Dynamic Behaviour Analysis of Linear Rotor-Bearing Systems using the Complex Transfer Matrix Technique

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(Received 9 June 2004; accepted 22 April 2005)

A complex transfer matrix method is developed in the present work for analysing the steady-state response of linear rotor-bearing systems in the frequency domain. The transfer matrix of the shaft segment is derived by considering the state variables of the shaft in, a continuous system sense, to give the most general formulation. In this analysis, all the influencing parameters of the shaft, disk, and bearings are included. A three-disks-rotor-bearings system has been used as the physical model to demonstrate the effectiveness of this matrix formulation for the evaluation of the dynamic characteristics of any rotor-bearing system. In order to establish the accuracy of this technique, experiments are also conducted on the same rotor-disks model under various bearing conditions as used in the numerical analysis. The numerical results evaluated by various researchers are also compared with these experimental results.

Nomenclature

a, b	– major and minor axis of elliptical whirling orbits, respectively
A	– area of cross-section
$[B]$	– bearing matrix
C	– bearing clearance
C_{xy}, C_{yx}	– cross-coupled bearing damping coefficients
C_{xx}, C_{yy}	– direct bearing damping coefficient
C_{fxx}, C_{fyy}	– direct bearing foundation damping coefficients
C_{fxy}, C_{fyx}	– cross-coupled bearing foundation damping coefficients
d	– diameter of the shaft
D	– diameter of the disk
D_b	– diameter of the bearing
$[D]$	– disk matrix
$e(x), e(y)$	– eccentricity of the disk in X and Y directions, respectively
E	– Young's modulus of rotor
EI	– bending stiffness
G	– shear modulus
h	– disk thickness
I_d, I_p	– transverse and polar mass moments of inertia of the disk, respectively
j	– imaginary unit
I, J	– transverse and polar area moments of inertia of the rotor, respectively
K_s	– form factor
K_{xy}, K_{yx}	– cross-coupled bearing stiffness coefficients
K_{xx}, K_{yy}	– direct bearing stiffness coefficients
K_{fxx}, K_{fyy}	– direct bearing foundation stiffness coefficients
K_{fxy}, K_{fyx}	– cross-coupled bearing foundation stiffness coefficients
l	– length of the rotor segment
L_b	– length of the bearing
m	– mass of the rotor segment for unit length
m_b	– mass at the supported bearing
m_e	– mass of the unbalance
M_d	– mass of the disk
M_x, M_y	– bending moments about X and Y axes, respectively
Q_x, Q_y	– shear forces along X and Y axes, respectively
r_w	– radius of the whirl
$[S]$	– state vectors
$[T]$	– transfer matrix
X, Y	– displacement along X and Y axis, respectively
α, β	– slopes in X-Z and Y-Z planes, respectively
α_t, β_t	– slopes in X-Z and Y-Z planes due to shear, respectively
α_b, β_b	– slopes in X-Z and Y-Z planes due to bending, respectively
ω, Ω	– rotating and whirling speeds, respectively
ρ	– mass density
μ	– coefficients of viscosity

Subscripts

C, S	– associated to cosine and sine terms, respectively
$0, n$	– stage number

Superscripts

L, R	– left and right to the station, respectively
t	– transpose of the array

1. INTRODUCTION

The transfer matrix method (TMM) can be used to solve dynamic problems in the frequency domain, which makes it suitable for analysing the steady-state responses of rotor-bearing systems with satisfactory accuracy. The TMM was first applied to a rotor-bearing system by Prohl,[1] who considered rigid bearing characteristics and four state variables. However, subsequently, this concept has been modified by incorporating the dynamic characteristics, such as stiffness and damping coefficients of fluid-film bearings, into the analysis. Kikuchi[2] and Lund[3,4] made a significant advancement by including the effects of gyroscopics, internal friction,