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Model updating of rotor systems by using Nonlinear least square optimization

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ABSTRACT

Mathematical models of structure or machineries are always different from the existing physical system, because the approach of numerical predictions to the behavior of a physical system is limited by the assumptions used in the development of the mathematical model. Model updating is, therefore necessary so that updated model should replicate the physical system. This work focuses on the model updating of rotor systems at various speeds as well as at different modes of vibration. Support bearing characteristics severely influence the dynamics of rotor systems like turbines, compressors, pumps, electrical machines, machine tool spindles etc. Therefore bearing parameters (stiffness and damping) are considered to be updating parameters. A finite element model of rotor systems is developed using Timoshenko beam element. Unbalance response in time domain and frequency response function have been calculated by numerical techniques, and compared with the experimental data to update the FE-model of rotor systems. An algorithm, based on unbalance response in time domain is proposed for updating the rotor systems at different running speeds of rotor. An attempt has been made to define Unbalance response assurance criterion (URAC) to check the degree of correlation between updated FE model and physical model.

1. Introduction

Model updating, at its most ambitious, is about correcting invalid assumptions by processing experimental test results [1]. If an updated model reproduces measured data like natural frequencies and mode shapes, then it might be quite useful for comparison with data obtained at another time for the purpose of condition monitoring of the system [2].

In structural dynamics numerous methods for model updating have been developed in recent decades [1,3]. Non-rotating structures are self-adjoint structures and the methods developed so far are easily applicable to them. Rotating structures are non-self-adjoint mainly due to gyroscopic and circulatory (cross-coupling stiffness) forces which create the non-symmetric system matrices during analysis. Due to asymmetry in their system matrices, analysis of the system and experimental extraction of parameters become difficult. Owing to this difference in the dynamic models of the system compared to stationary structures, conventional methods of updating have not been applied successfully. In that case, model updating using FRF seems to be more feasible since it involves direct measurement of FRF data from the experiments and hence error due to modal parameter extraction can be avoided [4–8].

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Nomenclature

FRF	frequency response function
$\mathbf{M}_R$	rotational mass matrix for Timoshenko beam
$\mathbf{M}_T$	translational mass matrix for Timoshenko beam
$\mathbf{K}_B$	bending stiffness matrix for Timoshenko beam
$\mathbf{K}_A$	axial stiffness matrix due to axial load for Timoshenko beam
$\mathbf{G}$	gyroscopic matrix for Timoshenko beam
u	$\{u_y, \theta_z, u_z, \theta_y\}^T$, the generalized degrees of freedom
F	external excitation force
$\mathbf{M}_d, \mathbf{G}_d$	mass and gyroscopic matrices of disc, respectively
$\mathbf{M}_s, \mathbf{D}_s, \mathbf{K}_s$	system mass, damping and stiffness matrices, respectively
y, z	stationary co-ordinate axes attached to disc plane
$\bar{y}$, $\bar{z}$	rotating co-ordinate axes attached to disc plane
Ω	angular speed of rotor
Ωt	angular displacement of rotating axes at any instant 't'
m	unbalance mass
e	eccentricity of unbalance mass from disc center
β	phase angle of unbalance
u_y, u_z	unbalances correspond to horizontal and vertical planes of disc
F_y, F_z	unbalance forces along horizontal and vertical directions

So far, numerous optimization techniques on the basis of FRF have been developed by different researchers for model updating of rotating structures. Ziaei-Rad [9] presented three different optimization techniques, namely Linear least squares (LLS), Genetic algorithm (GA), and Adaptive simulated annealing (ASA). Chouksey et al. [10] presented model updating of an actual rotor system mounted on ball bearings by using Inverse eigen sensitivity method (IESM).

Present work deals with model updating of rotor systems by using Nonlinear least square optimization (NLSQ) technique. The error between measured and predicted responses has been minimized by using NLSQ. Although NLSQ was used by some researchers for model updating based on frequency response function, to the best knowledge of the authors, no work has yet been reported on the model updating based on the unbalance response. Measurement of FRF for rotor systems in running condition is quite a difficult task and there are the possibilities of error during measurement. Contrary to that, unbalance responses are the easily measurable quantity for the running rotor, hence in the present work, an attempt has been made to develop an algorithm for the model updating of rotor systems at different speeds of rotor. FRF based model updating is carried out for updating the rotor systems at different modes of vibration whereas, unbalance response based model updating is used for updating the rotor systems at different speeds of rotor.

2. Finite element model of rotor systems

A Finite element model of rotor systems shown in Fig. 1 has been developed for the present study. The FE model includes gyroscopic moments, rotary inertia and transverse shear effects. The system characteristic equation will be assembled considering individual components using finite element method [11,12].

2.1. Finite rotor element

A Timoshenko beam element with four degrees of freedom per node [11] as shown in Fig. 2 is considered for present analysis, whose equation of motion is given as

$$(\mathbf{M}_R + \mathbf{M}_T)_e \ddot{u}_e + (-\Omega G)_e \dot{u}_e + (\mathbf{K}_B - \mathbf{K}_A)_e u_e = F_e \tag{1}$$

where 'e' stands for the element degrees of freedom.

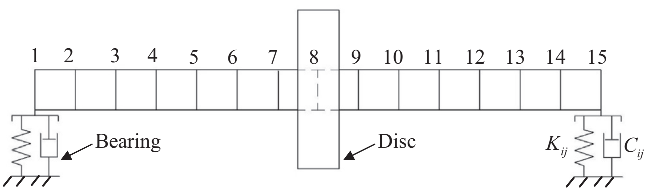

Fig. 1. FE model of rotor systems.