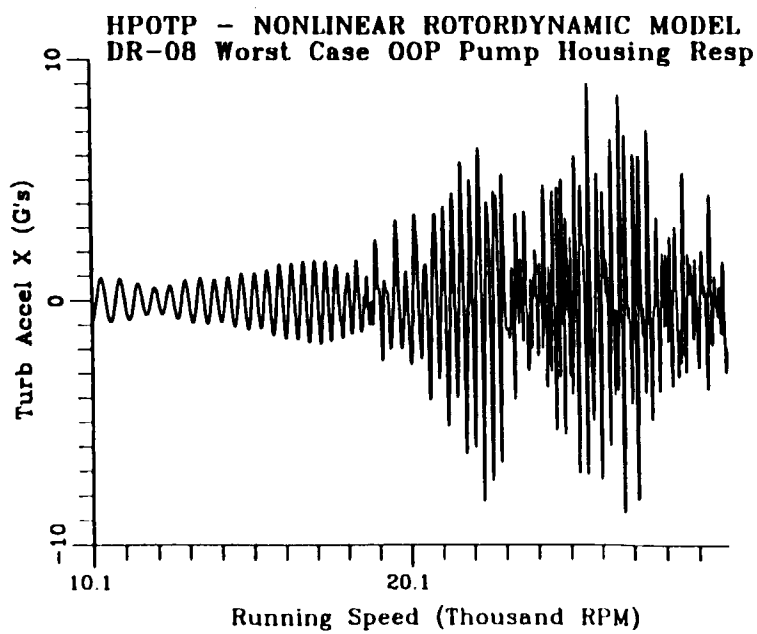

HPOTP - NONLINEAR ROTORDYNAMIC MODEL
DR-08 Worst Case OOP Pump Housing Resp
Pump Brg Reac X-Z
400
200
0
-200
10.1
20.1
Running Speed (Thousand RPM)

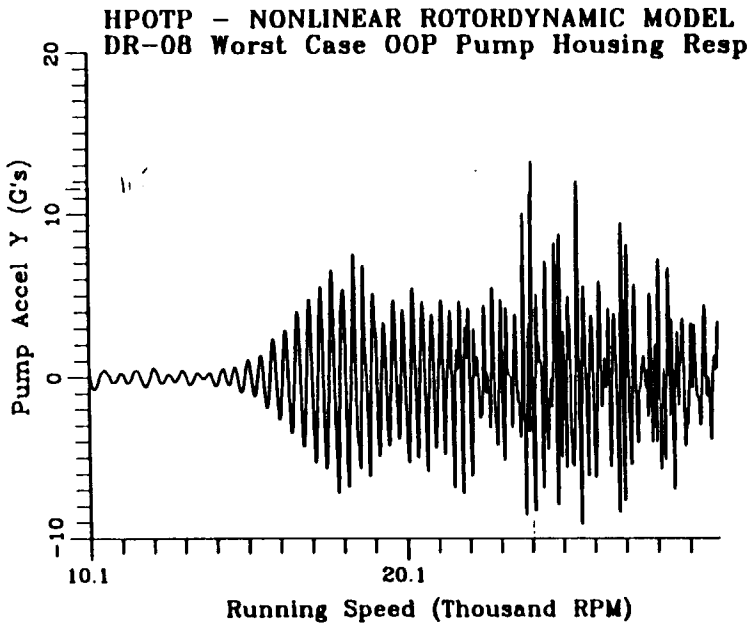

HPOTP - NONLINEAR ROTORDYNAMIC MODEL
DR-08 Worst Case OOP Pump Housing Resp
Turb Brg Reac X-Z
5000
0
-5000
10.1
20.1
Running Speed (Thousand RPM)

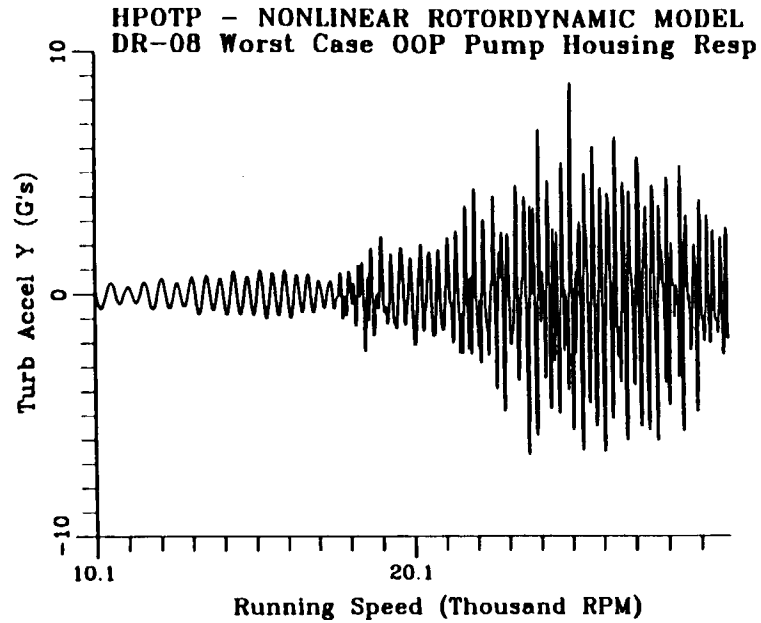

HPOTP - NONLINEAR ROTORDYNAMIC MODEL
DR-08 Worst Case OOP Pump Housing Resp
Pump Brg Reac Y-Z
200
0
-200
-400
10.1
20.1
Running Speed (Thousand RPM)

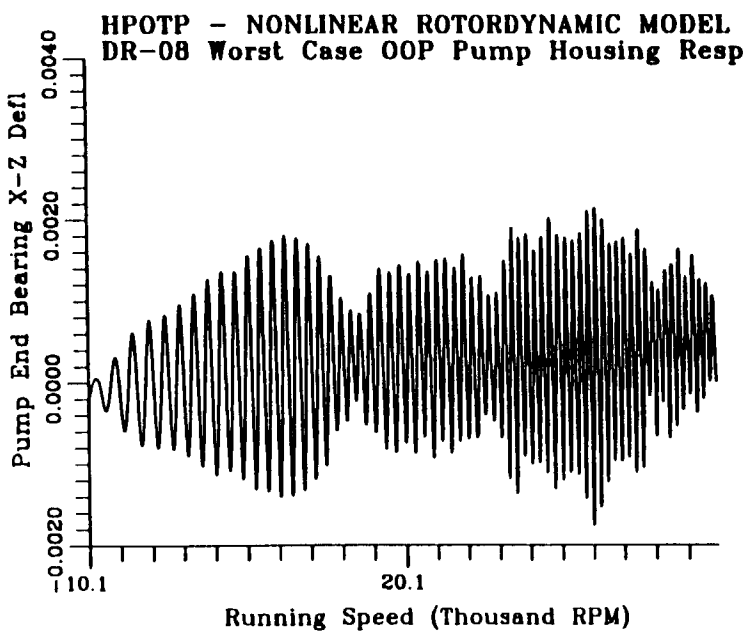

HPOTP - NONLINEAR ROTORDYNAMIC MODEL
DR-08 Worst Case OOP Pump Housing Resp
Turb Brg Reac Y-Z
5000
0
-5000
10.1
20.1
Running Speed (Thousand RPM)

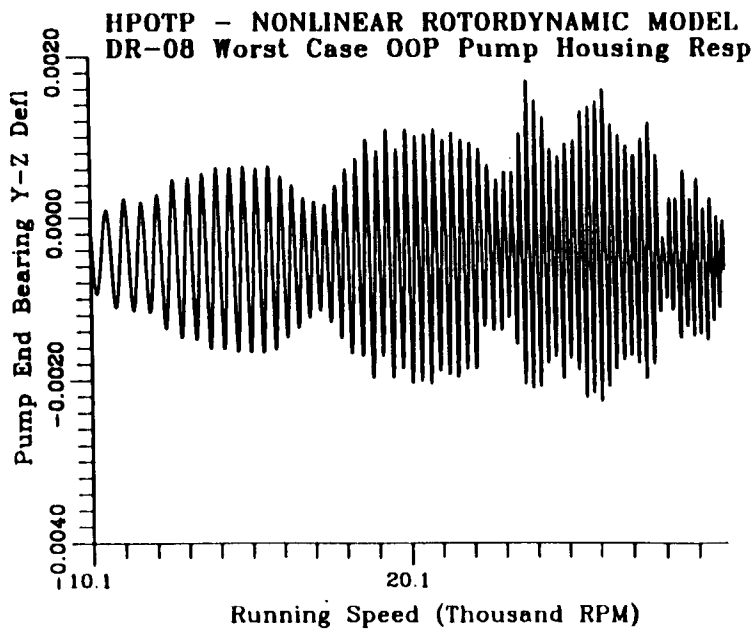

HPOTP - NONLINEAR ROTORDYNAMIC MODEL
DR-08 Worst Case OOP Pump Housing Resp
Pump Accel X (G's)
20
10
0
-20
10.1
20.1
Running Speed (Thousand RPM)

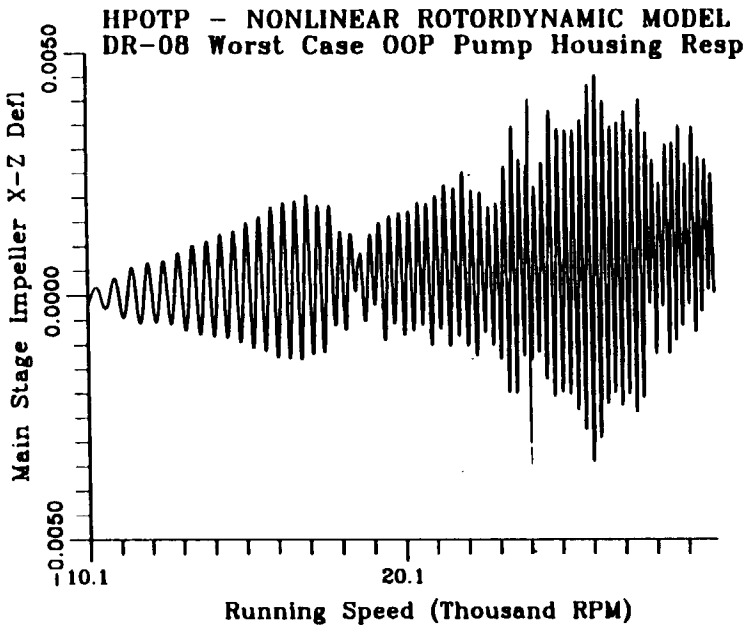

HPOTP - NONLINEAR ROTORDYNAMIC MODEL
DR-08 Worst Case OOP Pump Housing Resp
Turb Accel X (G's)
10
0
-10
10.1
20.1
Running Speed (Thousand RPM)

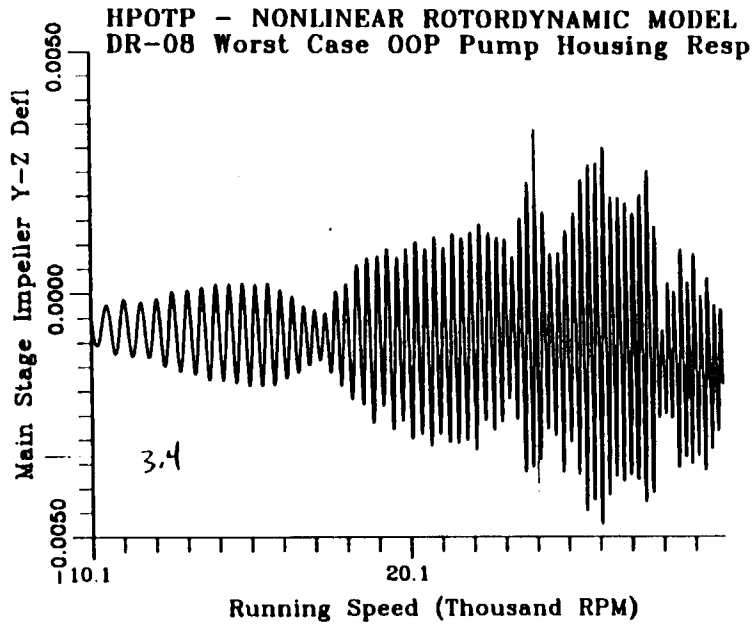

HPOTP - NONLINEAR ROTORDYNAMIC MODEL
DR-08 Worst Case OOP Pump Housing Resp
Pump Accel Y (G's)
20
10
0
-10
10.1
20.1
Running Speed (Thousand RPM)

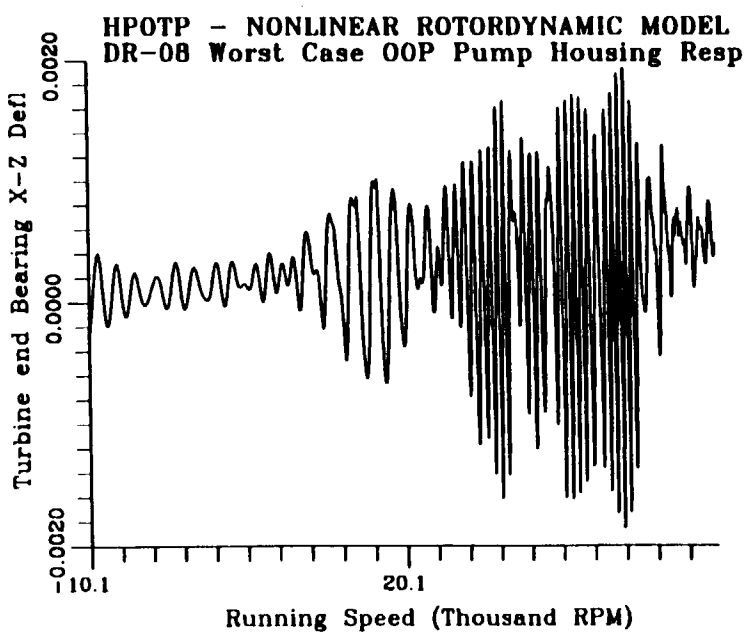

HPOTP - NONLINEAR ROTORDYNAMIC MODEL
DR-08 Worst Case OOP Pump Housing Resp
Turb Accel Y (G's)
10
0
-10
10.1
20.1
Running Speed (Thousand RPM)

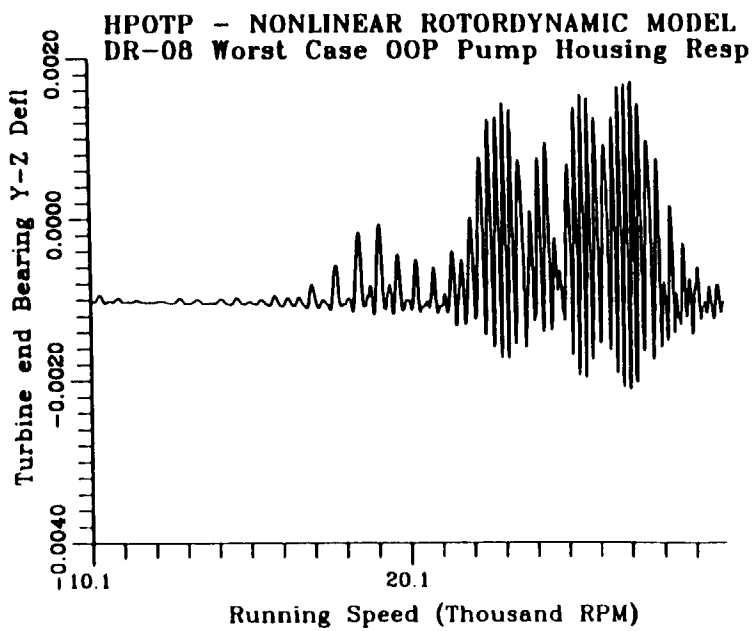

HPOTP - NONLINEAR ROTORDYNAMIC MODEL
DR-08 Worst Case OOP Pump Housing Resp
Pump End Bearing X-Z Defl
0.0040
0.0020
0.0000
-0.0020
-10.1
20.1
Running Speed (Thousand RPM)

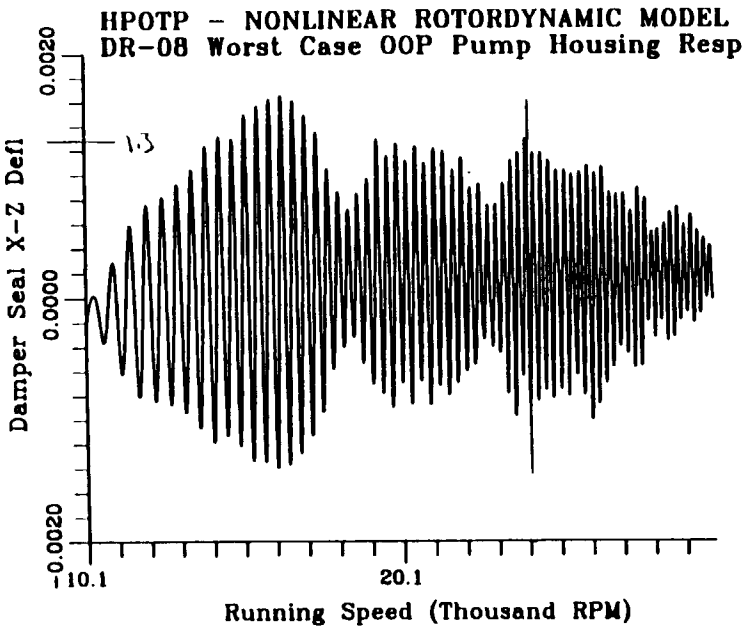

HPOTP - NONLINEAR ROTORDYNAMIC MODEL
DR-08 Worst Case OOP Pump Housing Resp
Pump End Bearing Y-Z Defl
0.0020
0.0000
-0.0020
-0.0040
-10.1
20.1
Running Speed (Thousand RPM)

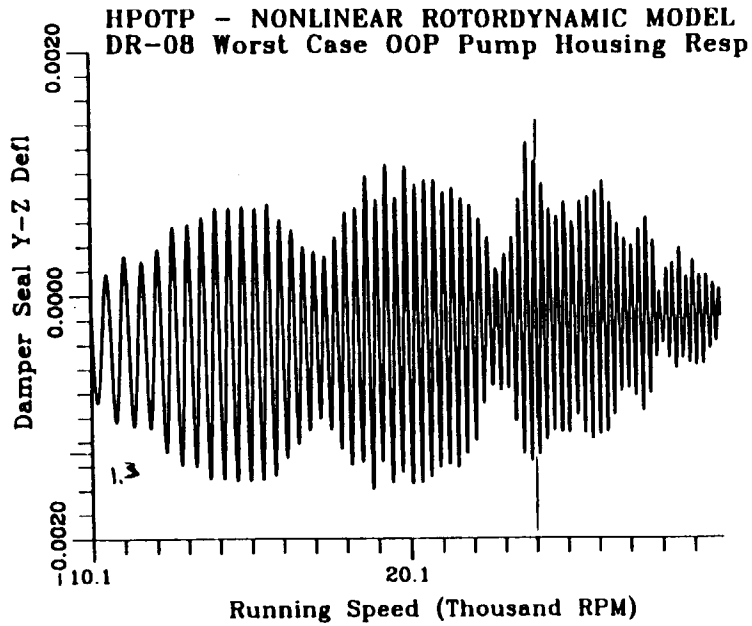

HPOTP - NONLINEAR ROTORDYNAMIC MODEL
DR-08 Worst Case OOP Pump Housing Resp
Main Stage Impeller X-Z Defl
0.0050
0.0000
-0.0050
-10.1
20.1
Running Speed (Thousand RPM)

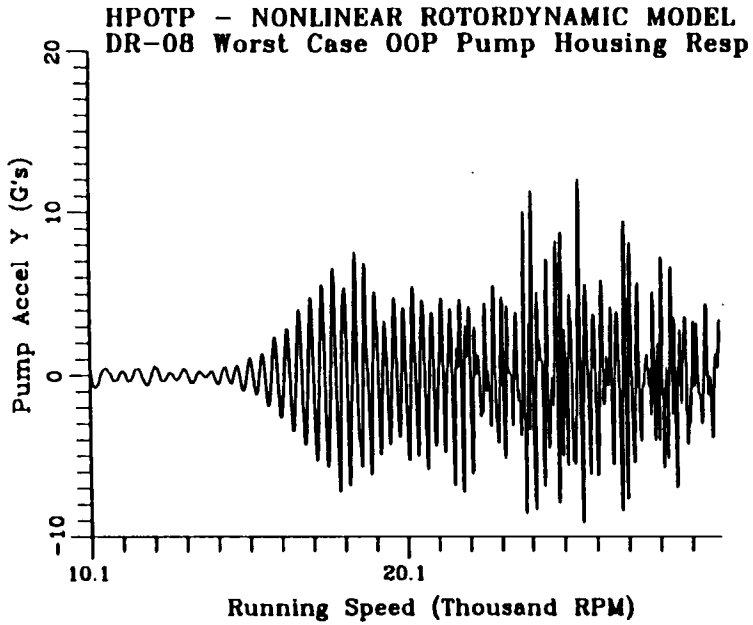

HPOTP - NONLINEAR ROTORDYNAMIC MODEL
DR-08 Worst Case OOP Pump Housing Resp
Main Stage Impeller Y-Z Defl
0.0050
0.0000
-0.0050
3.4
-10.1
20.1
Running Speed (Thousand RPM)

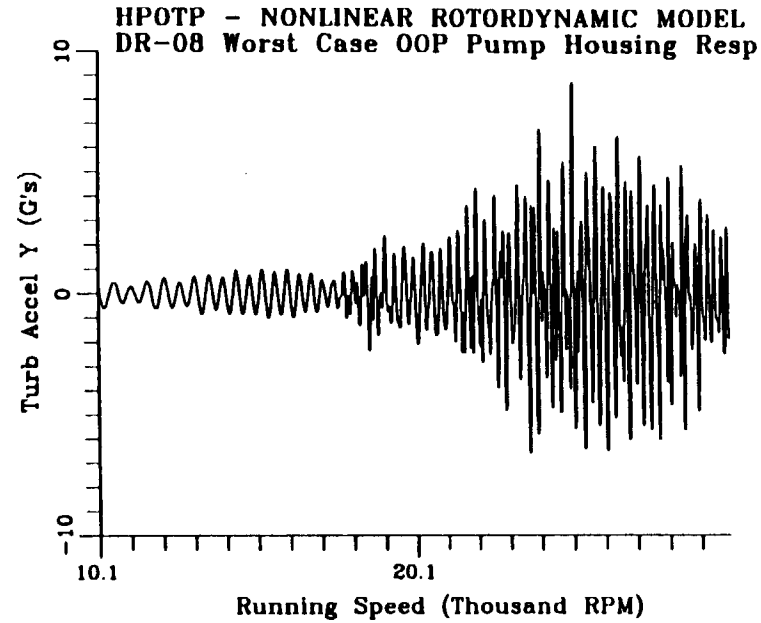

HPOTP - NONLINEAR ROTORDYNAMIC MODEL
DR-08 Worst Case OOP Pump Housing Resp
Turbine end Bearing X-Z Defl
0.0020
0.0000
-0.0020
-10.1
20.1
Running Speed (Thousand RPM)

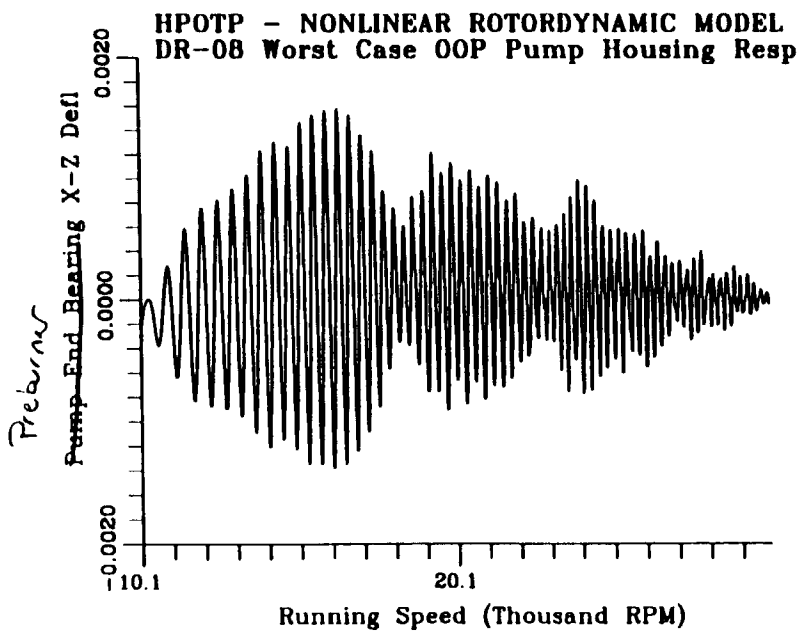

HPOTP - NONLINEAR ROTORDYNAMIC MODEL
DR-08 Worst Case OOP Pump Housing Resp
Turbine end Bearing Y-Z Defl
0.0020
0.0000
-0.0020
-0.0040
-10.1
20.1
Running Speed (Thousand RPM)

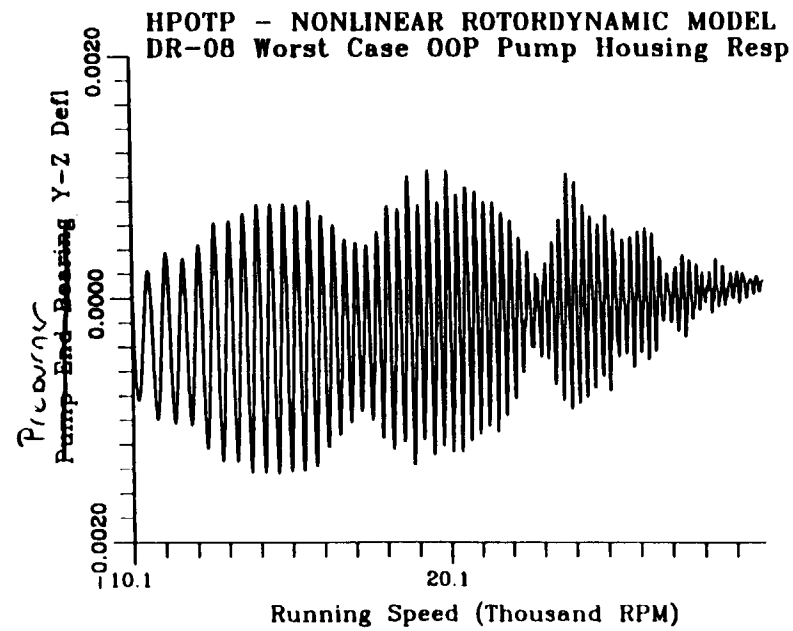

HPOTP - NONLINEAR ROTORDYNAMIC MODEL
DR-08 Worst Case OOP Pump Housing Resp
Damper Seal X-Z Defl
0.0020
0.0000
-0.0020
1.3
-10.1
20.1
Running Speed (Thousand RPM)

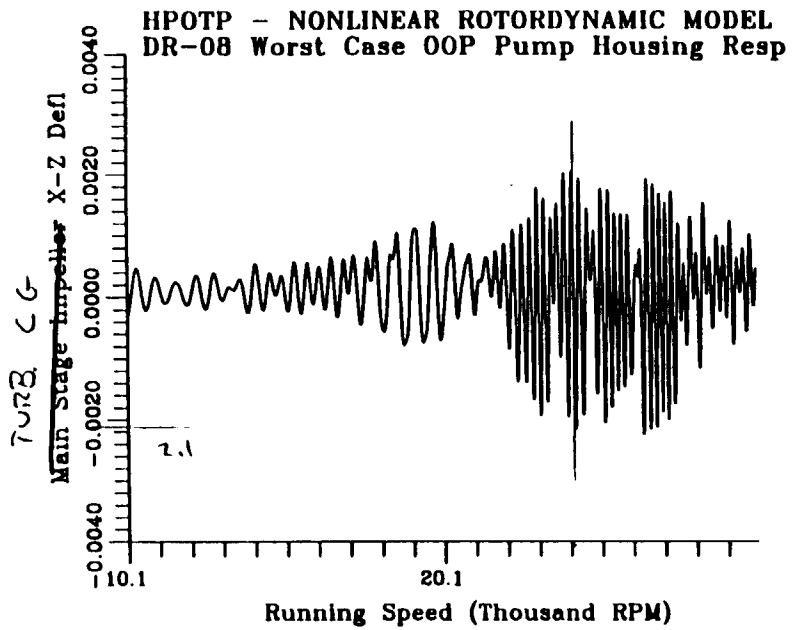

HPOTP - NONLINEAR ROTORDYNAMIC MODEL
DR-08 Worst Case OOP Pump Housing Resp
Damper Seal Y-Z Defl
0.0020
0.0000
-0.0020
1.3
-10.1
20.1
Running Speed (Thousand RPM)

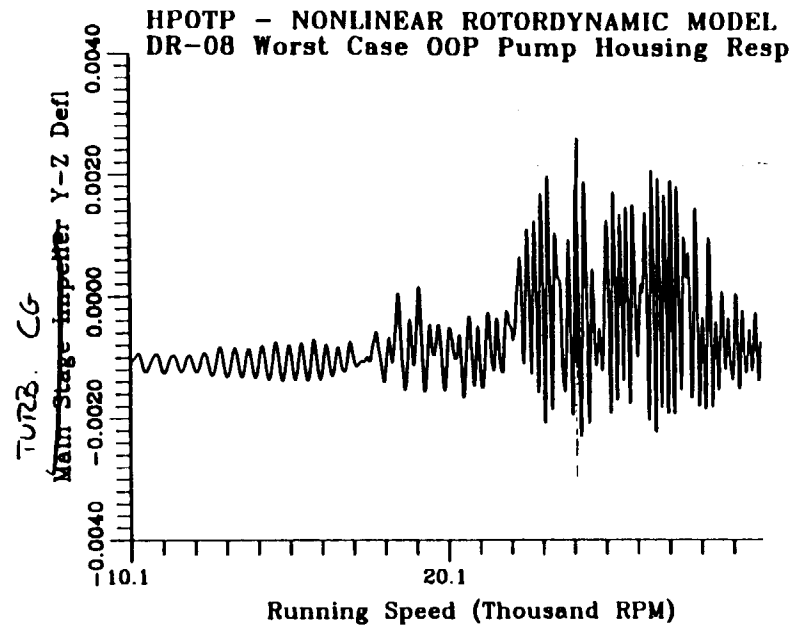

HPOTP - NONLINEAR ROTORDYNAMIC MODEL
DR-08 Worst Case OOP Pump Housing Resp
Pump Accel Y (G's)
20
10
0
-10
10.1
20.1
Running Speed (Thousand RPM)

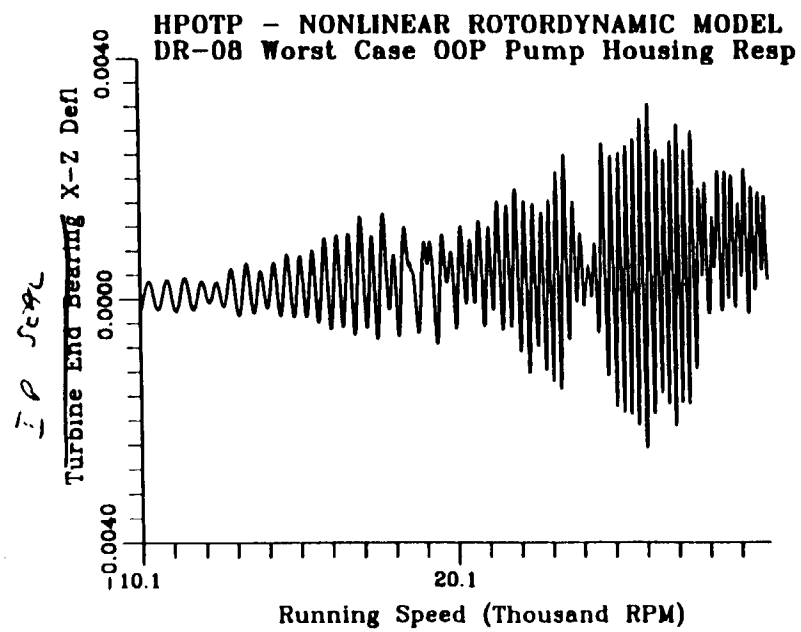

HPOTP - NONLINEAR ROTORDYNAMIC MODEL
DR-08 Worst Case OOP Pump Housing Resp
Turb Accel Y (G's)
10
0
-10
10.1
20.1
Running Speed (Thousand RPM)

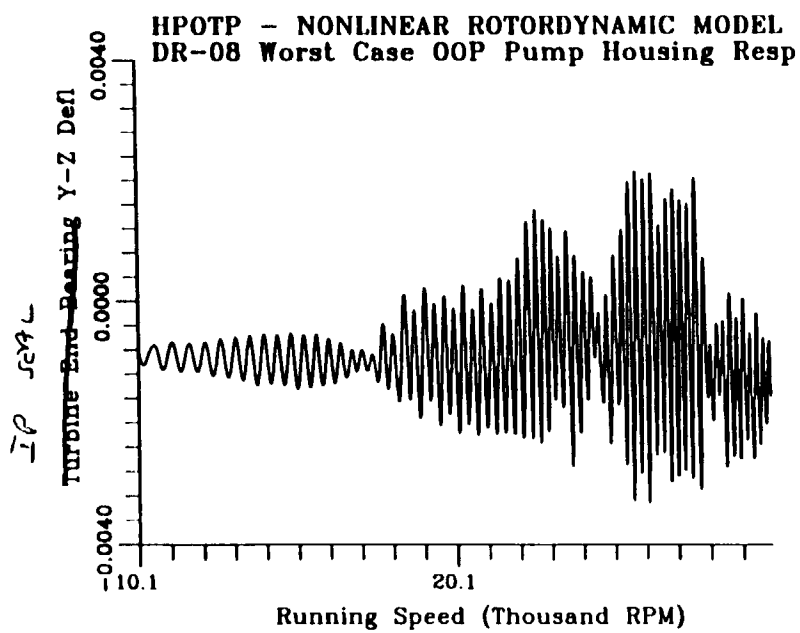

HPOTP - NONLINEAR ROTORDYNAMIC MODEL
DR-08 Worst Case OOP Pump Housing Resp
Pump End Bearing X-Z Defl
0.0020
0.0000
-0.0020
-10.1
20.1
Running Speed (Thousand RPM)


HPOTP - NONLINEAR ROTORDYNAMIC MODEL
DR-08 Worst Case OOP Pump Housing Resp
Pump End Bearing Y-Z Defl
0.0020
0.0000
-0.0020
-10.1
20.1
Running Speed (Thousand RPM)


HPOTP - NONLINEAR ROTORDYNAMIC MODEL
DR-08 Worst Case OOP Pump Housing Resp
TURB CG
Main Stage Impeller X-Z Defl
0.0040
0.0020
0.0000
-0.0020
-0.0040
-10.1
20.1
Running Speed (Thousand RPM)


HPOTP - NONLINEAR ROTORDYNAMIC MODEL
DR-08 Worst Case OOP Pump Housing Resp
TURB CG
Main Stage Impeller Y-Z Defl
0.0040
0.0020
0.0000
-0.0020
-0.0040
-10.1
20.1
Running Speed (Thousand RPM)


HPOTP - NONLINEAR ROTORDYNAMIC MODEL
DR-08 Worst Case OOP Pump Housing Resp
IP SEAL
Turbine End Bearing X-Z Defl
0.0040
0.0000
-0.0040
-10.1
20.1
Running Speed (Thousand RPM)


HPOTP - NONLINEAR ROTORDYNAMIC MODEL
DR-08 Worst Case OOP Pump Housing Resp
IP SEAL
Turbine End Bearing Y-Z Defl
0.0040
0.0000
-0.0040
-10.1
20.1
Running Speed (Thousand RPM)