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Part V

ROTOR-BEARING DYNAMICS DESIGN TECHNOLOGY

Part V : Computer Program Manual for Rotor Response and Stability

J. W. Lund

Mechanical Technology Incorporated

TECHNICAL REPORT AFAPL-TR-65-45, PART V

May 1965

Air Force Aero Propulsion Laboratory
Research and Technology Division
Air Force Systems Command
Wright-Patterson Air Force Base, Ohio

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FOREWORD

This report was prepared by Mechanical Technology Incorporated, 968 Albany-Shaker Road, Latham, New York 12110 under USAF Contract No. AF 33(615)-1895. The contract was initiated under Project No. 3145, "Dynamic Energy Conversion Technology" Task No. 314511, "Nuclear Mechanical Power Units." The work was administered under the direction of the Air Force Aero Propulsion Laboratory, Research and Technology Division, with Mr. John L. Morris (AFPL) acting as project engineer.

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This technical report has been reviewed and is approved.

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ABSTRACT

This report is a manual for using the two computer programs:

1. "Unbalance Response of a Rotor in Fluid Film Bearings"
2. "The Stability of a Rotor in Fluid Film Bearings"

The report gives the analysis on which the programs are based, and the instructions for preparing the computer input and for interpreting the computer output.

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SYMBOLS

A	Cross sectional area of shaft, in^2
a, b	Major and minor axis of ellipse, in (or: lbs, lbs.in)
a_n, b_n, c_n, d_n	Influence coefficients for shaft section, see Eqs.(4) to (7)
C	Radial bearing clearance, inch
$C_{xz}, C_{xy}, C_{yx}, C_{yy}$	Bearing damping coefficient for translatory whirl, lbs.sec/in
$D_{xz}, D_{xy}, D_{yx}, D_{yy}$	Bearing damping coefficients for conical whirl, lbs.in.sec/radian
E	Youngs modulus, lbs.in^2
e	Rotor mass eccentricity, inch
F_x, F_y	x-and y-components of bearing reaction, lbs.
I	Cross-sectional moment of inertia of shaft, (I_n between stations n and $(n+1)$), in^4
I_p	Polar mass moment ₂ of inertia of a rotor mass, lbs.in.sec^2 (in input: lbs.in^2)
I_T	Transverse mass moment of inertia of a rotor mass, lbs.in.sec^2 (in input: lbs.in^2)
$K_{xz}, K_{xy}, K_{yx}, K_{yy}$	Bearing spring coefficients for translatory whirl, lbs/in.
K_r	Rotor stiffness, lbs/in
L_n	Length of shaft section between station n and $(n+1)$, inch
L	Bearing length, inch
l	Rotor length, inch
M	Bending moment (M_n to the left, M'_n to the right of station n), lbs.in.
M_x, M_y	x and y-components of pedestal mass, $\text{lbs.sec}^2/\text{in}$ (in input: lbs).
M_T	Total rotor mass, $\text{lbs.sec}^2/\text{in}$
$M_{xz}, M_{xy}, M_{yx}, M_{yy}$	Bearing spring coefficients for conical whirl, lbs.in/radian
m_n	Mass at rotor station n , $\text{lbs.sec}^2/\text{in}$ (in input: lbs)
P_x, P_y	x and y-components for force transmitted to base, lbs.

t	Time, seconds
U_x, U_y	Cosine and sine-components of unbalance, lbs. sec^2 (in input: oz.in.)
V	Shear force (V_n to the right of station n), lbs.
W	Bearing reaction, lbs.
x, y	Components of the rotor amplitude, inch (in output: mils)
z	Coordinate along length of rotor, inch.
α	Phase angle between amplitude radius vector and unbalance see Fig. 5, radians
β	Angle between major axis and x-axis, see Fig. 5, radians
δ_x, δ_y	Pedestal damping coefficients for conical whirl, lbs.in. sec/rad .
θ, ϕ	$= \frac{dx}{dz}, \frac{dy}{dz}$, components of the slope of the deflected rotor, rad.
k_x, k_y	Pedestal spring coefficients, lbs/in.
c_x, c_y	Pedestal damping coefficients, lbs. sec/in.
ω	Angular speed of rotor, radians/sec.
ω_n	Critical rotor speed, radians/sec.

Subscripts and Superscripts

x	in x-direction
y	in y-direction
xx, xy, yx, yy	first index gives force direction, second index gives amplitude direction.
c	cosine component
s	sine component
n	applies to station n
p	pedestal
$()'$	relative between journal and pedestal

INTRODUCTION

A rotor supported in fluid film journal bearings is a complex dynamical system which exhibits a variety of physical characteristics: critical speeds, instability, unbalance vibrations, etc. In designing a rotor-bearing system for a given application it is necessary to have methods available from which these performance characteristics of the system can be predicted and thereby ensure that the design is adequate for the specified operational conditions. It is the purpose of the present report to describe two computer programs by which a particular rotor-bearing system can be investigated. The first program: "Unbalance Response of a Rotor in Fluid Film Bearings" calculates the whirl amplitudes induced by a specified unbalance. The second program: "The Stability of a Rotor in Fluid Film Bearings", calculates the threshold of instability for the rotor-bearing system.

In the dynamics of a rotor-bearing system the fluid film journal bearings play a very important role. They are normally the predominant source of damping such that without this source it would be impossible to run the rotor through any of its critical speeds. Secondly, the bearing film is flexible and therefore it may lower the critical speeds drastically. The film flexibility also causes the bearing to act as a vibration isolator, attenuating the dynamical forces transmitted to the pedestals. Finally, if the speed gets sufficiently high the bearing film loses its ability to dampen out any transient motion of the rotor and transfers instead energy from the rotation of the rotor into a whirling motion of the rotor mass. This is called fractional frequency whirl ("oil whip") and is a self-excited instability of the rotor bearing system. The speed at the onset of the instability is called the threshold speed and as the rotor speed is increased beyond the threshold speed the whirl amplitude increases rapidly, preventing further operation of the machine. It is, therefore, necessary at the design stage to ensure that the selected rotor-bearing system does not experience instability in the operating speed range. Likewise, it is also desirable to evaluate the magnitude of the rotor amplitude due to a residual unbalance such that too large amplitudes will not be encountered in the actual machine. The two computer programs described in the present report provide a method for performing these calculations.

The unbalance response program is very general. It calculates the rotor whirl amplitude and the force transmitted to the base due to a given rotor unbalance. The rotor is flexible and may have any arbitrary geometry. Also, there can be splined couplings in the rotor and several bearings. The bearing pedestals can be assigned both flexibility and damping. Since the bearing film forces are not the same in all directions the whirl motion of the rotor is treated as two-dimensional such that it becomes an orbit around the equilibrium position. The orbit is elliptical and its dimensions and orientation vary along the length of the rotor. The computer program calculates the whirl orbits for a number of points along the rotor and gives also the components of the force transmitted to the foundations.

The program for investigating the stability of the rotor-bearing system applies to an arbitrary rotor geometry. There may be several bearings and the stiffness and damping of the bearing pedestals can be included. The program calculates the speed at onset of instability (the threshold speed) and the corresponding whirl frequency.

In both programs, the dynamic properties of a fluid film bearing are expressed in terms of 8 coefficients: 4 spring coefficients and 4 damping coefficients. The coefficients depend on the bearing type, the bearing dimensions, the viscosity of the lubricant, the bearing load and the rotor speed. The values of the coefficients are given in a previous report (Ref. 6) for a wide variety of bearing types, geometries and operating conditions.

The report sets forth the analyses on which the computer programs are based. Detailed instructions are given for preparing the computer input and for interpreting the output.

DISCUSSION

a. General

The computer programs determine the interaction between the bearings and the rotor. The unbalance response program is concerned with the synchronous amplitude of the system under the action of unbalance forces and the stability program is concerned with the free, self-excited motion at the onset of hydrodynamic instability ("oil whip"). Whereas the dynamic properties of the bearings derive from lubrication theory (Ref. 4), the analysis of the rotor itself derives in its principle from the Myklestad-Prohl method (Refs. 1, 2, 3). However, in its original form, the Myklestad-Prohl method is set up only for calculating the critical speeds of the rotor and is further limited to plane vibrations. In the present analysis the motion is treated as two-dimensional, damping is included in the bearings in addition to stiffness and the analysis is valid for any speed, not just the critical speed.

In general a rotor's cross-sectional dimensions and its mass distribution varies along the length of the rotor. Thus, for calculation purposes it is convenient to break the rotor up into short sections, each section having a constant cross-section. Furthermore, when there are many sections, the mass of each section can be divided into two parts and lumped at the end points of the section. Concentrated masses like wheels, impellers, etc., can be made to coincide with an end point of a section. In this way the rotor is replaced by an idealized model consisting of a number of mass points connected by weightless, flexible bars. The model can be brought as close to the actual rotor as desired by making the subdivisions small but in practice only a limited number of divisions is needed to obtain a very good accuracy.

Since the bearing film properties to a large extent control the whirl motion and the stability of the rotor, it is necessary to represent the dynamical bearing film forces as accurately as possible. The method of representation is based on the assumption that the whirl amplitude is small compared to the bearing clearance such that the dynamical forces can be replaced by their gradients around the steady state journal center position. In this way the dynamical

forces become proportional to the whirl amplitude and to the corresponding velocity, and the factors of proportionality are called spring and damping coefficients. They differ from conventional mechanical spring-dashpot systems by also containing cross-coupling terms in addition to direct-coupling terms, i.e., the dynamical force in a given direction (say the x-direction) is not only proportional to the amplitude and velocity components in that direction but is also proportional to the amplitude and velocity components in the mutually perpendicular direction (i.e., the y-direction). Hence, in an arbitrary reference coordinate system with x and y-axes the two dynamical force components can be expressed by:

$$F_x = -K_{xx}x - C_{xx}\dot{x} - K_{xy}y - C_{xy}\dot{y}$$

$$F_y = -K_{yx}x - C_{yx}\dot{x} - K_{yy}y - C_{yy}\dot{y}$$

where x and y are the amplitude components, $\dot{x}$ and $\dot{y}$ are the velocity components K_{xx} and K_{yy} are the direct coupling spring coefficients, C_{xx} and C_{yy} are the direct-coupling damping coefficients, K_{xy} and K_{yx} are the cross-coupling spring coefficients, and C_{xy} and C_{yx} are the cross-coupling damping coefficients. These 8 coefficients are functions of the bearing Sommerfeld number defined through the rotor speed, the steady state bearing reactions, the lubricant viscosity and the bearing dimensions (for gas bearings the coefficients are functions of the compressibility number, the bearing eccentricity ratio and the whirl frequency). Thus, the coefficients vary with speed. A method for calculating the coefficients is given in Refs. 4 and 5 and values of the coefficients for several bearing types may be found in Ref. 6.

Frequently the pedestals, on which the bearings are mounted, are as flexible as the bearing film. In such cases, the pedestal stiffness must be included in the calculations. For completeness the analysis allows for both stiffness, damping and inertia in the pedestals. Furthermore, as the rotor bends under the influence of the unbalance forces, the journals become cocked in their bearings. The fluid film resists the tilting and this can be expressed by a set of 8 spring and damping coefficients in analogy to the previously discussed coefficients. The unbalance response analysis includes this effect, both in the bearings and in the pedestals. The resistance to tilt normally affects the rotor motion only at speeds above the second or third critical speed but if the pedestals are made

soft for alignment purposes resonance conditions may exist which can only be explored if the effect of tilt is included. For the stability analysis this effect is in almost all cases very small and it has been ignored.

Occasionally the rotor is not a single member but consists of several rotors connected by splined couplings (e.g., a turbine-generator set connected by a splined coupling). The unbalance response program allows for including splined couplings anywhere in the rotor and assumes that no bending moment is transferred through the coupling. This feature is not included in the stability program.

In the unbalance response program the whirling motion of the rotor is generated by unbalances built into the rotor. In general the unbalance varies in magnitude and circumferential location along the rotor such that under speed the unbalance forces may bend the rotor into complicated shapes (e.g., resembling a "cork-screw"). The bend rotor whirls around its steady state position (i.e., the position the rotor would occupy if there were no unbalance forces) with each point of the rotor axis describing an elliptical path. The dimensions and orientation of the ellipse varies along the length of the rotor.

If the rotor runs at high speed and has large disks (e.g., turbine wheels, etc.) mounted on the shaft the gyroscopic moment becomes important, especially if a wheel is overhung at one end of the rotor. The gyroscopic moment is proportional to the mass-moment of inertia of the wheel, the square of the speed and the deflection angle of the rotor. If the rotor motion is considered as a transverse vibration of a beam (i.e., the whirl orbit is a straight line) the gyroscopic moment tends to "soften" the rotor and lower the critical speed. On the other hand, if the bearing spring and damping coefficients are the same in the vertical and the horizontal direction the rotor whirl orbit becomes a circle and the gyroscopic moment stiffens the rotor. Actually, the whirl orbit is elliptical, i.e., somewhere between a straight line and a circle, and the effect of the gyroscopic moment can only be assessed by performing the complete rotor analysis. It is a non-linear effect since it depends on the dimensions of the elliptical whirl orbit. In the present analysis the gyroscopic moment is taken into account in the unbalance response program and is calculated by an iteration procedure.

b. Special Considerations in Performing the Numerical Calculations

The greatest difficulty encountered in performing the numerical calculations is the magnitude of the numbers and the loss of significant figures. These difficulties become pronounced when: a) there is an excessive number of rotor mass stations, b) the rotor is very stiff and, c) the bearings are very stiff. There is no universal remedy for the problem but if trouble arises two possibilities may be tried: a) reduce the number of rotor stations to the essential minimum and, b) apply a scale factor.

Let the scale factor be α . Then:

multiply the speed by α .

multiply (EI) by α^2 (e.g., multiply E by α^2)

multiply the bearing spring and damping coefficients by α^2

(i.e., multiply K_{xx} , ωC_{xx} , M_{xx} , ωD_{xx} etc. by α^2)

multiply the pedestal stiffness by α^2 and the pedestal damping coefficients by α .

(i.e., multiply $\mathcal{K}_x$ and $\mathcal{K}_y$ by α^2 , $\mathcal{C}_x$ and $\mathcal{C}_y$ by α)

leave the rotor masses, the rotor length, the pedestal masses and the unbalance unchanged.

The numerical results will give the amplitude unchanged whereas the bending moment and the transmitted force must be divided by α^2 to obtain the actual values.

c. Analysis and Dimensionless Equations

Referring to the sign convention given in Fig. 2 and considering first a continuous rotor the three basic equations for determining the rotor motion are:

(1-a) Force balance for a shaft increment, dz : $\frac{dV}{dz} = \rho A \omega^2 (x+a)$

(2-a) Moment balance for a shaft increment, dz : $\frac{dM}{dz} = V + \omega^2 (I_T - I_T) \frac{dz}{dz}$

(3-a) Shaft deflection: $M = EI \frac{d^2x}{dz^2}$

where:

x - amplitude in vertical direction, inch

y - amplitude in horizontal direction, inch

- z - coordinate along the rotor length, inch
- a - eccentricity between mass center and shaft center, inch
- A - cross-sectional area of shaft, in^2
- I - cross-section moment of inertia, in^4
- E - Youngs modulus, lbs/in^2
- ρ - mass density, $\text{lbs}\cdot\text{sec}^2/\text{in}^4$
- $(i_p - i_T)$ - mass moment of inertia per unit length, which is effective in gyroscopic moment, $\text{lbs}\cdot\text{sec}^2$
- ω - angular speed, radians/sec
- M - bending moment, $\text{lbs}\cdot\text{in}$
- V - shear force, lbs .

For the stability analysis set $a = 0$ and redefine ω to mean the whirl frequency. These three equations may be combined to give the familiar 4th-order differential equation governing the unbalance vibrations of a rotor:

$$(4-a) \quad \frac{d^2}{dz^2} (EI \frac{d^2 x}{dz^2}) = \rho A \omega^2 (x+a) + \omega^2 \frac{d}{dz} [(i_p - i_T) \frac{dx}{dz}]$$

and the same for the y -direction.
(see Ref. 3, page 330)

For a circular whirl orbit:

$$(i_p - i_T) = \rho I$$

For a straight line orbit:

$$(i_p - i_T) = -\rho I$$

For an elliptical whirl orbit, see Eq. (28) and (29) in this report.

At the bearings there is an abrupt change in the shear force and the bending moment due to the bearing reactions. Let the bearing be at $z = z_0$. Then:

$$(5-a) \quad V_{z=z_0^+} - V_{z=z_0^-} = -(K_{xx} + i\omega C_{xx})x - (K_{xy} + i\omega C_{xy})y$$

$$(6-a) \quad M_{z=z_0^+} - M_{z=z_0^-} = (M_{xx} + i\omega D_{xx})x + (M_{xy} + i\omega D_{xy})y$$

where K_{xx} , C_{xx} , M_{xx} , D_{xx} etc., are the bearing spring and damping coefficients. Actually, the effect of the pedestal should be included in the above equations as shown in Eq. (12) and (13) in the analysis.

The numerical method uses Eqs. (1-a), (2-a) and (3-a) by rewriting them into finite difference form:

$$\Delta V = \omega^2 (g A \Delta z) (x + a)$$

$$\Delta M = V \Delta z + \omega^2 [(i_p - i_T) \Delta z] \left(\frac{dx}{dz} \right)$$

$$\Delta \left(\frac{dx}{dz} \right) = \int_z^{z+\Delta z} \frac{M}{EI} dz$$

$$\Delta x = \left(\frac{dx}{dz} \right) \Delta z + \int_z^{z+\Delta z} \int_z^{z+\Delta z} \frac{M}{EI} dz dz$$

Together with Eqs. (5-a) and (6-a) these equations form a set of recurrence relationships which can be solved step by step, starting from one end of the rotor until reaching the other end. The details are given later.

Occasionally it is desired to perform a dimensionless analysis. The two governing quantities are:

$$(7-a) \quad \omega_n^2 = \frac{(EI)_0}{l^3 M_T} = \frac{K_r}{M_T}$$

$$(8-a) \quad K_r = \frac{(EI)_0}{l^3}$$

where:

- (EI) - reference value of EI, lbs.in²
- l - rotor span between bearings, inch
- M_T - $\int_0^l \rho A dz$, total rotor mass, lbs.sec²/in
- K_r - rotor stiffness, lbs/in
- ω_n - equal to or proportional to a critical rotor speed, rad/sec.

For a uniform shaft ($EI = \text{constant}$, $A = \text{Constant}$):

$$\omega_n^2 = \frac{\pi^4}{4} \frac{EI}{l^3 M_T} = \frac{(\frac{1}{4}\pi^4 EI)}{l^3 M_T}$$

where n designates the order of the critical speed. Thus, for the first mode:
 $n = 1$ i.e.,

$$(EI)_0 = \frac{\pi^2 h^4}{4} EI = 2.4674 \cdot EI \quad (\text{Uniform shaft, first mode})$$

However, it is not necessary that ω_n be a critical speed but Eq. (7-a) must be satisfied.

The dimensionless parameters become:

$$\begin{aligned} x' &= x/a_0 \\ z' &= z/\ell \\ (EI)' &= EI/(EI)_0 \\ V' &= V/a_0 k_r \\ M' &= M/a_0 k_r \ell \\ K'_{xx} &= K_{xx}/K_r = \left(\frac{W_0}{C_0 k_r}\right) \left(\frac{C_0 W}{C W_0}\right) \left(\frac{C K_{xx}}{W}\right) \\ (\omega C_{xx})' &= \omega C_{xx}/K_r = \left(\frac{W_0}{C_0 k_r}\right) \left(\frac{C_0 W}{C W_0}\right) \left(\frac{C \omega C_{xx}}{W}\right) \\ M'_{xx} &= M_{xx}/K_r \ell^2 = \left(\frac{W_0}{C_0 k_r}\right) \left(\frac{C_0 W}{C W_0}\right) \left(\frac{\ell}{\ell}\right)^2 \left(\frac{C M_{xx}}{W \ell^2}\right) \\ (\rho A)' &= \rho A/M_T \\ (i_p - i_T)' &= (i_p - i_T)/M_T \ell \end{aligned}$$

where:

- a_0 - reference value for the rotor mass eccentricity, inch
- C_0 - reference value for the radial bearing clearance, inch
- C - actual radial bearing clearance, inch
- W_0 - reference value for the bearing reaction, lbs.
- W - actual bearing reaction, lbs.
- L - bearing length, inch

The dimensionless bearing coefficients are given the form above since the values obtained from lubrication theory are CK_{xx}/W , $C\omega C_{xx}/W$, etc. Normally, a dimensionless analysis is only performed for a simple system where all bearings are identical, i.e. $C = C_0$ and $W = W_0$. In that case the basic dimensionless parameters are:

$$\begin{aligned} \text{speed ratio: } & \left(\frac{\omega}{\omega_n}\right) \\ \text{dimensionless rotor stiffness: } & K'_r = CK_r/W \\ \text{dimensionless bearing coefficients: } & CK_{xx}/W, C\omega C_{xx}/W, \left(\frac{\ell}{\ell}\right)^2 (CM_{xx}/WL^2) \text{ etc.} \end{aligned}$$

Thus, to perform a dimensionless calculation for a given value of K'_r , use as input to the unbalance response computer program:

$$\text{Speed} = \left(\frac{\omega}{\omega_n} \right) / .10471976$$

$$\text{Mass at station } i = \frac{m_i}{\sum_{j=1}^n m_j} 3.86069 \cdot 10^5 \quad (m = \text{station weight, lbs;} \\ n = \text{number of stations})$$

$$(I_P - I_T) \text{ at station } i = \frac{(I_P - I_T)}{M_T l^2} 3.86069 \cdot 10^5$$

Cross-sectional moment of inertia for section $i-(i+1)$: $1000 \cdot I / I_0$

Young modulus = 1

Length of section $i-(i+1) = l_i / l$

$$\text{Bearing spring coefficient} = \frac{1}{K'_r} \left(\frac{CK_{XX}}{W} \right)$$

$$\text{Bearing damping coefficient} = \frac{1}{K'_r} \left(\frac{CwC_{XX}}{W} \right)$$

$$\text{Unbalance such that: } \sum_{i=1}^n U_x (\text{oz.in}) = 6177.1 \quad \sum_{i=1}^n U_y (\text{oz.in}) = 6177.1$$

Then the computer output will give:

$$\text{amplitude} = \frac{x}{a_0} \quad \text{and} \quad \frac{y}{a_0}$$

$$\text{bending moment} = M' = M / a_0 K'_r l = M / \frac{a_0}{C} W l K'_r$$

$$\text{transmitted force} = (\text{actual force}) / a_0 K'_r = (\text{actual force}) / \frac{a_0}{C} W K'_r$$

COMPUTER PROGRAM: UNBALANCE RESPONSE OF A ROTOR IN FLUID FILM BEARINGS

This section of the report describes the basic analysis and the detailed instructions for using the computer program: PN0011: "Unbalance Response of a Rotor in Fluid Film Journal Bearings" for the IBM 704 digital computer. The program calculates the rotor deflection and bending moment, the pedestal deflection and the transmitted force resulting from a specified rotor unbalance. It differs from conventional programs by taking into account the variation of support flexibility and damping along the whirl path of the rotor.

The supports for the rotor consist of a fluid film bearing on a pedestal, both members possessing flexibility and damping for translatory and rotational motion. The flexibility and damping are linear in displacement and velocity respectively, the proportionality factors denoted as spring and damping coefficients. The fluid film is represented by 4 spring coefficients and 4 damping coefficients for translatory motion and similarly for rotational motion, thus allowing for coupling between the motion in two mutually perpendicular directions. The pedestal has no such coupling and is represented by 2 spring and 2 damping coefficients for both translatory and rotational motion with corresponding pedestal mass and mass moment of inertia. Hence, each point of the rotor will whirl in an elliptic path around its steady state position.

In addition, the program includes the effect of gyroscopic moment and provides for couplings in the rotor.

THEORETICAL ANALYSIS

The analysis is an extension of the Myklestad-Prohl method, see Ref. 1, 2 and 3. The rotor, which is actually a continuous system with an infinite number of degrees of freedom, is replaced by a finite number of lumped masses connected by weightless springs. The computer program calculates the vibrational response of this equivalent system exactly.

Thus the accuracy of the results depends only on how closely the idealized system resembles the actual rotor.

Starting from the left end of the rotor, the program calculates step by step the bending moment, shear force, slope and deflection along the rotor. Neglecting the shear force contribution to the deflection, we get from Fig. 1:

$$(1) \quad M_{n+1} = M'_n + L_n V_n$$

$$(2) \quad \theta_{n+1} = \theta_n + a_n M'_n + b_n V_n$$

$$(3) \quad X_{n+1} = X_n + L_n \theta_n + c_n M'_n + d_n V_n$$

where:

$$(4) \quad a_n = \int_0^{L_n} \frac{d\xi}{EI} = \frac{L_n}{EI} \quad \text{for EI constant in } 0 \leq \xi \leq L_n$$

$$(5) \quad b_n = \int_0^{L_n} \frac{\xi d\xi}{EI} = \frac{L_n^2}{2EI} \quad \text{" "}$$

$$(6) \quad c_n = L_n a_n - b_n = \frac{L_n^2}{2EI} \quad \text{" "}$$

$$(7) \quad d_n = L_n b_n - \int_0^{L_n} \frac{\xi^2 d\xi}{EI} = \frac{L_n^3}{6EI} \quad \text{" "}$$

The program assumes EI constant between mass points. At the mass points, the forces acting on the rotor are introduced. Four contributions exist: (1) inertia force, (2) unbalance forces, (3) bearing reaction, and (4) gyroscopic moment. In general, not all 4 contributions apply to each mass point.

Inertia force. The rotor performs harmonic vibrations at the same frequency as the rotational speed. Thus the inertia force is:

$$(8) \quad -m \frac{\partial^2 x}{\partial t^2} = m\omega^2 x$$

$$(9) \quad -m \frac{\partial^2 y}{\partial t^2} = m\omega^2 y$$

Unbalance forces. To allow for change in circumferential position of the unbalance along the rotor, the unbalance is given two components U_x and U_y . This gives rise to an x and y component of the unbalance force:

$$(10) \quad (V_{xn} - V_{x,n+1})_{unb.} = \omega^2 U_x \cos \omega t - \omega^2 U_y \sin \omega t$$

$$(11) \quad (V_{yn} - V_{y,n+1})_{unb.} = \omega^2 U_y \cos \omega t + \omega^2 U_x \sin \omega t$$

Bearing reaction. The bearing supports have flexibility and damping for both translatory and rotational motion of the rotor. Since the equations for the two types of motion are analogous, only the equations for translatory motion will be derived.

The bearing support is shown in Fig. 3. It consists of a pedestal with mass (M_{ax}, M_{ay}) , supported by springs (K_x, K_y) and dashpots (C_x, C_y) . There is no coupling between the x and y direction, i.e. no transfer impedance, nor between the translatory and rotational motion. The pedestal supports the bearing fluid film which is represented by 4 springs and 4 damping coefficients. If the relative motion between the journal center and the bearing housing is denoted (x', y') , then the bearing reaction becomes:

$$(12) \quad \begin{aligned} (V_{xn} - V_{x,n+1})_{bearing} &= -K_{xx}x' - C_{xx}\dot{x}' - K_{xy}y' - C_{xy}\dot{y}' \\ (V_{yn} - V_{y,n+1})_{bearing} &= -K_{yx}x' - C_{yx}\dot{x}' - K_{yy}y' - C_{yy}\dot{y}' \end{aligned}$$

Setting:

$$x' = x'_c \cos \omega t + x'_s \sin \omega t$$

$$y' = y'_c \cos \omega t + y'_s \sin \omega t.$$

we get from Newton's second law for the pedestal mass:

$$\begin{aligned}
& (K_{xx} + \lambda_x - \omega^2 M_{ox}) X'_c + \omega (C_{xx} + \delta_x) X'_s + K_{xy} y'_c + \omega C_{xy} y'_s = (\lambda_x - \omega^2 M_{ox}) X_c + \omega \delta_x X_s \\
(13) \quad & -\omega (C_{xx} + \delta_x) X'_c + (K_{xx} + \lambda_x - \omega^2 M_{ox}) X'_s - \omega C_{xy} y'_c + K_{xy} y'_s = -\omega \delta_x X_c + (\lambda_x - \omega^2 M_{ox}) X_s \\
& K_{yx} X'_c + \omega C_{yx} X'_s + (K_{yy} + \lambda_y - \omega^2 M_{oy}) y'_c + \omega (C_{yy} + \delta_y) y'_s = (\lambda_y - \omega^2 M_{oy}) y_c + \omega \delta_y y_s \\
& -\omega C_{yx} X'_c + K_{yx} X'_s - \omega (C_{yy} + \delta_y) y'_c + (K_{yy} + \lambda_y - \omega^2 M_{oy}) y'_s = -\omega \delta_y y_c + (\lambda_y - \omega^2 M_{oy}) y_s
\end{aligned}$$

Solving the equations we obtain:

$$\begin{aligned}
(V_{xm} - V_{x,n-1})_{bearing} &= (-\Delta V_{ax} X_c - \Delta V_{bx} X_s - \Delta V_{cx} y_c - \Delta V_{dx} y_s) \cos \omega t \\
(14) \quad & + (\Delta V_{bx} X_c - \Delta V_{ax} X_s + \Delta V_{cx} y_c - \Delta V_{dx} y_s) \sin \omega t \\
(V_{ym} - V_{y,n-1})_{bearing} &= (-\Delta V_{cy} X_c - \Delta V_{dy} X_s - \Delta V_{ay} y_c - \Delta V_{by} y_s) \cos \omega t \\
& + (\Delta V_{dy} X_c - \Delta V_{cy} X_s + \Delta V_{ay} y_c - \Delta V_{by} y_s) \sin \omega t
\end{aligned}$$

where:

$$\begin{aligned}
\Delta V_{ax} &= K_{xx} f + \omega C_{xx} g + K_{xy} g + \omega C_{xy} r \\
\Delta V_{bx} &= -K_{xx} g + \omega C_{xx} f - K_{xy} r + \omega C_{xy} g \\
\Delta V_{cx} &= K_{xx} h + \omega C_{xx} i + K_{xy} s + \omega C_{xy} t \\
(15) \quad \Delta V_{dx} &= -K_{xx} i + \omega C_{xx} h - K_{xy} t + \omega C_{xy} s \\
\Delta V_{ay} &= K_{yx} h + \omega C_{yx} i + K_{yy} s + \omega C_{yy} t \\
\Delta V_{by} &= -K_{yx} i + \omega C_{yx} h - K_{yy} t + \omega C_{yy} s \\
\Delta V_{cy} &= K_{yx} f + \omega C_{yx} g + K_{yy} g + \omega C_{yy} r \\
\Delta V_{dy} &= -K_{yx} g + \omega C_{yx} f - K_{yy} r + \omega C_{yy} g
\end{aligned}$$

and:

$$f = \frac{GE + FD}{F^2 + G^2}$$

$$h = \frac{GJ + FH}{F^2 + G^2}$$

$$F = A - K_{xy}Q + \omega C_{xy}R$$

$$H = -K_{xy}S + \omega C_{xy}T$$

$$Q = \frac{K_{yx}a + \omega C_{yx}b}{a^2 + b^2}$$

$$S = \frac{ad + be}{a^2 + b^2}$$

$$A = K_{xx} + \delta_x - \omega^2 M_{xx}$$

$$D = \delta_x - \omega^2 M_{xx}$$

$$a = K_{yy} + \delta_y - \omega^2 M_{yy}$$

$$d = \delta_y - \omega^2 M_{yy}$$

$$g = -Qf - Rg$$

$$s = S - Qh - Ri$$

$$g = \frac{GD - FE}{F^2 + G^2}$$

$$i = \frac{GH - FJ}{F^2 + G^2}$$

$$G = B - K_{xy}R - \omega C_{xy}Q$$

$$J = -K_{xy}T - \omega C_{xy}S$$

$$R = \frac{\omega C_{yx}a - K_{yx}b}{a^2 + b^2}$$

$$T = \frac{ae - bd}{a^2 + b^2}$$

$$B = \omega (C_{xx} + \sigma_x)$$

$$E = \omega \sigma_x$$

$$b = \omega (C_{yy} + \sigma_y)$$

$$e = \omega \sigma_y$$

$$r = -Qg + Rf$$

$$t = -T - Qi + Rh$$

The equations for rotational motion are analogous to eq. (14) except for a sign reversal (sign convention, see Fig. 2):

$$(M'_{xx} - M_{xx})_{\text{bearing}} = (\Delta M_{xx}\theta_c + \Delta M_{xx}\theta_s + \Delta M_{cx}\phi_c + \Delta M_{cx}\phi_s) \cos \omega t \\ + (-\Delta M_{xx}\theta_c + \Delta M_{xx}\theta_s - \Delta M_{cx}\phi_c + \Delta M_{cx}\phi_s) \sin \omega t$$

(16)

$$(M'_{yy} - M_{yy})_{\text{bearing}} = (\Delta M_{yy}\theta_c + \Delta M_{yy}\theta_s + \Delta M_{cy}\phi_c + \Delta M_{cy}\phi_s) \cos \omega t \\ + (-\Delta M_{yy}\theta_c + \Delta M_{yy}\theta_s - \Delta M_{cy}\phi_c + \Delta M_{cy}\phi_s) \sin \omega t$$

where the coefficients $\Delta M_{ay}, \Delta M_{bx}$ etc. are computed from eq. (15) as $\Delta M_{ax} = \Delta V_{ax}$, $\Delta M_{bx} = \Delta V_{bx}$ etc. by replacing the translatory spring and damping coefficients by the corresponding rotational coefficients.

Since the fluid film coefficients are functions of speed, directly through the Sommerfeld number and indirectly through the decrease of eccentricity ratio with increasing speed, the computer program provides for expressing the coefficients as a function of speed, e.g.

$$(18) \quad K_{xx} = K_{xx,0} + K_{xx,1} \cdot \omega + K_{xx,2} \cdot \omega^2$$

and similarly for the other coefficients. ω is the rotor speed in radians/sec.

Gyroscopic Moment. The gyroscopic moment derives from the change of the angular momentum vector of the rotating rotor mass as it whirls in an elliptical path around the steady state position of the rotor. For two special cases the gyroscopic moment is known:

$$(19) \quad \text{circular whirl path: } M_{gyr.} = (I_p - I_r) \omega^2 \theta$$

$$\text{straight line (transverse vibrations): } M_{gyr.} = -I_r \omega^2 \theta$$

where θ is the slope of the rotor deflection and I_p and I_r are the polar and transverse mass moments of inertia. For an elliptical path the gyroscopic moment is no longer linear with respect to the slope of the rotor, indicating that an elliptical path is actually not possible. However, in general the effect of the gyroscopic moment is not too big and for the present analysis an elliptical path will be assumed.

The coordinate system is shown in Fig. 4, where O is the steady state shaft center position and O' is the whirling shaft center. The moving coordinate system (ξ, η, ζ) is defined by its unit vectors:

$$\begin{aligned}
\bar{e}_3 &= \left(\frac{\theta/\sqrt{\theta^2+\varphi^2}}{\sqrt{1+\theta^2+\varphi^2}}, \frac{\varphi/\sqrt{\theta^2+\varphi^2}}{\sqrt{1+\theta^2+\varphi^2}}, \frac{-\sqrt{\theta^2+\varphi^2}}{\sqrt{1+\theta^2+\varphi^2}} \right) \approx \left(\frac{\theta}{\sqrt{\theta^2+\varphi^2}}, \frac{\varphi}{\sqrt{\theta^2+\varphi^2}}, \sqrt{\theta^2+\varphi^2} \right) \\
(20) \quad \bar{e}_1 &= \left(\frac{-\varphi}{\sqrt{\theta^2+\varphi^2}}, \frac{\theta}{\sqrt{\theta^2+\varphi^2}}, 0 \right) \\
\bar{e}_2 &= \left(\frac{\theta}{\sqrt{1+\theta^2+\varphi^2}}, \frac{\varphi}{\sqrt{1+\theta^2+\varphi^2}}, \frac{1}{\sqrt{1+\theta^2+\varphi^2}} \right) \approx (\theta, \varphi, 1)
\end{aligned}$$

The angular velocity vector becomes:

$$(21) \quad \bar{\omega} = (\omega_3, \omega_1, \omega_2) = (\dot{e}_1 e_3, \dot{e}_2 e_3, \dot{e}_3 e_1) = \left(\frac{\dot{\theta}\varphi - \theta\dot{\varphi}}{\sqrt{\theta^2+\varphi^2}}, \frac{\theta\dot{\theta} + \varphi\dot{\varphi}}{\sqrt{\theta^2+\varphi^2}}, -\frac{(\dot{\theta}\varphi - \theta\dot{\varphi})}{\theta^2+\varphi^2} \right)$$

The moment needed to sustain the motion is given by Eulers equations:

$$\begin{aligned}
M_3 &= I_T \dot{\omega}_3 + (I_p - I_T) \omega_1 \omega_2 \\
(22) \quad M_1 &= I_T \dot{\omega}_1 + (I_p - I_T) \omega_2 \omega_3 \\
M_2 &= I_p \dot{\omega}_2
\end{aligned}$$

where I denotes mass moment of inertia and $I_3 = I_T$, $I_1 = I_T$ and $I_2 = I_p$.

Let us first assume that (x, y) corresponds to the directions of the major and minor axis in the elliptical variation of the rotor slope. Then:

$$\begin{aligned}
\theta_1 &= E \cos(\omega t + \alpha) \\
(23) \quad \varphi_1 &= G \sin(\omega t + \alpha)
\end{aligned}$$

Combining eq. (20), (21) and (22):

$$\begin{aligned}
(24) \quad -M_x &= -I_T \omega^2 \varphi_1 + I_p \omega^2 EG \left[2EG \frac{\varphi_1}{(\theta_1^2 + \varphi_1^2)} + \frac{\dot{\theta}_1 \dot{\varphi}_1}{\theta_1^2 + \varphi_1^2} \right] \\
M_y &= -I_T \omega^2 \theta_1 + I_p \omega^2 EG \left[2EG \frac{\theta_1}{(\theta_1^2 + \varphi_1^2)} - \frac{\dot{\theta}_1 \dot{\varphi}_1}{\theta_1^2 + \varphi_1^2} \right]
\end{aligned}$$

which clearly shows that the gyroscopic moment is not linear with respect to the rotor slope. However, only the first harmonic can do

work on the rotor. Hence a Fourier analysis will be performed. The following integrals apply:

$$\begin{aligned} \int_0^{2\pi} \frac{\sin x \cos x \, dx}{E^2 \cos^2 x + G^2 \sin^2 x} &= 0 \\ \int_0^{2\pi} \frac{\sin x \cos x \, dx}{(E^2 \cos^2 x + G^2 \sin^2 x)^2} &= 0 \\ \int_0^{2\pi} \frac{\sin^2 x \, dx}{E^2 \cos^2 x + G^2 \sin^2 x} &= \frac{2\pi}{G(E+G)} \\ \int_0^{2\pi} \frac{\sin^2 x \, dx}{(E^2 \cos^2 x + G^2 \sin^2 x)^2} &= \frac{\pi}{EG^3} \\ \int_0^{2\pi} \frac{dx}{E^2 \cos^2 x + G^2 \sin^2 x} &= \frac{2\pi}{EG} \\ \int_0^{2\pi} \frac{dx}{(E^2 \cos^2 x + G^2 \sin^2 x)^2} &= \frac{\pi(E^2 + G^2)}{E^3 G^3} \end{aligned}$$

Then the first harmonic becomes:

$$\begin{aligned} -M_x &= \left(\frac{2E}{E+G} I_p - I_T \right) \omega^2 \varphi_1 \\ (24) \quad M_y &= \left(\frac{2G}{E+G} I_p - I_T \right) \omega^2 \theta_1 \end{aligned}$$

In the limit, eqs. (24) agree with eqs. (19).

Eqs. (24) must be transformed back to the actual (θ, φ) -coordinate system. Setting

$$\begin{aligned} \theta &= \theta_c \cos \omega t + \theta_s \sin \omega t \\ (25) \quad \varphi &= \varphi_c \cos \omega t + \varphi_s \sin \omega t \end{aligned}$$

describing an elliptical variation of slope, we get:

$$\begin{aligned} \left. \begin{aligned} \frac{E}{G} \right\} &= \sqrt{\frac{1}{2}(\theta_c^2 + \theta_s^2 + \varphi_c^2 + \varphi_s^2) \pm \sqrt{\frac{1}{4}(\theta_c^2 + \theta_s^2 + \varphi_c^2 + \varphi_s^2)^2 - (\theta_c \varphi_s - \theta_s \varphi_c)^2}} \\ (26) \quad \cos 2\beta &= \frac{\theta_c^2 + \theta_s^2 - \varphi_c^2 - \varphi_s^2}{\sqrt{(\theta_c^2 + \theta_s^2 - \varphi_c^2 - \varphi_s^2)^2 + 4(\theta_c \varphi_c + \theta_s \varphi_s)^2}} \\ \sin 2\beta &= \frac{2(\theta_c \varphi_c + \theta_s \varphi_s)}{\sqrt{(\theta_c^2 + \theta_s^2 - \varphi_c^2 - \varphi_s^2)^2 + 4(\theta_c \varphi_c + \theta_s \varphi_s)^2}} \end{aligned} \end{aligned}$$

where β is the angle from the position X-axis to the major axis E, position in the same direction as ω . Then:

$$\begin{aligned} (27) \quad \theta_1 &= \theta \cos \beta + \varphi \sin \beta \\ \varphi_1 &= -\theta \sin \beta + \varphi \cos \beta \end{aligned}$$

Substituting eq. (26)-(27) into eqs. (24) gives:

$$(28) \quad M_y = (M_{yn} - M_{xn})_{\text{gyro}} = \omega^2 [2\Delta M_{\text{ex}} I_p - \theta_c I_T] \cos \omega t + \omega^2 [2\Delta M_{\text{ey}} I_p - \theta_s I_T] \sin \omega t$$

$$(29) \quad -M_x = (M_{yn} - M_{xn})_{\text{gyro}} = \omega^2 [-2\Delta M_{\text{ey}} I_p - \varphi_c I_T] \cos \omega t + \omega^2 [2\Delta M_{\text{ex}} I_p - \varphi_s I_T] \sin \omega t$$

where

$$(30) \quad \Delta M_{\text{ex}} = \frac{(\theta_c + \varphi_s)(\theta_c \varphi_s - \theta_s \varphi_c)}{(\theta_c + \varphi_s)^2 + (\theta_s - \varphi_c)^2}$$

$$(31) \quad \Delta M_{\text{ey}} = \frac{(\theta_s - \varphi_c)(\theta_c \varphi_s - \theta_s \varphi_c)}{(\theta_c + \varphi_s)^2 + (\theta_s - \varphi_c)^2}$$

Since eq. (28) and eq. (29) are not linear, an iterative method is used. For each rotor speed, the program performs a number of iterations. The first iteration is done without gyroscopic moment. After the first iteration, the gyroscopic moment is calculated from eq. (28)-(29) and these values are used in the second iteration and so on. The calculation has converged when the relative change in rotor amplitude and slope between two iterations is smaller than a specified limit.

EQUATIONS FOR ROTOR CALCULATION

The bending moment, the shear force, the slope and the deflection are expressed by:

$$M_x = M_{xc} \cos \omega t + M_{xs} \sin \omega t$$

$$V_x = V_{xc} \cos \omega t + V_{xs} \sin \omega t$$

$$\theta = \theta_c \cos \omega t + \theta_s \sin \omega t$$

$$X = X_c \cos \omega t + X_s \sin \omega t$$

and similarly for the y-direction. Then eq. (1), (2), (3), (8), (9), (10), (11), (14), (16), (17), and (29) may be combined to give the equations used in the rotor calculation (see Fig. 2):

$$\begin{aligned} M'_{xcn} &= M_{xcn} + \Delta M_{axn} \theta_{cn} + \Delta M_{byn} \theta_{sn} + \Delta M_{cyn} \phi_{cn} + \Delta M_{asn} \phi_{sn} + (M'_{xcn} - M_{xcn})_{ayro} \\ M'_{xsn} &= M_{xsn} - \Delta M_{bxn} \theta_{cn} + \Delta M_{ayn} \theta_{sn} - \Delta M_{asn} \phi_{cn} + \Delta M_{cyn} \phi_{sn} + (M'_{xsn} - M_{xsn})_{ayro} \\ M'_{ycn} &= M_{ycn} + \Delta M_{cyn} \theta_{cn} + \Delta M_{ayn} \theta_{sn} + \Delta M_{asn} \phi_{cn} + \Delta M_{bxn} \phi_{sn} + (M'_{ycn} - M_{ycn})_{ayro} \\ M'_{ysn} &= M_{ysn} - \Delta M_{byn} \theta_{cn} + \Delta M_{cyn} \theta_{sn} - \Delta M_{bxn} \phi_{cn} + \Delta M_{asn} \phi_{sn} + (M'_{ysn} - M_{ysn})_{ayro} \\ V_{xcn} &= V_{xc,n-1} + [m_n \omega^2 - \Delta V_{axn}] X_{cn} - \Delta V_{bxn} X_{sn} - \Delta V_{cyn} Y_{cn} - \Delta V_{asn} Y_{sn} + \omega^2 U_{xn} \\ (32) \quad V_{xsn} &= V_{xs,n-1} + \Delta V_{bxn} X_{cn} + [m_n \omega^2 - \Delta V_{ayn}] X_{sn} + \Delta V_{asn} Y_{cn} - \Delta V_{cyn} Y_{sn} - \omega^2 U_{yn} \\ V_{ycn} &= V_{yc,n-1} - \Delta V_{cyn} X_{cn} - \Delta V_{ayn} X_{sn} + [m_n \omega^2 - \Delta V_{ayn}] Y_{cn} - \Delta V_{bxn} Y_{sn} + \omega^2 U_{yn} \\ V_{ysn} &= V_{ys,n-1} + \Delta V_{ayn} X_{cn} - \Delta V_{bxn} X_{sn} + \Delta V_{cyn} Y_{cn} + [m_n \omega^2 - \Delta V_{ayn}] Y_{sn} + \omega^2 U_{xn} \\ M_{ax,n+1} &= M'_{xcn} + L_n V_{xcn} \\ M_{ay,n+1} &= M'_{xsn} + L_n V_{xsn} \end{aligned}$$

$$M_{yc,nsi} = M'_{ycn} + L_n V_{ycn}$$

$$M_{ys,nsi} = M'_{ysn} + L_n V_{ysn}$$

$$\theta_{c,nsi} = \theta_{cn} + a_n M'_{xcn} + b_n V_{xcn}$$

$$\theta_{s,nsi} = \theta_{sn} + a_n M'_{xsn} + b_n V_{xsn}$$

$$\phi_{c,nsi} = \phi_{cn} + a_n M'_{ycn} + b_n V_{ycn}$$

$$\phi_{s,nsi} = \phi_{sn} + a_n M'_{ysn} + b_n V_{ysn}$$

$$X_{c,nsi} = X_{cn} + L_n \theta_{cn} + b_n M'_{xcn} + d_n V_{xcn}$$

$$X_{s,nsi} = X_{sn} + L_n \theta_{sn} + b_n M'_{xsn} + d_n V_{xsn}$$

$$Y_{c,nsi} = Y_{cn} + L_n \phi_{cn} + b_n M'_{ycn} + d_n V_{ycn}$$

$$Y_{s,nsi} = Y_{sn} + L_n \phi_{sn} + b_n M'_{ysn} + d_n V_{ysn}$$

In the above equations a_n , b_n , d_n are given by eq. (4), (5) and (7), ΔM_{asn} , ΔM_{bsn} ----- ΔM_{dyn} and ΔV_{asn} , ΔV_{bsn} ----- ΔV_{dyn} by eqs. (15) and $(M'_{xcn} - M'_{xsn})_{dy=0}$ ----- $(M'_{ysn} - M'_{ysn})_{dy=0}$ by eq. (28)-(29).

Boundary Conditions. The rotor is assumed to have free ends. No loss in generality occurs by this condition since it may be changed by letting the end points have bearing support. A proper choice of support coefficients will then allow for any type of end conditions.

For a rotor with free ends the bending moment and the shear force are zero at the end:

$$(33) \quad M_{xci} = M_{xsi} = M_{yci} = M_{ysi} = V_{xci} = V_{ysi} = V_{yci} = V_{ysi} = 0$$

$$(34) \quad M'_{xci} = M'_{xsi} = M'_{yci} = M'_{ysi} = V_{xci} = V_{ysi} = V_{yci} = V_{ysi} = 0$$

Starting from the left end of the rotor (see Fig. 2), eq. (33) is used. However, the slope and the deflection are unknown. Using the superposition principle, each unknown is applied separately. A summation gives the combined effect. Ten calculations are performed, using eqs. (32).

1. $\theta_{c1} = 1$ $\theta_{s1} = \phi_{c1} = \phi_{s1} = \chi_{c1} = \chi_{s1} = \psi_{c1} = \psi_{s1} = u_{xn} = u_{yn} = 0$
2. $\theta_{s1} = 1$ $\theta_{c1} = \phi_{c1} = \phi_{s1} = \chi_{c1} = \chi_{s1} = \psi_{c1} = \psi_{s1} = u_{xn} = u_{yn} = 0$
3. $\phi_{c1} = 1$ $\theta_{c1} = \theta_{s1} = \phi_{s1} = \chi_{c1} = \chi_{s1} = \psi_{c1} = \psi_{s1} = u_{xn} = u_{yn} = 0$
4. $\phi_{s1} = 1$ $\theta_{c1} = \theta_{s1} = \phi_{c1} = \chi_{c1} = \chi_{s1} = \psi_{c1} = \psi_{s1} = u_{xn} = u_{yn} = 0$
5. $\chi_{c1} = 1$ $\theta_{c1} = \theta_{s1} = \phi_{c1} = \phi_{s1} = \chi_{s1} = \psi_{c1} = \psi_{s1} = u_{xn} = u_{yn} = 0$
6. $\chi_{s1} = 1$ $\theta_{c1} = \theta_{s1} = \phi_{c1} = \phi_{s1} = \chi_{c1} = \psi_{c1} = \psi_{s1} = u_{xn} = u_{yn} = 0$
7. $\psi_{c1} = 1$ $\theta_{c1} = \theta_{s1} = \phi_{c1} = \phi_{s1} = \chi_{c1} = \chi_{s1} = \psi_{s1} = u_{xn} = u_{yn} = 0$
8. $\psi_{s1} = 1$ $\theta_{c1} = \theta_{s1} = \phi_{c1} = \phi_{s1} = \chi_{c1} = \chi_{s1} = \psi_{c1} = u_{xn} = u_{yn} = 0$
9. $u_{xn} = u_{xn}$ $u_{yn} = u_{yn}$ $\theta_{c1} = \theta_{s1} = \phi_{c1} = \phi_{s1} = \chi_{c1} = \chi_{s1} = \psi_{c1} = \psi_{s1} = 0$
10. Gyroscopic moment applied $\theta_{c1} = \theta_{s1} = \phi_{c1} = \phi_{s1} = \chi_{c1} = \chi_{s1} = \psi_{c1} = \psi_{s1} = u_{xn} = u_{yn} = 0$

For each calculation eqs. (32) are used to calculate the bending moment, the shear force, the slope and the deflection along the rotor. At the right rotor end, station r , eq. (34) must be satisfied, i.e.

$$(35) \quad \begin{Bmatrix} M_{xcr,1} & M_{xcr,2} & \dots & M_{xcr,8} \\ M_{xsr,1} & M_{xsr,2} & \dots & M_{xsr,8} \\ M_{ycr,1} & M_{ycr,2} & \dots & M_{ycr,8} \\ M_{ysr,1} & M_{ysr,2} & \dots & M_{ysr,8} \\ V_{xcr,1} & V_{xcr,2} & \dots & V_{xcr,8} \\ V_{xsr,1} & V_{xsr,2} & \dots & V_{xsr,8} \\ V_{ycr,1} & V_{ycr,2} & \dots & V_{ycr,8} \\ V_{ysr,1} & V_{ysr,2} & \dots & V_{ysr,8} \end{Bmatrix} \begin{Bmatrix} \theta_{c1} \\ \theta_{s1} \\ \phi_{c1} \\ \phi_{s1} \\ \chi_{c1} \\ \chi_{s1} \\ \psi_{c1} \\ \psi_{s1} \end{Bmatrix} = \begin{Bmatrix} -M_{xcr,9} - M_{xcr,10} \\ -M_{xsr,9} - M_{xsr,10} \\ -M_{ycr,9} - M_{ycr,10} \\ -M_{ysr,9} - M_{ysr,10} \\ -V_{xcr,9} - V_{xcr,10} \\ -V_{xsr,9} - V_{xsr,10} \\ -V_{ycr,9} - V_{ycr,10} \\ -V_{ysr,9} - V_{ysr,10} \end{Bmatrix}$$

Eqs. (35) are then solved for $\theta_{c1}, \theta_{s1}, \dots, \psi_{s1}$, and the actual values of bending moment, shear force etc, along the rotor can be determined.

At a given rotor speed, eqs. (35) are first solved without gyroscopic

moment, i.e. $M'_{xcr,10} = \dots = V_{sr,10} = 0$. Then the gyroscopic moment is applied according to eq. (28)-(29) and new values are found for $\theta_{si}, \theta_{si}, \dots, y_{si}$ from eqs. (35). This process is repeated until at the k 'th iteration:

$$(36) \quad \frac{|\theta_{ci}^{(k)} - \theta_{ci}^{(k-1)}| + |\theta_{si}^{(k)} - \theta_{si}^{(k-1)}| + |\varphi_{ci}^{(k)} - \varphi_{ci}^{(k-1)}| + \dots + |y_{si}^{(k)} - y_{si}^{(k-1)}|}{|\theta_{ci}^{(k)}| + |\theta_{si}^{(k)}| + |\varphi_{ci}^{(k)}| + \dots + |y_{si}^{(k)}|} \leq \epsilon_{\text{con}}$$

where ϵ_{con} is the convergence limit specified by the computer input. If the calculation does not converge within a specified number of iterations, the program goes on to a new rotor speed.

In the computer output, the rotor deflection is given by the dimensions of the elliptical whirl path. We have:

$$(37) \quad \begin{aligned} X &= X_c \cos \omega t + X_s \sin \omega t \\ Y &= Y_c \cos \omega t + Y_s \sin \omega t \end{aligned}$$

As shown in Fig. 5, the (X, Y) -coordinate system is rotated an angle β in the same direction as ω to become (X_1, Y_1) . Then

$$(38) \quad \begin{aligned} X_1 &= a \cos(\omega t + \alpha) \\ Y_1 &= b \sin(\omega t + \alpha) \end{aligned}$$

where a and b are the major and minor axis respectively of the ellipse. From Fig. 5:

$$\begin{aligned} X_1 &= X \cos \beta + Y \sin \beta \\ Y_1 &= -X \sin \beta + Y \cos \beta \end{aligned}$$

Then:

$$(39) \quad \left. \begin{matrix} a \\ b \end{matrix} \right\} = \sqrt{\frac{1}{2} \left[(X_c^2 + X_s^2 + Y_c^2 + Y_s^2) \pm \sqrt{(X_c^2 + X_s^2 - Y_c^2 - Y_s^2)^2 + 4(X_c Y_c + X_s Y_s)^2} \right]}$$

Here it is necessary to allow b to become negative. The reason is that the transformation from the x - y -coordinates to the ellipse must be able to discern between forward and backward whirl (i.e. the shaft center may travel in the same direction or in the opposite direction of the direction of rotation depending on the values of x_c , x_s , y_c and y_s). Let the angle between the x -axis and the instantaneous radius vector be γ :

$$\gamma = \tan^{-1}\left(\frac{y}{x}\right)$$

Then:

$$\dot{\gamma} = \frac{x\dot{y} - \dot{x}y}{x^2 + y^2} = \frac{\omega[x_c y_s - x_s y_c]}{x^2 + y^2}$$

i.e.

$$(x_c y_s - x_s y_c) > 0 \quad : \text{forward whirl}$$

$$(x_c y_s - x_s y_c) < 0 \quad : \text{backward whirl}$$

$$(x_c y_s - x_s y_c) = 0 \quad : \text{straight line orbit } (b=0)$$

Therefore:

$$(39a) \quad \dot{\gamma} = \frac{(x_c y_s - x_s y_c)}{|x_c y_s - x_s y_c|} \sqrt{\frac{1}{2}[(x_c^2 + x_s^2 + y_c^2 + y_s^2) - \sqrt{(x_c^2 + x_s^2 - y_c^2 - y_s^2)^2 + 4(x_c y_s + x_s y_c)^2}]}$$

To find α and β expand Eq. (38)

$$(a) \quad a \cos \alpha = x_c \cos \beta + y_c \sin \beta$$

$$(b) \quad -a \sin \alpha = x_s \cos \beta + y_s \sin \beta$$

$$(c) \quad b \sin \alpha = -x_c \sin \beta + y_c \cos \beta$$

$$(d) \quad b \cos \alpha = -x_s \sin \beta + y_s \cos \beta$$

Then:

$$(a)^2 + (b)^2 + (c)^2 + (d)^2 : a^2 + b^2 = x_c^2 + x_s^2 + y_c^2 + y_s^2$$

$$(a)^2 + (b)^2 - (c)^2 - (d)^2 : a^2 - b^2 = (x_c^2 + x_s^2 - y_c^2 - y_s^2) \cos 2\beta + 2(x_c y_c + x_s y_s) \sin 2\beta$$

$$\text{i.e. } \cos 2\beta = \frac{x_c^2 + x_s^2 - y_c^2 - y_s^2}{a^2 - b^2} \quad \sin 2\beta = \frac{2(x_c y_c + x_s y_s)}{a^2 - b^2}$$

Next:

$$-(a) \cdot (b) - (c) \cdot (d) : \frac{1}{2}(a^2 - b^2) \sin 2\alpha = -(x_c x_s + y_c y_s)$$

$$(a)^2 - (b)^2 + (c)^2 - (d)^2 : (a^2 - b^2) \cos 2\alpha = x_c^2 - x_s^2 + y_c^2 - y_s^2$$

$$\text{i.e. } \cos 2\alpha = \frac{x_c^2 - x_s^2 + y_c^2 - y_s^2}{a^2 - b^2} \quad \sin 2\alpha = \frac{-2(x_c x_s + y_c y_s)}{a^2 - b^2}$$

Thus in total:

$$(40) \quad \tan 2\beta = \frac{2(X_c Y_c + X_s Y_s)}{X_c^2 + X_s^2 - Y_c^2 - Y_s^2}$$

$$\cos 2\beta = \frac{X_c^2 - Y_c^2 - Y_s^2}{b^2}$$

$$(41) \quad \tan 2\alpha = \frac{-2(X_c X_s + Y_c Y_s)}{X_c^2 - X_s^2 + Y_c^2 - Y_s^2}$$

$$\cos 2\alpha = \frac{X_c^2 - X_s^2 + Y_c^2 - Y_s^2}{a^2 - b^2}$$

Thus β is the angle from the positive X-axis to the major axis of the ellipse (positive with ω) and α is the phase angle for the radius vector, measured positive from the major axis in the direction of ω . The computer output gives a, b, β and α for both the deflection and the bending moment.

Coupling Stations. The programs allow for couplings in the rotor. At these stations, the bending moment vanishes, i.e. $M_n' = 0$ (the coupling point is taken just to the right of the mass station). When the program encounters a coupling station, say station i , the following equations are set up:

$$(42) \quad \begin{bmatrix} M_{xi,1} & M_{xi,2} & \dots & M_{xi,4} \\ M_{xi,1} & M_{xi,2} & \dots & M_{xi,4} \\ M_{yi,1} & M_{yi,2} & \dots & M_{yi,4} \\ M_{yi,1} & M_{yi,2} & \dots & M_{yi,4} \end{bmatrix} \begin{bmatrix} \theta_{xi} \\ \theta_{xi} \\ \phi_{xi} \\ \phi_{xi} \end{bmatrix} = - \begin{bmatrix} M'_{xi,5} & \dots & M'_{xi,9} \\ M'_{xi,5} & \dots & M'_{xi,9} \\ M'_{yi,5} & \dots & M'_{yi,9} \\ M'_{yi,5} & \dots & M'_{yi,9} \end{bmatrix} \begin{bmatrix} X_{xi} \\ X_{xi} \\ Y_{xi} \\ Y_{xi} \end{bmatrix} - \begin{bmatrix} M'_{xi,9} + M'_{xi,10} \\ M'_{xi,9} + M'_{xi,10} \\ M'_{yi,9} + M'_{yi,10} \\ M'_{yi,9} + M'_{yi,10} \end{bmatrix}$$

or upon solving

$$(43) \quad \theta_i = a_i X_j + b_i \quad (i, j = 1, 2, 3, 4)$$

where $\theta_1 = \theta_{c1}, \theta_2 = \theta_{c2}$ etc. and $X_1 = X_{c1}, X_2 = X_{c1}$ etc. Then the bending moment, shear force, slope and deflection before the coupling station become functions of X_{c1}, X_{s1}, Y_{c1} and Y_{s1} only. As an example, let the shear force at a station be:

$$V_{xcn} = V_1 \theta_{c1} + V_2 \theta_{s1} + V_3 \phi_{c1} + V_4 \phi_{s1} + V_5 X_{c1} + V_6 X_{s1} + V_7 Y_{c1} + V_8 Y_{s1} + V_9 + V_{10}$$

Introducing eq. (43) gives:

$$\begin{aligned}
 V_{xcn} = & [V_5 + a_{11}V_1 + a_{21}V_2 + a_{31}V_3 + a_{41}V_4]x_{c1} + [V_6 + a_{12}V_1 + a_{22}V_2 + a_{32}V_3 + a_{42}V_4]x_{s1} \\
 (44) \quad & + [V_7 + a_{13}V_1 + a_{23}V_2 + a_{33}V_3 + a_{43}V_4]y_{c1} + [V_8 + a_{14}V_1 + a_{24}V_2 + a_{34}V_3 + a_{44}V_4]y_{s1} \\
 & + [V_9 + V_{10} + b_1V_1 + b_2V_2 + b_3V_3 + b_4V_4]
 \end{aligned}$$

and similarly for $V_{xsn}, V_{ycn}, V_{ysn}, M_{xcn}, \dots, -y_{sn}$. Instead of $\Theta_{c1}, \Theta_{s1}, \varphi_{c1}$ and φ_{s1} we have as new variables the slopes just to the right of the coupling station m , i.e. $\Theta_{cm}, \Theta_{sm}, \varphi_{cm}, \varphi_{sm}$. Then the calculation proceeds as before until either a new coupling station or the right end of the rotor is reached.

Transmitted Force and Pedestal Motion

Let the force transmitted to the pedestal at station n be denoted F .

From Eq. (12) it is seen:

$$\begin{aligned}
 F_{xc} &= V_{xc,n-1} - V_{xcn} + m_n \omega^2 x_{cn} + \omega^2 U_{xn} \\
 (45) \quad F_{xs} &= V_{xs,n-1} - V_{xsn} + m_n \omega^2 x_{sn} - \omega^2 U_{yn} \\
 F_{yc} &= V_{yc,n-1} - V_{ycn} + m_n \omega^2 y_{cn} + \omega^2 U_{yn} \\
 F_{ys} &= V_{ys,n-1} - V_{ysn} + m_n \omega^2 y_{sn} + \omega^2 U_{xn}
 \end{aligned}$$

Denoting the amplitude of the pedestal masses x_p and y_p (see Fig. 3)

we get:

$$\begin{aligned}
 x_p &= \frac{F_{xc} - iF_{xs}}{\alpha_x - M_x \omega^2 + i\omega \delta_x} \\
 y_p &= \frac{F_{yc} - iF_{ys}}{\alpha_y - M_y \omega^2 + i\omega \delta_y} \\
 \text{or} \\
 x_{pc} &= \frac{F_{xc}(\alpha_y - M_y \omega^2) - F_{xs} \omega \delta_y}{(\alpha_x - M_x \omega^2)^2 + (\omega \delta_x)^2} \\
 x_{ps} &= \frac{F_{xc} \omega \delta_x + F_{xs}(\alpha_x - M_x \omega^2)}{(\alpha_x - M_x \omega^2)^2 + (\omega \delta_x)^2} \\
 (46) \quad y_{pc} &= \frac{F_{yc}(\alpha_y - M_y \omega^2) - F_{ys} \omega \delta_y}{(\alpha_y - M_y \omega^2)^2 + (\omega \delta_y)^2} \\
 y_{ps} &= \frac{F_{yc} \omega \delta_y + F_{ys}(\alpha_y - M_y \omega^2)}{(\alpha_y - M_y \omega^2)^2 + (\omega \delta_y)^2}
 \end{aligned}$$

The force transmitted to the base becomes:

$$\begin{aligned}
 P_x &= \alpha_x x_p + i\omega \delta_x x_p \\
 P_y &= \alpha_y y_p + i\omega \delta_y y_p
 \end{aligned}$$

or:

$$\begin{aligned}
 P_{xc} &= F_{xc} + M_x \omega^2 x_{pc} \\
 P_{xs} &= F_{xs} + M_x \omega^2 x_{ps} \\
 P_{yc} &= F_{yc} + M_y \omega^2 y_{pc} \\
 P_{ys} &= F_{ys} + M_y \omega^2 y_{ps}
 \end{aligned}
 \tag{47}$$

Energy Balance

Let the relative amplitude between rotor and pedestal mass be $X' = X - X_p$ and $Y' = Y - Y_p$ at a bearing station. Then the energy dissipated in the bearing and the pedestal per revolution becomes:

$$\begin{aligned}
 \text{Energy Dissipated} = & \\
 (48) \quad & \pi \left\{ \omega C_{xx} (x_c'^2 + x_s'^2) + \omega C_{yy} (y_c'^2 + y_s'^2) + (\omega C_{xy} + \omega C_{yx}) (x_c' y_c' + x_s' y_s') \right. \\
 & \left. - (K_{xy} - K_{yx}) (x_c' y_s' - x_s' y_c') + \omega \delta_x (x_{pc}^2 + x_{ps}^2) + \omega \delta_y (y_{pc}^2 + y_{ps}^2) \right\} \\
 & + \pi \left\{ \omega D_{xx} (\theta_c'^2 + \theta_s'^2) + \omega D_{yy} (\phi_c'^2 + \phi_s'^2) + (\omega D_{xy} + \omega D_{yx}) (\theta_c' \phi_c' + \theta_s' \phi_s') \right. \\
 & \left. - (M_{xy} - M_{yx}) (\theta_c' \phi_s' - \theta_s' \phi_c') + \omega \delta_x (\theta_{pc}^2 + \theta_{ps}^2) + \omega \delta_y (\phi_{pc}^2 + \phi_{ps}^2) \right\}
 \end{aligned}$$

A summation over all bearings gives the total dissipated energy.

At each unbalance station there is an energy input:

$$(49) \quad \text{Energy Input: } \pi \left\{ \omega^2 U_x (x_s - y_c) + \omega^2 U_y (x_c + y_s) \right\}$$

Summing over all unbalance stations gives the total energy input which must equal the dissipated energy.

COMPUTER INPUT

The input data is prepared according to the following instructions. Note that, unless specifically stated, no input card may be omitted.

Card 1 and 2: (72 cols. Hollerith) Identification:- Any descriptive text may be punched in cols. 2-72. These two cards must always be included.

Card 3: (1015) Control parameters -

Word 1. Number of rotor mass stations - The number of mass stations is determined by the above considerations. Also, there must be a mass station at each rotor end, at each bearing, at each unbalance and at

each coupling point. The mass at a station may be zero. The maximum number of mass stations is 80.

Word 2. Number of bearings - This integer denotes the total number of bearings along the rotor. A maximum of 25 bearings is possible.

Word 3. Number of unbalance stations - This integer gives the total number of mass stations at which unbalance is applied. A maximum of 80 unbalance stations is possible.

Word 4. Number of coupling stations - This integer gives the total number of coupling points. It cannot exceed 20.

Word 5. Pedestal flexible/rigid - If this integer is zero, the program assumes the pedestal to be rigid for both translatory and rotational motion and no pedestal data is included. If the integer is 1, the pedestal has flexibility and damping and pedestal data must be provided.

Word 6. Support tilting - If this integer is zero, neither the bearings nor the pedestals resist rotation. In that case, neither the input for the bearing dynamic coefficients for rotational motion nor the pedestal data for rotational motion can be included. If the integer is 1, the bearings and the pedestals have flexibility and damping for rotational motion.

Word 7. Gyroscopic moment - If this integer is zero, no gyroscopic moment is included in the calculation. If gyroscopic moment is desired, the integer should be 1.

Word 8. Number of computations - It was indicated above that the eight bearing parameters were dynamic coefficients and so could account for the variation of parameters with running speed in an approximate manner. However, if a more precise representation of these parameters is desired, these values can be entered each time a new running speed is designated. In order to facilitate this, there is provision in the

program for entering only the bearing or bearing and pedestal data and the corresponding running speed without re-entering the rotor, coupling or unbalance data. Then this word 8 of the control parameters designates the number of sets of parameters which are to be run. If this value is 1, the program assumes that the bearing data is being entered as coefficients of quadratic equations in ω . Note below that the input format of the bearing data differs depending on whether this value is equal to or greater than one.

Word 9. Diagnostic - If this integer is zero, no diagnostic will be performed. A value of 1 will provide the diagnostic output: the diagnostic increases the amount of output a considerable amount and is provided primarily for use in trouble-shooting the program and so this value should always be zero.

Word 10. Input - If this integer is zero, the program will return to read in a new set of input upon completion of the computation. For the last set of input this value should be 1.

Card 4. (1P4E15.7)

Word 1 is Young's modulus E in lbs/in^2 . It is constant throughout the rotor. Since the program never uses E by itself but always in the product EI (I =cross-sectional moment of inertia) any actual variation in E can be absorbed by changing I accordingly.

Word 2 is the scale factor for the determinant in the simultaneous equation subroutine. In general this item is 1.0. It is a factor by which the determinant is multiplied to control computer over/underflow. The simultaneous equation subroutine is used 4 places in the program: once when solving for the unknown end deflections (i.e. Eq.(35)) and 3 times when solving for the unknown slopes in the coupling calculation (i.e. Eq. (42)). If an over/underflow occurs during the calculation the program output will contain: "OVER/UNDERFLOW IN XSIMEQF AT _ _ (integer)" where the value of the integer is 1 to 4. If it is 1, 2 or 3 the error is in the coupling calculation. If it is 4 the error is in solving Eq. (35). Changing the scale-factor may eliminate the trouble.

If the determinant is singular the output gives: "MATRIX IS SINGULAR IN XSIMEQF AT _ _ (integer)". If either of the two errors occur the program proceeds with a new rotor speed.

ROTOR DATA

The rotor data will differ depending on whether the effect of the gyroscopic moment is included in the computation. For the case where no gyroscopic moment is included; i.e. where word 7 of card 3 is zero, the rotor data is entered as follows:

Card: (1P3E14.6) - An input card must be given for each mass station. Each card has 3 items.

Word 1 - the mass at the station in lbs.

Word 2 - the length of the shaft section to the right of the station in inches.

Word 3 - the cross-sectional moment of inertia of the shaft section to the right of the station in in^4 .

For the last mass station the shaft length and the cross-sectional moment of inertia has no meaning and may be set equal to zero.

If gyroscopic motion is included and word 7, card 3, is not equal to zero, then each card contains two more items in addition to the 3 items indicated just above. Also for this case, the rotor data cards are immediately preceded by a card which contains two values defined as follows:

Card: (15,1PE23.6). Gyroscopic moment parameters -

Word 1 - Number of iterations - For each rotor speed the program first calculates the unbalance response without gyroscopic moment. Based on

the thus obtained rotor slopes, the gyroscopic moment is computed and applied to the rotor, resulting in new values of the slope and the process is repeated. The program counts the number of iterations, excluding the calculation without gyroscopic moment. If the count exceeds this input item, the results obtained are printed out, the iteration count is reset to 1 and a new rotor speed calculation starts.

Word 2 - Convergence limit - After each gyroscopic moment iteration, the following relative error is calculated:

$$\frac{|\theta_{c1}^{(k)} - \theta_{c1}^{(k-1)}| + |\theta_{s1}^{(k)} - \theta_{s1}^{(k-1)}| + \dots + |\psi_{s1}^{(k)} - \psi_{s1}^{(k-1)}|}{|\theta_{c1}^{(k)}| + |\theta_{s1}^{(k)}| + |\phi_{c1}^{(k)}| + \dots + |\psi_{s1}^{(k)}|}$$

where θ_{c1} , θ_{s1} , ϕ_{c1} and ϕ_{s1} are the slopes and χ_{c1} , χ_{s1} , ψ_{c1} and ψ_{s1} are the deflections at the left rotor end. The superscript is the iteration number. For each iteration the computer output gives the iteration number and the error. When the error is less than or equal to the input convergence limit, the program prints the results, resets the iteration count to 1 and proceeds with a new rotor speed.

Following this card are the rotor data cards.

Card: (1P5E14.6). An input card is required for each mass station. Each card contains 5 items; the first 3 words are the same as those for the non-gyroscopic moment case above and the remaining two are:

Word 4 - the polar mass moment of inertia in lbs.in²

Word 5 - the transverse mass moment of inertia in lbs.in²

LOCATION OF BEARING SUPPORTS

Card: (14I5). This list provides the numbers of the mass stations at which there is a bearing.

UNBALANCE DATA

Card: (15, 1P2E15.7). A card is provided for each of the unbalance stations. Each card contains 3 values:

Word 1 - an integer which denotes the number of the mass station at which the unbalance applies.

Word 2 - the cosine component of the unbalance in oz. in.

Word 3 - the sine component of the unbalance in oz. in.

By providing two unbalance components, it is possible to take into consideration the circumferential variation of unbalance along the rotor.

COUPLING DATA

If the rotor does not contain couplings, (Word 4, card 3 is zero), then no coupling data is necessary. If word 4, card 3 is not zero, the following card must be included.

Card: (14I5) - This is a list of integers denoting the mass stations at which there is a coupling.

PEDESTAL DATA

If the pedestal is considered to be infinitely rigid, then no pedestal data is required. In this case word 5, card 3, pedestal flexible/rigid is zero. Otherwise, pedestal data is required. The pedestal data, like the bearing data, is separated into translatory and rotational parameters. Also, as before, the control parameter is the word 6, card 3, support tilting.

Card: (1P6E12.4) - A card must be provided for each bearing. On it are 6 values as follows:

Word 1 - the weight of the pedestal in the X coordinate in lbs.

Word 2 - the pedestal stiffness along the X coordinate in lbs/in.

Word 3 - the pedestal damping along the X coordinate in lbs-sec/in.

Word 4 - same as word 1 but for the Y coordinate.

Word 5 - same as word 2 but for the Y coordinate.

Word 6 - same as word 3 but for the Y coordinate.

If word 6, card 3, support tilting, is not zero, then all of the cards concerned with the translatory parameters are followed by the cards for the rotational parameters. Again there are 6 values on each card as follows:

Word 1 - the mass moment of inertia of the pedestal mass, associated with the X coordinate in lbs.in²

Word 2 - the pedestal spring coefficient for rotational motion, associated with the X coordinate in lbs-in./rad.

Word 3 - the pedestal damping coefficient for rotational motion, associated with the X coordinate in lbs-in.-sec/rad.

Word 4 - same as word 1 but associated with the Y coordinate.

Word 5 - same as word 2 but associated with the Y coordinate.

Word 6 - same as word 3 but associated with the Y coordinate.

SPEED AND BEARING DATA

Each bearing is represented by 16 dynamic coefficients, 8 for translatory motion and 8 for rotational motion. Of the 8 coefficients, 4 are spring coefficients and 4 are damping coefficients. Since the coefficients in general change with speed, each coefficient is expressed by three components; e.g.

$$K_{xx} = K_{xx,0} + K_{xx,1} \omega + K_{xx,2} \omega^2$$

where ω is the rotor speed in rad/sec, $K_{xx,0}$ in lbs/in., $K_{xx,1}$ in lbs-sec/in.rad. and $K_{xx,2}$ in lbs-sec²/in.rad². Similar equations hold for the other 15 coefficients. As indicated earlier, if it is desired to enter the bearing data at each value of frequency, there is provision for this in the program.

If word 8, card 3 is 1, the program assumes the bearing data is provided as frequency dependent coefficients. In this case, a card is provided with the speed range and increment and this is followed by the bearing data. An input card is given for each coefficient at each bearing. Each card contains three items, namely the above mentioned three speed components. The sequence of the input cards is: first all the cards for the translatory motion and then all the cards for the rotational motion. The cards for the rotational motion are not required if word 6, card 3, support tilting, is zero. The cards should be given in the following order: $K_{xx}, \omega C_{xx}, K_{xy}, \omega C_{xy}, K_{yy}, \omega C_{yy}, K_{yx}, \omega C_{yx}$ for bearing 1, $K_{xx}, \omega C_{xx}, \dots, \omega C_{yx}$ for bearing 2, etc. to the last bearing, then (if word 6, card 3 $\neq 0$), $M_{xx}, \omega D_{xx}, M_{xy}, \omega D_{xy}, M_{yy}, \omega D_{yy}, M_{yx}, \omega D_{yx}$

for bearing 1, etc. to and including the last bearing.

Card: (1P3E14.6) - Speed data.

Word 1 - initial speed.

Word 2 - final speed.

Word 3 - speed increment.

Card: (1P3E14.6) - Bearing data - in the order defined above with three values on each card as follows:

Word 1 - the coefficient A_0 of the expression $A = A_0 + A_1 \omega + A_2 \omega^2$

Word 2 - the coefficient A_1 of this expression.

Word 3 - the coefficient A_2 of this expression.

If word 8, card 3, is greater than 1, the program assumes the bearing data will be provided for each value of speed. In this case, a card is provided with a single speed value and this is followed by the bearing data as follows: all of the translatory stiffness and damping coefficients are provided in the order; two cards for each bearing. The first card contains the X coordinate translatory coefficients $K_{xx}, \omega C_{xx}, K_{xy}$ and ωC_{xy} and the second card the Y coordinate translatory coefficients $K_{yy}, \omega C_{yy}, K_{yx}$ and ωC_{yx} , both cards for bearing one followed by two cards for bearing two, etc., to the total number of bearings. Again, if word 6, card 3 is zero, no rotational parameters are required, otherwise, they are provided in a similar manner: one card of values $M_{xx}, \omega D_{xx}, M_{xy}, \omega D_{xy}$ and a second card of $M_{yy}, \omega D_{yy}, M_{yx}, \omega D_{yx}$ for bearing 1 followed by two cards each for the remaining bearings.

The card format in this case is then:

Card: (1PE14.6) - Speed.

Card: (1P4E14.6) - Bearing data in the order defined above with these values on each card as follows:

Card 1 - Word 1 - $K_{xx,n}$

Word 2 - $\omega C_{xx,n}$

Word 3 - $K_{xy,n}$

Word 4 - $\omega C_{xy,n}$

Card 2 - Word 1 - Kuyin

Word 2 - wCuyin

Word 3 - Kuyin

Word 4 - wCuyin

COMPUTER OUTPUT

The computer output is largely self-explanatory and each output item is identified by a descriptive text. Two sample cases are shown in Appendix A. The output first lists all the input data, i.e. the two heading cards, the control words, Youngs Modulus, the rotor data, the bearing stations, the unbalance data, the coupling stations, the pedestal data, the speed data and finally the bearing data. Thereafter follow the results of the calculations with one set of output for each specified rotor speed. First, the speed is given in RPM which may be followed by the input bearing data if it is new for every speed. Next, a 9 column list gives the rotor amplitude and bending moment at each rotor station. Both the amplitude and the bending moment require four quantities for their description. Since each rotor station whirls in an elliptical orbit it is convenient to express the four quantities in terms of the dimensions of the ellipse. Then the four quantities become:

1. the major axis of the ellipse: a (i.e. the maximum amplitude or the maximum bending moment during one revolution.
2. the minor axis of the ellipse: b
3. the angle between the x-axis of the overall reference system and the major axis of the ellipse: β , degrees (in output identified by: ANGLE X-MAJOR)
4. the phase angle with respect to the cosine-component of the unbalance: α , degrees.

The amplitude is given in thousands of an inch (mils) and the bending moment is given in lbs.in.

The selected method of presentation is illustrated by Fig. 5 and is given in detail in the analysis by Eqs. (37) to (41). However, a general description will also be given here.

The presentation is based on two reference coordinate systems. The first reference system is the stationary x-y system fixed with respect to ground, and which has at each rotor station its origin in the center of the statically deflected rotor (i.e. the deflection due to gravity). The x-y-system is "communicated" to the rotor via the specified values of the bearing spring and damping coefficients

($K_{xx}, K_{xy}, \omega C_u$, etc.) and the corresponding pedestal data. In other words, the directions of the x-axis and the y-axis are chosen when preparing the computer input and the choice reflects in the input values used for K_{xx}, K_{xy} etc. Then the elliptical rotor orbit is centered in the origin of the x-y-system (i.e. the steady state shaft center), it has a major axis a , a minor axis b , and the orientation of the ellipse is defined by the angle β between the x-axis and the major axis, measured in direction of rotor rotation. Note, that both a , b and β vary along the rotor. A negative value for b signifies backward whirl.

Thus a , b and β specify the dimensions and the orientation of the elliptical orbit but one more quantity is needed to specify the position of the moving shaft center on the ellipse at any given time. The phase angle α serves this purpose. Let the major axis be the x_1 -axis and the minor axis the y_1 -axis (see Fig.5), i.e. the x_1 - y_1 -system is obtained by rotating the x-y-system an angle β in the direction of rotor rotation. Then the instantaneous position of the shaft center is given by:

$$x_1 = a \cos(\omega t + \alpha)$$

$$y_1 = b \sin(\omega t + \alpha)$$

Note that the orientation of the x_1 - y_1 -system changes along the rotor since β does with respect to the x-y-system the instantaneous shaft center position is given by:

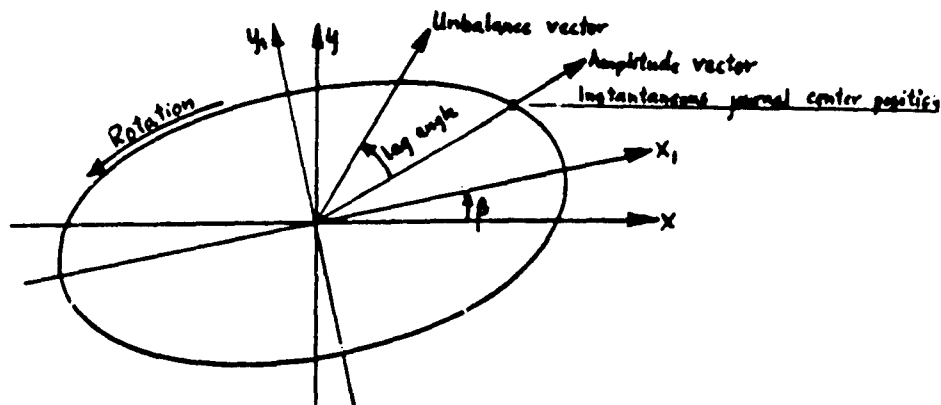
$$x = \sqrt{(a \cos \beta)^2 + (b \sin \beta)^2} \cdot \cos(\omega t + \alpha + \tan^{-1}(\frac{b}{a} \tan \beta))$$

$$y = \sqrt{(a \sin \beta)^2 + (b \cos \beta)^2} \cdot \sin(\omega t + \alpha + \tan^{-1}(\frac{b}{a} \tan \beta))$$

In addition to determining the instantaneous position of the shaft center with respect to a stationary coordinate system it also may be desired to know the position with respect to the rotor unbalance. The location of the unbalance in the rotor is defined by a coordinate system which is fixed in the rotating shaft and whose axes are called "the cosine axis" and "the sine axis". Hence, each unbalance consists of two components: a cosine component and a sine component (in the analysis the symbols U_x and U_y are used, respectively, see Eqs.(10) and (11)). The instantaneous orientation of the cosine-system is defined by the angle (ωt) between the fixed axis and the cosine-axis. Thus, the instantaneous phase angle between the amplitude vector (i.e. the radius vector from the center of the elliptical orbit going through the instantaneous shaft center position) and the total rotor unbalance vector is:

angle by which amplitude vector lags unbalance vector =

$$\omega t - \beta + \tan^{-1}\left(\frac{\sum U_{yn}}{\sum U_{xn}}\right) - \tan^{-1}\left(\frac{b}{a} \tan(\omega t + \alpha)\right)$$



Here, $\sum U_{xn}$ and $\sum U_{yn}$ indicates the summations of the cosine-components and the sine-components, respectively, of all unbalances. It is seen that the lag-angle is not constant as the shaft center moves around its orbit. It attains its maximum and minimum values when:

$$\tan^2(\omega t + \alpha) = \frac{a}{b}$$

Although the discussion above is primarily aimed at describing the motion of the shaft center (i.e. the computer output for the amplitude) the same description applies to the output for the bending moment. However, for each rotor station the output lists one line for the amplitude but two lines for the bending moment. Whereas the output for the amplitude applies at the rotor station itself the bending moment has one value immediately to the left of the station and another value immediately to the right of the station. The output gives the left hand value first (i.e. the output gives M_n and M'_n respectively, see Fig. 2). The two values are in general the same unless the particular station is a bearing station which resists tilting. The last listed value of the bending moment should always be zero (i.e. corresponding values of the major and minor axis should be zero). In general they are not exactly zero but very small. The amount by which the values differ from zero gives an indication of the accuracy of the calculation. Note, that for this reason the last values of the angles β and α are meaningless.

Following the output for the amplitude and for the bending moment come the results for the force transmitted to the bearing housing (equal to the dynamic bearing reaction). If the pedestals are flexible, the force transmitted to the foundation and the amplitude of the pedestal mass are also given. Each of the three quantities are presented in two ways: first in terms of the corresponding ellipse (i.e. in analogy to the rotor amplitude) and secondly by its x and y-components. Thus, if the transmitted force is F the output gives the quantities: the major axis, the minor axis, the orientation angle β , the angle α , $|F_x|$, α_x , $|F_y|$ and α_y where the last four items are defined as:

$$\text{force in x-direction: } F_x = |F_x| \cos(\omega t + \alpha_x)$$

$$\text{force in y-direction: } F_y = |F_y| \sin(\omega t + \alpha_y)$$

The transmitted force is given in lbs and the pedestal amplitude in thousandths of an inch (mils).

The next line of output serves as a check on the calculation. It gives the energy per revolution put into the system by the unbalance forces and the energy dissipated per revolution in the bearings and pedestals. Theoretically, the two values should be equal but numerical inaccuracies in the calculations cause a discrepancy. Normally they differ in the fifth or sixth decimal place. The energy is given in lbs.inch/revolution.

To convert it into HP multiply the energy value by the speed in RPM and divide by $3.96 \cdot 10^5$.

If the input does not include any gyroscopic moment effects the calculations are repeated for a new rotor speed and the output will follow the description given above. If the gyroscopic moment is included there are two sets of output for each rotor speed, each set having the format as explained above. The first set applies to a rotor without any gyroscopic moments, and the second set gives the final result for the calculation with the gyroscopic moment included. The

two sets are separated by a two column list giving the sequential results of the iterations needed to perform the gyroscopic moment calculation. The first column identifies the iteration number and the second column gives the relative convergence of the iteration procedure as explained in describing the computer input.

COMPUTER PROGRAM: THE STABILITY OF A ROTOR IN FLUID FILM BEARINGS

This section sets forth the basic analysis and the detailed instructions for using the computer program: PNO017: "The Stability of a Rotor in Fluid Film Bearings" for the IBM 704 digital computer. The program calculates the speed at onset of instability (the threshold speed) and the corresponding whirl frequency.

Each rotor support consists of a fluid film bearing mounted in a pedestal, both members possessing flexibility and damping. The bearing fluid film is represented by 8 dynamic coefficients and it is the value of these coefficients which primarily govern the instability mechanism. For a given application they vary with the speed of the rotor and they must be specified in the computer input for each speed to be tested. The bearing pedestals are represented by 2 spring coefficients and 2 damping coefficients (in the vertical and the horizontal direction, respectively) and the corresponding masses may also be given.

The program is to a large extent compatible with the unbalance response program such that much of the input data used in the latter program also applies to the stability program.

THEORETICAL ANALYSIS

The analysis is an extension of the methods used in the previous section to determine the unbalance response of the rotor. Thus, the following discussion assumes familiarity with the earlier given analysis. The rotor is again represented by a finite number of mass stations connected by weightless but stiff shaft sections which can be brought to approximate the actual rotor to any degree of accuracy depending on the number of mass stations. Each bearing is represented by 8 dynamic coefficients: K_{xx} , C_{xx} , K_{xy} , C_{xy} , K_{yx} , C_{yx} , K_{yy} and C_{yy} , which depend on the operating speed of the rotor: ω , radians/sec.

The purpose of the analysis is to establish the onset of instability of the rotor-bearing system. No external forces act on the rotor (i.e. there are no unbalance forces), instead the dynamical equilibrium of the steady-state operation of the

system is tested for a series of discrete speed values over a speed range. This is done by disturbing the rotor with an assigned frequency ν radians/sec. To this end the previously established equations are used as summarized in Eqs.(32) by replacing ω with ν or since ω is given, the disturbing frequency is specified as a ratio of the speed:

$$\frac{\nu}{\omega} \quad (\text{note: } \nu = \left(\frac{\nu}{\omega}\right) \omega)$$

The rotor unbalance components U_{xn} and U_{yn} are eliminated. Applying Eqs.(32) and the boundary conditions Eqs. (33) and (34) yields Eq.(35) where the right hand side is now equal to zero.

Since the assigned frequency is a pure frequency and does not contain a transient term the outlined procedure applies to the threshold of instability. In other words, the calculation determines the state of neutral stability at which the effect of any disturbance continues indefinitely without either increasing or decreasing. Hence, at the point of neutral stability there must be a finite, although undetermined, solution for the rotor amplitudes, i.e. the 8 end values, $\theta_{c1}, \theta_{s1}, \dots, y_{s1}$ cannot all vanish. This implies that the determinant on the left hand side of Eq.(35) must be zero for the system to be neutrally stable.

On this basis, a calculation procedure can be devised. Select a sufficiently low value of the rotor speed that the system is known to be stable and scan the entire frequency range to obtain the value of the determinant for each frequency. Repeat the calculations for an increased rotor speed and proceed in this way until a speed is encountered at which the determinant becomes zero. At that particular speed the rotor-bearing system is on the threshold of instability and any further increase in the rotor speed will make the system unstable.

Although the method is quite simple in principle certain difficulties arise in applying the method. Considering the matrix in Eq.(35) it is seen to be an 8 by 8 matrix in which all elements are real. Actually, it can be written as a 4 by 4 matrix with complex elements. Therefore, its determinant will always be positive and in applying the outlined calculation procedure the zero-point of the determinant will appear as a minimum. There will be no cross-over from a positive value to a negative value, or, in other words, at the onset of

instability the chosen form of the determinant has a repeated root. Thus, it is necessary to plot the determinant as a function of the rotor speed to be able to establish when it becomes zero. However, the determinant also depends on the disturbing frequency and it only vanishes for a particular value of that frequency. It is, therefore, also necessary to know the frequency-value at which the determinant should be evaluated at each rotor speed.

For this reason it is chosen to calculate the real and imaginary part of the 4 by 4 complex determinant which is equivalent to the 8 by 8 real determinant.

Denote the real matrix:

$$B_{2n} = \begin{Bmatrix} b_{11} & \dots & b_{1,2n} \\ \vdots & & \vdots \\ b_{2n,1} & \dots & b_{2n,2n} \end{Bmatrix} \quad (n = 4 \text{ in the present case})$$

and let the corresponding complex matrix by:

$$A_n = \begin{Bmatrix} a_{11} & \dots & a_{1n} \\ \vdots & & \vdots \\ a_{n1} & \dots & a_{nn} \end{Bmatrix} \quad (n = 4 \text{ in the present case})$$

With the convention followed in the present analysis the two matrices are related by:

$$\begin{aligned} b_{11} &= \operatorname{Re} \{a_{11}\} & b_{12} &= \operatorname{Im} \{a_{11}\} \\ b_{21} &= -\operatorname{Im} \{a_{11}\} & b_{22} &= \operatorname{Re} \{a_{11}\} \end{aligned}$$

etc.

Let these matrices be the coefficient matrices in a set of linear equations:

$$(50) \quad B_{2n} \cdot X = U$$

$$(51) \quad A_n \cdot Z = W$$

where:

$$X = \begin{Bmatrix} x_1 \\ y_1 \\ x_2 \\ \vdots \\ y_n \end{Bmatrix} \quad U = \begin{Bmatrix} u_1 \\ v_1 \\ u_2 \\ \vdots \\ v_n \end{Bmatrix} \quad Z = \begin{Bmatrix} z_1 \\ z_2 \\ \vdots \\ z_n \end{Bmatrix} \quad W = \begin{Bmatrix} w_1 \\ w_2 \\ \vdots \\ w_n \end{Bmatrix}$$

such that:

$$z_j = x_j - iy_j \quad j = 1, n$$

$$w_j = u_j - iv_j \quad j = 1, n$$

Since the two equations are equivalent they must yield the same solution. Therefore, first set: $w_1 = w_2 = \dots = w_{n-1} = 0$ and $w_n = i$ which means: $u_1, u_2, \dots, u_n = 0$, $v_1 = v_2 = \dots = v_{n-1} = 0$ and $v_n = -1$. Solve Eq.(51) for z_n :

$$(52) \quad z_n = \frac{i \bar{A}_{n-1}}{\bar{A}_n} = \frac{i \bar{A}_{n-1} (\Delta_{nr} - i \Delta_{ni})}{\Delta_{nr}^2 + \Delta_{ni}^2}$$

where $\bar{A}_n$ is the determinant of A_n , $\bar{A}_{n-1}$ is the determinant of A_n with the n'th column and row removed, and:

$$\Delta_{nr} + i \Delta_{ni} = \bar{A}_n$$

i.e., Δ_{nr} and Δ_{ni} are the real and imaginary parts, respectively of the complex matrix and it is desired to calculate them.

Next, solve Eq.(50) for x_n and y_n with $v_n = -1$:

$$(53) \quad x_n = -\frac{\bar{B}'_{2n-1}}{\bar{B}_{2n}}$$

$$(54) \quad y_n = -\frac{\bar{B}_{2n-1}}{\bar{B}_{2n}}$$

where $\bar{B}_{2n}$ is the determinant of B_{2n} , $\bar{B}_{2n-1}$ is the determinant of B_{2n} with the n'th column and row removed, and $\bar{B}'_{2n-1}$ is the determinant of B_{2n} with the (n-1)'th column and the n'th row removed. Furthermore, it is known that:

$$\bar{B}_{2n} = |\bar{A}_n|^2 = \Delta_{nr}^2 + \Delta_{ni}^2$$

Equate Eqs. (52), (53) and (54) to get:

$$\frac{i \bar{A}_{n-1} (\Delta_{nr} - i \Delta_{ni})}{\Delta_{nr}^2 + \Delta_{ni}^2} = \frac{\bar{B}'_{2n-1} + i \bar{B}_{2n-1}}{\Delta_{nr}^2 + \Delta_{ni}^2}$$

or:

$$(55) \quad \Delta_{nr} - i \Delta_{ni} = \frac{\bar{B}_{2n-1} - i \bar{B}'_{2n-1}}{\bar{A}_{n-1}} = \frac{\bar{B}_{2n-1} - i \bar{B}'_{2n-1}}{\bar{B}_{2n-2}} (\Delta_{n-1,r} - i \Delta_{n-1,i})$$

where $\bar{B}_{2n-2}$ is the determinant of B_{2n} with the two last columns and rows deleted and:

$$\Delta_{n-1,r} + i\Delta_{n-1,i} = \bar{A}_{n-1}$$

Thus, Eq.(55) gives a recurrence formula where the order of the original determinant is reduced by 1. If it is applied repeatedly the final result becomes:

$$(56) \quad \Delta_{nr} - i\Delta_{ni} = \prod_{k=1}^n \frac{\bar{B}_{2k-1} - i\bar{B}'_{2k-1}}{\bar{B}_{2k-2}}$$

with the definition:

$$\bar{B}_0 = 1$$

and:

(57) $\bar{B}_{2k-1}$ is the determinant corresponding to the first $(2k-1)$ columns and rows of the matrix B_{2n}

(58) $\bar{B}'_{2k-1}$ is the determinant corresponding to the first $(2k-1)$ columns and rows of the matrix B_{2n} but where the $(2k-1)$ 'th column has been interchanged with the $2k$ 'th column.

(59) $\bar{B}_{2k-2}$ is the determinant corresponding to the first $(2k-2)$ columns and rows of the matrix B_{2n} .

Thus a method has been established to calculate the real and imaginary part of an n by n complex determinant. The method is used to evaluate the determinant of the 8 by 8 matrix in Eq. (35).

It may be noted that Eq. (35) and Eq. (50) are identical except for the change in nomenclature. Hence, in Eq. (50) X represents the 8 rotor end coordinates: $\theta_{cl}, \theta_{sl}, \dots, y_{cl}, y_{sl}$ and V represents the moment and shear components at the other end of the rotor: $M_{xcr}, M_{xsr}, \dots, V_{ycr}, V_{ysr}$. Eq. (50) is solved in Eqs. (53) and (54) for the case of $v_n = -1$, i.e. for $V_{ysr} = -1$ which means that a force:

$$force = -\sin vt$$

has been applied to the rotor end. The corresponding amplitude at the same rotor end can be computed as described in the rotor response analysis. Let the y -component be:

$$amplitude = y_{cr} \cos Vt + y_{sr} \sin Vt$$

The energy input imparted to the rotor motion is:

$$(60) \quad \text{Energy per cycle} = \int_0^{2\pi} -\sin vt (-\nu y_r \sin vt + \nu y_s \cos vt) dt = \pi y_{cr}$$

A positive energy input implies that energy is required to sustain the particular vibratory motion, i.e. the motion is stable. On the other hand, a negative energy input signifies an unstable motion. When the energy input is zero the motion is neutrally stable. It must be noted that the motion itself may not be possible unless the previously discussed determinant is also zero, i.e. the outlined energy criterion can not be used alone to test the stability of the rotor-bearing system. However, the criterion can be used to determine the value of the instability frequency.

A simple example may serve as an illustration. Let a single mass M be supported on a spring with a coefficient K and a dashpot coefficient C . The amplitude is:

$$y_c \cos vt + y_s \sin vt$$

Apply a force $V_{ys} \sin vt$ such that the equations of motion become:

$$\begin{Bmatrix} (K-Mv^2) & \nu C \\ -\nu C & (K-Mv^2) \end{Bmatrix} \begin{Bmatrix} y_c \\ y_s \end{Bmatrix} = \begin{Bmatrix} 0 \\ V_{ys} \end{Bmatrix}$$

in analogy to Eq. (35). The determinant becomes:

$$(K-Mv^2)^2 + (\nu C)^2 \quad (\text{note: the determinant is always positive})$$

which vanishes when $\nu C = 0$ and $v^2 = K/M$, i.e. the frequency must be such that it simultaneously makes the damping νC zero and also equals the natural frequency of the system. Next, solving for y_c and computing the energy input yields:

$$\text{Energy input per cycle} = -\pi V_{ys} y_c = \pi V_{ys}^2 \frac{\nu C}{(K-Mv^2)^2 + (\nu C)^2}$$

Applying the energy criterion from above the motion is unstable when νC is negative and vice versa, which is of course evident in this simple case. However, the system is only neutrally stable if in addition the frequency also equals the natural frequency: $v = \sqrt{\frac{K}{M}}$.

In calculating the energy input from Eq.(60) it is seen that a difficulty arises when the system determinant is equal to zero in which case the amplitude y_{cr} cannot be determined. To circumvent this problem, y_{cr} is not computed as its actual value. In evaluating $\theta_{cl}, \theta_{sl}, \dots, y_{sl}$ from Eq. (35) with $V_{ysr} = -1$, Cramer's rule is used but such that the system determinant is always set equal to 1 regardless of its true value. Thus, the resulting calculated energy should actually be divided by the system determinant to obtain the real value of the energy input.

To solve for the onset of instability the procedure is:

- a. Select a rotor speed sufficiently small that the system is known to be stable.
- b. Scan the frequency range and determine those frequency values at which the real part and the imaginary part of the system determinant equal zero.
- c. Repeat the calculation for several values of the rotor speed covering a sufficiently large speed range.
- d. Plot curves of frequency versus rotor speed, obtaining one (or more) curve corresponding to the real part of the determinant being zero and one (or more) curve corresponding to the imaginary part being zero. The intersection of the curves determines the threshold speed.

To assist in searching for the instability frequency the single bearing frequency value is determined for each bearing. This value is derived by considering a stiff, symmetric rotor supported in similar bearings. Let the rotor mass per bearing be M whereby the equations of motion becomes:

$$(61) \quad \begin{Bmatrix} (K_{xx} - Mv^2 + i\nu C_{xx}) & (K_{xy} + i\nu C_{xy}) \\ (K_{yx} + i\nu C_{yx}) & (K_{yy} - Mv^2 + i\nu C_{yy}) \end{Bmatrix} \begin{Bmatrix} x \\ y \end{Bmatrix} = 0$$

The real and the imaginary parts of the determinant have to equal zero separately:

$$(62) \quad (K_{xx} - Mv^2)(K_{yy} - Mv^2) - K_{xy}K_{yx} - v^2(C_{xx}C_{yy} - C_{xy}C_{yx}) = 0$$

$$(63) \quad (K_{xx} - Mv^2)C_{yy} + (K_{yy} - Mv^2)C_{xx} - K_{xy}C_{yx} - K_{yx}C_{xy} = 0$$

Solve the equations to get:

$$(64) \quad \left(\frac{v}{\omega}\right)^2 = \frac{(K_{xx} - Mv^2)(K_{yy} - Mv^2) - K_{xy}K_{yx}}{\omega C_{xx}\omega C_{yy} - \omega C_{xy}\omega C_{yx}}$$

$$(65) \quad Mv^2 = \frac{K_{xx}\omega C_{yy} + K_{yy}\omega C_{xx} - K_{xy}\omega C_{yx} - K_{yx}\omega C_{xy}}{\omega C_{xx} + \omega C_{yy}}$$

Computing Eq. (65) first and substituting into Eq. (64) yields the instability frequency ratio $\frac{v}{\omega}$ for the bearing. Since for the actual rotor the bearing reactions are in general unequal and the 8 bearing coefficients, therefore, differ in value among the bearings the instability frequency will not have the same value for all the bearings. However, the instability frequency for the rotor-bearing system will lie between the minimum and maximum value of the bearing frequencies.

COMPUTER INPUT

The input data is prepared according to the instructions given in the following. Note, that unless stated otherwise no input card may be omitted.

Card 1 FORMAT (49 cols. Hollerith) Any descriptive text, used to identify the particular calculation, may be punched in cols. 2-49.

Card 2 FORMAT (6I5) Control parameters:

Word 1 (NS) Number of rotor mass stations. The number of stations is selected according to the previous discussion. There must be a mass station at each rotor end and at each bearing. The mass at a station may be zero. The maximum number of stations is 30.

Word 2 (NB) Number of bearings. This integer denotes the total number of bearings along the rotor. A maximum of 10 bearings is allowed.

Word 3 (NFR) Number of frequency ratios. This integer specifies the number of items in the input list for the frequency ratios.

Word 4 (NCAL) Number of speed and bearing data input sets. Each set of data consists of a speed range and the values of the 8 dynamic coefficients for each bearing. The speed range is specified by an initial speed, a final speed and a speed increment. For each speed value in the speed range the frequency range is scanned and the corresponding values of the system determinant are calculated. There is no limitation on the value of the input item.

Word 5 (NPST) Pedestal flexible/rigid. If this integer is zero the program assumes the pedestals to be rigid and no pedestal data can be furnished. If the integer is 1 the pedestal has both flexibility and damping and the pedestal data must be given.

Word 6 (INP) Input. If this integer is zero the program will return to read in a new set of input upon completion of the computation. For the last set of input the integer should be 1.

CARD 3: FORMAT (1XE13.6)

This card contains a single word, Youngs modulus E in lbs/in^2 . It is constant throughout the rotor. Since the program never uses E by itself but always in the product EI (I = cross-sectional moment of inertia) any actual variation in E can be absorbed in a corresponding change of I .

Rotor Data: FORMAT (4(1XE13.6))

The rotor data consist of as many cards as there are mass stations (card 2, word 1). Each card has 4 words:

Word 1: the mass at the station in lbs.

Word 2: the length of the shaft section to the right of the station in inches

Word 3: the cross-sectional moment of inertia of the shaft section to the right of the station in in^4 .

Word 4: the polar mass moment of inertia minus the transverse mass moment of inertia, lbs.in^2 .

For the last mass station the shaft length and the cross-sectional moment of inertia has no meaning and may be set equal to zero.

LOCATION OF BEARING SUPPORTS: FORMAT (10(1X14))

This list of integers provides the number of each mass station at which there is a bearing. The stations should be listed in sequence, beginning with the lowest number.

PEDESTAL DATA: FORMAT (6(1XE11.4))

If the pedestals are rigid no pedestal data are required and item 5, card 2, must be zero. Otherwise, the data for each pedestal must be provided. There is one card for each pedestal and they should be in the same sequence as the bearing station numbers in the previous list. Each card contains 6 words:

Word 1: the vibratory mass of the pedestal for motion in the x-direction, lbs.

Word 2: the pedestal stiffness in the x-direction, lbs/in

Word 3: the pedestal damping coefficient in the x-direction, lbs.sec/in

Word 4: the vibratory mass of the pedestal for motion in the y-direction, lbs.

Word 5: the pedestal stiffness in the y-direction, lbs/in

Word 6: the pedestal damping coefficient in the y-direction, lbs.sec/in

LIST OF FREQUENCY RATIO VALUES: FORMAT (4(1XE13.6))

This input list gives the values of the frequency ratio $\frac{v}{\omega}$ at which the program evaluates the system determinant (v = disturbance frequency, radians/sec, ω = angular speed of rotor, radians/sec). The values should be given in descending order, for instance: $\frac{v}{\omega} = .55, .50, .49, .45, .40 \dots$. The program automatically inserts in the list the "eigen-instability" frequency ratio from each bearing determined from Eqs. (64) and (65). In most cases these values are equal to approximately .5 but may be less for heavily loaded bearings. Unfortunately, the "instability" frequency ratio is very sensitive to even small deviations in the dynamic bearing coefficients from their accurate values. It is, therefore, recommended that the input values of the bearing coefficients be checked beforehand by means of Eqs. (64) and (65). If the thus calculated frequency ratio value differs much from .5 the bearing coefficients should be checked.

ROTOR SPEED AND BEARING DATA

The following input data should be repeated as many times as specified by word card 2. First comes a card giving the speed range for the calculations. The speed range is defined by an initial speed value, a final speed value and a speed increment, all in RPM. Thus, if the initial speed is given as 3000 RPM, the final speed as 9000 RPM, and the speed increment as 1000 RPM calculations are performed for 3000, 4000, 5000, 6000, 7000, 8000 and 9000 RPM.

Next follows the 8 dynamic coefficients for each bearing. There are 4 values per card, hence, there are 2 cards per bearing. The first card gives K_{xx} , ωC_{xx} , K_{xy} and ωC_{xy} , and the second card gives K_{yy} , ωC_{yy} , K_{yx} and ωC_{yx} . All the coefficients are measured in lbs/inch. The cards should be given in the same sequence as the bearing station numbers in the previous input list.

COMPUTER OUTPUT

An example of the output is included in Appendix B.

The first page of the output lists the input values for checking and control purposes. Next, follows the results of the calculations with the results for each rotor speed given separately. The first line specifies the particular speed

and then follows the "eigen" - instability frequency in RPM and the "eigen" - mass in lbs for each bearing as determined from Eqs. (64) and (65). They are labeled: "INST.FREQ, RPM" and "INST.WEIGHT", respectively. Thereafter the results of the calculations for each frequency are listed in 5 columns. The first column, labeled "FREQ.RAT.", gives the frequency ratio $\frac{v}{\omega}$. The second column, labeled "DETERMINANT", gives the square root of the system determinant (i.e. of the matrix in Eq. (35)). The third and the fourth columns, labeled "RE(DET)" AND "IM(DET)" gives the real and the imaginary part of the system determinant, respectively (i.e. Δ_{nr} and Δ_{ni} from Eq. (56)). The last column, labeled "ENERGY", is proportional to the energy input given by Eq. (60).

It should be noted that in order to determine if the rotor is stable or unstable it is necessary to find at which speed it becomes unstable. Hence, results must be available over a range of speeds. To determine that speed, at which instability sets in, the results must be plotted. One method is as follows: for each speed, plot the real and imaginary part of the system determinant against the frequency ratio. Find those frequency ratio values at which the two functions become zero, (there are usually several values). Next, plot the "zero-point" frequency ratios against the rotor speed, obtaining a curve corresponding to the imaginary part of the determinant. Where the two curves intersect is the threshold speed. Thus, for the output example given in Appendix B the threshold speed is found to be 8,350 RPM at a frequency ratio of .4937.

ACKNOWLEDGMENT

The analyses and the computer program described in the present report are developed from two basic computer programs which resulted from an internal research program by Mechanical Technology Inc.

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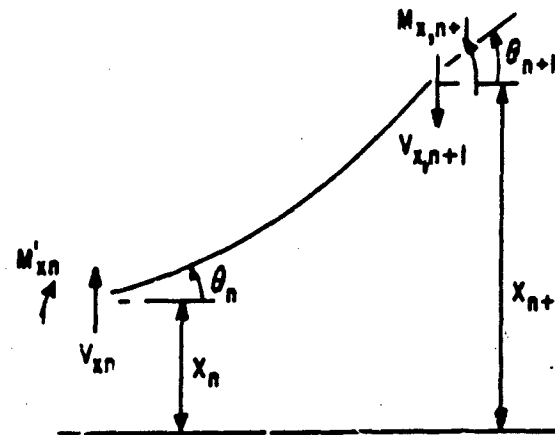


FIG.1 SHAFT SECTION BETWEEN TWO MASS STATIONS

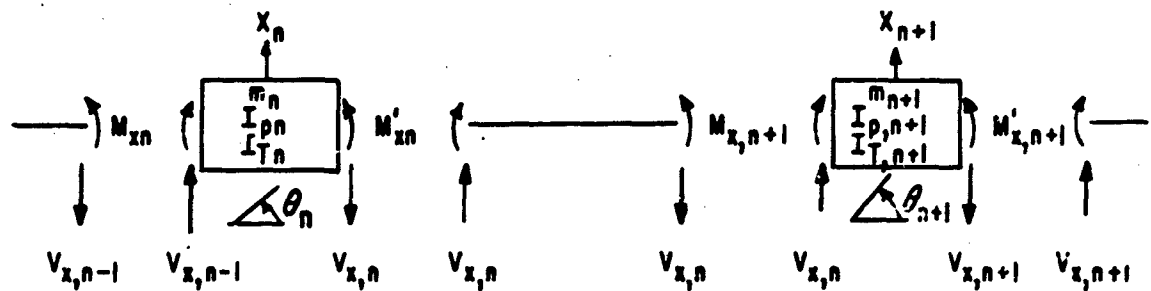


FIG.2 CONVENTION AND NOMENCLATURE FOR ROTOR CALCULATION

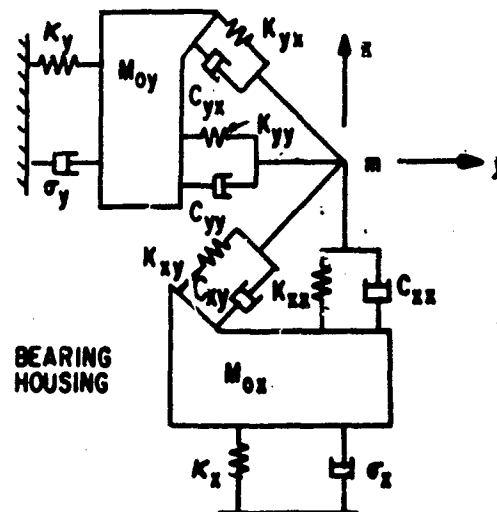


FIG.3 BEARING AND PEDESTAL SYSTEM FOR TRANSLATORY MOTION

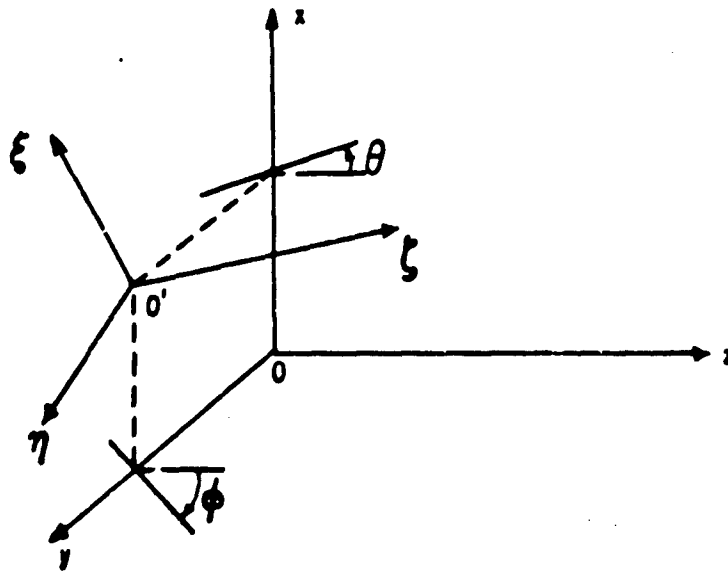


FIG. 4 GYROSCOPIC MOMENT CALCULATION

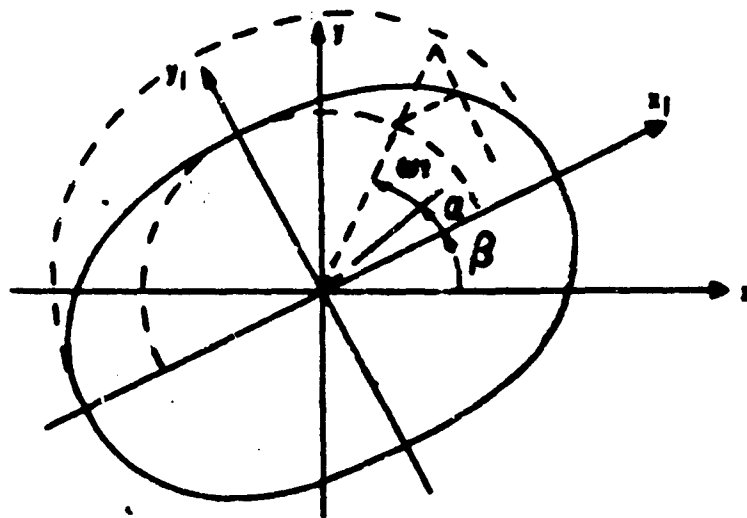


FIG. 5 ELLIPTICAL UMRL PATH

APPENDIX A

SAMPLE CALCULATIONS AND INPUT FORMS FOR THE COMPUTER PROGRAM
"UNBALANCE RESPONSE OF A ROTOR IN FLUID FILM BEARINGS"

```

SUNO          0.5.5000          65-341.FREEMAN,SESCD
SINJOR FREMAN FLOCS,MAP
SIBETC ROTOR M94,XR7,NODECK,LIST
C MECHANICAL TECHNOLOGY,INC. JORGEN W. LUND
C UNBALANCE RESPONSE OF ROTOR IN NON-UNIFORM BEARINGS PNOG11
  DIMENSION B(XC(10,80),BMXS(10,80),BMYC(10,80),BMSY(10,80),VXC
11(10,41),VXS(10,41),VYC(10,41),VYS(10,41),DXC(10,40),DAS(10,40),DYC
21(10,40),DYS(10,40),XC(10,40),XS(10,40),YC(10,40),YS(10,40),DMXA(40
31),DMXB(40),DMXC(40),DMXD(40),DMA(40),DMYB(40),DMYC(40),DMYD(40),
40VXA(40),DVXB(40),LC(40),DVXD(40),DVYA(40),DVYB(40),DVYC(40),
50VYD(40),RM(40),RL(40),RS(40),RIP(40),RIT(40),DIA(40),DIS(40),DIC(
640),DID(40),AN(40),BN(40),DN(40),UX(40),UY(40),LU(40),LB(25),BKXX(
73,25),BCXX(3,25),BKXY(3,25),BCXY(3,25),BKYY(3,25),BCYY(3,25),BKXY(
83,25),BCYX(3,25),BSMXX(3,25),BDMXX(3,25),BSMXY(3,25),BDMXY(3,25),
9BSMYX(3,25),BDMYY(3,25),BSMYX(3,25),BDMYX(3,25)
  DIMENSION PMX(25),PMY(25),PKX(25),PCX(25),PKY(25),PCY(25),PIX(25),
1PIY(25),PSMX(25),POMX(25),PSMY(25),PDMY(25),LC(20),A(8,8),B(8,4),
2C(8,4),D(8,1),F(4,4,20),CFM(8,8),ENT(10),RHS(8,1),DVUX(80),
3 DVUY(80),DUMMY(300),SHA(3),SHB(3),SHC(3),SHD(3),AUX(25,4,3),
4BUX(25,4,3),DUM1(100),CLNR(8)
  COMMON A , B , C , D , CFM , ENT
  COMMON RHS , DUM1 , CF9 , MAT , KFN , CLNR
  COMMON PRN3
  COMMON NS,NB,NU,NC,NPST,NMOM,NGYK,NCAL,NDIAG,INPUT,YM,SCF,RM,RL,
1RS,NIT,DGYR,RIP,RIT,LB,LU,UX,U",LC,PMX,PKX,PCX,PMY,PKY,PCY,KST,
2PIX,PSMX,PDXX,PIY,PSMY,PDY,SPST,SPFN,SPINC,BKXX,BCXX,BKXY,BCXY,
3BKYY,BCYY,BKXX,BCYX,BSMXX,BDMXX,BSMXY,BDMXY,BSMYX,BDMYY,BSMYX,
4BDMYX,CF1K,CF1C,CF1D,CF1E,CF2K,CF2C,CF2D,CF2E,CF2A,CF2B,CF2M,CF2N,
5CF1A,CF1B,CF1M,CF1N,CF1,CF2,CF3,CF4,CF5,CF6,CF7,CF8,STF,ANSP2,
6ANSP,SPCAL,DVXA,DVXB,DVXC,DVXD,DVYA,DVYB,DVYC,DVYD,DMXA,DMXB,DMXC,
7DMXD,DMYA,DMYB,DMYC,DMYD,AN,BN,DN,III
  COMMON BMXC,BMXS,BMYC,BMSY,XC,XS,YC,YD,DXC,DXS,DYC,DYS,XC,XS,
1YC,YS,DIA,DIB,DIC,DID,DVUX,DVUY,DUMMY,SHA,SHB,SHC,SHD,AUX,BUX
  COMMON JCAL,AMS,NITC
201 III=1
200 CALL SUBR
C ROTOR CALCULATION
400 CF1=0.0
  CF2=0.0
  CF3=0.0
  CF4=0.0
  CF5=0.0
  CF6=0.0
  CF7=0.0
  CF8=0.0
  NITC=1
  IST=1
  ITN=9
401 JST=1
  NCC=1
  IF(INC) 403,403,402
402 JFN=LC(1)
  GO TO 404
403 JFN=NS
404 DO 405 J=1,NS
  DVUX(J)=0.0
405 DVUY(J)=0.0
  DO 422 I=1,T,IFN
  KST=J
  IF(JST-1) 411,411,406
406 KFN=JST+JST
  BMXC(1,KFN)=0.0
  BMXS(1,KFN)=0.0

```

BMXC(1,KFN)=0.0	3270
BMXS(1,KFN)=0.0	3280
DXC(1,JST)=0.0	3290
DXS(1,JST)=0.0	3300
DYC(1,JST)=0.0	3310
DYS(1,JST)=0.0	3320
GO TO (407,408,409,410,418,418,418,416,418),KST	3330
407 DXC(1,JST)=1.0	3340
GO TO 418	3350
408 DXS(2,JST)=1.0	3360
GO TO 418	3370
409 DYC(3,JST)=1.0	3380
GO TO 418	3390
410 DYS(4,JST)=1.0	3400
GO TO 418	3410
411 BMXC(1,1)=0.0	3420
BMXS(1,1)=0.0	3430
BMXC(1,1)=0.0	3440
BMXS(1,1)=0.0	3450
VXC(1,1)=0.0	3460
VXS(1,1)=0.0	3470
VYC(1,1)=0.0	3480
VYS(1,1)=0.0	3490
XC(1,1)=0.0	3500
XS(1,1)=0.0	3510
YC(1,1)=0.0	3520
YS(1,1)=0.0	3530
DXC(1,1)=0.0	3540
DXS(1,1)=0.0	3550
DYC(1,1)=0.0	3560
DYS(1,1)=0.0	3570
GO TO (407,408,409,410,412,413,414,415,416,418),KST	3580
412 XC(5,1)=1.0	3590
GO TO 418	3600
413 XS(5,1)=1.0	3610
GO TO 418	3620
414 YC(7,1)=1.0	3630
GO TO 418	3640
415 YS(8,1)=1.0	3650
GO TO 418	3660
416 DO 417 J=1,N0	3670
KST=LU(J)	3680
DVUX(KST)=UX(J)*ANSP2	3690
417 DVUY(KST)=UY(J)*ANSP2	3700
418 DO 422 J=JST,JFN	3710
KST=J+J	3720
KFN=KST-1	3730
KMD=KST+1	3740
IF(JST-1) 420,420,419	3750
419 IF(J-JST) 421,421,420	3760
420 BMXC(1,KST)=BMXC(1,KFN)+DMXA(J)*DXC(1,J)+DMXB(J)*DXS(1,J)+DMXC(J)*	3770
1DYC(1,J)+DMXD(J)*DYS(1,J)+DMY(J)	3780
BMXS(1,KST)=BMXS(1,KFN)-DMXH(J)*DXC(1,J)+DMXA(J)*DXS(1,J)-DMXD(J)*	3790
1DYC(1,J)+DMXC(J)*DYS(1,J)+DMY(J)	3800
BMXC(1,KST)=BMXC(1,KFN)+DMYC(J)*XC(1,J)+DMYB(J)*XS(1,J)+DMY(J)*	3810
1DYC(1,J)+DMYH(J)*YS(1,J)+DMY(J)	3820
BMXS(1,KST)=BMXS(1,KFN)-DMYB(J)*XC(1,J)+DMYC(J)*XS(1,J)-DMYH(J)*	3830
1DYC(1,J)+DMYH(J)*YS(1,J)+DMY(J)	3840
VXC(1,J+1)=VXC(1,J)+DVXA(J)*XC(1,J)-DVXB(J)*XS(1,J)-DVXC(J)*YC(1,J	3850
1)-DVXD(J)*YS(1,J)+DVYX(J)	3860
VXS(1,J+1)=VXS(1,J)+DVXB(J)*XC(1,J)+DVXA(J)*XS(1,J)+DVXD(J)*YC(1,J	3870
1)-DVXC(J)*YS(1,J)-DVYX(J)	3880
VYC(1,J+1)=VYC(1,J)-DVYC(J)*XC(1,J)-DVYB(J)*XS(1,J)+DVYA(J)*YC(1,J	3890

	1) -DVY(I,J)*YS(I,J)+DVUY(I,J)	3907
	VYS(I,J+1)=VYS(I,J)+DVYD(I,J)*XC(I,J)-DVYC(I,J)*XS(I,J)+DVYB(I,J)*YC(I,J)	3910
	1) +DVYA(I,J)*YS(I,J)+DVUX(I,J)	3920
	IF(JFN-J) 422,422,421	3930
421	BMXC(I,KMD)=BMXC(I,KST)+RL(I,J)*VXC(I,J+1)	3940
	BMXS(I,KMD)=BMXS(I,KST)+RL(I,J)*VXS(I,J+1)	3950
	BMYC(I,KMD)=BMYC(I,KST)+RL(I,J)*VYC(I,J+1)	3960
	BMYS(I,KMD)=BMYS(I,KST)+RL(I,J)*VYS(I,J+1)	3970
	DXC(I,J+1)=DXC(I,J)+AN(I,J)*BMXC(I,KST)+BN(I,J)*VXC(I,J+1)	3980
	DXS(I,J+1)=DXS(I,J)+AN(I,J)*BMXS(I,KST)+BN(I,J)*VXS(I,J+1)	3990
	DYC(I,J+1)=DYC(I,J)+AN(I,J)*BMYC(I,KST)+BN(I,J)*VYC(I,J+1)	4000
	DYS(I,J+1)=DYS(I,J)+AN(I,J)*BMYS(I,KST)+BN(I,J)*VYS(I,J+1)	4010
	XC(I,J+1)=XC(I,J)+RL(I,J)*DXC(I,J)+BN(I,J)*BMXC(I,KST)+DN(I,J)*VXC(I,J+1)	4020
	1)	4030
	XS(I,J+1)=XS(I,J)+RL(I,J)*DXS(I,J)+BN(I,J)*BMXS(I,KST)+DN(I,J)*VXS(I,J+1)	4040
	1)	4050
	YC(I,J+1)=YC(I,J)+RL(I,J)*DYC(I,J)+BN(I,J)*BMYC(I,KST)+DN(I,J)*VYC(I,J+1)	4060
	1)	4070
	YS(I,J+1)=YS(I,J)+RL(I,J)*DYS(I,J)+BN(I,J)*BMYS(I,KST)+DN(I,J)*VYS(I,J+1)	4080
	1)	4090
422	CONTINUE	4100
	IF(NDIAG) 423,424,423	4110
C	DIAGNOSTIC 2	4120
423	WRITE (6,136)	4130
	WRITE (6,116) (IST,JFN,JST,JFN,KST,KFN,KMD,NCC	4140
	WRITE (6,144) ((DXC(I,J),DXS(I,J),DYC(I,J),DYS(I,J), XC(I,J),XS(I	4150
	1),J),YC(I,J),YS(I,J),I=1,10),J=1,NS)	4160
	WRITE (6,145) (DIA(I,J),DIR(I,J),DIC(I,J),DID(I,J),DVUX(I,J), DVUY(I,J),J=1	4170
	1,NS)	4180
	KST=NS+1	4190
	WRITE (6,104) ((VXC(I,J),VXS(I,J),VYC(I,J),VYS(I,J), I=1,10),J=1	4200
	1,KST)	4210
	KST=NS+NS	4220
	WRITE (6,104) ((BMXC(I,J),BMXS(I,J),BMYC(I,J),BMYS(I,J),I=1,10),J=1	4230
	1,KST)	4240
424	IF(NS-JFN) 446,444,425	4250
C	ROTOR HAS COUPLING STATIONS	4260
425	KST=JFN+JFN	4270
	IF(IST-10) 426,438,438	4280
426	DO 427 J=1,4	4290
	F(1,J,NCC)=BMXC(J,KST)	4300
	F(2,J,NCC)=BMXS(J,KST)	4310
	F(3,J,NCC)=BMYC(J,KST)	4320
	F(4,J,NCC)=BMYS(J,KST)	4330
	KFN=J+4	4340
	B(1,J)=-BMXC(KFN,KST)	4350
	B(2,J)=-BMXS(KFN,KST)	4360
	B(3,J)=-BMYC(KFN,KST)	4370
	B(4,J)=-BMYS(KFN,KST)	4380
	DO 427 I=1,4	4390
	A(I,J)=F(I,J,NCC)	4400
427	C(I,J)=F(I,J,NCC)	4410
	CF9=5CF	4420
	MA7=1	4430
	IF(NDIAG) 429,430,429	4440
C	DIAGNOSTIC 3	4450
429	WRITE (6,137)	4460
	WRITE (6,104) ((C(I,J),I=1,4),J=1,4),((B(I,J),I=1,4),J=1,4),((A(I,J	4470
	1),I=1,4),J=1,4),((F(I,J,NCC),I=1,4),J=1,4)	4480
430	KFN=KFN	4490
	CALL EQS	4500
	GO TO (431,510,511),KFN	4510
431	D(1,1)=-BMXC(9,KST)	4520

V(2,1)=-BMXS(9,KST)	4530
U(3,1)=-BMYC(9,KST)	4540
D(4,1)=-BMYS(9,KST)	4550
C79=SCF	4560
MAT=7	4570
KFN=KFN	4580
CALL EQS	4590
GO TO (432,510,511),KFN	4600
432 DO 433 I=1,4	4610
433 A(I,5)=C(I,1)	4620
DO 434 J=JST,JFN	4630
DO 434 K=1,5	4640
KST=K+4	4650
DO 434 I=1,4	4660
VXC(KST,J+1)=VXC(KST,J+1)+VXC(I,J+1)*A(I,K)	4670
VXS(KST,J+1)=VXS(KST,J+1)+VXS(I,J+1)*A(I,K)	4680
VYC(KST,J+1)=VYC(KST,J+1)+VYC(I,J+1)*A(I,K)	4690
VYS(KST,J+1)=VYS(KST,J+1)+VYS(I,J+1)*A(I,K)	4700
XC(KST,J)=XC(KST,J)+XC(I,J)*A(I,K)	4710
XS(KST,J)=XS(KST,J)+XS(I,J)*A(I,K)	4720
YC(KST,J)=YC(KST,J)+YC(I,J)*A(I,K)	4730
YS(KST,J)=YS(KST,J)+YS(I,J)*A(I,K)	4740
DXC(KST,J)=DXC(KST,J)+DXC(I,J)*A(I,K)	4750
DXS(KST,J)=DXS(KST,J)+DXS(I,J)*A(I,K)	4760
DYC(KST,J)=DYC(KST,J)+DYC(I,J)*A(I,K)	4770
434 DYS(KST,J)=DYS(KST,J)+DYS(I,J)*A(I,K)	4780
KFN=JFN+JFN	4790
KMD=JST+JST	4800
DO 436 J=KMD,KFN	4810
DO 436 K=1,5	4820
KST=K+4	4830
DO 436 I=1,4	4840
BMXC(KST,J)=BMXC(KST,J)+BMXC(I,J)*A(I,K)	4850
BMXS(KST,J)=BMXS(KST,J)+BMXS(I,J)*A(I,K)	4860
BMYC(KST,J)=BMYC(KST,J)+BMYC(I,J)*A(I,K)	4870
436 BMYS(KST,J)=BMYS(KST,J)+BMYS(I,J)*A(I,K)	4880
GO TO 442	4890
438 D(1,1)=-BMXC(10,KST)	4900
D(2,1)=-BMXS(10,KST)	4910
D(3,1)=-BMYC(10,KST)	4920
D(4,1)=-BMYS(10,KST)	4930
D7 428 J=1,4	4940
D7 428 I=1,4	4950
428 C(I,J)=F(I,J,NCC)	4960
C79=SCF	4970
MAT=7	4980
KFN=KFN	4990
CALL EQS	5000
GO TO (439,510,511),KFN	5010
439 DO 440 J=JST,JFN	5020
DO 440 I=1,4	5030
VXC(10,J+1)=VXC(10,J+1)+VXC(I,J+1)*C(I,1)	5040
VXS(10,J+1)=VXS(10,J+1)+VXS(I,J+1)*C(I,1)	5050
VYC(10,J+1)=VYC(10,J+1)+VYC(I,J+1)*C(I,1)	5060
VYS(10,J+1)=VYS(10,J+1)+VYS(I,J+1)*C(I,1)	5070
XC(10,J)=XC(10,J)+XC(I,J)*C(I,1)	5080
XS(10,J)=XS(10,J)+XS(I,J)*C(I,1)	5090
YC(10,J)=YC(10,J)+YC(I,J)*C(I,1)	5100
YS(10,J)=YS(10,J)+YS(I,J)*C(I,1)	5110
DXC(10,J)=DXC(10,J)+DXC(I,J)*C(I,1)	5120
DXS(10,J)=DXS(10,J)+DXS(I,J)*C(I,1)	5130
DYC(10,J)=DYC(10,J)+DYC(I,J)*C(I,1)	5140
440 DYS(10,J)=DYS(10,J)+DYS(I,J)*C(I,1)	5150

KFN=JFN+JFN	5160
KMD=JST+JST	5170
DO 441 J=KMD,KFN	5180
DO 441 I=1,4	5190
BMXC(10,J)=BMXC(10,J)+BMXC(I,J)*C(I,1)	5200
BMXS(10,J)=BMXS(10,J)+BMXS(I,J)*C(I,1)	5210
BMYC(10,J)=BMYC(10,J)+BMYC(I,J)*C(I,1)	5220
441 BMYS(10,J)=BMYS(10,J)+BMYS(I,J)*C(I,1)	5230
442 JST=JFN	5240
NCC=NCC+1	5250
IF(NCC-NC) 444,444,443	5260
443 JFN=NS	5270
GO TO 445	5280
444 JFN=LC(NCC)	5290
445 GO TO 404	5300
C	5310
END CONDITIONS	5320
446 KST=NS+NS	5330
KFN=NS+1	5340
DO 447 J=1,8	5350
CFM(1,J)=BMXC(J,KST)	5360
CFM(2,J)=BMXS(J,KST)	5370
CFM(3,J)=BMYC(J,KST)	5380
CFM(4,J)=BMYS(J,KST)	5390
CFM(5,J)=VXC(J,KFN)	5400
CFM(6,J)=VXS(J,KFN)	5410
CFM(7,J)=VYC(J,KFN)	5420
447 CFM(8,J)=VYS(J,KFN)	5430
RHS(1,1)=-BMXC(9,KST)	5440
RHS(2,1)=-BMXS(9,KST)	5450
RHS(3,1)=-BMYC(9,KST)	5460
RHS(4,1)=-BMYS(9,KST)	5470
RHS(5,1)=-VXC(9,KFN)	5480
RHS(6,1)=-VXS(9,KFN)	5490
RHS(7,1)=-VYC(9,KFN)	5500
RHS(8,1)=-VYS(9,KFN)	5510
IF(IIST-10) 449,448,448	5520
448 RHS(1,1)=RHS(1,1)-BMXC(10,KST)	5530
RHS(2,1)=RHS(2,1)-BMXS(10,KST)	5540
RHS(3,1)=RHS(3,1)-BMYC(10,KST)	5550
RHS(4,1)=RHS(4,1)-BMYS(10,KST)	5560
RHS(5,1)=RHS(5,1)-VXC(10,KFN)	5570
RHS(6,1)=RHS(6,1)-VXS(10,KFN)	5580
RHS(7,1)=RHS(7,1)-VYC(10,KFN)	5590
RHS(8,1)=RHS(8,1)-VYS(10,KFN)	5600
449 CF9=CF	5610
MAT=4	5620
IF(NDIAG) 450,451,450	5630
C	5640
DIAGNOSTIC 4	5650
450 WRITE (6,138)	5660
WRITE (6,104)((C(I,J),I=1,4),J=1,4),((A(I,J),I=1,4),J=1,5)((CFM(I,	5670
I,J),I=1,8),J=1,8),(RHS(I,1),I=1,8),CF9	5680
WRITE (6,144)((DXC(I,J),DXS(I,J),DYC(I,J),DYS(I,J),	5690
II,J),YC(I,J),YS(I,J),I=1,10),J=1,NS)	5700
451 KFN=KFN	5710
CALL EQS	5720
GO TO (452,510,511),KFN	5730
452 ENT(9)=1.0	5740
IF (NDIAG) 496,497,476	5750
C	5760
DIAGNOSTIC 5	5770
496 WRITE (6,139)	5780
WRITE (6,144)((CFM(I,J),I=1,8),J=1,8)	
497 IF(IIST-10) 453,500,500	
493 IF(NCAL-1) 474,473,474	

473	WRITE (6,146) LOCAL	5790
474	ENT(1)=0.0	5800
	IF (NCRY) 454,455,456	5810
454	WRITE (6,147)	5820
	KVD=2	5830
	GO TO 455	5840
455	KVD=1	5850
C	WRITE OUTPUT	5860
456	WRITE (6,151)	5870
	WRITE (6,150)	5880
	DO 457 I=1,4	5890
457	ENT(I)=CFM(I,1)	5900
	IF (NC) 458,460,458	5910
458	KFN=LC(NC)+1	5920
	DO 459 I=1,4	5930
459	ENT(I)=0.0	5940
	GO TO 461	5950
460	KFN=NS+1	5960
461	DO 715 J=1,NU	5970
	MNB=LU(J)	5980
	DVUX(MNB)=UX(J)*ANSP2	5990
715	DVUY(MNB)=UY(J)*ANSP2	6000
	DISS=0.0	6010
	ENGY=0.0	6020
	MNB=1	6030
	VBR=1	6040
	LBRG=LB(1)	6050
	LJBL=LU(1)	6060
	DO 470 J=1,NS	6070
	IF (J-KFN) 454,462,464	6080
462	DO 463 I=1,4	6090
463	ENT(I)=CFM(I,1)	6100
464	KST=J+J	6110
	KC=KST-1	6120
	DO 465 K=1,3	6130
	DO 465 I=1,4	6140
465	H(I,K)=0.0	6150
	DO 466 I=1,IFN	6160
	H(1,1)=B(1,1)+XC(I,J)*ENT(I)	6170
	H(2,1)=B(2,1)+XS(I,J)*ENT(I)	6180
	B(3,1)=B(3,1)+YC(I,J)*ENT(I)	6190
	H(4,1)=B(4,1)+YS(I,J)*ENT(I)	6200
	H(1,2)=B(1,2)+B*XC(I,KC)*ENT(I)	6210
	B(2,2)=B(2,2)+B*XS(I,KC)*ENT(I)	6220
	B(3,2)=B(3,2)+B*YC(I,KC)*ENT(I)	6230
	H(4,2)=B(4,2)+B*YS(I,KC)*ENT(I)	6240
	B(1,3)=B(1,3)+B*XC(I,KST)*ENT(I)	6250
	B(2,3)=B(2,3)+B*XS(I,KST)*ENT(I)	6260
	B(3,3)=B(3,3)+B*YC(I,KST)*ENT(I)	6270
	B(4,3)=B(4,3)+B*YS(I,KST)*ENT(I)	6280
466	IF (J-LBRG) 705,703,707	6290
C	TRANSMITTED FORCE, PEDESTAL MOTION	6300
703	CF1A=RV(J)*ANSP2	6310
	SHA(1)=CF1A*B(1,1)+DVUX(J)	6320
	SHB(1)=CF1A*B(2,1)+DVUY(J)	6330
	SHC(1)=CF1A*B(3,1)+DVUX(J)	6340
	SHD(1)=CF1A*B(4,1)+DVUY(J)	6350
	DO 704 I=1,IFN	6360
	SHA(I)=SHA(1)+(VXC(I,J)-VXC(I,J+1))*ENT(I)	6370
	SHB(I)=SHB(1)+(XS(I,J)-XS(I,J+1))*ENT(I)	6380
	SHC(I)=SHC(1)+(VYC(I,J)-VYC(I,J+1))*ENT(I)	6390
704	SHD(I)=SHD(1)+(VYS(I,J)-VYS(I,J+1))*ENT(I)	6400
	IF (NPST) 705,706,705	6410

705	CF1C=PCY(MHR)/386.067*ANSP2/AMS	6420
	CF1V=PCY(MHR)/386.067*ANSP2/AMS	6430
	CF1A=PCX(MHR)/AMS-CF1K	6440
	CF1B=PCY(MHR)/AMS-CF1M	6450
	CF1C=PCX(MHR)/AMS*ANSP	6460
	CF1D=PCY(MHR)/AMS*ANSP	6470
	CF1E=CF1A*CF1A+CF1C*CF1C	6480
	SHA(1)=(SHA(1)*CF1A-SHB(1))*CF1C/CF1E	6490
	SHB(1)=(SHA(1)*CF1C+SHB(1))*CF1A/CF1E	6500
	CF1E=CF1B*CF1B+CF1D*CF1D	6510
	SHC(1)=(SHC(1)*CF1B-SHD(1))*CF1D/CF1E	6520
	SHD(1)=(SHC(1)*CF1D+SHD(1))*CF1B/CF1E	6530
	SHA(2)=SHA(1)+CF1K*SHA(1)	6540
	SHB(2)=SHB(1)+CF1K*SHB(1)	6550
	SHC(2)=SHC(1)+CF1M*SHC(1)	6560
	SHD(2)=SHD(1)+CF1M*SHD(1)	6570
	CF1A=B(1,1)-SHA(1)	6580
	CF1B=B(2,1)-SHB(1)	6590
	CF1K=B(3,1)-SHC(1)	6600
	CF1V=B(4,1)-SHD(1)	6610
	GO TO 707	6620
706	CF1A=B(1,1)	6630
	CF1B=B(2,1)	6640
	CF1K=B(3,1)	6650
	CF1V=B(4,1)	6660
	SHA(2)=SHA(1)	6670
	SHB(2)=SHB(1)	6680
	SHC(2)=SHC(1)	6690
	SHD(2)=SHD(1)	6700
	SHA(3)=0.0	6710
	SHB(3)=0.0	6720
	SHC(3)=0.0	6730
	SHD(3)=0.0	6740
	CF1C=0.0	6750
	CF1D=0.0	6760
707	CF2A=BCXX(1,MHR)+BCXX(2,MHR)*ANSP+BCXX(3,MHR)*ANSP2	6770
	CF2B=BCXY(1,MHR)+BCXY(2,MHR)*ANSP+BCXY(3,MHR)*ANSP2	6780
	CF2C=BCYX(1,MHR)+BCYX(2,MHR)*ANSP+BCYX(3,MHR)*ANSP2	6790
	CF2D=BCYY(1,MHR)+BCYY(2,MHR)*ANSP+BCYY(3,MHR)*ANSP2	6800
	CF2M=BKXY(1,MHR)+BKXY(2,MHR)*ANSP+BKXY(3,MHR)*ANSP2	6810
	CF2N=BKYY(1,MHR)+BKYY(2,MHR)*ANSP+BKYY(3,MHR)*ANSP2	6820
	DIS5=DIS5+3.1415927*(CF2A*(CF1A*CF1A+CF1C*CF1C)+CF2B*(CF1A*CF1A+CF1C*CF1C)+CF2C*(CF1A*CF1A+CF1C*CF1C)+CF2D*(CF1A*CF1A+CF1C*CF1C)+CF2M*(CF1A*CF1A+CF1C*CF1C)+CF2N*(CF1A*CF1A+CF1C*CF1C))	6830
	DIS5=DIS5+3.1415927*(CF2A*(CF1A*CF1A+CF1C*CF1C)+CF2B*(CF1A*CF1A+CF1C*CF1C)+CF2C*(CF1A*CF1A+CF1C*CF1C)+CF2D*(CF1A*CF1A+CF1C*CF1C)+CF2M*(CF1A*CF1A+CF1C*CF1C)+CF2N*(CF1A*CF1A+CF1C*CF1C))	6840
	DIS5=DIS5+3.1415927*(CF2A*(CF1A*CF1A+CF1C*CF1C)+CF2B*(CF1A*CF1A+CF1C*CF1C)+CF2C*(CF1A*CF1A+CF1C*CF1C)+CF2D*(CF1A*CF1A+CF1C*CF1C)+CF2M*(CF1A*CF1A+CF1C*CF1C)+CF2N*(CF1A*CF1A+CF1C*CF1C))	6850
	IF (NMOD) 717,716,717	6860
717	CF1A=0.0	6870
	CF1B=0.0	6880
	CF1K=0.0	6890
	CF1V=0.0	6900
	DO 740 I=1,IFN	6910
	CF1A=CF1A+DXC(I,J)*ENT(I)	6920
	CF1B=CF1B+DXS(I,J)*ENT(I)	6930
	CF1K=CF1K+DYC(I,J)*ENT(I)	6940
	CF1V=CF1V+DYS(I,J)*ENT(I)	6950
740	CF2A=B(1,1)-B(1,2)-DIA(I)	6960
	CF2B=B(2,1)-B(2,2)-DIB(I)	6970
	CF2C=B(3,1)-B(3,2)-DIC(I)	6980
	CF2D=B(4,1)-B(4,2)-DID(I)	6990
	IF (NPST) 741,742,741	7000
741	CF2M=(PSMX(MHR)-PIX(MHR)/386.067*ANSP2)/AMS	7010
	CF2N=(PSMY(MHR)-PIY(MHR)/386.067*ANSP2)/AMS	7020
	CF1C=PCMX(MHR)/AMS*ANSP	7030
		7040

CF1 = PDIV(MBR)/AMS*ANSP	7050
CF1E = CF2M*CF2M+CF1C*CF1C	7060
CF3A = (CF2A*CF2M-CF2B*CF1C)/CF1E	7070
CF3B = (CF2A*CF1C+CF2B*CF2M)/CF1E	7080
CF1E = CF2N*CF2N+CF1D*CF1D	7090
CF3C = (CF2C*CF2N-CF2D*CF1D)/CF1E	7100
CF3D = (CF2C*CF1D+CF2D*CF2N)/CF1E	7110
CF1A = CF1A-CF3A	7120
CF1B = CF1B-CF3B	7130
CF1K = CF1K-CF3C	7140
CF1M = CF1M-CF3D	7150
CF2M = CF1C*(CF3A*CF3A+CF3B*CF3B)+CF1D*(CF3C*CF3C+CF3D*CF3D)	7160
GO TO 743	7170
742 CF2M=0.0	7180
743 DISS=DISS+3.1415927*(CF2A*CF1B-CF2B*CF1A+CF2C*CF1M-CF2D*CF1K+CF2M)	7190
716 D) 708 I=1,3	7200
CF1A=SHA(I)	7210
CF1B=-SHB(I)	7220
CF1C=SHC(I)	7230
CF1D=SHD(I)	7240
AUX(MBR,1,I)=SQRT(CF1A*CF1A+CF1B*CF1B)	7250
AUX(MBR,2,I)=ANG(CF1A,CF1B)	7260
AUX(MBR,3,I)=SQRT(CF1C*CF1C+CF1D*CF1D)	7270
AUX(MBR,4,I)=ANG(CF1C,CF1D)	7280
CF2A=CF1A*CF1A	7290
CF2B=CF1B*CF1B	7300
CF2C=CF1C*CF1C	7310
CF2D=CF1D*CF1D	7320
CF1E=(CF2A+CF2B-CF2C+CF2D)/2.0	7330
CF1K=(CF2A+CF2B-CF2C-CF2D)/2.0	7340
CF1M=CF1A*CF1C-CF1B*CF1D	7350
CF1N=CF1A*CF1B-CF1C*CF1D	7360
CF2A=(CF2A-CF2B+CF2C-CF2D)/2.0	7370
CF2B=SQRT(CF1K*CF1K+CF1M*CF1M)	7380
CF3B=CF1A*CF1D+CF1B*CF1C	7390
CF3B=CF3B/ABS(CF3B)	7400
BUX(MBR,1,I)=SQRT(CF1E+CF2B)	7410
BUX(MBR,2,I)=CF3B*SQRT(CF1E-CF2B)	7420
BUX(MBR,3,I)=ANG(CF1K,CF1M)/2.0	7430
708 BUX(MBR,4,I)=ANG(CF2A,CF1N)/2.0	7440
IF(MBR-NB) 702,701,701	7450
701 LBRG=NS+2	7460
GO TO 709	7470
702 MBR=MBR+1	7480
LBRG=LB(MBR)	7490
709 IF (J-LNBL) 714,710,714	7500
710 IF (MNB-NU) 712,711,711	7510
711 LNBL=NS+2	7520
GO TO 713	7530
712 MNB=MNB+1	7540
LNBL=LU(MNB)	7550
713 E4GY=ENGY+3.1415927*(DVLX(J)*(B(2,I)-B(3,I))+DVUY(J)*(B(1,I)+	7560
B(4,I)))	7570
C) CONVERT RESULTS TO ELLIPSIS	7580
714 D) 469 I=1,3	7590
CF1A=B(1,I)*B(1,I)	7600
CF1B=B(2,I)*B(2,I)	7610
CF1C=B(3,I)*B(3,I)	7620
CF1D=B(4,I)*B(4,I)	7630
CF1E=(CF1A+CF1B+CF1C+CF1D)/2.0	7640
CF1K=(CF1A+CF1B-CF1C-CF1D)/2.0	7650
CF1M=B(1,I)*B(3,I)+B(2,I)*B(4,I)	7660
CF1N=(CF1A-CF1B+CF1C-CF1D)/2.0	7670

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CF1B=-H(1,1)*H(2,1)+H(3,1)*H(4,1)
CF1C=SQR(CF1K*CF1K+CF1M*CF1M)
CF3H=H(1,1)*H(4,1)-H(2,1)*H(3,1)
CF3J=CF3I/ABS(CF3H)
H(1,1)=SQR(CF1E*CF1E)
H(2,1)=CF3H*SQR(CF1E-CF1C)
467 H(3,1)=ABS(CF1K*CF1M)/2.0
468 H(4,1)=ANG(CF1K*CF1M)/2.0
469 CONTINUE
WRITE (6,148) J,B(1,1),B(2,1),B(3,1),B(4,1),U(1,2), B(2,2),B(3,
121,B(4,2)
470 WRITE (6,149) B(1,3),B(2,3),B(3,3),B(4,3)
CF1A=AMS*AMS
DISS=DISS/CF1A
FNGY=FNGY/AMS
WRITE (6,730)
DO 725 I=1,3
IF (I-2) 723,720,722
720 IF (NPST) 721,726,721
721 WRITE (6,731)
GO TO 723
722 WRITE (6,732)
723 WRITE (6,733)
724 J=1,NB
IR=LB(J)
724 WRITE (6,148) MHR,BUX(J,1,1),BUX(J,2,1),BUX(J,3,1), BUX(J,4,1),AU
IX(J,1,1),AUX(J,2,1),AUX(J,3,1),AUX(J,4,1)
725 CONTINUE
726 WRITE (6,734) FNGY,DISS
GO TO (513,480,513),CMO
C MAKE READY FOR GYROSCOPIC MOMENT CALCULATION
480 IST=10
IFN=10
WRITE (6,153)
C CALCULATE GYROSCOPIC MOMENT
481 DO 482 I=1,8
482 ENT(I)=CFV(I,1)
IF (NC) 483,495,483
483 KFN=LC(NC)
DO 484 I=1,4
484 ENT(I)=0.0
GO TO 485
485 KFN=NS+1
486 DO 493 J=1,NS
IF (J-KFN) 487,487,489
487 DO 488 I=1,4
488 ENT(I)=CFV(I,1)
489 CF1A=0.0
CF1B=0.0
CF1C=0.0
CF1D=0.0
DO 490 I=1,IFN
CF1A=CF1A+DXC(I,J)*ENT(I)
CF1B=CF1B+DXS(I,J)*ENT(I)
CF1C=CF1C+DYC(I,J)*ENT(I)
490 CF1D=CF1D+DYS(I,J)*ENT(I)
CF1E=CF1A*CF1D
CF1K=CF1B*CF1C
CF1M=CF1A*CF1D-CF1B*CF1C
CF1N=CF1E*CF1K+CF1K*CF1K
IF (CF1N) 492,491,492
491 DIA(J)=0.0
DIA(J)=0.0

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	DIC(J)=0.0	8310
	DID(J)=0.0	8320
	GO TO 491	8330
492	CF1M=CF1M/CF1N	8340
	CF1N=PIPI(J)*ANSP2	8350
	CF1E=CF1N*CF1F*CF1M	8360
	CF1K=CF1N*CF1K*CF1M	8370
	CF1N=PIPI(J)*ANSP2	8380
	DIA(J)=CF1E-CF1N*CF1A	8390
	DIH(J)=CF1K-CF1N*CF1H	8400
	DIC(J)=CF1K-CF1N*CF1C	8410
	DID(J)=CF1K-CF1N*CF1D	8420
493	CONTINUE	8430
	IF(NDIAG) 494,495,494	8440
C	DIAGNOSTIC 0	8450
494	WRITE (6,140)	8460
	WRITE (6,104)(DIA(J),DIH(J),DIC(J),DID(J),J=1,NS),	CF1A,CF1B,C 8470
	IF1C,CF1D,CF1E,CF1K,CF1M,CF1N,CF1,CF2,CF3,CF4,	CF5,CF6,CF7 8480
	2,CF8,(CFM(1,1),ENT(1),1=1,6)	8490
495	GO TO 401	8500
C	GYROSCOPIC MOMENT ITERATION	8510
500	CF2A=ABS(CFM(1,1)-CF1)+ABS(CFM(2,1)-CF2)+ABS(CFM(3,1)-CF3)+	ABS 8520
	1(CFM(4,1)-CF4)+ABS(CFM(5,1)-CF5)+ABS(CFM(6,1)-CF6)+	ABS(CF 8530
	2M(7,1)-CF7)+ABS(CFM(8,1)-CF8)	8540
	CF2B=0.0	8550
	DO 501 I=1,8	8560
501	CF2B=CF2B+ABS(CFM(I,1))	8570
	IF(CF2B) 502,503,502	8580
502	CF2A=CF2A/CF2B	8590
503	WRITE (6,152)NITC,CF2A	8600
	IF(CF2A-DGYR) 506,506,504	8610
504	NITC=NITC+1	8620
	IF(NITC-NIT) 505,505,506	8630
505	CF1=CFM(1,1)	8640
	CF2=CFM(2,1)	8650
	CF3=CFM(3,1)	8660
	CF4=CFM(4,1)	8670
	CF5=CFM(5,1)	8680
	CF6=CFM(6,1)	8690
	CF7=CFM(7,1)	8700
	CF8=CFM(8,1)	8710
	GO TO 481	8720
506	WRITE (6,154)	8730
	KMD=3	8740
	ENT(10)=1.0	8750
	GO TO 456	8760
C	ADVANCE SPEED	8770
513	IF(INCAL-1) 512,507,512	8780
512	JCAL=JCAL+1	8790
	IF(INCAL-JCAL) 508,901,901	
901	III=2	
	GO TO 200	
507	SPCAL=SPCAL+SPINC	8810
	ANSP=0.19471976*SPCAL	8820
	IF(SPCAL-SPCAL) 504,902,902	
902	III=3	
	GO TO 200	
508	IF(INPUT) 504,201,509	8830
C	PROGRAM END	8840
509	WRITE (6,999)	
999	FORMAT (1H1,17HLAST SET OF INPUT)	
	STOP	
C	XSIMOF DIAGNOSTIC	8880

510 WRITE (6,155)MAT		8890
GO TO 513		8900
511 WRITE (6,156)MAT		8910
GO TO 513		8920
100 FORMAT(72H0		8930
1		8940
101 FORMAT(72H		8950
1		8960
102 FORMAT(120H1		8970
1M NON-UNIFORM HEARING SUPPORTIC	UNBALANCE RESPONSE OF ROTOR WIT	
103 FORMAT(120H	PN0011	8980
1A. TECHNOLOGY, INC.	MECHANIC	8990
104 FORMAT(1P4E15,7)		9000
105 FORMAT(1015)		9010
106 FORMAT(15,1PE23,6)		9020
107 FORMAT(1040YOUNGS MODULUS SCALE FACTOR)		9030
108 FORMAT(120,0 STATION NO. BRGS. NO. UNBAL. NO. COUPL. PED. F		9040
1LEX. BRG. MOVENT CYRO. MOM. NO. CASES DIAGNOSTIC INPUT		9050
109 FORMAT(1P5E15,7)		9060
110 FORMAT(17,9112)		9070
111 FORMAT(36H0		9080
112 FORMAT(1P3E14,6)	ROTOR DATA	9090
113 FORMAT(1P5E14,6)		9100
114 FORMAT(17,1P3E20,7)		9110
115 FORMAT(17,1P5E20,7)		9120
116 FORMAT(72H STATION NO. MASS LENGTH CROSS		9130
1 SECT. INERTIA		9140
117 FORMAT(120H STATION NO. MASS LENGTH CROS		9150
15 SECT. INERTIA POLAR MOM. INERTIA TRANSV. MOM. INERTIA		9160
118 FORMAT(1415)		9170
119 FORMAT(36H0 ITERAT. ITERAT. CONVERG. LIMIT		9180
120 FORMAT(18H0 HEARING STATIONS		9190
121 FORMAT(71H0		9200
1AT STATION NO. 12)	HEARING	9210
122 FORMAT(120H		9220
1		9230
123 FORMAT(1P6E15,6)		9240
124 FORMAT(120H		9250
1		9260
125 FORMAT(1P6E12,4)		9270
126 FORMAT(17,1P6E16,4)		9280
127 FORMAT(102H BRG. STATION MASS. X-DIR. KY		9290
1 MASS. Y-DIR. KY		9300
128 FORMAT(78H0		9310
1TRANSLATORY MOTION	PEDESTAL DATA.	9320
129 FORMAT(78H0		9330
1ROTATIONAL MOTION	PEDESTAL DATA.	9340
130 FORMAT(102H BRG. STATION INERTIA. X MY		9350
1 INERTIA. Y MY		9360
131 FORMAT(15,1P2E15,7)		9370
132 FORMAT(17,1P2E21,7)		9380
133 FORMAT(154H0 UNBALANCE ST. X-UNBALANCE		9390
134 FORMAT(18H0 COUPLING STATIONS)	Y-UNBALANCE	9400
135 FORMAT(18H0 DIAGNOSTIC 1		9410
136 FORMAT(18H0 DIAGNOSTIC 2		9420
137 FORMAT(18H0 DIAGNOSTIC 3		9430
138 FORMAT(18H0 DIAGNOSTIC 4		9440
139 FORMAT(18H0 DIAGNOSTIC 5		9450
140 FORMAT(18H0 DIAGNOSTIC 6		9460
141 FORMAT(42H0 INITIAL SPEED FINAL SPEED SPEED INCR. 1		9470
144 FORMAT(1P6E15,7)		9480
145 FORMAT(1P6E15,7)		9490
146 FORMAT(13H0 ROTOR SPEED=,1PE14,7,3HRPM)		9500
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147 FORMAT(30H WITHOUT GYROSCOPIC MOMENT ) 1 9520
148 FORMAT(14.1PE15.5,1P3E14.7,1PE17.5,1P3E14.5) 9530
149 FORMAT(1PE18.5,1P3E14.5) 9540
150 FORMAT(120H STATION MAJOR AXIS MINOR AXIS ANGLE X-MAJOR PHASE 9550
1 ANGLE MAJOR AXIS MINOR AXIS ANGLE X-MAJOR PHASE ANGLE 9560
151 FORMAT(120H AMPLITUDE 9570
1 BENDING MOMENT) 9580
152 FORMAT(17.1PE17.7) 9590
153 FORMAT(24H01TRAT.NO. ERROR ) 9600
154 FORMAT(24H WITH GYROSCOPIC MOMENT ) 9610
155 FORMAT(30H0OVER/UNDERFLOW IN XSIMEGF AT 11) 9620
156 FORMAT(24H0MATRIX IS SINGULAR IN XSIMEGF AT 11) 9630
157 FORMAT(1P4E14.6) 9640
160 FORMAT(30H0 FORCE TRANSMITTED TO BEARING HOUSING) 9650
161 FORMAT(30H0 FORCE TRANSMITTED TO FOUNDATION) 9660
162 FORMAT(18H0 PEDESTAL MOTION ) 9670
163 FORMAT(120H BRG.NO. MAJOR AXIS MINOR AXIS ANGLE X-MAJOR PHASE 9680
1 ANGLE X-AMPLITUDE X-PHASE ANG Y-AMPLITUDE Y-PHASE ANG) 9690
164 FORMAT(15H0 ENERGY INPUT=,1PE14.7,21H ENERGY DISSIPATED=,1PE14.7 9700
1) 9710
END 9720
SIBFIC SUBRS X94,XR7,LIST,NODECK
SUBROUTINE SUBR
DIMENSION BMXC(10, 90),BMXS(10, 80),BMYC(10, 80),BMYS(10, 80),VXC
1(10,41),VXS(10,41),VC(10,41),VYS(10,41),DXC(10,40),DXS(10,40),DYC
2(10,40),DYS(10,40),XC(10,40),XS(10,40),YC(10,40),YS(10,40),DMXA(40
3),DMXB(40),DMXC(40),DMXD(40),DMYA(40),DMYB(40),DMYC(40),DMYD(40),
4DMXA(40),DMXB(40),DMXC(40),DMXD(40),DMYA(40),DMYB(40),DMYC(40),
5DMYD(40),RM(40),RL(40),RS(40),RIP(40),RIT(40),DIA(40),DIB(40),DIC(
640),DID(40),AN(40),BN(40),DN(40),UX(40),UY(40),LU(40),LB(25),BKXX(
73,25),BKXY(3,25),BCXX(3,25),BCXY(3,25),BKYY(3,25),BCYY(3,25),BKXY(
83,25),BCYX(3,25),BSMXX(3,25),BSMXY(3,25),BSMYX(3,25),BSMYX(3,25),
9BSMYX(3,25),BSMYX(3,25),BSMYX(3,25),BSMYX(3,25)
DIMENSION PMX(25),PMY(25),PKX(25),PCX(25),PKY(25),PCY(25),PIX(25),
1PIY(25),PSMX(25),PSMY(25),PCMX(25),PCMY(25),LC(20),A(8,8),B(8,4),
2C(8,4),D(8,1),F(4,4,20),CFM(8,8),ENT(10),RHS(8,1),DVUX(80),
3DVUY(80),DUMMY(300),SHA(3),SHB(3),SHC(3),SHD(3),AUX(25,4,3),
4BUX(25,4,3),DUM1(100),CLNR(8)
COMMON A B C D CFM ENT
COMMON RHS DUM1 CF9 MAT KFN CLNR
COMMON PRN3
COMMON NS,NB,NJ,NC,NPST,NMOM,NGYR,NCAL,NDIAG,INPUT,YM,SCF,RM,RL,
1RS,NIT,DGY,RIP,RIT,LB,LU,UX,UY,LC,PMX,PKX,PCX,PMY,PKY,PCY,KST,
2PIX,PSMX,PMYX,PIY,PSMY,PDMY,SPST,SPFN,SPINC,BKXX,BCXX,BKXY,BCXY,
3BKYY,BCYY,BKXX,BCYX,BSMXX,BSMXY,BSMYX,BSMYX,BSMYX,BSMYX,BSMYX,
4BSMYX,CF1K,CF1C,CF1D,CF1E,CF2K,CF2C,CF2D,CF2E,CF2A,CF2B,CF2M,CF2N,
5CF1A,CF1B,CF1M,CF1N,CF1,CF2,CF3,CF4,CF5,CF6,CF7,CF8,STF,ANSP2,
6ANSP,SPCAL,DVXA,DVXH,DVXC,DVXD,DVYA,DVYH,DVYC,DVYD,DMXA,DMXB,DMXC,
7DMXD,DMYA,DMYB,DMYC,DMYD,AN,BN,DN,111
COMMON BMXC,BMXS,BMYC,BMYS,VXC,VXS,VYC,VYS,DXC,DXS,DYC,DYS,XC,XS,
1YC,YS,DIA,DIB,DIC,DIN,DVUX,DVUY,DUMMY,SHA,SHB,SHC,SHD,AUX,BUX
COMMON JCAL,AWS,NITC
100 FORMAT(72H0 8930
1 8940
101 FORMAT(72H 8950
1 8960
102 FORMAT(120H1 UNBALANCE RESPONSE OF ROTOR AT 8970
1H NON-UNIFORM BEARING SUPPORTS PNO011 8980
103 FORMAT(120H MECHANIC 8990
1A1 TECHNOLOGY,1N4. 9000
104 FORMAT(1P4E15.7) 9010
105 FORMAT(1015) 9020
106 FORMAT(15.1PE23.6) 9030

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107 FORMAT(30H0YOUNGS MODULUS SCALE FACTOR: 9040
108 FORMAT(120H0 STATIONS NO,BRGS. NO,UNBAL. NO,COUPL. PED,F 9050
1LEX. BRG,MOMENT GYRO,MOM. NO,CASES DIAGNOSTIC INPUT ) 9060
109 FORMAT(1P5E15.7) 9070
110 FORMAT(17.9112) 9080
111 FORMAT(35H0 ROTOR DATA ) 9090
112 FORMAT(1P3E14.6) 9100
113 FORMAT(1P5E14.6) 9110
114 FORMAT(17.1P3E20.7) 9120
115 FORMAT(17.1P5F20.7) 9130
116 FORMAT(12H STATION NO. MASS LENGTH CROSS 9140
1 SECT,INERTIA ) 9150
117 FORMAT(120H STATION NO. MASS LENGTH CROS 9160
15 SECT,INERTIA POLAR MOM,INERTIA TRANSV,MOM,INERTIA ) 9170
118 FORMAT(14I5) 9180
119 FORMAT(136H0ITERAT. ITERAT,CONVERG,LIMIT ) 9190
120 FORMAT(18H0BEARING STATIONS ) 9200
121 FORMAT(71H0 BEARING 9210
1AT STATION NO. 12) 9220
122 FORMAT(120H KXX CXX KXY CX 9230
1 KYY CVY KYX CYX ) 9240
123 FORMAT(1P8E15.6) 9250
124 FORMAT(120H MXX DXX MXV DXY 9260
1 MYV DYV MYX DYX ) 9270
125 FORMAT(1P6E12.4) 9280
126 FORMAT(17.1P6F15.4) 9290
127 FORMAT(102H BRG,STATION MASS,X-DIR. KX CX 9300
1 MASS,Y-DIR. KY CY ) 9310
128 FORMAT(78H0 PEDESTAL DATA. 9320
1TRANSLATORY MOTION ) 9330
129 FORMAT(78H0 PEDESTAL DATA. 9340
1ROTATIONAL MOTION ) 9350
130 FORMAT(102H BRG,STATION INERTIA,X MX DX 9360
1 INERTIA,Y MY DY ) 9370
131 FORMAT(15.1P2F15.7) 9380
132 FORMAT(17.1P2F21.7) 9390
133 FORMAT(54H0UNBALANCE ST. X-UNBALANCE Y-UNBALANCE ) 9400
134 FORMAT(18H0COUPLING STATIONS) 9410
135 FORMAT(18H0DIAGNOSTIC ) 9420
141 FORMAT(42H0INITIAL SPEED FINAL SPEED SPEED INCR.) 9460
144 FORMAT(1P8E15.7) 9490
145 FORMAT(1P6E15.7) 9500
146 FORMAT(13H0ROTOR SPEED=.1PE14.7.3HRPM) 9510
156 FORMAT(34H0MATRIX IS SINGULAR IN XSIMEQF AT 11) 9630
157 FORMAT (1P4E14.6)
GO TO (900,227,300),III
900 READ (5,100) 0400
READ (5,101) 0410
READ (5,105)NS,NB,NU,NC,NPST,NMOM,NGYR,NCAL,NDIAG,INPUT 0420
READ (5,104)YM,SCF 0430
WRITE (6,102) 0440
WRITE (6,103) 0450
WRITE (6,100) 0460
WRITE (6,101) 0470
WRITE (6,108) 0480
WRITE (6,110)NS,NB,NU,NC,NPST,NMOM,NGYR,NCAL,NDIAG,INPUT 0490
WRITE (6,107) 0500
WRITE (6,104)YM,SCF 0510
IF(NGYR) 202,201,202
201 READ (5,112)RM(J),RL(J),RS(J),J=1,NS) 0520
WRITE (6,111) 0530
WRITE (6,116) 0540
WRITE (6,114)J,RM(J),RL(J),RS(J),J=1,NS) 0550

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DO 201		0560
202 READ (5,106)INIT,NGYR		0570
WRITE (6,119)		0580
WRITE (6,125)INIT,NGYR		0590
WRITE (6,111)		0600
READ (5,113)(RY(J),RL(J),RS(J),RIP(J),RIT(J),J=1,NS)		0610
WRITE (6,117)		0620
WRITE (5,115)(J,RM(J),RL(J),RS(J),RIP(J),RIT(J),J=1,NS)		0630
203 READ (5,118)(LB(J),J=1,NB)		0640
WRITE (6,120)		0650
WRITE (6,118)(LB(J),J=1,NB)		0660
212 READ (5,131)(LX(J),UX(J),UY(J),J=1,NU)		0670
WRITE (6,133)		0680
WRITE (6,132)(LX(J),UX(J),UY(J),J=1,NU)		0690
214 IF(NC) 215,207,215		0700
215 READ (5,116)(LC(J),J=1,NC)		0710
WRITE (6,134)		0720
WRITE (6,118)(LC(J),J=1,NC)		0730
207 IF(INPST) 208,228,209		0740
208 WRITE (6,129)		0750
WRITE (6,127)		0760
DO 209 J=1,NH		0770
READ (5,125)(PMX(J),PKX(J),PCX(J),PMY(J),PKY(J),PCY(J)		0780
KST=LB(J)		0790
209 WRITE (6,126)(KST,PMX(J),PKX(J),PCX(J),PMY(J),PKY(J), PCY(J)		0800
IF(INMOV) 210,228,210		0810
210 WRITE (6,129)		0820
WRITE (6,130)		0830
DO 211 J=1,NB		0840
READ (5,125)(PIX(J),PSMX(J),PDMX(J),PIY(J),PSMY(J), PDMY(J)		0850
KST=LB(J)		0860
211 WRITE (6,126)(KST,PIX(J),PSMX(J),PDMX(J),PIY(J),PSMY(J),PDMY(J)		0870
228 IF(INCAL-1) 221,220,221		0880
220 READ (5,112)(PST,SPFN,SPINC		0890
WRITE (6,141)		0900
WRITE (6,112)(PST,SPFN,SPINC		0910
READ (5,112)((KXX(I,J),I=1,3),(KXX(I,J),I=1,3), (KXX(I,J),I=1,3),		0920
(KXX(I,J),I=1,3),(KXX(I,J),I=1,3),(KXX(I,J),I=1,3),(KXX(I,J),I=1,3),		0930
(KXX(I,J),I=1,3),(KXX(I,J),I=1,3),(KXX(I,J),I=1,3),(KXX(I,J),I=1,3)		0940
DO 204 J=1,NH		0950
KST=LB(J)		0960
WRITE (6,121)KST		0970
WRITE (6,122)		0980
204 WRITE (6,123)(KXX(I,J),KXX(I,J),KXX(I,J),KXX(I,J), KXX(I,J),		0990
KXX(I,J),KXX(I,J),KXX(I,J),I=1,3)		1000
IF(INMOV) 205,216,205		1010
205 READ (5,112)((BSMXX(I,J),I=1,3),(BSMXX(I,J),I=1,3),(BSMXX(I,		1020
J),I=1,3),(BSMXX(I,J),I=1,3),(BSMXX(I,J),I=1,3),(BSMXX(I,J),I=1,		1030
2,3),(BSMXX(I,J),I=1,3),(BSMXX(I,J),I=1,3),(BSMXX(I,J),I=1,3)		1040
DO 205 J=1,NH		1050
KST=LB(J)		1060
WRITE (6,121)KST		1070
WRITE (6,124)		1080
206 WRITE (6,123)(BSMXX(I,J),BSMXX(I,J),BSMXX(I,J),BSMXX(I,J),BSMXX(I,		1090
J),BSMXX(I,J),BSMXX(I,J),BSMXX(I,J),I=1,3)		1100
GO TO 216		1110
221 JCAL=1		1120
227 READ (5,157)CST		1130
READ (5,157)(KXX(I,J),KXX(I,J),KXX(I,J),KXX(I,J), KXX(I,J),		1140
KXX(I,J),KXX(I,J),KXX(I,J),KXX(I,J),J=1,NB)		1150
WRITE (6,146)CST		1160
DO 223 J=1,NH		1170
KST=LB(J)		1180

WRITE (6,121)KST	
WRITE (6,122)	1190
223 WRITE (6,123)BKXX(1,J),BCXX(1,J),BKXY(1,J),BCXY(1,J),BKYY(1,J),BCY	1200
1Y(1,J),BKYY(1,J),BCYX(1,J)	1210
IF(INMOD) 224,216,224	1220
224 READ (5,157)(BSMXX(1,J),BDMXX(1,J),BSMXY(1,J),BDMXY	1230
1YY(1,J),BDMYY(1,J),BSMYX(1,J),BDMYX(1,J),J=1,NB)	1240
DO 226 J=1,NB	1250
KST=LB(J)	1260
WRITE (6,121)KST	1270
WRITE (6,124)	1280
225 WRITE (6,123)BSMXX(1,J),BDMXX(1,J),BSMXY(1,J),BDMXY(1,J),BSMYY(1,J	1290
1),BDMYY(1,J),BSMYX(1,J),BDMYX(1,J)	1300
DO 226 I=2,3	1310
BKXX(1,J)=0.0	1320
BCXX(1,J)=0.0	1330
BKXY(1,J)=0.0	1340
BCXY(1,J)=0.0	1350
BKYY(1,J)=0.0	1360
BCYY(1,J)=0.0	1370
BKX(1,J)=0.0	1380
BCYX(1,J)=0.0	1390
BSMXX(1,J)=0.0	1400
BDMXX(1,J)=0.0	1410
BSMXY(1,J)=0.0	1420
BDMXY(1,J)=0.0	1430
BSMYY(1,J)=0.0	1440
BDMYY(1,J)=0.0	1450
BSMYX(1,J)=0.0	1460
BDMYX(1,J)=0.0	1470
226 CONTINUE	1480
216 GO TO 250	1490
C	1500
CONVERT INPUT UNITS	1510
250 AMS=1000.0	1520
CF1=386.069*AMS	1530
CF2=CF1/2.0	1540
RS(NS)=RS(1)	1550
DO 251 J=1,NS	1560
RM(J)=RM(J)/CF1	1570
RIP(J)=RIP(J)/CF2	1580
RIT(J)=RIT(J)/CF1	1590
STF=YM/AMS*RS(J)	1600
AN(J)=RL(J)/STF	1610
BN(J)=RL(J)/2.0*AN(J)	1620
251 DN(J)=RL(J)/3.0*BN(J)	1630
DO 252 J=1,NU	1640
UX(J)=UX(J)/6177.1	1650
252 UY(J)=UY(J)/6177.1	1660
SPCAL=SPST	1670
ANSP=0.10471976*SPCAL	1680
NITC=1	1690
C	1700
SPEED DEPENDENT PARAMETERS	1710
300 ANSP2=ANSP*ANSP	1720
DO 301 J=1,NS	1730
DMXA(J)=0.0	1740
DMXB(J)=0.0	1750
DMXC(J)=0.0	1760
DMXD(J)=0.0	1770
DMYA(J)=0.0	1780
DMYB(J)=0.0	1790
DMYC(J)=0.0	1800
DMYD(J)=0.0	1810
SIF=RM(J)*ANSP2	

CVXA(J)=STF	1820
DVYA(J)=STF	1830
DVXB(J)=0.0	1840
DVXC(J)=0.0	1850
DVXD(J)=0.0	1860
DVYE(J)=0.0	1870
DVYC(J)=0.0	1880
DVYD(J)=0.0	1890
DIA(J)=0.0	1900
DIB(J)=0.0	1910
DIC(J)=0.0	1920
301 DIN(J)=0.0	1930
302 DO 311 J=1,NB	1940
KST=LB(J)	1950
KFN=0	1960
CF1K=BKXX(1,J)+BKXX(2,J)*ANSP+BKXX(3,J)*ANSP2	1970
CF1C= BCXX(1,J)+BCXX(2,J)*ANSP+BCXX(3,J)*ANSP2	1980
CF1D=BKXY(1,J)+BKXY(2,J)*ANSP+BKXY(3,J)*ANSP2	1990
CF1E= BKXY(1,J)+BKXY(2,J)*ANSP+BKXY(3,J)*ANSP2	2000
CF2K=BKYY(1,J)+BKYY(2,J)*ANSP+BKYY(3,J)*ANSP2	2010
CF2C= BCYY(1,J)+BCYY(2,J)*ANSP+BCYY(3,J)*ANSP2	2020
CF2D=BKXX(1,J)+BKXX(2,J)*ANSP+BKXX(3,J)*ANSP2	2030
CF2E= BCXX(1,J)+BCXX(2,J)*ANSP+BCXX(3,J)*ANSP2	2040
IF(INPST) 303,305,303	2050
303 CF1M=PKX(J)-PMX(J)/386.069*ANSP2	2060
CF1N=PCX(J)*ANSP	2070
CF1A=CF1K+CF1M	2080
CF1B=CF1C+CF1N	2090
CF2M=PKY(J)-PMY(J)/386.069*ANSP2	2100
CF2N=PCY(J)*ANSP	2110
CF2A=CF2K+CF2M	2120
CF2B=CF2C+CF2N	2130
GO TO 307	2140
304 KFN=1	2150
CF1K=BSMXX(1,J)+BSMXX(2,J)*ANSP+BSMXX(3,J)*ANSP2	2160
CF1C= BDMXX(1,J)+BDMXX(2,J)*ANSP+BDMXX(3,J)*ANSP2	2170
CF1D=BSMXY(1,J)+BSMXY(2,J)*ANSP+BSMXY(3,J)*ANSP2	2180
CF1E= BDMXY(1,J)+BDMXY(2,J)*ANSP+BDMXY(3,J)*ANSP2	2190
CF2K=BSMYX(1,J)+BSMYX(2,J)*ANSP+BSMYX(3,J)*ANSP2	2200
CF2C= BDMYY(1,J)+BDMYY(2,J)*ANSP+BDMYY(3,J)*ANSP2	2210
CF2D=BSMYX(1,J)+BSMYX(2,J)*ANSP+BSMYX(3,J)*ANSP2	2220
CF2E= BDMXX(1,J)+BDMXX(2,J)*ANSP+BDMXX(3,J)*ANSP2	2230
IF(INPST) 305,306,305	2240
305 CF1M=PSMX(J)-PIX(J)/386.069*ANSP2	2250
CF1N=PDMX(J)*ANSP	2260
CF1A=CF1K+CF1M	2270
CF1B=CF1C+CF1N	2280
CF2M=PSMY(J)-PIY(J)/386.069*ANSP2	2290
CF2N=PDMY(J)*ANSP	2300
CF2A=CF2K+CF2M	2310
CF2B=CF2C+CF2N	2320
GO TO 307	2330
306 CF1=CF1K	2340
CF2=CF1C	2350
CF3=CF1D	2360
CF4=CF1E	2370
CF5=CF2D	2380
CF6=CF2E	2390
CF7=CF2K	2400
CF8=CF2C	2410
GO TO 308	2420
307 CF4=CF2A+CF2A+CF2B+CF2B	2430
CF1=(CF2A+CF2C+CF2D+CF2E)/CF4	2440

CF2=(CF2A+CF2E+CF2U+CF2D)/CF4	2450
CF3=(CF2A+CF2V+CF2S+CF2N)/CF4	2460
CF4=(CF2A+CF2N+CF2U+CF2M)/CF4	2470
CF5=CF1A+CF1C+CF1U+CF1E	2480
CF6=CF1U+CF2C+CF1U+CF1E	2490
CF7=CF1C+CF1U+CF4C+CF1E	2500
CF8=CF4C+CF1D+CF3C+CF1E	2510
CF2N=CF5C+CF5C+CF6C+CF6	2520
CF2A=(CF5C+CF1M+CF6C+CF1N)/CF2N	2530
CF2U=(CF5C+CF1M+CF6C+CF1M)/CF2N	2540
CF2V=(CF5C+CF7C+CF6C+CF6)/CF2N	2550
CF2M=(CF5C+CF8C+CF5C+CF7)/CF2N	2560
CF1A=CF1C+CF2A+CF2C+CF2D	2570
CF1U=CF1C+CF2U+CF2C+CF2A	2580
CF1M=CF3C+CF1C+CF2M+CF2C+CF2N	2590
CF1N=CF4C+CF1C+CF2N+CF2C+CF2M	2600
CF1C=CF1K+CF2A+CF1C+CF2B+CF1U+CF1A+CF1E+CF1D	2610
CF2C=CF1K+CF2U+CF1C+CF2A+CF1U+CF1J+CF1E+CF1A	2620
CF3C=CF1K+CF2M+CF1C+CF2N+CF1U+CF1M+CF1E+CF1N	2630
CF4C=CF1K+CF2N+CF1C+CF2M+CF1U+CF1N+CF1E+CF1M	2640
CF5C=CF2U+CF2A+CF2E+CF2H+CF2K+CF1A+CF2C+CF1U	2650
CF6C=CF2U+CF2D+CF2E+CF2A+CF2K+CF1U+CF2C+CF1A	2660
CF7C=CF2U+CF2M+CF2E+CF2N+CF2K+CF1N+CF2C+CF1N	2670
CF8C=CF2U+CF2N+CF2E+CF2M+CF2K+CF1N+CF2C+CF1M	2680
308 IF (KFN) 310,309,310	2690
309 DVXA(KST)=DVXA(KST)-CF1/AMS	2700
DVXB(KST)=CF2/AMS	2710
DVXC(KST)=CF3/AMS	2720
DVXD(KST)=CF4/AMS	2730
DVYA(KST)=DVYA(KST)-CF7/AMS	2740
DVYB(KST)=CF8/AMS	2750
DVYC(KST)=CF5/AMS	2760
DVYD(KST)=CF6/AMS	2770
IF (NMOM) 304,311,304	2780
310 DMXA(KST)=CF1/AMS	2790
DMXB(KST)=CF2/AMS	2800
DMXC(KST)=CF3/AMS	2810
DMXD(KST)=CF4/AMS	2820
DMYA(KST)=CF7/AMS	2830
DMYB(KST)=CF8/AMS	2840
DMYC(KST)=CF5/AMS	2850
DMYD(KST)=CF6/AMS	2860
311 CONTINUE	2870
IF (INDIAG) 312,313,312	2880
C DIAGNOSTIC 1	2890
312 WRITE (6,135)	2900
WRITE (6,109) (CF1K,CF1C,CF1U,CF1E,CF2K,CF2C,CF2U,CF2E, CF2A,CF2D,C	2910
1F2M,CF2N,CF1A,CF1C,CF1M,CF1N,CF1C,CF2C,CF3C,CF4C,CF5C,CF6C, CF7C,CF8C,STF	2920
2,ANSP2,ANSP,SPCAL	2930
WRITE (6,118) (KST,KFN	2940
WRITE (6,144) (DVXA(J),DVXB(J),DVXC(J),DVXD(J),DVYA(J), DVYB(J),DVY	2950
1C(J),DVYD(J),J=1,NS), (DMXA(J),DMXB(J),DMXC(J),DMXD(J), DMYA(J),DMY	2960
2B(J),DMYC(J),DMYD(J),J=1,NS)	2970
WRITE (6,145) (RM(J),RIP(J),MIT(J),AN(J),BH(J),DN(J), J=1,NS)	2980
313 RETURN	
END	
SIBFTC ARCT M94,HR7	0020
C ARCTAN ROUTINE	0010
FUNCTION ANGIAPCS,AFSN)	0030
ACS=AFCS	0040
ASN=AFSN	0050
800 IF (ASN) 804,801,804	0060
801 IF (ACS) 802,803,803	

802 ANG=180.0	0070
GO TO 812	0080
803 ANG=0.0	0090
GO TO 812	0100
804 IF(ACS) 809,805,808	0110
805 IF(ASN) 806,803,807	0120
806 ANG=-90.0	0130
GO TO 812	0140
807 ANG=90.0	0150
GO TO 812	0160
808 ANG=0.0	0170
GO TO 810	0180
809 ANG=-180.0	0190
810 ASN=ASN/ACS	0200
ACS=ABS(ASN)	0210
ACS=ATAN(ACS)	0220
ANG=ANG+ACS*57.295780	0230
IF(ASN) 811,812,812	0240
811 ANG=-ANG	0250
812 RETURN	0260
END	0270
SIBFTC EQSS M94,XR7	
SUBROUTINE EQS	
DIMENSION A(8,8),B(8,4),C(8,4),D(8,1),CFM(8,8),ENT(10),RMS(8,1),	
1DUM(100),CLNR(8)	0010
COMMON A B C D CFM ENT	0020
COMMON RMS DUM CF9 MAT KFN CLNR	0030
COMMON PRN3	0060
KFN=KFN	0070
KFN=1	0080
GO TO (240,260,260,280),MAT	0120
240 DO 254 J=1,4	0130
PRNR=1.0	0140
PRN2=0.0	0150
PRN3=1.0	0160
PRN4=0.0	0170
K4=0	0180
DO 248 I=1,4	0190
PRN1=A(I,J)	0200
IF(PRN1) 242,241,243	0210
241 PRN2=PRN2+1.0	0220
GO TO 244	0230
242 PRN1=-PRN1	0240
243 PRNR=PRNR*(PRN1**0.25)	0250
244 PRN1=B(I,J)	0260
IF(PRN1) 246,245,247	0270
245 PRN4=PRN4+1.0	0280
K4=K4+1	0290
GO TO 248	0300
246 PRN1=-PRN1	0310
247 PRN3=PRN3*(PRN1**0.25)	0320
248 CONTINUE	0330
IF(PRN2) 250,250,249	0340
249 PRN2=4.0/(4.0-PRN2)	0350
PRNR=PRNR**PRN2	0360
250 CLNR(I)=PRNR	0370
IF(PRN4) 252,252,251	0380
251 IF(K4-4) 251,252,252	0390
252 PRN4=4.0/(4.0-PRN4)	0400
PRN3=PRN3**PRN4	0410
252 DUM(I)=PRN3	0420
DO 253 I=1,4	0430
A(I,J)=A(I,J)/PRNR	0440
	0450
	0460

253	B(I,J)=B(I,J)/PRN3	
254	CONTINUE	0470
	CALL MATINV(A,4,B,4,CF9)	0480
	DO 256 J=1,4	0490
	PRN1=DUM1(J)	0500
	DO 255 I=1,4	0510
255	A(I,J)=B(I,J)/CLNR(1)*PRN1	0520
256	CONTINUE	0530
	GO TO 297	0540
260	PRN3=1.0	0550
	PRN4=0.0	0560
	K4=0	0570
	DO 271 J=1,4	0580
	PRNR=1.0	0590
	PRN2=0.0	0600
	DO 264 I=1,4	0610
	PRN1=C(I,J)	0620
	IF (PRN1) 262,261,263	0630
261	PRN2=PRN2+1.0	0640
	GO TO 264	0650
262	PRN1=-PRN1	0660
263	PRNR=PRNR*(PRN1**0.25)	0670
264	CONTINUE	0680
	IF (PRN2) 266,266,265	0690
265	PRN2=4.0/(4.0-PRN2)	0700
	PRNR=PRNR**PRN2	0710
266	CLNR(J)=PRNR	0720
	DO 267 I=1,4	0730
267	C(I,J)=C(I,J)/PRNR	0740
	PRN1=D(I,J)	0750
	IF (PRN1) 269,268,270	0760
268	PRN4=PRN4+1.0	0770
	K4=K4+1	0780
	GO TO 271	0790
269	PRN1=-PRN1	0800
270	PRN3=PRN3*(PRN1**0.25)	0810
271	CONTINUE	0820
	IF (PRN4) 273,273,272	0830
272	IF (K4-4) 277,273,273	0840
277	PRN4=4.0/(4.0-PRN4)	0850
	PRN3=PRN3**PRN4	0860
273	DO 274 J=1,4	0870
274	D(I,J)=D(I,J)/PRN3	0880
	CALL MATINV(C,4,D,4,CF9)	0890
275	DO 276 I=1,4	0900
276	C(I,1)=D(I,1)/CLNR(1)*PRN3	0910
	GO TO 297	0920
280	PRN3=1.0	0930
	PRN4=0.0	0940
	K4=0	0950
	DO 291 J=1,4	0960
	PRNR=1.0	0970
	PRN2=0.0	0980
	DO 284 I=1,4	0990
	PRN1=CFM(I,J)	1000
	IF (PRN1) 282,281,283	1010
281	PRN2=PRN2+1.0	1020
	GO TO 284	1030
282	PRN1=-PRN1	1040
283	PRNR=PRNR*(PRN1**0.125)	1050
284	CONTINUE	1060
	IF (PRN2) 286,286,285	1070
285	PRN2=8.0/(8.0-PRN2)	1080
		1090

PRNR=PRNR**PRN2	1100
286 CLNR(J)=PRNR	1110
DO 287 I=1,8	1120
287 CFM(I,J)=CFM(I,J)/PRNR	1130
PRN1=RHS(J,1)	1140
IF (PRN1) 289,288,290	1150
288 PRN4=PRN4+1.0	1160
K4=K4+1	1170
GO TO 291	1180
289 PRN1=-PRN1	1190
290 PRN3=PRN3*(PRN1**0.125)	1200
291 CONTINUE	1210
IF (PRN4) 293,293,292	1220
292 IF(K4-8) 290,293,293	1230
298 PRN4=8.0/(8.0-PRN4)	1240
PRN3=PRN3**PRN4	1250
293 DO 294 J=1,8	1260
294 RHS(J,1)=RHS(J,1)/PRN3	1270
CALL MATINV(CFM,8,RHS,1,CF9)	1280
295 DO 296 I=1,8	1290
296 CFM(I,1)=RHS(I,1)/CLNR(I)*PRN3	1300
297 RETURN	1310
END	1320
SIBFTC MATRIX M94,XR7	
C MATRIX INVERSION WITH ACCOMPANYING SOLUTION OF LINEAR EQUATIONS	0020
C	0030
C SUBROUTINE MATINV(A,N,B,M,DETERM)	0010
C	0040
C DIMENSION IPIVOT(8), A(8,8), B(8,4), INDEX(8,2), PIVOT(8)	0050
C EQUIVALENCE (IROW,JROW), (ICOLUMN,JCOLUMN), (AMAX, I, SWAP)	0070
C	0080
C INITIALIZATION	0090
C	0100
10 DETERM=1.0	0110
15 DO 20 J=1,N	0120
20 IPIVOT(J)=0	0130
30 DO 550 I=1,N	0140
C	0150
C SEARCH FOR PIVOT ELEMENT	0160
C	0170
40 AMAX=0.0	0180
45 DO 105 J=1,N	0190
50 IF (IPIVOT(J)-1) 60, 105, 60	0200
60 DO 100 K=1,N	0210
70 IF (IPIVOT(K)-1) 80, 100, 740	0220
80 IF (ABS(AMAX)-ABS(A(I,J,K))) 85, 100, 100	0230
85 IROW=J	0240
90 ICOLUMN=K	0250
95 AMAX=A(I,J,K)	0260
100 CONTINUE	0270
105 CONTINUE	0280
110 IPIVOT(ICOLUMN)=IPIVOT(ICOLUMN)+1	0290
C	0300
C INTERCHANGE ROWS TO PUT PIVOT ELEMENT ON DIAGONAL	0310
C	0320
130 IF (IROW-ICOLUMN) 140, 260, 140	0330
140 DETERM=-DETERM	0340
150 DO 200 L=1,N	0350
160 SWAP=A(IROW,L)	0360
170 A(IROW,L)=A(ICOLUMN,L)	0370
200 A(ICOLUMN,L)=SWAP	0380
205 IF(M) 260, 260, 210	0390
210 DO 250 L=1, M	0400

220	SWAP=B(IROW,L)	0410
230	B(IROW,L)=B(ICOLUMN,L)	0420
250	B(ICOLUMN,L)=SWAP	0430
260	INDEX(I,1)=IROW	0440
270	INDEX(I,2)=ICOLUMN	0450
310	PIVOT(I)=A(ICOLUMN,ICOLUMN)	0460
320	DETERM=DETERM*PIVOT(I)	0470
C		0480
C	DIVIDE PIVOT ROW BY PIVOT ELEMENT	0490
C		0500
330	A(ICOLUMN,ICOLUMN)=1.0	0510
340	DO 350 L=1,N	0520
350	A(ICOLUMN,L)=A(ICOLUMN,L)/PIVOT(I)	0530
355	IF(M) 380, 380, 360	0540
360	DO 370 L=1,M	0550
370	B(ICOLUMN,L)=B(ICOLUMN,L)/PIVOT(I)	0560
C		0570
C	REDUCE NON-PIVOT ROWS	0580
C		0590
380	DO 550 L1=1,N	0600
390	IF(L1-ICOLUMN) 400, 550, 400	0610
400	T=A(L1,ICOLUMN)	0620
420	A(L1,ICOLUMN)=0.0	0630
430	DO 450 L=1,N	0640
450	A(L1,L)=A(L1,L)-A(ICOLUMN,L)*T	0650
455	IF(M) 550, 550, 460	0660
460	DO 500 L=1,M	0670
500	B(L1,L)=B(L1,L)-B(ICOLUMN,L)*T	0680
550	CONTINUE	0690
C		0700
C	INTERCHANGE COLUMNS	0710
C		0720
600	DO 710 I=1,N	0730
610	L=N+1-I	0740
620	IF (INDEX(L,1)-INDEX(L,2)) 630, 710, 630	0750
630	JROW=INDEX(L,1)	0760
640	JCOLUMN=INDEX(L,2)	0770
650	DO 705 K=1,N	0780
660	SWAP=A(K,JROW)	0790
670	A(K,JROW)=A(K,JCOLUMN)	0800
700	A(K,JCOLUMN)=SWAP	0810
705	CONTINUE	0820
710	CONTINUE	0830
740	RETURN	0840
750	END	0850
-	END OF FILE	

SAMPLE CALCULATION NO:1
 ROTOR IN RIGID PEDFSTALS NO GYROSCOPIC MOMENT

27	4	1	0	0	0	1	0	0
3.130000E+01	1.000000E+00							
7.600000E+01	3.750000E+00	5.250000E+01						
2.140000E+01	4.000000E+00	4.880000E+01						
3.000000E+01	5.310000E+00	4.880000E+01						
1.250000E+02	5.620000E+00	1.440000E+02						
1.240000E+02	2.250000E+00	3.020000E+02						
3.820000E+02	5.910000E+00	7.780000E+02						
3.760000E+02	9.780000E+00	2.580000E+03						
7.770000E+02	7.190000E+00	8.380000E+02						
5.700000E+02	8.570000E+00	3.950000E+02						
4.530000E+02	7.190000E+00	3.850000E+02						
2.350000E+02	5.000000E+00	3.210000E+02						
3.000000E+02	6.620000E+00	6.130000E+02						
3.130000E+02	4.870000E+00	1.930000E+02						
8.200000E+01	2.130000E+00	6.800000E+01						
3.200000E+01	3.190000E+00	4.180000E+01						
3.572000E+01	7.420000E+00	2.000000E+01						
2.821000E+01	8.650000E+00	5.476000E+00						
9.043000E+01	1.237500E+01	3.120000E-01						
4.297000E+00	1.237500E+00	3.120000E-01						
4.297000E+00	1.237500E+00	3.120000E-01						
7.852000E+01	4.750000E+00	2.000000E+01						
3.423000E+01	5.320000E+00	1.092000E+02						
9.820000E+01	6.190000E+00	8.540000E+02						
2.431000E+02	6.510000E+00	1.602000E+03						
3.300000E+02	6.210000E+00	8.360000E+02						
2.843000E+02	4.300000E+00	1.554000E+02						
6.370000E+01	0.000000E+00	0.000000E+00						
3	16	22	27					
10	1.000000E+01	0.000000E+00						
1.000000E+03	5.100000E+03	2.000000E+03						
1.542000E+06	0.000000E+00	0.000000E+00						
3.362000E+06	0.000000E+00	0.000000E+00						
-8.010000E+05	0.000000E+00	0.000000E+00						
1.302000E+06	0.000000E+00	0.000000E+00						
1.542000E+05	0.000000E+00	0.000000E+00						
1.040000E+06	0.000000E+00	0.000000E+00						
9.720000E+05	0.000000E+00	0.000000E+00						
1.302000E+06	0.000000E+00	0.000000E+00						
1.463000E+06	0.000000E+00	0.000000E+00						
3.296000E+06	0.000000E+00	0.000000E+00						
-1.045000E+06	0.000000E+00	0.000000E+00						
1.781000E+06	0.000000E+00	0.000000E+00						
-1.197000E+05	0.000000E+00	0.000000E+00						
1.754000E+06	0.000000E+00	0.000000E+00						
1.175000E+06	0.000000E+00	0.000000E+00						
1.781000E+06	0.000000E+00	0.000000E+00						
1.463000E+06	0.000000E+00	0.000000E+00						
3.296000E+06	0.000000E+00	0.000000E+00						
-1.045000E+06	0.000000E+00	0.000000E+00						
1.781000E+06	0.000000E+00	0.000000E+00						
-1.197000E+05	0.000000E+00	0.000000E+00						

1.754000E+06	0.000000E+00	0.000000E+00
1.175000E+05	0.000000E+00	0.000000E+00
1.781000E+06	0.000000E+00	0.000000E+00

1

1.754000E+06

UNBALANCE RESPONSE OF ROTOR WITH NON-UNIFORM BEARING SUPPORTS PH0011 MECHANICAL TECHNOLOGY, INC.

SAMPLE CALCULATION NO. 1
ROTOR IN RIGID PEDESTALS, NO GYROSCOPIC MOMENT

STATIONS NO. BESS. NO. UNBAL. NO. COUPL. PED. FLEX. BRG. MOMENT GYRO. MOM. NO. CASES DIAGNOSTIC INPUT

YOUNG'S MODULUS SCALE FACTOR
3.130000E 07 1.000000E 00

ROTOR DATA

CROSS SECT. INERTIA

STATION NO.	MASS	LENGTH
1	7.400000E 01	3.750000E 00
2	2.140000E 01	4.090000E 00
3	3.000000E 01	5.309999E 00
4	1.250000E 02	6.619999E 00
5	1.750000E 02	2.250000E 00
6	3.620000E 02	5.910000E 00
7	8.760000E 02	9.780000E 00
8	7.770000E 02	7.190000E 00
9	5.700000E 02	8.569999E 00
10	4.530000E 02	7.190000E 00
11	2.350000E 02	5.000000E 00
12	3.000000E 02	6.619999E 00
13	3.130000E 02	4.849999E 00
14	8.199999E 01	2.130000E 00
15	3.200000E 01	3.190000E 00
16	3.672000E 01	7.420000E 00
17	2.621000E 01	8.430000E 00
18	9.042999E 01	1.237500E 01
19	4.297000E 00	1.237500E 00
20	4.297000E 00	1.237500E 00
21	7.051999E 01	4.750000E 00
22	3.422999E 01	5.320000E 00
23	9.819999E 01	6.190000E 00
24	2.431000E 02	6.210000E 00
25	3.200000E 02	6.210000E 00
26	2.043000E 02	4.330000E 00
27	6.369999E 01	6.

GEARING STATIONS

3 16 22 27

UNBALANCE ST. X-UNBALANCE V-UNBALANCE
10 1.000000E 01 0.

INITIAL SPEED FINAL SPEED SPEED INCR.
1.000000E 03 5.100000E 03 2.000000E 03

KX	CHX	KXY	CHY	CVX	KVX	CVY	CYX
1.542000E 06	3.342000E 06	-8.010000E 03	1.302000E 06	1.342000E 05	1.040000E 06	1.040000E 06	1.302000E 06
0.	0.	0.	0.	0.	0.	0.	0.
0.	0.	0.	0.	0.	0.	0.	0.

KX	CHX	KXY	CHY	CVX	KVX	CVY	CYX
1.542000E 06	3.342000E 06	-8.010000E 03	1.302000E 06	1.342000E 05	1.040000E 06	1.040000E 06	1.302000E 06
0.	0.	0.	0.	0.	0.	0.	0.
0.	0.	0.	0.	0.	0.	0.	0.

BEARING AT STATION NO. 22

REV	REV	REV	REV	REV	REV
1.463000E 06	3.296000E 06	-1.045000E 06	1.781000E 06	1.754000E 06	1.781000E 06
0.	0.	0.	0.	0.	0.
0.	0.	0.	0.	0.	0.

BEARING AT STATION NO. 27

REV	REV	REV	REV	REV	REV
1.463000E 06	3.296000E 06	-1.045000E 06	1.781000E 06	1.754000E 06	1.781000E 06
0.	0.	0.	0.	0.	0.
0.	0.	0.	0.	0.	0.

MOTOR SPEED 1.000000E 03RPM

STATION	MAJOR AXIS	MINOR AXIS	AMPLITUDE	ANGLE X-MAJOR	PHASE ANGLE
1	1.34030E-02	-3.50166E-03	8.83056E 01	-6.00124E 00	0.
2	1.44877E-02	-3.64268E-03	-6.24256E 01	3.85389E 00	-6.00124E 00
3	1.57165E-02	-3.14360E-03	-7.41771E 01	1.26949E 01	-4.70114E 00
4	1.77963E-02	-1.99191E-03	-6.17332E 01	2.02376E 01	-4.70114E 00
5	2.02243E-02	-5.52424E-04	-6.32125E 01	2.51267E 01	-4.70114E 00
6	2.10180E-02	-1.30511E-04	-6.24077E 01	2.611720E 01	-4.70114E 00
7	2.24630E-02	6.07364E-04	-6.09944E 01	2.82806E 01	-4.70114E 00
8	2.57277E-02	2.45862E-03	-5.93827E 01	3.06820E 01	-4.70114E 00
9	2.75485E-02	3.37057E-03	-5.80331E 01	3.18730E 01	-4.70114E 00
10	2.85957E-02	3.49158E-03	-5.71351E 01	3.21666E 01	-4.70114E 00
11	2.81183E-02	2.40871E-03	-6.04866E 01	3.13150E 01	-4.70114E 00
12	2.71913E-02	1.11387E-03	-6.21360E 01	2.99770E 01	-4.70114E 00
13	2.54653E-02	-9.21174E-04	-6.34592E 01	2.70966E 01	-4.70114E 00
14	2.40795E-02	-2.49571E-03	-6.90475E 01	2.38066E 01	-4.70114E 00
15	2.34276E-02	-3.19155E-03	-7.11461E 01	2.18327E 01	-4.70114E 00
16	2.24164E-02	-4.17627E-03	-7.51407E 01	1.80098E 01	-4.70114E 00
17	2.04700E-02	-5.38908E-03	-6.70756E 01	6.33905E 00	-4.70114E 00
18	1.83379E-02	-4.30640E-03	7.82280E 01	-8.32867E 00	-4.70114E 00
19	2.10922E-03	-4.03484E-04	8.74200E 01	-3.40966E 01	-4.70114E 00
20	1.39982E-03	-4.11679E-04	-8.21965E 01	-4.37242E 01	-4.70114E 00
21	1.11647E-03	-4.64966E-04	-7.58186E 01	-5.29730E 01	-4.70114E 00
22	8.97826E-04	-4.23363E-04	-7.20060E 01	-5.33575E 01	-4.70114E 00
23	6.44014E-04	-3.34198E-04	-7.01691E 01	-5.50956E 01	-4.70114E 00

MAJOR AXIS	MINOR AXIS	BENDING ANGLE	WAVELENGTH	PHASE ANGLE
0.	0.	0.	0.	0.
1.12550E-01	-2.88330E-02	8.30356E 01	-6.00124E 00	0.
1.12550E-01	-2.88330E-02	8.30356E 01	-6.00124E 00	0.
2.70675E-01	-6.98215E-02	8.92816E 01	-4.70114E 00	0.
2.70675E-01	-6.98215E-02	8.92816E 01	-4.70114E 00	0.
4.44200E 01	3.59123E 01	-4.72744E 01	4.7527E 01	0.
4.44200E 01	3.59123E 01	-4.72744E 01	4.7527E 01	0.
9.46397E 01	8.05669E 01	-4.72571E 01	4.73374E 01	0.
9.46397E 01	8.05669E 01	-4.72571E 01	4.73374E 01	0.
1.18241E 02	9.57621E 01	-4.72528E 01	4.73570E 01	0.
1.18241E 02	9.57621E 01	-4.72528E 01	4.73570E 01	0.
1.85933E 02	1.35790E 02	-4.72325E 01	4.73911E 01	0.
1.85933E 02	1.35790E 02	-4.72325E 01	4.73911E 01	0.
2.19638E 02	2.02187E 02	-4.71864E 01	4.73731E 01	0.
2.19638E 02	2.02187E 02	-4.71864E 01	4.73731E 01	0.
2.89980E 02	2.50845E 02	-4.71668E 01	4.74685E 01	0.
2.89980E 02	2.50845E 02	-4.71668E 01	4.74685E 01	0.
3.46376E 02	3.08586E 02	-4.72006E 01	4.75272E 01	0.
3.46376E 02	3.08586E 02	-4.72006E 01	4.75272E 01	0.
2.83627E 02	2.89285E 02	-4.77030E 01	4.74036E 01	0.
2.83627E 02	2.89285E 02	-4.77030E 01	4.74036E 01	0.
2.05211E 02	1.74121E 02	-4.91803E 01	4.74809E 01	0.
2.05211E 02	1.74121E 02	-4.91803E 01	4.74809E 01	0.
1.26467E 02	1.01144E 02	-4.91472E 01	4.75485E 01	0.
1.26467E 02	1.01144E 02	-4.91472E 01	4.75485E 01	0.
4.75908E 01	4.74421E 01	-5.08808E 01	4.75238E 01	0.
4.75908E 01	4.74421E 01	-5.08808E 01	4.75238E 01	0.
4.18095E 01	2.93378E 01	-5.28014E 01	4.72094E 01	0.
4.18095E 01	2.93378E 01	-5.28014E 01	4.72094E 01	0.
1.25434E 01	-1.15343E 00	6.16690E 01	-1.93548E 01	0.
1.25434E 01	-1.15343E 00	6.16690E 01	-1.93548E 01	0.
8.73306E 00	-7.66293E-01	6.15569E 01	-1.96470E 01	0.
8.73306E 00	-7.66293E-01	6.15569E 01	-1.96470E 01	0.
4.21940E 00	-2.51842E-01	6.04563E 01	-2.11744E 01	0.
4.21940E 00	-2.51842E-01	6.04563E 01	-2.11744E 01	0.
2.87531E 00	-5.95496E-01	6.97393E 01	-1.12864E 01	0.
2.87531E 00	-5.95496E-01	6.97393E 01	-1.12864E 01	0.
3.37571E 00	-6.89892E-01	6.84754E 01	-1.26143E 01	0.
3.37571E 00	-6.89892E-01	6.84754E 01	-1.26143E 01	0.
4.27813E 00	-7.82237E-01	6.76525E 01	-1.34830E 01	0.
4.27813E 00	-7.82237E-01	6.76525E 01	-1.34830E 01	0.
6.98599E 00	-1.12831E 00	6.81646E 01	-1.51876E 01	0.
6.98599E 00	-1.12831E 00	6.81646E 01	-1.51876E 01	0.
5.74537E 00	-8.75143E-01	6.54791E 01	-1.51402E 01	0.
5.74537E 00	-8.75143E-01	6.54791E 01	-1.51402E 01	0.

24	4.10740E-04	-2.18190E-04	-6.81780E 01	-5.20223E 01	4.35583E 00	-7.48033E-01	6.42444E 01	-1.48810E 01
25	1.73559E-04	-9.74245E-05	-5.80558E 01	-4.02266E 01	4.35583E 00	-7.48033E-01	6.42444E 01	-1.48810E 01
26	7.63932E-05	-1.75002E-05	-8.73840E 01	-8.79455E 01	2.79182E 00	-7.54467E-01	5.98641E 01	-1.66316E 01
27	2.37679E-04	-1.12993E-04	-7.96813E 01	-7.22591E 01	2.79182E 00	-7.54467E-01	5.98641E 01	-1.66316E 01

FORCE TRANSMITTED TO BEARING HOUSING

SRC.NO.	MAJOR AXIS	MINOR AXIS	ANGLE X-MAJOR	PHASE ANGLE	X-AMPLITUDE	X-PHASE ANG	Y-AMPLITUDE	Y-PHASE ANG
3	8.43201E 00	6.70134E 00	-4.72276E 01	4.34201E 01	7.54992E 00	2.75485E 00	7.68249E 00	-1.02352E 01
16	1.20823E 01	1.14087E 01	-4.15562E 01	4.05873E 01	1.17906E 01	6.56143E-01	1.17098E 01	-2.60517E 00
22	8.07698E-01	-1.18499E-01	6.52614E 01	-1.80327E 01	3.54725E-01	1.44305E 02	7.35247E-01	-1.04165E 02
27	3.03708E-01	1.08020E-02	5.90307E 01	-6.96806E 01	1.56555E-01	-3.37633E 00	2.60470E-01	8.18091E 01

ENERGY INPUT= 8.1158408E-04 ENERGY DISSIPATED= 8.1159989E-04

MOTOR SPEED= 3.0000000E 03RPM

STATION	AMPLITUDE				BENDING MOMENT				PHASE ANGLE
	MAJOR AXIS	MINOR AXIS	ANGLE X-MAJOR	PHASE ANGLE	MAJOR AXIS	MINOR AXIS	ANGLE X-MAJOR	PHASE ANGLE	
1	2.25113E-01	-1.20761E-02	-6.53596E 01	7.06737E 01	0.	0.	0.	0.	
2	2.22621E-01	-4.12056E-02	-6.41933E 01	7.58705E 01	1.64014E 01	-8.79843E-01	-6.53596E 01	7.06737E 01	
3	2.22508E-01	-7.17640E-02	-6.10487E 01	8.25551E 01	1.64014E 01	-8.79843E-01	-6.53596E 01	7.06737E 01	
4	2.27319E-01	-1.04808E-01	-5.37431E 01	-8.66328E 01	9.93888E 02	-1.54137E 02	-2.65076E 00	-2.63657E 01	
5	2.37905E-01	-1.26332E-01	-4.28350E 01	-7.26149E 01	9.93888E 02	-1.54137E 02	-2.65076E 00	-2.63657E 01	
6	2.41845E-01	-1.25361E-01	-3.95670E 01	-6.84684E 01	2.20906E 03	-3.50189E 02	-2.60913E 00	-2.64684E 01	
7	2.53626E-01	-1.31873E-01	-3.23703E 01	-5.91497E 01	2.60890E 03	-4.04149E 02	-2.52602E 00	-2.63330E 01	
8	2.76827E-01	-1.26514E-01	-2.46449E 01	-6.82487E 01	3.54693E 03	-4.44783E 02	-1.94408E 00	-2.54447E 01	
9	2.92014E-01	-1.18514E-01	-2.18218E 01	-6.32519E 01	4.62679E 03	-1.92208E 02	-2.63920E-01	-2.28431E 01	
10	2.93920E-01	-1.06701E-01	-2.19397E 01	-6.07448E 01	5.07213E 03	3.06927E 02	1.17131E 00	-2.07164E 01	
11	2.77009E-01	-9.64618E-02	-2.54143E 01	-6.16787E 01	5.28573E 03	1.03679E 03	2.94429E 00	-1.80740E 01	
12	2.57237E-01	-8.82535E-02	-2.99613E 01	-6.40639E 01	4.14477E 03	6.61495E 02	1.73308E 00	-1.84990E 01	
13	2.27914E-01	-7.36636E-02	-3.88404E 01	-6.92526E 01	3.27966E 03	4.40290E 02	7.56919E-01	-1.88137E 01	
14	2.07438E-01	-5.81558E-02	-4.76044E 01	-5.43428E 01	2.02667E 03	2.11765E 02	-7.46050E-01	-1.91622E 01	
15	1.99113E-01	-4.92778E-02	-5.21554E 01	-5.68612E 01	2.02667E 03	2.11765E 02	-7.46050E-01	-1.91622E 01	
16	1.88003E-01	-3.29200E-02	-5.96697E 01	-6.06174E 01	1.03342E 03	9.12326E 01	-2.35901E 00	-1.92107E 01	
17	1.72623E-01	1.08120E-02	-7.65800E 01	-6.48289E 01	5.94199E 02	4.38652E 01	-4.35613E 00	-1.91705E 01	
18	1.62301E-01	5.33585E-02	8.37872E 01	-5.99221E 01	8.46701E 01	2.00979E 01	3.57348E 01	-2.84783E 01	
19	1.74169E-02	7.73079E-03	-7.23095E 01	7.65660E 01	6.80213E 01	2.18212E 01	4.41070E 01	-5.30327E 01	
20	1.22379E-02	1.00904E-03	-6.49986E 01	5.51075E 01	4.51754E 01	1.74547E 01	5.24506E 01	-3.87729E 01	

21	1.05029E-02	-1.71160E-03	-6.84949E 01	4.31113E 01	4.18719E 01	1.53511E 01	6.70562E 01	-4.72442E 01
22	8.44241E-03	-2.30981E-03	-7.47452E 01	3.56103E 01	4.18719E 01	1.53511E 01	6.70562E 01	-4.72442E 01
23	6.50403E-03	-2.05238E-03	-7.69285E 01	3.37688E 01	6.93213E 01	2.69244E 01	6.44931E 01	-4.63859E 01
24	4.29383E-03	-1.52242E-03	-8.15433E 01	3.23981E 01	6.93213E 01	2.69244E 01	6.44931E 01	-4.63859E 01
25	2.04262E-03	-9.21702E-04	8.18132E 01	2.58433E 01	5.38153E 01	2.05519E 01	6.42131E 01	-4.35408E 01
26	9.80178E-04	7.85178E-05	-3.19948E 00	6.29771E 00	5.38153E 01	2.05519E 01	6.42131E 01	-4.35408E 01
27	1.96710E-03	-1.69705E-05	-5.61947E 01	2.57598E 01	3.45171E 01	2.06931E 01	7.27444E 01	-3.31248E 01

FORCE TRANSMITTED TO BEARING HOUSING

ORG. NO.	MAJON AXIS	MINOR AXIS	ANGLE X-MAJON	PHASE ANGLE
3	1.89720E 02	-4.18999E 01	-3.52855E 00	-2.85199E 01
16	2.10944E 02	1.98094E 01	-8.30463E-03	-1.96138E 01
22	8.74956E 00	3.34633E 00	5.96144E 01	-5.13449E 01
27	3.42944E 00	1.09874E 00	1.96419E 01	3.32119E 01

ENERGY INPUT= 4.3496344E-02 ENERGY DISSIPATED= 8.3500748E-02

ROTOR SPEED= 5.0000000E 03RPM

STATION	AMPLITUDE			
	MAJON AXIS	MINOR AXIS	ANGLE X-MAJON	PHASE ANGLE
1	3.69461E-01	3.18251E-01	3.96219E 01	7.21398E 01
2	2.46381E-01	2.07587E-01	-3.49226E 01	-1.38118E 01
3	3.14400E-01	1.34460E-02	-2.42506E 01	2.56888E 00
4	4.39942E-01	1.82067E-02	-2.95821E 00	2.42929E 01
5	6.12675E-01	4.48158E-02	8.05374E 03	3.56832E 01
6	6.56664E-01	5.87874E-02	9.30958E 00	3.73761E 01
7	7.54378E-01	9.83087E-02	1.32927E 01	4.08392E 01
8	8.87827E-01	1.67624E-01	1.66985E 01	4.43320E 01
9	9.53177E-01	2.16944E-01	1.82077E 01	4.59323E 01
10	9.29264E-01	2.62879E-01	1.87900E 01	4.66177E 01
11	8.06731E-01	2.88029E-01	1.79498E 01	4.59327E 01
12	6.72240E-01	2.99050E-01	1.64008E 01	4.46177E 01
13	6.57666E-01	3.11264E-01	1.22341E 01	4.16456E 01
14	3.24350E-01	2.83158E-01	-7.80530E 01	-5.79206E 01
15	3.33680E-01	2.02699E-01	-8.40872E 01	-5.89729E 01
16	3.60323E-01	4.34787E-02	8.71575E 01	-6.65709E 01
17	5.40095E-01	-8.40086E-02	6.11134E 01	8.77301E 01

STATION	BENDING MOMENT			
	MAJON AXIS	MINOR AXIS	ANGLE X-MAJON	PHASE ANGLE
1	0.	0.	0.	0.
2	7.47731E 01	6.44091E 01	3.92219E 01	7.21398E 01
3	1.68744E 02	1.52533E 02	3.91108E 01	7.41443E 01
4	6.35129E 03	8.85621E 02	2.19590E 01	7.81443E 01
5	1.39000E 04	1.88807E 03	2.19531E 01	4.95654E 01
6	1.63318E 04	2.22745E 03	2.19320E 01	4.94543E 01
7	2.17929E 04	3.07847E 03	2.26012E 01	4.95339E 01
8	2.63951E 04	4.07626E 03	2.48350E 01	5.26649E 01
9	2.64232E 04	4.31165E 03	2.72588E 01	5.48980E 01
10	2.34855E 04	4.17694E 03	3.17617E 01	5.94024E 01
11	1.91171E 04	3.69775E 03	3.03310E 01	5.79547E 01
12	1.54637E 04	3.18315E 03	2.94423E 01	5.70148E 01
13	9.75539E 03	2.15687E 03	2.86289E 01	5.60945E 01
14	5.12270E 03	1.12674E 03	2.84408E 01	5.59402E 01
15	3.07077E 03	6.45238E 02	2.95186E 01	5.61017E 01
16	1.47461E 02	4.80859E 01	-7.30929E 01	-7.95474E 01
17	1.47461E 02	4.80859E 01	-7.30929E 01	-7.95474E 01

18	8.55182E-01	-1.21549E-01	4.6882E 01	7.29325E 01	3.08900E 02	-2.99844E 01	3.89169E 01	6.78332E 01
19	1.05272E-01	-1.57027E-02	5.87849E 01	5.56783E 01	3.08900E 02	-2.99844E 01	3.89169E 01	6.78332E 01
20	5.68401E-02	-1.71455E-02	7.32543E 01	4.39008E 01	1.63326E 02	-2.12169E 01	4.15069E 01	7.20501E 01
21	4.05544E-02	-2.13940E-02	8.59406E 01	3.65630E 01	2.10823E 02	-2.64258E 01	4.11373E 01	7.13910E 01
22	2.93276E-02	-2.12347E-02	-8.27374E 01	3.57796E 01	2.58483E 02	-3.16274E 01	4.09374E 01	7.09543E 01
23	2.21186E-02	-1.87502E-02	-6.72217E 01	4.49263E 01	2.58483E 02	-3.16274E 01	4.09374E 01	7.09543E 01
24	1.43919E-02	-1.30546E-02	-5.45806E 01	5.13101E 01	4.55606E 02	-5.07780E 01	4.15833E 01	6.93005E 01
25	8.80776E-03	-6.52649E-03	7.45577E 00	-8.50465E 01	3.63754E 02	-3.64535E 01	4.05170E 01	7.67355E 01
26	6.87963E-03	-3.06026E-03	5.02161E 01	7.47993E 01	2.79548E 02	-2.01352E 01	3.87578E 01	8.80541E 01
27	1.01824E-02	-4.80606E-03	6.90885E 01	5.19171E 01	1.98177E 02	-2.76374E 01	4.13458E 01	-7.18486E 01

FORCE TRANSMITTED TO BEARING HOUSING

ORG. NO.	MAJOR AXIS	MINOR AXIS	ANGLE	X-MAJOR	PHASE ANGLE
3	1.13053E 03	1.28511E 02	2.02245E 01	4.77805E 01	
16	9.43631E 02	2.49322E 02	2.67030F 01	5.48980E 01	
22	5.61379E 01	-6.49720E 00	4.45372E 01	5.87467E 01	
27	3.11491E 01	-1.96309E 00	4.50874E 01	-6.95669E 01	

ENERGY INPUT= 1.5114504E 00 ENERGY DISSIPATED= 1.5119938E 00

X-AMPLITUDE	X-PHASE ANG	Y-AMPLITUDE	Y-PHASE ANG
1.08801E 03	-1.29871E 02	4.18262E 02	-5.89681E 01
8.50404E 02	-1.17532E 02	4.78973E 02	-6.28135E 01
4.02735E 01	5.22249E 01	3.96450E 01	1.55455E 02
2.20360E 01	-7.31840E 01	2.21028E 01	2.40283E 01

SAMPLE CALCULATION NO.2
 ROTOR IN FLEXIBLE PEDESTALS AND GYROSCOPIC MOMENT

27	4	3	0	1	1	1	1	0	1
3.1300000E+07	1.0000000E+00								
7	1.0000000E-03								
7.6000000E+01	3.7500000E+00	5.2500000E+01	1.2420000E+04	7.1100000E+03					
2.1400000E+01	4.0900000E+00	4.8800000E+01	0.0000000E+00	0.0000000E+00					
3.0000000E+01	5.3100000E+00	4.8800000E+01	0.0000000E+00	0.0000000E+00					
1.2500000E+02	6.6200000E+00	1.4400000E+02	0.0000000E+00	0.0000000E+00					
1.2400000E+02	2.2500000E+00	3.0200000E+02	0.0000000E+00	0.0000000E+00					
3.8200000E+02	5.9100000E+00	7.7880000E+02	0.0000000E+00	0.0000000E+00					
8.7600000E+02	9.7800000E+00	2.5800000E+03	0.0000000E+00	0.0000000E+00					
7.7700000E+02	7.1900000E+00	8.3800000E+02	0.0000000E+00	0.0000000E+00					
5.7000000E+02	8.5700000E+00	3.9500000E+02	0.0000000E+00	0.0000000E+00					
4.5300000E+02	7.1900000E+00	3.8500000E+02	0.0000000E+00	0.0000000E+00					
2.3500000E+02	5.0000000E+00	3.2100000E+02	0.0000000E+00	0.0000000E+00					
3.0000000E+02	6.6200000E+00	6.1300000E+02	0.0000000E+00	0.0000000E+00					
3.1300000E+02	4.8700000E+00	1.9300000E+02	0.0000000E+00	0.0000000E+00					
9.2000000E+01	2.1300000E+00	6.8000000E+01	0.0000000E+00	0.0000000E+00					
3.2000000E+01	3.1900000E+00	4.1800000E+01	0.0000000E+00	0.0000000E+00					
3.6720000E+01	7.4200000E+00	2.0000000E+01	0.0000000E+00	0.0000000E+00					
2.8210000E+01	8.6500000E+00	5.4760000E+00	1.8200000E+02	9.7000000E+01					
9.0430000E+01	1.2375000E+01	3.1200000E-01	1.0500000E+03	5.4500000E+02					
4.2970000E+00	1.2375000E+00	3.1200000E-01	0.0000000E+00	0.0000000E+00					
4.2970000E+00	1.2375000E+00	3.1200000E-01	0.0000000E+00	0.0000000E+00					
7.8520000E+01	4.7500000E+00	2.0000000E+01	1.6500000E+03	8.8000000E+02					
3.4230000E+01	5.3200000E+00	1.0920000E+02	0.0000000E+00	0.0000000E+00					
9.8200000E+01	6.1900000E+00	8.5400000E+02	0.0000000E+00	0.0000000E+00					
2.4310000E+02	6.5100000E+00	1.6020000E+03	0.0000000E+00	0.0000000E+00					
3.3000000E+02	6.2100000E+00	8.3600000E+02	0.0000000E+00	0.0000000E+00					
2.8430000E+02	4.3300000E+00	1.5540000E+02	0.0000000E+00	0.0000000E+00					
6.3700000E+01	0.0000000E+00	0.0000000E+00	0.0000000E+00	0.0000000E+00					
3	16	22	27						
1	1.0000000E+01	0.0000000E+00							
10	1.0000000E+01	1.0000000E+01							
18	-1.0000000E+01	0.0000000E+00							
5.2000E+01	8.2000E+05	2.2000E+01	5.2000E+01	5.3000E+05	2.2000E+01				
5.2000E+01	8.2000E+05	2.2000E+01	5.2000E+01	5.3000E+05	2.2000E+01				
4.4000E+01	1.3000E+06	3.4000E+01	4.4000E+01	9.0000E+05	3.4000E+01				
4.4000E+01	1.3000E+06	3.4000E+01	4.4000E+01	9.0000E+05	3.4000E+01				
9.5000E+01	1.7000E+06	1.8000E+01	9.5000E+01	1.3000E+06	1.8000E+01				
9.5000E+01	1.7000E+06	1.8000E+01	9.5000E+01	1.3000E+06	1.8000E+01				
8.5000E+01	1.9000E+06	2.7000E+01	8.5000E+01	1.3000E+06	2.7000E+01				
8.5000E+01	1.9000E+06	2.7000E+01	8.5000E+01	1.3000E+06	2.7000E+01				
1.0000000E+03	5.1000000E+03	2.0000000E+03							
1.5420000E+06	0.0000000E+00	0.0000000E+00							
3.3620000E+06	0.0000000E+00	0.0000000E+00							
-8.0100000E+05	0.0000000E+00	0.0000000E+00							
1.3020000E+06	0.0000000E+00	0.0000000E+00							
1.5420000E+05	0.0000000E+00	0.0000000E+00							
1.0400000E+06	0.0000000E+00	0.0000000E+00							
9.7200000E+05	0.0000000E+00	0.0000000E+00							
1.3020000E+06	0.0000000E+00	0.0000000E+00							
1.5420000E+06	0.0000000E+00	0.0000000E+00							
3.3620000E+06	0.0000000E+00	0.0000000E+00							
-8.0100000E+05	0.0000000E+00	0.0000000E+00							
1.3020000E+06	0.0000000E+00	0.0000000E+00							
1.5420000E+05	0.0000000E+00	0.0000000E+00							
1.0400000E+06	0.0000000E+00	0.0000000E+00							
9.7200000E+05	0.0000000E+00	0.0000000E+00							
1.3020000E+06	0.0000000E+00	0.0000000E+00							
1.4630000E+06	0.0000000E+00	0.0000000E+00							
3.2960000E+06	0.0000000E+00	0.0000000E+00							

-1.045000E+06	0.000000E+00	0.000000E+00
1.701000E+06	0.000000E+00	0.000000E+00
-1.137000E+05	0.000000E+00	0.000000E+00
1.754000E+06	0.000000E+00	0.000000E+00
1.175000E+05	0.000000E+00	0.000000E+00
1.781000E+05	0.000000E+00	0.000000E+00
1.463000E+05	0.000000E+00	0.000000E+00
3.296000E+06	0.000000E+00	0.000000E+00
-1.045000E+06	0.000000E+00	0.000000E+00
1.781000E+05	0.000000E+00	0.000000E+00
-1.197000E+05	0.000000E+00	0.000000E+00
1.754000E+06	0.000000E+00	0.000000E+00
1.175000E+06	0.000000E+00	0.000000E+00
1.781000E+06	0.000000E+00	0.000000E+00
1.070000E+06	0.000000E+00	0.000000E+00
2.240000E+06	0.000000E+00	0.000000E+00
-5.700000E+05	0.000000E+00	0.000000E+00
7.140000E+05	0.000000E+00	0.000000E+00
1.070000E+05	0.000000E+00	0.000000E+00
6.800000E+05	0.000000E+00	0.000000E+00
6.320000E+05	0.000000E+00	0.000000E+00
9.140000E+05	0.000000E+00	0.000000E+00
1.070000E+06	0.000000E+00	0.000000E+00
2.240000E+06	0.000000E+00	0.000000E+00
-5.700000E+05	0.000000E+00	0.000000E+00
9.140000E+05	0.000000E+00	0.000000E+00
1.070000E+05	0.000000E+00	0.000000E+00
6.800000E+05	0.000000E+00	0.000000E+00
6.320000E+05	0.000000E+00	0.000000E+00
9.140000E+05	0.000000E+00	0.000000E+00
9.800000E+05	0.000000E+00	0.000000E+00
2.160000E+06	0.000000E+00	0.000000E+00
-7.000000E+05	0.000000E+00	0.000000E+00
1.330000E+06	0.000000E+00	0.000000E+00
-8.700000E+04	0.000000E+00	0.000000E+00
1.200000E+06	0.000000E+00	0.000000E+00
7.600000E+05	0.000000E+00	0.000000E+00
1.330000E+06	0.000000E+00	0.000000E+00
9.800000E+05	0.000000E+00	0.000000E+00
2.160000E+06	0.000000E+00	0.000000E+00
-7.000000E+05	0.000000E+00	0.000000E+00
1.330000E+06	0.000000E+00	0.000000E+00
-8.700000E+04	0.000000E+00	0.000000E+00
1.200000E+06	0.000000E+00	0.000000E+00
7.600000E+05	0.000000E+00	0.000000E+00
1.330000E+06	0.000000E+00	0.000000E+00

END OF FILE

SAMPLE CALCULATION 11.2

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CROSS S.I.C.T. INERTIA
5,2449999= CI
1-2W2000E 04
PULAR MIN. INERTIA
7,110000C 03
TRANS. WIM. INERTIA

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9. 4. 000 306 04 2
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Year	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036	2037	2038	2039	2040	2041	2042	2043	2044	2045	2046	2047	2048	2049	2050	2051	2052	2053	2054	2055	2056	2057	2058	2059	2060	2061	2062	2063	2064	2065	2066	2067	2068	2069	2070	2071	2072	2073	2074	2075	2076	2077	2078	2079	2080	2081	2082	2083	2084	2085	2086	2087	2088	2089	2090	2091	2092	2093	2094	2095	2096	2097	2098	2099
1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036	2037	2038	2039	2040	2041	2042	2043	2044	2045	2046	2047	2048	2049	2050	2051	2052	2053	2054	2055	2056	2057	2058	2059	2060	2061	2062	2063	2064	2065	2066	2067	2068	2069	2070	2071	2072	2073	2074	2075	2076	2077	2078	2079	2080	2081	2082	2083	2084	2085	2086	2087	2088	2089	2090	2091	2092	2093	2094	2095	2096	2097	2098	2099	

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PEDESTAL DATA TRANSLATORY UNIT
CX MASS-Y-DIR.

2.2000E 01	10 30002.2
2.2000E 01	10 30002.2
5.2000E 01	10 30002.2
5.2000E 01	10 30002.2

10 3000*4	10 3000*3
10 3000*4	10 3000*3

PEDESTAL DATA, ROTATIONAL MOTION
INERTIA, Y

2014-11-15-2014-11-15

1000

3	9.5000E 01	1.7000E 06	1.8000E 01	9.5000E 01	1.3000E 06	1.8000E 01
16	9.5000E 01	1.7000E 06	1.8000E 01	9.5000E 01	1.3000E 06	1.8000E 01
22	8.5000E 01	1.9000E 06	2.7000E 01	8.5000E 01	1.5000E 06	2.7000E 01
27	8.5000E 01	1.9000E 06	2.7000E 01	8.5000E 01	1.5000E 06	2.7000E 01

INITIAL SPEED: FINAL SPEED: SPEED INCR.
1.00000E 03 5.10000E 03 2.00000E 03

BEARING AT STATION NO. 3						
MXK	LXK	KXV	CXV	KVX	CVY	CYX
1.542000E 06	3.342000E 06	-8.010000E 05	1.302000E 06	1.542000E 05	1.040000E 06	1.302000E 06
0.	0.	0.	0.	0.	0.	0.
0.	0.	0.	0.	0.	0.	0.
BEARING AT STATION NO. 16						
MXK	LXK	KXV	CXV	KVX	CVY	CYX
1.542000E 05	3.362000E 05	-8.010000E 05	1.302000E 06	1.542000E 05	1.040000E 06	1.302000E 06
0.	0.	0.	0.	0.	0.	0.
0.	0.	0.	0.	0.	0.	0.
BEARING AT STATION NO. 22						
MXK	LXK	KXV	CXV	KVX	CVY	CYX
1.463000E 06	3.294000E 05	-1.045000E 06	1.781000E 06	1.175000E 06	1.754000E 06	1.781000E 06
0.	0.	0.	0.	0.	0.	0.
0.	0.	0.	0.	0.	0.	0.
BEARING AT STATION NO. 27						
MXK	LXK	KXV	CXV	KVX	CVY	CYX
1.463000E 05	3.294000E 06	-1.045000E 06	1.781000E 06	1.175000E 06	1.754000E 06	1.781000E 06
0.	0.	0.	0.	0.	0.	0.
0.	0.	0.	0.	0.	0.	0.
BEARING AT STATION NO. 3						
MXK	LXK	KXV	CXV	KVX	CVY	CYX
1.070000E 06	2.240000E 06	-5.700000E 05	9.143000E 05	1.070000E 05	6.800000E 05	9.143000E 05
0.	0.	0.	0.	0.	0.	0.
0.	0.	0.	0.	0.	0.	0.
BEARING AT STATION NO. 16						
MXK	LXK	KXV	CXV	KVX	CVY	CYX
1.270000E 06	2.240000E 06	-5.700000E 05	9.143000E 05	1.070000E 05	6.800000E 05	9.143000E 05
0.	0.	0.	0.	0.	0.	0.
0.	0.	0.	0.	0.	0.	0.
BEARING AT STATION NO. 22						
MXK	LXK	KXV	CXV	KVX	CVY	CYX
9.800000E 05	2.160000E 05	-7.000000E 05	1.330000E 06	9.800000E 05	1.200000E 06	1.330000E 06
0.	0.	0.	0.	0.	0.	0.
0.	0.	0.	0.	0.	0.	0.
BEARING AT STATION NO. 27						
MXK	LXK	KXV	CXV	KVX	CVY	CYX
9.800000E 05	2.160000E 06	-7.000000E 05	1.330000E 06	9.800000E 05	1.200000E 06	1.330000E 06
0.	0.	0.	0.	0.	0.	0.
0.	0.	0.	0.	0.	0.	0.

ROTOR SPEED= 1.000000E 03RPM
WITHOUT GYROSCOPIC MOMENT

STATION MAJOR AXIS				MINOR AXIS				MAJOR AXIS				MINOR AXIS				BENDING MOMENT				PHASE ANGLE			
1.33225E-01				3.16944E-02				-6.60054E 01				5.63501E 01				0.				0.			
AMPLITUDE				ANGLE X-MAJOR				ANGLE X-MAJOR				ANGLE X-MAJOR				PHASE ANGLE							
1				1				1				1				1							

BRG.NO. MAJOR AXIS MINOR AXIS ANGLE X-MAJOR PHASE ANGLE
 3 3.60461E-01 3.17056E-01 -6.14367E-01 7.47195E-01
 14 1.43688E-01 1.14893E-01 -9.35752E-00 -5.48593E-01
 22 5.79086E-00 4.77407E-00 -4.23719E-01 3.60288E-01
 27 1.55896E-00 1.32019E-00 -4.39478E-01 3.74267E-01

PEDESTAL POSITION

BRG.NO. MAJOR AXIS MINOR AXIS ANGLE X-MAJOR PHASE ANGLE
 3 6.64499E-02 3.95680E-02 -8.41662E-01 -8.34243E-01
 14 2.19403E-02 1.73113E-02 -8.10013E-01 1.61245E-01
 22 5.94239E-03 3.47523E-03 -7.59149E-01 6.83912E-01
 27 1.61451E-03 1.03575E-03 -7.79186E-01 7.03337E-01

ENERGY INPUT= 5.7557180E-03 ENERGY DISSIPATED= 5.6887764E-03

ITERAT.NO. LR-CK
 1 9.9999996E-01
 2 1.5206409E-06
 WITH GYROSCOPIC MOMENT

STATION	AMPLITUDE			BENDING MOMENT			PHASE ANGLE		
	MAJOR AXIS	MINOR AXIS	ANGLE X-MAJOR	MAJOR AXIS	MINOR AXIS	ANGLE X-MAJOR	MAJOR AXIS	MINOR AXIS	ANGLE X-MAJOR
1	1.33219E-01	3.16725E-02	-6.60012E-01	5.63507E-01	0.	0.	0.	0.	0.
2	1.25491E-01	2.35193E-02	-6.54994E-01	5.77229E-01	5.62438E-02	2.12195E-01	5.58859E-01	5.62438E-02	2.12195E-01
3	1.11734E-01	2.58758E-02	-6.48147E-01	5.94431E-01	6.65619E-01	5.90063E-01	5.89962E-01	6.65619E-01	5.90063E-01
4	1.11553E-01	2.45266E-02	-6.37690E-01	6.19856E-01	1.41699E-01	6.02130E-01	6.01479E-01	1.41699E-01	6.02130E-01
5	1.04053E-01	2.44569E-02	-6.25653E-01	6.53150E-01	1.41111E-02	1.38071E-02	5.83030E-01	1.41111E-02	1.38071E-02
6	1.01557E-01	2.45215E-02	-6.22065E-01	6.64759E-01	8.25553E-01	6.43095E-01	3.69937E-01	8.25553E-01	6.43095E-01
7	9.50166E-02	2.47821E-02	-6.13274E-01	6.97459E-01	1.21028E-02	7.85333E-01	7.61433E-01	1.21028E-02	7.85333E-01
8	8.49441E-02	2.55585E-02	-6.07838E-01	7.60089E-01	1.55110E-02	1.04991E-02	8.14418E-01	1.55110E-02	1.04991E-02
9	7.72605E-02	2.61977E-02	-5.95358E-01	8.17399E-01	1.55110E-02	1.04991E-02	8.14418E-01	1.55110E-02	1.04991E-02
10	6.87373E-02	2.57265E-02	-5.97373E-01	8.99157E-01	2.48938E-02	1.83671E-02	8.66154E-01	2.48938E-02	1.83671E-02
11	5.98267E-02	2.39000E-02	-6.07674E-01	8.11178E-01	3.70793E-02	3.17236E-02	5.08852E-01	3.70793E-02	3.17236E-02
12	5.33284E-02	2.07220E-02	-6.17842E-01	7.29509E-01	4.83442E-02	4.13048E-02	8.5622E-01	4.83442E-02	4.13048E-02
13	4.56877E-02	1.65968E-02	-6.28591E-01	5.86486E-01	5.83758E-02	5.24018E-02	8.79970E-01	5.83758E-02	5.24018E-02
14	4.16839E-02	1.4521E-02	-6.23982E-01	4.50560E-01	5.83758E-02	5.24018E-02	8.79970E-01	5.83758E-02	5.24018E-02
15	4.05512E-02	1.25318E-02	-6.13393E-01	3.80772E-01	4.83537E-02	4.36319E-02	8.52522E-01	4.83537E-02	4.36319E-02
16	4.00520E-02	1.15693E-02	-5.78879E-01	2.59426E-01	4.13458E-02	3.75764E-02	8.39857E-01	4.13458E-02	3.75764E-02
17	5.26791E-02	2.14154E-02	-4.48027E-01	4.49430E-00	3.21574E-02	2.97171E-02	8.00117E-01	3.21574E-02	2.97171E-02
18	9.55543E-02	6.05909E-02	-3.93608E-01	2.39970E-01	3.21574E-02	2.97171E-02	8.00117E-01	3.21574E-02	2.97171E-02
19	2.65246E-02	8.15440E-03	-4.39194E-01	2.23345E-01	2.58032E-02	2.42166E-02	7.12086E-01	2.58032E-02	2.42166E-02
20	2.04058E-02	3.60398E-03	-4.65544E-01	1.93087E-01	2.58032E-02	2.42166E-02	7.12086E-01	2.58032E-02	2.42166E-02

11	1.96848E 00	2.47918E-01	4.38656E 00	5.56149E C1	1.76222E 04	1.96381E 03	1.91044E 01	6.35992E 01
12	1.69207E 00	1.60796E-01	8.81326E-01	5.43186E 01	1.46900E 04	1.42724E 03	1.86463E 01	6.43330E 01
13	1.77659E 00	5.74777E-02	-4.77449E 00	5.17134E C1	1.20914E 04	1.00510E 03	1.89022E 01	6.55425E 01
14	1.69206E 00	-2.21752E-03	-3.92946E 00	4.89475E 01	7.79880E 03	4.62332E 02	2.18334E 01	6.98958E 01
15	1.65625E 00	-2.02802E-02	-1.25796E 01	4.74133E C1	4.26433E 03	3.45155E 02	3.20603E 01	8.16468E 01
16	1.61116E 00	-2.95271E-02	-1.71408E 01	4.46288E 01	2.95271E 03	6.00610E 02	4.29908E 01	8.16468E 01
17	1.64157E 00	8.87774E-02	-2.86498E 01	3.73073E 01	1.90050E 03	1.81107E 03	1.61493E 01	-8.56408E 01
18	1.90117E 00	4.88199E-01	-3.79674E 01	3.23251E 01	2.01311E 03	1.82421E 03	2.24614E 01	-1.11540E 01
19	4.64756E-01	1.86537E-02	-4.37875E 01	1.47369E 01	9.45668E 02	7.28762E 02	4.13734E 01	-1.82973E 01
20	3.67164E-01	-1.88275E-02	-4.67940E 01	8.02847E C0	4.97095E 02	2.77480E 02	4.81562E 01	-3.42802E 01
21	3.21191E-01	-3.18126E-02	-4.99735E 01	5.10709E C0	2.78231E 02	1.27910E 02	4.25849E 01	3.78339E 01
22	2.55836E-01	-3.22043E-02	-5.01592E 01	2.46971E C0	3.50087E 02	1.68274E 02	4.33173E 01	3.86775E 01
23	1.95971E-01	-2.70402E-02	-5.04217E 01	6.59812E-01	4.34432E 02	2.08651E 02	4.37697E 01	3.84635E 01
24	1.29124E-01	-1.98089E-02	-5.04148E 01	-2.41954E 00	7.61319E 02	3.59911E 02	4.38876E 01	3.65058E 01
25	6.03944E-02	-1.23844E-02	-5.08338E 01	-1.27457E 01	7.57466E 02	3.55614E 02	4.40788E 01	3.66401E 01
26	2.76099E-02	-1.83292E-03	-6.51812E 01	6.79911E C1	5.75793E 02	3.00170E 02	4.67866E 01	4.16216E 01
27	5.99291E-02	-2.64682E-03	-5.44395E 01	2.48664E 01	3.93154E 02	2.27362E 02	5.25277E 01	5.04006E 01

FORCE TRANSMITTED TO HEARING HOUSING

BAG.NO.	MAJOR AXIS	MINOR AXIS	ANGLE X-MAJOR	PHASE ANGLE	X-AMPLITUDE	X-PHASE ANG	Y-AMPLITUDE	Y-PHASE ANG
3	1.04706E 03	3.44396E 02	2.95798E 01	6.59514E 01	9.28332E 02	-1.03473E 02	5.97377E 02	-5.41394E 01
16	9.43342E 02	1.61250E 02	2.55023E 00	4.98750E 01	9.42435E 02	-1.29689E 02	1.66449E 02	-1.15321E 02
22	1.05837E 02	4.16590E 01	-4.21140E 01	2.97761E C1	8.33337E 01	-1.69811E 02	7.74113E 01	1.43305E 02
27	2.42550E 01	1.31212E 01	-5.81267E 01	5.76618E 01	1.87646E 01	1.86383E 01	2.17319E 01	-1.37465E 01

FORCE TRANSMITTED TO FOUNDATION

BAG.NO.	MAJOR AXIS	MINOR AXIS	ANGLE X-MAJOR	PHASE ANGLE	X-AMPLITUDE	X-PHASE ANG	Y-AMPLITUDE	Y-PHASE ANG
3	1.06664E 03	3.52540E 02	2.98556E 01	6.57762E C1	9.41596E 02	-1.03481E 02	6.12743E 02	-5.41388E 01
16	9.43342E 02	1.61250E 02	2.55023E 00	4.98750E 01	9.42435E 02	-1.29689E 02	1.70731E 02	-1.15340E 02
22	1.05837E 02	4.16590E 01	-4.22656E 01	2.98733E 01	8.40610E 01	-1.69815E 02	7.83909E 01	1.43296E 02
27	2.45159E 01	1.32492E 01	-5.83071E 01	5.78059E 01	1.71246E 01	1.66342E 01	2.20069E 01	-1.37551E 01

PEDESTAL MOTION

BAG.NO.	MAJOR AXIS	MINOR AXIS	ANGLE X-MAJOR	PHASE ANGLE	X-AMPLITUDE	X-PHASE ANG	Y-AMPLITUDE	Y-PHASE ANG
3	1.52448E 00	5.69827E-01	4.52559E 01	5.59972E 01	1.14825E 00	-1.03966E 02	1.15602E 00	-5.49060E 01
16	1.17996E 00	3.11985E-01	4.07808E 00	4.87321E 01	1.14821E 00	-1.30130E 02	3.22144E-01	-1.16287E 02
22	1.01715E-01	3.76905E-02	-5.62118E 01	3.88904E 01	6.46601E-02	-1.70288E 02	8.70949E-02	1.42616E 02
27	2.55491E-02	1.08420E-02	-7.11528E 01	6.73291E 01	1.31723E-02	1.61634E 01	2.44503E-02	-1.64351E 01

ENERGY INPUT= 1.8328001E 00 ENERGY DISSIPATED= 1.7368715E 00

ITERAT.NO. ERRCP
1 1.0000000E 00

2 1.0567462E-02
3 4.0740172E-04
MFM GYROSCOPIC MOMENT

STATION	MAJOR AXIS	MINOR AXIS	ANGLE H-MAJOR	AMPLITUDE	PHASE ANGLE	MAJOR AXIS	MINOR AXIS	ANGLE A-PAJOM	PHASE ANGLE
1	1.41840E 00	1.16224E-01	7.74191E 01	7.74191E 01	2.00515E 01	0.	0.	0.	0.
2	1.43311E 00	0.05137E-01	6.33977E 01	6.33977E 01	2.70899E 01	9.09622E 01	-2.91400E 00	-1.40873E 01	6.40242E 01
3	1.49402E 00	0.30981E-01	5.29604E 01	5.29604E 01	3.58428E 01	7.10327E 02	5.90796E 02	-6.13301E 01	3.61481E 01
4	1.61800E 00	0.42627E-01	6.00539E 01	6.00539E 01	4.47830E 01	7.10327E 02	5.90796E 02	-6.13301E 01	3.61481E 01
5	1.74967E 00	0.95572E-01	3.05131E 01	3.05131E 01	5.08447E 01	1.40807E 01	1.24310E 03	-5.03801E 01	4.29008E 01
6	1.71127E 00	1.67443E-01	2.81934E 01	2.81934E 01	5.21326E 01	1.39222E 03	1.25367E 03	-5.43011E 01	4.95746E 01
7	1.85416E 00	7.90045E-01	2.31694E 01	2.31694E 01	5.45200E 01	1.60510E 03	1.84727E 03	1.05873E 01	5.02715E 01
8	1.96202E 00	0.42927E-01	1.67947E 01	1.67947E 01	5.64856E 01	1.18149E 04	1.55330E 04	1.62434E 01	5.53833E 01
9	2.02461E 00	5.27127E-01	1.29344E 01	1.29344E 01	5.69333E 01	1.18149E 04	1.55330E 04	1.62434E 01	5.53833E 01
10	2.02761E 00	0.75073E-01	0.47776E 00	0.47776E 00	5.66244E 01	1.38287E 04	4.09408E 03	1.62434E 01	5.53833E 01
11	1.96123E 00	4.50305E-01	4.23140E 00	4.23140E 00	5.55771E 01	4.02198E 03	5.02198E 03	1.57275E 01	5.74407E 01
12	1.77060E 00	6.37654E-02	-4.47211E 00	-4.47211E 00	5.17440E 01	4.82646E 03	4.82646E 03	1.74707E 01	5.92104E 01
13	1.64654E 00	5.58863E-03	-1.31246E 01	-1.31246E 01	4.90318E 01	4.82646E 03	4.82646E 03	1.74707E 01	5.92104E 01
14	1.65043E 00	-1.14911E-02	-1.27752E 01	-1.27752E 01	4.75303E 01	4.82646E 03	4.82646E 03	1.74707E 01	5.92104E 01
15	1.60521E 00	-2.03715E-02	-1.73149E 01	-1.73149E 01	4.48111E 01	4.82646E 03	4.82646E 03	1.74707E 01	5.92104E 01
16	1.63215E 00	0.493703E-02	-2.87692E 01	-2.87692E 01	3.76995E 01	4.82646E 03	4.82646E 03	1.74707E 01	5.92104E 01
17	1.67752E 00	4.93703E-01	-3.81407E 01	-3.81407E 01	3.29932E 01	4.82646E 03	4.82646E 03	1.74707E 01	5.92104E 01
18	3.96374E-01	2.73252E-02	-4.30360E 01	-4.30360E 01	1.71375E 01	4.82646E 03	4.82646E 03	1.74707E 01	5.92104E 01
19	3.00403E-01	-1.10280E-02	-4.60149E 01	-4.60149E 01	1.08072E 01	4.82646E 03	4.82646E 03	1.74707E 01	5.92104E 01
20	2.60354E-01	-2.41938E-02	-4.84228E 01	-4.84228E 01	6.63329E 00	4.82646E 03	4.82646E 03	1.74707E 01	5.92104E 01
21	2.16792E-01	-2.52861E-02	-4.95615E 01	-4.95615E 01	3.89348E 00	4.82646E 03	4.82646E 03	1.74707E 01	5.92104E 01
22	1.73572E-01	-2.10718E-02	-4.98318E 01	-4.98318E 01	1.27652E 00	4.82646E 03	4.82646E 03	1.74707E 01	5.92104E 01
23	1.26540E-01	-1.97946E-02	-5.00081E 01	-5.00081E 01	-3.32986E 00	4.82646E 03	4.82646E 03	1.74707E 01	5.92104E 01
24	7 7C173E-02	-1.62777E-02	-5.11655E 01	-5.11655E 01	-1.44605E 01	4.82646E 03	4.82646E 03	1.74707E 01	5.92104E 01
25	3.97652E-02	-1.09632E-02	-6.09969E 01	-6.09969E 01	-5.26642E 01	4.82646E 03	4.82646E 03	1.74707E 01	5.92104E 01
26	3.96971E-02	-2.39634E-03	-6.59563E 01	-6.59563E 01	7.53187E 01	4.82646E 03	4.82646E 03	1.74707E 01	5.92104E 01
27						4.82646E 03	4.82646E 03	1.74707E 01	5.92104E 01

FORCE TRANSMITTED TO HEARING HOUSING

FORCE TRANSMITTED TO FOUNDATION									
BULG.NO.	MAJOR AXIS	MINOR AXIS	ANGLE X-MAJOR	PHASE ANGLE	X-AMPLITUDE	X-PHASE ANG	Y-AMPLITUDE	Y-PHASE ANG	Y-PHASE ANG
3	1.02104E 03	3.48828E 02	2.9961CE 01	6.57263C 01	9.35614E 02	-1.03543E 02	6.10018E 02	-5.39707E 01	-5.39707E 01
16	9.54752E 01	1.68074E 01	2.58031E 00	4.98483E 01	9.53843E 02	-1.29704E 02	1.73153E 02	-1.16006E 02	-1.16006E 02
22	9.21152E 01	3.87400E 01	-4.09883E 01	3.02656E 01	7.41135E 01	-1.69743E 02	6.70353E 01	-1.46171E 02	-1.46171E 02
27	1.73307E 01	4.75482E 00	-8.55632E 01	-6.539C7E 01	4.92650E 00	4.04007E 01	1.72827E 01	2.58220E 01	2.58220E 01
PDLSTAL PUTIN									
BULG.NO.	MAJOR AXIS	MINOR AXIS	ANGLE X-MAJOR	PHASE ANGLE	X-AMPLITUDE	X-PHASE ANG	Y-AMPLITUDE	Y-PHASE ANG	Y-PHASE ANG
3	1.51949E 00	5.63433E-01	4.53273E 01	5.54148E 01	1.14095E 00	-1.04026E 02	1.15080E 00	-5.47178E 01	-5.47178E 01
16	1.16585E 00	3.17022E-01	4.03175E 00	4.87149E 01	1.16318E 00	-1.30187E 02	3.26688E-01	-1.16754E 02	-1.16754E 02
22	8.70535E-02	3.69097E-02	-5.55688E 01	4.01330E 01	5.70085E-02	1.70214E 02	7.44784E-02	1.45491E 02	1.45491E 02
27	1.42768E-03	3.65928E-03	-8.70097E 01	-6.54209E 01	3.78949E-03	3.99299E 01	1.92016E-02	2.51489E 01	2.51489E 01
ENERGY INPUT= 1.4061321E 00 ENERGY DISSIPATED= 1.7106649E 00									
ROTARY SPEED= 5.0000000E 03RPM WITHOUT CYCLOSCOPIC MOMENT									
STATION	MAJOR AXIS	MINOR AXIS	ANGLE X-MAJOR	PHASE ANGLE	MAJOR AXIS	MINOR AXIS	BENDING MOMENT	PHASE ANGLE	PHASE ANGLE
1	3.30049E 00	-9.78419E-01	-1.32549E 01	-5.42544E 01	0.	0.	0.	0.	0.
2	3.01417E 00	-6.95441E-01	-1.59324E 01	-5.71440E 01	2.20063E 03	1.33456E 03	1.69728E 01	-2.40267E 01	-2.40267E 01
3	2.72622E 00	-7.39853E-01	-1.1270E 01	-6.04243E 01	2.20063E 03	1.33456E 03	1.69728E 01	-2.40267E 01	-2.40267E 01
4	2.38254E 00	-6.34830E-01	-2.18864E 01	-6.38258E 01	4.66506E 03	2.69527E 03	1.65225E 01	-2.45026E 01	-2.45026E 01
5	1.91930E 00	-4.26958E-01	-2.44890E 01	-6.70658E 01	5.82459E 03	1.93310E 03	-5.05905E 01	-7.96635E 01	-7.96635E 01
6	1.74907E 00	-3.54102E-01	-2.53557E 01	-6.81960E 01	1.00786E 04	6.59499E 02	-3.82120E 01	-8.72450E 01	-8.72450E 01
7	1.79200E 00	-1.57951E-01	-2.80978E 01	-7.19878E 01	1.13190E 04	4.82850E 02	-3.57626E 01	-8.49849E 01	-8.49849E 01
8	5.49721E-01	1.92874E-01	-3.32819E 01	-8.70355E 01	1.19921E 04	7.75460E 02	-3.16886E 01	-8.32437E 01	-8.32437E 01
9	5.22524E-01	5.24449E-02	3.03470E 01	-9.11565E-01	5.72771E 03	2.07235E 03	-1.51953E 01	8.18128E 01	8.18128E 01
10	1.03959E 00	-3.68456E-01	1.28288E 01	-2.52928E 01	3.36099E 03	-1.99087E 03	5.35735E 01	3.94613E 01	3.94613E 01
11	1.56208E 00	-6.03922E-01	4.40389E 00	-3.51665E 01	3.36099E 03	-1.99087E 03	5.35735E 01	3.94613E 01	3.94613E 01
12	1.89847E 00	-7.30927E-01	1.64330E 00	-3.85498E 01	1.17126E 04	3.36584E 03	-4.76338E 01	-8.21824E 01	-8.21824E 01
13	2.33540E 00	-9.71261E-01	-2.04422E-01	-4.10064E 01	1.17993E 04	-3.46333E 03	-4.93346E 01	-8.52324E 01	-8.52324E 01
14	2.65550E 00	-9.93062E-01	-7.03255E-01	-4.18654E 01	1.03863E 04	-1.44265E 03	-5.70955E 01	6.60702E 01	6.607

ENERGY INPUT= 1.4C61J21E 00 ENERGY DISSIPATED= 1.7106469E 00

ROT'Z SPEED: 5.000000E 03MPH
WITHOUT CYCLOSCOPIC MOUNT

INPUT FOR PNO011:

UNBALANCE RESPONSE OF A FLEXIBLE ROTOR IN FLEXIBLE, DAMPED BEARINGS

Card 1 Text Col. 2-72

Card 2 Text Col. 2-72

Card 3 (1015)

- _____ 1. NS. Number of rotor mass stations (≤ 80)
- _____ 2. NB. Number of bearings (≤ 25)
- _____ 3. NU. Number of unbalance stations (≤ 80)
- _____ 4. NC. Number of coupling stations (≤ 20)
- _____ 5. NPST. 0: Rigid Pedestal 1: Flexible Pedestal
- _____ 6. NMOM. 0: No bearing resistance to moment 1: Moment resistance 1
- _____ 7. NGYR. 0: No gyroscopic moment 1: Gyroscopic moment calculation
- _____ 8. NCAL. 1: 1st type of bearing data input ≥ 2 : 2nd type of bearing data input.
- _____ 9. 0: no diagnostic 1: diagnostic given
- _____ 10. 0: More input follows 1: last set of input

Card 4 (1P4E15.7)

- _____ 1. E, Youngs modulus, lbs/in^2
- _____ 2. Scale factor in simultaneous equation solution

IF NGYR = 1

Card (15, 1PE23.6)

- _____ 1. NIT. Number of iterations in gyroscopic mom.
- _____ 2. Convergence limit for gyroscopic moment calc.

ROTOR DATA

If NGYR = 0, use only first 3 columns, FORMAT (1P3E14.6)

If NGYR = 1, use all 5 columns, FORMAT (1P5E14.6)

Give one card for each rotor station, in total NS cards

Rotor Station (don't punch)	Station Mass lbs.	Length of shaft section inch	Cross sectional Moment of Inertia in ⁴	Polar Mass Moment of Inertia ₂ lbs.in ²	Transverse Mass Moment of Inertia lbs.in ²
1					
2					
3					
4					
5					
6					
7					
8					
9					
10					
11					
12					
13					
14					
15					

Rotor Stations with Bearing Support

(14I5)

Give NB items

Unbalance Data

(15,1P2E15.7)

Give one card for each rotor station with unbalance, in total NU cards

- _____ 1. Rotor station number
- _____ 2. X-component of unbalance, oz.inch
- _____ 3. Y-component of unbalance, oz.inch

Rotor Stations with Coupling

(1415)

Applies only if NC $\neq$ 0. Give NC items.

Pedestal Data for Translatory Motion

(1P6E12.4)

Applies only when NPST = 1. Give one card for each bearing, in total NB card

Pedes.Mass x-direction lbs.	Pedes.Stiffn x-direction lbs/in	Pedes.Damping x-direction lbs.sec/in	Pedes.Mass y-direction lbs.	Pedes.Stiffn. y-direction lbs/in	Pedes.D y-directi lbs.se

Pedestal Data for Tilting

(1P6E12.4)

Applies only when NPST = 1 and NMOM = 1. Give on card for each bearing, in total NB cards.

Mass Mom. of Inert. x-direction lbs.in ²	Angular Stiffn. x-direction lbs.in/rad	Angular Damping x-direction lbs.in.sec/rad	Mass Mom. of Inert. y-direction lbs.in ²	Angular Stiffn. y-direction lbs.in/rad	Angular Damping y-directi lbs.in.se

Type 1 Bearing Data, NCAL = 1

Speed Data (1P3E14.6)

- | | |
|-------|-------------------------|
| _____ | 1. Initial speed, RPM |
| _____ | 2. Final speed, RPM |
| _____ | 3. Speed increment, RPM |

Bearing Coefficients for Translatory Motion

(1P3E14.6)

Give 8 cards per bearing, in total 8•NB cards. Each card gives one coefficient in the form: $K_{xx} = K_{xx,0} + K_{xx,1}\omega + K_{xx,2}\omega^2$, $\omega C_{xx} = C_{xx,0} + C_{xx,1}\omega + C_{xx,2}\omega^2$, etc.

_____	_____	_____	K_{xx}
_____	_____	_____	ωC_{xx}
_____	_____	_____	K_{xy}
_____	_____	_____	ωC_{xy}
_____	_____	_____	K_{yy}
_____	_____	_____	ωC_{yy}
_____	_____	_____	K_{yx}
_____	_____	_____	ωC_{yx}
_____	_____	_____	K_{xx}
_____	_____	_____	ωC_{xx}
_____	_____	_____	K_{xy}
_____	_____	_____	ωC_{xy}
_____	_____	_____	K_{yy}
_____	_____	_____	ωC_{yy}
_____	_____	_____	K_{yx}
_____	_____	_____	ωC_{yx}

Bearing Coefficients for Tilting

(1P3E14.6)

Applies only when NMOM = 1. Give 8 cards per bearing, in total 8•NB cards.

Each card gives one coefficient in the form:

$$M_{xx} = M_{xx,0} + M_{xx,1}\omega + M_{xx,2}\omega^2, \quad \omega D_{xy} = D_{xx,0} + D_{xx,1}\omega + D_{xx,2}\omega^2, \text{ etc.}$$

_____	_____	_____	M_{xx}
_____	_____	_____	ωD_{xx}
_____	_____	_____	M_{xy}
_____	_____	_____	ωD_{xy}
_____	_____	_____	M_{yy}
_____	_____	_____	ωD_{yy}
_____	_____	_____	M_{yx}
_____	_____	_____	ωD_{yx}
_____	_____	_____	M_{xx}
_____	_____	_____	ωD_{xx}
_____	_____	_____	M_{xy}
_____	_____	_____	ωD_{xy}
_____	_____	_____	M_{yy}
_____	_____	_____	ωD_{yy}
_____	_____	_____	M_{yx}
_____	_____	_____	ωD_{yx}

Type 2 Bearing Data, NCAL $\geq$ 2.

Repeat the following input as many times as given by PCA'.

Speed Data (1P4E14.6)

_____. Speed, RPM

Bearing Coefficients for Translatory Motion

(1P4E14.6)

_____	_____	_____	_____	$K_{xx}, \omega C_{xx}, K_{xy}, \omega C_{xy}$
_____	_____	_____	_____	$K_{yy}, \omega C_{yy}, K_{yx}, \omega C_{yx}$
_____	_____	_____	_____	$K_{xx}, \omega C_{xx}, K_{xy}, \omega C_{xy}$
_____	_____	_____	_____	$K_{yy}, \omega C_{yy}, K_{yx}, \omega C_{yx}$

Bearing Coefficients for Tilting

(1P4E14.6)

Applies only when NMOM=1. Give 2 cards per bearing, in total 2*NB cards

_____	_____	_____	_____	$M_{xx}, \omega D_{xx}, M_{xy}, \omega D_{xy}$
_____	_____	_____	_____	$M_{yy}, \omega D_{yy}, M_{yx}, \omega D_{yx}$
_____	_____	_____	_____	$M_{xx}, \omega D_{xx}, M_{xy}, \omega D_{xy}$
_____	_____	_____	_____	$M_{yy}, \omega D_{yy}, M_{yx}, \omega D_{yx}$

APPENDIX B

**SAMPLE CALCULATION AND INPUT FORMS FOR THE COMPUTER PROGRAM
"THE STABILITY OF A ROTOR IN FLUID FILM BEARINGS"**

```

$JOB          0.5.5000          65-341.FREEMAN.SESCD
$EXECUTE      18JOB
$1BJOB FREMAN  MAP
$1HFTC ROTORZ  M94.XRZ.NODECK
COMMON XC(9,30),XS(9,30),YC(9,30),YS(9,30),DMXA(30),DMYA(30),DV
1XA(30),DVXB(30),DVXD(30),DVYA(30),DVYB(30),DVYC(30),DVYD(30),DVXC(
230),RM(30),RL(30),RS(30),RIP(30),AN(30),BN(30),DN(30),
3 LB(10),BKXX(10),BCXX(10),BKXY(10),BCXY(10),BKYY(10),BCYY(
430),BKYX(10),BCYX(10),PRMS(10),BRFR(10),FRQ1(100),FREQ(10), PMX(
510),PMY(10),PKX(10),PCX(10),PKY(10),PCY(10), CFM(8,8),ENT(9)
6,CLNR(8),B2N1(8,8),B2NP(8,8),B2N2(8,8),CF9,FRW,DT,DR,DE,ENGY1,B21,
7B2P,B22
200 READ (5,100)
READ (5,105)NS,NB,NFR,NCAL,NPST,INP
READ (5,103)YM
WRITE (6,100)
WRITE (6,104)
WRITE (6,110)NS,NB,NFR,NCAL,NPST,INP
WRITE (6,104)YM
WRITE (6,111)
WRITE (6,116)
DO 201 J=1,NS
READ (5,103)RM(J),RL(J),RS(J),RIP(J)
201 WRITE (6,114)J,RM(J),RL(J),RS(J),RIP(J)
READ (5,118)(LB(J),J=1,NB)
WRITE (6,120)
WRITE (6,116)(LB(J),J=1,NB)
IF(NPST) 208,228,208
208 WRITE (6,128)
WRITE (6,127)
DO 209 J=1,NB
READ (5,125)PMX(J),PKX(J),PCX(J),PMY(J),PKY(J),PCY(J)
KST=LB(J)
209 WRITE (6,126)KST,PMX(J),PKX(J),PCX(J),PMY(J),PKY(J),PCY(J)
228 READ (5,103)(FRQ1(J),J=1,NFR)
WRITE (6,101)
WRITE (6,103)(FRQ1(J),J=1,NFR)
C CONVERT INPUT UNITS
250 A4S=1000.0
C=1=386.069*AMS
RS(NS)=RS(1)
DO 251 J=1,NS
RM(J)=RM(J)/CF1
RIP(J)=RIP(J)/CF1
STF=YM/AMS*RS(J)
AN(J)=RL(J)/STF
BN(J)=RL(J)/2.0*AN(J)
251 DN(J)=RL(J)/3.0*BN(J)
229 READ (5,103)SPST,SPFN,SPINC
WRITE (6,141)
WRITE (6,103)SPST,SPFN,SPINC
DO 204 J=1,NB
KST=LB(J)
READ (5,103)BKXX(J),BCXX(J),BKXY(J),BCXY(J)
READ (5,103)BKYY(J),BCYY(J),BKYX(J),BCYX(J)
WRITE (6,121)KST
WRITE (6,122)
WRITE (6,103)BKXX(J),BCXX(J),BKXY(J),BCXY(J)
WRITE (6,123)
WRITE (6,103)BKYY(J),BCYY(J),BKYX(J),BCYX(J)
C1=BKXX(J)+BCYY(J)
C1=(BKXX(J)*BCYY(J)+BKYY(J)*BCXX(J)-BKXY(J)*BCYX(J)-BKYX(J)*BCXY(J)
1)/C1

```

```

0010
0020
0030
0040
0050
0060
0070
0080
0120
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0270
0280
0290
0300
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0370
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0390
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0570
0580
0590
0600
0610
0620

```

C2=DCXX(J)*BCYY(J)-BCXY(J)*BCYX(J)	0630
C2=((19KXX(J)-C1)*BKYY(J)-C1)*BCXY(J)+BKYX(J))/C2	0640
C4=386.06/C2+C1	0650
IF(C2) 206,205,205	0660
205 C2=SQR(C2)	0670
C3=C2	0680
GO TO 207	0690
206 C3=-1.0	0700
207 WRITE (6,124)	0710
WRITE (6,103)C2,C1,C4	0720
PRMS(J)=C4	0730
D/XA(J)=C3	0740
204 BFR(J)=C3	0750
MFR=1	0760
MFR=0	0770
214 KST=0	0780
MBR=MBR+1	0790
FRW=FRQ1(MFR)	0800
DO 213 J=1,NB	0810
C1=DVXA(J)	0820
IF(C1) 213,219,210	0830
210 IF(C1-FRW) 219,212,211	0840
211 FRW=C1	0850
MFR=MFR-1	0860
212 KST=J	0870
213 CONTINUE	0880
IF(KST) 216,216,215	0890
215 DVXA(KST)=-1.0	0900
216 FREQ(MBR)=FRW	0910
IF(MFR) 217,218,210	0920
217 MFR=0	0930
218 MFR=MFR+1	0940
IF(MFR-MFR) 214,214,219	0950
219 C2=-0.6	0960
KST=0	0970
DO 222 J=1,NB	0980
C1=DVXA(J)	0990
IF(C1) 222,222,220	1000
220 IF(C1-C2) 222,222,221	1010
221 C2=C1	1020
KST=J	1030
222 CONTINUE	1040
IF(KST) 224,224,223	1050
223 MBR=MBR+1	1060
FREQ(MBR)=C2	1070
DVXA(KST)=-1.0	1080
GO TO 219	1090
224 MFR1=MBR	1100
SPCAL=SPST	1110
225 WRITE (6,146)SPCAL	1120
ANSPR=0.10471976*SPCAL	1130
C2=ANSPR*ANSPR	1140
WRITE (6,148)	1150
DO 226 J=1,NB	1160
KST=L9(J)	1170
C1=PRMS(J)/C2	1180
C3=BRFR(J)*SPCAL	1190
226 WRITE (6,117)KST,C3,C1	1200
WRITE (6,147)	1210
KDC=0	1220
MFR=1	1230
C	1240
300 FRW=FREQ(MFR)	1250
FREQUENCY DEPENDENT PARAMETERS	

ANSP=ANSPR*FRW	1260
ANSP2=ANSP*ANSP	1270
DO 301 J=1,N5	1280
STF=R1P(J)*ANSP2	1290
DVXA(J)=STF	1300
DVYA(J)=STF	1310
STF=RV(J)*ANSP2	1320
DVXA(J)=STF	1330
DVYA(J)=STF	1340
DVXB(J)=0.0	1350
DVXC(J)=0.0	1360
DVXD(J)=0.0	1370
DVYB(J)=0.0	1380
DVYC(J)=0.0	1390
301 DVYD(J)=0.0	1400
302 DO 311 J=1,NH	1410
KST=LR(J)	1420
CF1K=BKXX(J)	1430
CF1C=BCXX(J)*FRW	1440
CF1D=BKXY(J)	1450
CF1E=RCXY(J)*FRW	1460
CF2K=BKYY(J)	1470
CF2C=BCYY(J)*FRW	1480
CF2D=BKXX(J)	1490
CF2E=BCYY(J)*FRW	1500
IF(INPST) 303,306,307	1510
303 CF1M=BKX(J)-DXX(J)/386.069*ANSP2	1520
CF1N=PCX(J)*ANSP	1530
CF1A=CF1K+CF1M	1540
CF1B=CF1C+CF1N	1550
CF2M=BKY(J)-PMY(J)/386.069*ANSP2	1560
CF2N=PCY(J)*ANSP	1570
CF2A=CF2K+CF2M	1580
CF2B=CF2C+CF2N	1590
GO TO 307	1600
306 CF1=CF1K	1610
CF2=CF1C	1620
CF3=CF1D	1630
CF4=CF1E	1640
CF5=CF2D	1650
CF6=CF2E	1660
CF7=CF2C	1670
CF8=CF2C	1680
GO TO 308	1690
307 CF4=CF2A+CF2A+CF2B+CF2B	1700
CF1=(CF2A+CF2D+CF2B+CF2E)/CF4	1710
CF2=(CF2A+CF2F+CF2B+CF2D)/CF4	1720
CF3=(CF2A+CF2M+CF2B+CF2N)/CF4	1730
CF4=(CF2A+CF2N+CF2B+CF2M)/CF4	1740
CF5=CF1A-CF1B+CF1D+CF2*CF1E	1750
CF6=CF1B-CF2*CF1D-CF1*CF1E	1760
CF7=-CF3*CF1D+CF4*CF1E	1770
CF8=-CF4*CF1D-CF3*CF1E	1780
CF2N=CF5*CF5+CF6*CF6	1790
CF2A=(CF5*CF1M+CF6*CF1N)/CF2N	1800
CF2B=(CF5*CF1N+CF6*CF1M)/CF2N	1810
CF2M=(CF5*CF7+CF6*CF8)/CF2N	1820
CF2N=(CF5*CF8-CF6*CF7)/CF2N	1830
CF1A=-CF1*CF2A+CF2*CF2B	1840
CF1B=CF1*CF2B+CF2*CF2A	1850
CF1M=CF3-CF1*CF2M+CF2*CF2N	1860
CF1N=CF4-CF1*CF2N+CF2*CF2M	1870
CF1=CF1K+CF2A-CF1C+CF2D+CF1M+CF1A+CF1E+CF1B	1880

CF2=CF1K*CF2D+CF1C*CF2A-CF1D*CF1B+CF1E*CF1A	1890
CF3=CF1K*CF2M-CF1C*CF2N+CF1D*CF1M-CF1E*CF1N	1900
CF4=CF1K*CF2N+CF1C*CF2M+CF1D*CF1N+CF1E*CF1M	1910
CF5=CF2D*CF2A-CF2E*CF2B+CF2K*CF1A+CF2C*CF1B	1920
CF6=CF2D*CF2B+CF2E*CF2A-CF2K*CF1B+CF2C*CF1A	1930
CF7=CF2D*CF2M-CF2E*CF2N+CF2K*CF1M-CF2C*CF1N	1940
CF8=CF2D*CF2N+CF2E*CF2M+CF2K*CF1N+CF2C*CF1M	1950
308 DVXA(KST)=DVXA(KST)-CF1/AMS	1960
DVXB(KST)=CF2/AMS	1970
DVXC(KST)=CF3/AMS	1980
DVXD(KST)=CF4/AMS	1990
DVYA(KST)=DVYA(KST)-CF7/AMS	2000
DVYB(KST)=CF8/AMS	2010
DVYC(KST)=CF5/AMS	2020
DVYD(KST)=CF6/AMS	2030
311 CONTINUE	2040
C ROTOR CALCULATION	2050
DO 428 I=1,8	2060
KST=I	2070
BMXC=0.0	2080
BMXS=0.0	2090
BMYC=0.0	2100
BMYS=0.0	2110
VXC=0.0	2120
VXS=0.0	2130
VYC=0.0	2140
VYS=0.0	2150
XC(I,1)=0.0	2160
XS(I,1)=0.0	2170
YC(I,1)=0.0	2180
YS(I,1)=0.0	2190
DXC=0.0	2200
DXS=0.0	2210
DYC=0.0	2220
DYS=0.0	2230
G) TO (407,408,409,410,412,413,414,415)	2240
407 DXC=1.0	2250
GO TO 418	2260
408 DXS=1.0	2270
GO TO 418	2280
409 DYC=1.0	2290
GO TO 418	2300
410 DYS=1.0	2310
GO TO 418	2320
412 XC(5,1)=1.0	2330
GO TO 418	2340
413 XS(6,1)=1.0	2350
GO TO 418	2360
414 YC(7,1)=1.0	2370
GO TO 418	2380
415 YS(8,1)=1.0	2390
418 DO 424 J=1,NS	2400
BMXC=BMXC+DMXA(J)*DXC	2410
BMXS=BMXS+DMXA(J)*DXS	2420
BMYC=BMYC+DMYA(J)*DYC	2430
BMYS=BMYS+DMYA(J)*DYS	2440
C1=DVXA(J)*XC(I,J)-DVXB(J)*XS(I,J)-DVXC(J)*YC(I,J)-DVXD(J)*YS(I,J)	2450
C2=DVXB(J)*XC(I,J)+DVXA(J)*XS(I,J)+DVXD(J)*YC(I,J)-DVXC(J)*YS(I,J)	2460
C3=-DVYC(J)*XC(I,J)-DVYB(J)*XS(I,J)+DVYA(J)*YC(I,J)-DVYD(J)*YS(I,J)	2470
1)	2480
C4=DVYD(J)*XC(I,J)-DVYC(J)*XS(I,J)+DVYB(J)*YC(I,J)+DVYA(J)*YS(I,J)	2490
VXC=VXC+C1	2500
VXS=VXS+C2	2510

00000

	VYC=VYC+C3		2520
	VYS=VYS+C4		2530
422	IF(NS-J) 424,424,423		2540
423	XC(I,J+1)=XC(I,J)+RL(J)*DXC	+BN(J)*BMXC	+DN(J)*VXC
	XS(I,J+1)=XS(I,J)+RL(J)*DXS	+BN(J)*BMXS	+DN(J)*VXS
	YC(I,J+1)=YC(I,J)+RL(J)*DYC	+BN(J)*BMYC	+DN(J)*VYC
	YS(I,J+1)=YS(I,J)+RL(J)*DYS	+BN(J)*BMYS	+DN(J)*VYS
	DYC=DXC+AN(J)*BMXC+BN(J)*VXC		2590
	DXS=DXS+AN(J)*BMXS+BN(J)*VXS		2600
	DYC=DYC+AN(J)*BMYC+BN(J)*VYC		2610
	DYS=DYS+AN(J)*BMYS+BN(J)*VYS		2620
	B*XC=BMXC+RL(J)*VXC		2630
	BMXS=BMXS+RL(J)*VXS		2640
	BMYC=BMYS+RL(J)*VYC		2650
	BMYS=BMYS+RL(J)*VYS		2660
424	CONTINUE		2670
	CFM(1,1)=BMXC		2680
	CFM(2,1)=BMXS		2690
	CFM(3,1)=BMYC		2700
	CFM(4,1)=BMYS		2710
	CFM(5,1)=VXC		2720
	CFM(6,1)=VXS		2730
	CFM(7,1)=VYC		2740
	CFM(8,1)=VYS		2750
428	CONTINUE		2760
	CALL EQS		2770
506	MFR=MFR+1		2780
	IF(MFR-MFR1) 300,300,507		2790
C	ADVANCE SPEED		2800
507	SPCAL=SPCAL+SPINC		2810
	IF(SPCAL-SPCAL) 511,225,225		2820
C	PROGRAM END		2830
511	KDC=KDC+1		2840
	IF(INCAL-KDC) 510,510,229		2850
510	IF(INP) 509,200,509		2860
509	STOP		2870
100	FORMAT(49H0		2880
101	FORMAT(17H0FREQUENCY RATIOS)		2890
103	FORMAT(4(1XE13.6))		2900
104	FORMAT(16H0YOUNG'S MODULUS=. E14.7)		2910
105	FORMAT(7I5)		2920
108	FORMAT(58H0 STATIONS NO.BRGS. NO.FREQ NO.SPEED PED.FLEX I		2930
	INP)		2940
110	FORMAT(4X14.6(6X14))		2950
111	FORMAT(14H0 ROTOR DATA)		2960
114	FORMAT(4X14.7XE13.6,1XE13.6,1XE13.6,1XE13.6)		2970
116	FORMAT(67H STATION NO. MASS LENGTH CHO.SECT.INER		2980
	IT (IP-IT))		2990
117	FORMAT(4X14.7XE13.6,1XE13.6)		3000
118	FORMAT(10(1X14))		3010
120	FORMAT(18H0BEARING STATIONS)		3020
121	FORMAT(24H0 BEARING AT STATION NO.,13)		3030
122	FORMAT(52H0 KXX KCXX KXY KCXY)		3040
123	FORMAT(52H0 KYY KCYY KYX KCYX)		3050
124	FORMAT(43H0 INST.FREQ,RT MASS*(FREQ)**2 WEIGHT*(W)**2)		3060
125	FORMAT(6(1XE11.4))		3070
125	FORMAT(11X14.4XE11.4,1XE11.4,1XE11.4,1XE11.4,1XE11.4,1XE11.4)		3080
127	FORMAT(76H0 BRG.ST. MASS,X-DIR. KX CX MASS,Y-DIR		3090
	1. KY CY)		3100
128	FORMAT(15H0 PEDESTAL DATA)		3110
141	FORMAT(42H0INITIAL SPEED FINAL SPEED SPEED INCR.)		3120
146	FORMAT(13H1RLTOR SPEED=. E13.6,3MRPM)		3130
147	FORMAT(16H0 FREQ.RAT. DETERMINANT RE(DET) IM(DET)		3140

1	ENERGY	3150
148	FORMAT(42H0 BQG,STATION INST,FREQ,RPM INST,WEIGHT)	3160
	END	3170
SIBFTC	SEQS M94,XR7	
	SUBROUTINE EQS	0010
	COMMON XC(9,30),XS(9,30),YC(9,30),YS(9,30),DMXA(30),DMYA(30),DV	0020
	IXA(30),DVX(30),DVXD(30),DVYA(30),DVYB(30),DVYC(30),DVYD(30),DVXC(	0030
	230),RMI(30),RL(30),R4(30),RIP(30),ANI(30),BNI(30),DNI(30),	0040
	3 LB(10),BKXX(10),BCXX(10),BKXY(10),BCXY(10),BKYY(10),BCYY(	0050
	430),BKYY(10),BCYY(10),PRMS(10),BRFR(10),FRG(100),FREQ(10),PMX(	0060
	510),PMY(10),PMX(10),PCX(10),PKY(10),PCY(10),CFM(8,8),ENT(9)	0070
	6,CLNR(8),J2N1(3,8),B2NP(8,8),B2N2(8,8),CF9,FRW,DT,DR,DE,ENGY1,B21,	0080
	7B2P,B22	0090
	PRN3=1.0	0100
	DO 850 I=1,8	0110
	ENT(I)=0.0	0120
	DO 850 J=1,8	0130
850	B2N1(I,J)=CFM(I,J)	0140
	CALL MATINV(B2N1,8,ENT,1,DT)	0150
	DT=SQRT(PRN3*DT)	0160
	M=7	0170
	D1=CFM(1,1)	0180
	D2=CFM(1,2)	0190
851	DO 853 I=1,MD	0200
	DO 852 J=1,MD	0210
	B2N1(I,J)=CFM(I,J)	0220
	B2NP(I,J)=CFM(I,J)	0230
852	B2N2(I,J)=CFM(I,J)	0240
853	B2NP(I,MD)=CFM(I,MD+1)	0250
	CALL MATINV(B2N1,MD,ENT,1,B21)	0260
	CALL MATINV(B2NP,MD,ENT,1,B2P)	0270
	IF(MD-7) 855,854,854	0280
854	ENGY1=3.1415927*B2P	0290
855	MD=MD-1	0300
	CALL MATINV(B2N2,MD,ENT,1,B22)	0310
	B21=B21/B22	0320
	B2P=B2P/B22	0330
	C1=B21*DR-B2P*DE	0340
	DE=B21*DE+B2P*DR	0350
	DR=C1	0360
	MD=MD-1	0370
	IF(MD-3) 856,851,851	0380
856	WRITE (6,880)FRW,DT,DR,DE,ENGY1	0390
	RETURN	0400
880	FORMAT(5(1XE13.6))	0410
	END	0420
SIBFTC	SMATIN M94,XR7	0430
	SUBROUTINE MATINV (A,N,B,MD,ETER)	0440
C	MATRIX INVERSION WITH ACCOMPANYING SOLUTION OF LINEAR EQUATIONS	0450
	DIMENSION A(8,8),PIV(9),PIVOT(9)	0010
	ETER=1.0	0020
	DO 17 J=1,N	0030
	KC=0	0040
	KR=0	0050
	DO 14 I=1,N	0060
	IF(A(I,J)) 11,12,11	0070
11	KC=1	0080
12	IF(A(J,I)) 13,14,13	0090
13	KR=1	0100
14	CONTINUE	0110
	IF(KC) 15,16,15	0120
15	IF(KR) 17,16,17	0130
16	ETER=0.0	0140
		0150
		0160
		0170

GO TO 600	0180
17 CONTINUE	0190
DO 20 J=1,N	0200
20 IPIVO(J)=0	0210
DO 550 I=1,N	0220
C	0230
C SEARCH FOR PIVOT ELEMENT	0240
C	0250
AMAX=0.0	0260
DO 105 J=1,N	0270
IF (IPIVO(J)-1) 60,105,60	0280
60 DO 100 K=1,N	0290
IF (IPIVO(K)-1) 80, 100, 600	0300
80 IF (ABS(AMAX)-ABS(A(J,K))) 85,100,100	0310
85 IROW=J	0320
ICOLU =K	0330
AMAX=A(J,K)	0340
100 CONTINUE	0350
105 CONTINUE	0360
IPIVO(ICOLU)=IPIVO(ICOLU)+1	0370
C	0380
C INTERCHANGE ROWS TO PUT PIVOT ELEMENT ON DIAGONAL	0390
C	0400
IF (IROW-ICOLU) 140, 260, 140	0410
140 DETER =-DETER	0420
DO 200 L=1,N	0430
AMAX=A(IROW,L)	0440
A(IROW,L)=A(ICOLU,L)	0450
200 A(ICOLU,L)=AMAX	0460
AMAX=B(IROW)	0470
B(IROW)=B(ICOLU)	0480
B(ICOLU)=AMAX	0490
260 PIVOT(I)=A(ICOLU,ICOLU)	0500
DETER =DETER*PIVOT(I)	0510
C	0520
C DIVIDE PIVOT ROW BY PIVOT ELEMENT	0530
C	0540
A(ICOLU,ICOLU)=1.0	0550
DO 350 L=1,N	0560
350 A(ICOLU,L)=A(ICOLU,L)/PIVOT(I)	0570
B(ICOLU)=B(ICOLU)/PIVOT(I)	0580
C	0590
C REDUCE NON-PIVOT ROWS	0600
C	0610
380 DO 550 L1=1,N	0620
IF (L1-ICOLU) 400, 550, 400	0630
400 AMAX=A(L1,ICOLU)	0640
A(L1,ICOLU) =0.0	0650
DO 450 L=1,N	0660
450 A(L1,L)=A(L1,L)-A(ICOLU,L)*AMAX	0670
B(L1)=B(L1)-B(ICOLU)*AMAX	0680
550 CONTINUE	0690
600 RETURN	0700
END	0710
END OF FILE	

TEST CASE 1. UNSYMMETRICAL ROTOR

9	2	4	1	0	1
0.3000000E+08					
0.162000E+02	0.370000E+01	0.695000E+01	0.114200E+03		
0.391000E+02	0.775000E+01	0.105100E+02	0.254000E+03		
0.227000E+02	0.830000E+01	0.836000E+01	0.000000E+00		
0.121000E+02	0.615000E+01	0.695000E+01	0.000000E+00		
0.391000E+02	0.104700E+02	0.105100E+02	0.254000E+03		
0.563000E+02	0.665000E+01	0.665000E+01	0.563000E+03		
0.378000E+02	0.575000E+01	0.695000E+01	0.000000E+00		
0.127000E+02	0.425000E+01	0.695000E+01	0.000000E+00		
0.212000E+02	0.000000E+00	0.000000E+00	0.166000E+03		
2					
0.500000E+00	0.495000E+00	0.495000E+00	0.480000E+00		
0.835700E+04	0.850000E+04	0.500000E+02			
0.124740E+06	0.130350E+07	0.619710E+06	0.118230E+06		
0.108760E+06	0.181920E+06	-0.864860E+05	0.118230E+06		
0.478420E+06	0.773830E+06	0.312950E+06	0.158120E+06		
0.124770E+06	0.924700E+05	0.109000E+05	0.157820E+06		
-	END OF FILE				
-	END OF FILE				

FREMAN

08/12/65

21. .10CSM 22046 .TCHEX 22042 .BASIN 22045 .
22. // 73460

I/O BUFFERS

22046 THRU 73371
UNUSED CODE
TEST CASE 1, UNSYMMETRICAL ROTOR 73372 THRU 73437

STATIONS NO. BRGS. NO. FREQ NO. SPEED PEN. FLEX IMP
9 2 4 1 0 1

YOUNGS MODULUS= 0.3000000E 08

STATION NO.	MASS	LENGTH	CROSS-SECT. INERT	IMP-111
1	0.162000E 02	0.370000E 01	0.695000E 01	0.114200E 03
2	0.391000E 02	0.775000E 01	0.105100E 02	0.234000E 03
3	0.227000E 02	0.430000E 01	0.838000E 01	0.
4	0.121000E 02	0.615000E 01	0.695000E 01	0.
5	0.391000E 02	0.104000E 02	0.105100E 02	0.254000E 03
6	0.563000E 02	0.865000E 01	0.869000E 01	0.583000E 03
7	0.378000E 02	0.575000E 01	0.695000E 01	0.
8	0.127000E 02	0.425000E 01	0.695000E 01	0.
9	0.212000E 02	0.	0.	0.166000E 03

BEARING STATIONS
2 8

FREQUENCY RATIOS
0.500000E 00 0.495000E-00 0.490000E-00 0.480000E-00
INITIAL SPEED FINAL SPEED SPEED INCR.
0.835000E 04 0.450000E 04 0.500000E 02
BEARING AT STATION NO. 2

STATION	MASS	LENGTH	CROSS-SECT. INERT	IMP-111
1	0.162000E 02	0.370000E 01	0.695000E 01	0.114200E 03
2	0.391000E 02	0.775000E 01	0.105100E 02	0.234000E 03
3	0.227000E 02	0.430000E 01	0.838000E 01	0.
4	0.121000E 02	0.615000E 01	0.695000E 01	0.
5	0.391000E 02	0.104000E 02	0.105100E 02	0.254000E 03
6	0.563000E 02	0.865000E 01	0.869000E 01	0.583000E 03
7	0.378000E 02	0.575000E 01	0.695000E 01	0.
8	0.127000E 02	0.425000E 01	0.695000E 01	0.
9	0.212000E 02	0.	0.	0.166000E 03

INST. FREQ. RT MASS (IFREQ) **2 WEIGHT (W) **2
0.506281E 00 0.688392E 05 0.103605E 09
BEARING AT STATION NO. 8

STATION	MASS	LENGTH	CROSS-SECT. INERT	IMP-111
1	0.162000E 02	0.370000E 01	0.695000E 01	0.114200E 03
2	0.391000E 02	0.775000E 01	0.105100E 02	0.234000E 03
3	0.227000E 02	0.430000E 01	0.838000E 01	0.
4	0.121000E 02	0.615000E 01	0.695000E 01	0.
5	0.391000E 02	0.104000E 02	0.105100E 02	0.254000E 03
6	0.563000E 02	0.865000E 01	0.869000E 01	0.583000E 03
7	0.378000E 02	0.575000E 01	0.695000E 01	0.
8	0.127000E 02	0.425000E 01	0.695000E 01	0.
9	0.212000E 02	0.	0.	0.166000E 03

ROTOR SPEED= 0.835000L 04KPM

BAG. STATION INST. FREQ. RPM INST. HEIGHT
2 0.422745E 04 C.135609E 03
8 0.294457E 04 0.405522E 03

FREQ. NAT.	DETERMINANT	REIDLT	IMDET	ENERGY
0.506281L 00	0.244251E 15	0.75570E 14	-0.232267E 15	-0.299044E 28
0.500000L 00	0.124161E 15	0.342070E 14	-0.119164E 15	-0.161673E 24
0.495000L -00	0.218870E 14	0.660811E 13	-0.208653E 14	-0.257902E 27
0.490000L -00	0.465557E 14	-0.154465E 14	0.150835E 14	0.130422E 28
0.480000L -00	0.521633E 15	-0.443332E 14	0.318530E 15	0.491536E 24
0.352643L -00	0.528244E 16	0.223351E 16	0.478546E 16	0.145530E 24

ROTOR SPEED= 0.840000E 04RPM

ARG-STATION INST-FREQ-RPM INST-EIGHT
2 0.425276E 04 0.13399E 03
8 0.296220E 04 0.40070E 03

FREQ-RAT.	DETERMINANT	RECDCTI	IM(DCTI)	ENERGY
0.506281E 00	0.283196E 15	0.105908E 15	-0.262647E 15	-0.283772E 28
0.500000E 00	0.166933E 15	0.637894E 14	-0.154270E 15	-0.157593E 28
0.495000E 00	0.590471E 14	0.354134E 14	-0.592738E 14	-0.296435E 27
0.490000E 00	0.448993E 14	0.119875E 14	0.432693E 14	0.119572E 28
0.480000E 00	0.770884E 15	-0.185800E 14	0.270239E 15	0.469746E 28
0.352643E 00	0.520152E 16	0.221611E 16	0.470581E 16	0.157555E 29

47	841691.0	91	3555255.5	51	3516167.0	9	3167210.0	5	3500004.0
48	390691.0	92	3536360.0	52	3516167.0	10	3167210.0	6	3500004.0
87	359691.0	13	3526360.0	53	3516167.0	11	3167210.0	7	3500004.0
12	231333.0	14	3516167.0	54	3516167.0	12	3167210.0	8	3500004.0
17	390182.0	15	3506167.0	55	3516167.0	13	3167210.0	9	3500004.0
42	358692.0	16	3506167.0	56	3516167.0	14	3167210.0	10	3500004.0
APR-83		17	3506167.0	57	3516167.0	15	3167210.0	11	3500004.0

ROTOR SPEED- 0.85000E 04RPM

BRC. STATION INST-FREQ-RPM INST-HEIGHT
2 0.430339E 04 0.130865E 03
8 0.299747E 04 0.391336E 03

FREQ-RAT.	DETERMINANT	RELOFT	IMIDEIT	ENERGY
0.506281E 00	0.358201E 15	0.163515E 15	-0.318702E 15	-0.251727E 28
0.500000E 00	0.250151E 15	0.120144E 15	-0.219410E 15	-0.148224E 28
0.495000E-00	0.159558E 15	0.904240E 14	-0.131462E 15	-0.364940E 27
0.490000E-00	0.745147E 14	0.653618E 14	-0.357811E 14	0.982928E 27
0.480000E-00	0.180697E 15	0.306025E 14	0.178086E 15	0.425403E 28
0.352643E-00	0.503972E 16	0.217208E 16	0.454762E 16	0.180460E 29

INPUT FOR PNO017:

STABILITY OF A FLEXIBLE ROTOR IN FLUID FILM BEARINGS

Card 1 Text Col. 2-49

Card 2 (6I5)

- _____ 1. NS Number of rotor mass stations (≤ 30)
_____ 2. NB Number of bearings (≤ 10)
_____ 3. NFR Number of frequency ratios (≤ 100)
_____ 4. NCAL Number of rotor speeds
_____ 5. NPST 0: Rigid Pedestal 1: Flexible pedestal
_____ 6. 0: more input follows 1: last set of input

Card 3 (1XE13.6)

- _____ 1. E, Youngs modulus, lbs/in^2

ROTOR DATA

FORMAT (4(1XE13.6))

Give one card for each rotor station, in total NS cards

Rotor Station (don't punch)	Station Mass lbs.	Length of Shaft Sec inch	Cross sectional Mment of Inertia, in^4	Polar-Transver Mass Moment of Inertia lbs.in^2
1				
2				
3				
4				
5				
6				
7				
8				
9				
10				
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Rotor Stations with Bearing Support

(10(1XI4))

Give NB items

Pedestal Data

(6(1XE11.4))

Applies only when NPST = 1. Give one card for each bearing, in total NB cards.

Pedes.Mass x-direction	Pedes.Stiffn. x-direction	Pedes.Damping x-direction	Pedes.Mass. y-direction	Pedes.Stiffn. y-direction	Pedes.Damping y-direction
lbs.	lbs/in	lbs.sec/in	lbs.	lbs./in	lbs.sec/in

FREQUENCY RATIO VALUES

(4(1XE13.6))

Applies only when NFR $\geq$ 1. List as many values as given by NFR, 4 values per card.

BEARING DATA

Repeat the following input as many times as given by NCAL

Speed Data (4(1XE13.6))

- _____ 1. Initial Speed, RPM
_____ 2. Final Speed, RPM
_____ 3. Speed Increment, RPM

Bearing Coefficients

(4(1XE13.6))

Give 2 cards per bearing with 4 coefficients per card, in total 2 NB Cards

_____	_____	_____	_____	$K_{xx}, \omega C_{xx}, K_{xy}, \omega C_{xy}$
_____	_____	_____	_____	$K_{yy}, \omega C_{yy}, K_{yx}, \omega C_{yx}$
_____	_____	_____	_____	$K_{xx}, \omega C_{xx}, K_{xy}, \omega C_{xy}$
_____	_____	_____	_____	$K_{yy}, \omega C_{yy}, K_{yx}, \omega C_{yx}$

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13. ABSTRACT This report is a manual for using the two computer programs: 1. "Unbalance Response of a Rotor in Fluid Film Bearings." 2. "The Stability of a Rotor in Fluid Film Bearings." The report gives the analysis on which the programs are based, and the instructions for preparing the computer input and for interpreting the computer output.		

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KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
Bearings Lubrication Fluid Film Hydrodynamic Hydrostatic Motor-Bearing Dynamics Stability Critical Speed Laminar Film Turbulent film						

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