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Nonlinear Dynamics of a Rigid Unbalanced Rotor in Journal Bearings. Part I: Theoretical Analysis

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Abstract. The dynamic behaviour of a rigid rotor supported on plain journal bearings was studied, focusing particular attention on its nonlinear aspects. Under the hypothesis that the motion of the rotor mass center is plane, the rotor has five Lagrangian co-ordinates which are represented by the co-ordinates of the mass center and the three angular co-ordinates needed to express the rotor's rotation with respect to its center of mass. In such conditions, the system is characterised not only by the nonlinearity of the bearings but also by the nonlinearity due to the trigonometric functions of the three assigned angular co-ordinates. However, if two angular co-ordinates have values that are generally quite small because of the small radial clearances in the bearings, the system is *de facto* linear in these angular co-ordinates. Moreover, if the third angular co-ordinate is assumed to be cyclic [18], the number of degrees of freedom in the system is reduced to four and nonlinearity depends solely on the presence of the journal bearings, whose reactions were predicted with the π-film, short bearing model. After writing the equations of motion in this way and determining a numerical routine for a Runge–Kutta integration the most significant aspects of the dynamics of a symmetrical rotor were studied, in the presence of either pure static or pure couple unbalance and also when both types of unbalance were present. Two categories of rotors, whose motion is prevailingly a cylindrical whirl or a conical whirl, were put under investigation.

Key words: Rotor dynamics, rigid rotors, chaos, conical whirl, journal bearings.

Nomenclature

c_i; c	= radial clearance of i-bearing; radial clearance of bearings for the symmetrical system
C	= center of the rotor
C_i	= center of the journal of the bearing i, along the geometrical axis of the rotor ($i = 1, 2$)
d	= distance of the two planes that are perpendicular to the ζ-axis and contain m_1 and m_2
D_i; D	= diameter of i-bearing; diameter of bearings for the symmetrical system
e	= dimensional unbalance of the rotor
$f_{i,K}$	= $F_{i,K}/(\sigma_i P_i)$, ($i = 1, 2$; $K = X, Y$): nondimensional components of the fluid film force, bearing i, along the K-axis
$F_{i,K}$	= ($i = 1, 2$; $K = X, Y$): dimensional component of the fluid film force, bearing i, along the K-axis (N)
$\mathcal{F}$; $\mathcal{F}_i$	= resultant force due to the unbalancing masses; force due to the mass m_i
g	= acceleration of gravity
G	= center of mass of the rotor
I_{ii}; I_{ij}	= moment of inertia; product of inertia of the rotor, axes i, j
$[I]$	= inertia matrix of the rotor, with respect to the frame $Gxyz$
[I]	= inertia matrix of the rotor, with respect to $C\xi\eta\zeta$
l_i	= distance between C_1 and C
ℓ_1; ℓ_2	= l_1; $-l_2$
L$_i$; L	= axial length of bearing i; length of bearings for the symmetrical system
L_R	= axial length of the rotor
L_1, L_2; L	= different assigned distances between supports; generic distance between supports
m	= $(\omega^2 c/\sigma g)$: nondimensional mass of rotor
M	= mass of rotor (kg)
m_1, m_2; m_U	= unbalancing masses; common value ($m_1 = m_2 = m_U$)