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A method for the identification of dynamic constraint parameters in multi-supported flexible structures

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ABSTRACT

In this paper, a new method for identifying the dynamical parameters of local constraining supports such as mass, stiffness, and damping was developed through combining the measured frequency transfer functions and structural modification techniques. Since measurement noise often leads to erroneous identifications, regularization techniques have been implemented to reduce noise amplification in the inverse problem. The developed technique has been validated by numerical tests on a multi-supported flexible structure, which can be seen as an idealized electricity generator rotor shaft. The results are satisfactory for noise-free data as well as under realistic noise levels. The sensitivity of the identified support features to noise levels is asserted through a parametric study

1. Introduction

Rotors such as gas turbines, centrifugal compressors and fans are among the most important mechanical components in many engineering fields. High-speed rotating machines are often required; yet, they become prone to vibration issues and dynamic instabilities when reaching critical speed regimes. Thus, for reliability reasons, it is necessary to ensure a good stability of the machinery. Hence, rotor instability causes have been investigated for many decades. Newkirk [1] described the “oil whip” phenomenon for the bearing induced instability. It has been shown later that rotor instability can be related to the bearing dynamic coefficients. Stiffness and damping coefficients of the bearings must be known in order to create the rotor’s design, as shown by Ramsden [2]. Further conclusions were then made by Dawson and Taylor [3] through experiments on rotor dynamics, which are required to study the bearings and supports effects on the rotor response. Thermal and elastic distortion effects must be also taken into account and, to this end, the characterization of the dynamic behavior of the bearings is needed. Nordmann and Scholhom [4] proposed a procedure to identify the stiffness and damping parameters of a plain bearing. For rotors mounted on two symmetrical bearings, the impact method was used by Chan and White [5] to identify the dynamic bearing parameters, by adjusting the resulting model on the frequency response functions (FRFs). As bearing parameters are not symmetrical in most cases, the use of their method is restricted. A method for the identification

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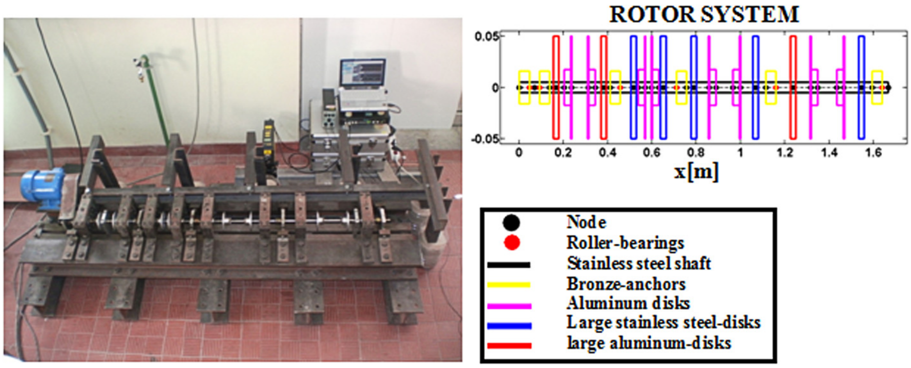

Fig. 1. Picture of the rotor test rig at LDA of IST/CTN (left); detailed sketch of the components of the rotor model (right).

of the structural parameters of joints was later proposed by Wang and Liu [6], then extended by Ammugam et al. [7] to identify the linearized parameters of an oil film by using experimental or theoretical FRFs. Qiu and Tieu [8] developed an algorithm to identify the dynamic parameters of a bearing from its impulse response. Chen and Lee [9] proposed a method to estimate the linearized coefficients of rolling element bearings, using the relations of unbalance responses and known system parameters to predict the coefficients of the rolling element bearings. Tiwari et al. [10] proposed an identification algorithm to characterize bearing dynamic properties in a flexible rotor-bearing system, based on unbalance responses. Experimental identification of the dynamic parameters of bearings and seals was further detailed by Tiwari et al. [11]. De Santiago and San Andrés [12] used recorded transient rotor responses, due to impact and unbalance, to identify the bearing support parameters. Tiwari and Chakravarthy [13] presented two identification algorithms to predict the residual unbalance and bearing parameters in a rigid rotor-bearing system. Han et al. [14] suggested an iterative method, based on a Kriging surrogate model and evolutionary algorithm to identify the bearing properties in a rotor-bearing system.

In the present paper, a method for the identification of local structural characteristics, based on the formulation of structural modifications previously proposed by Özgüven [15] and Debut et al. [16] is further developed and applied. It is used for the identification of the linearized support parameters – i.e. mass, stiffness and damping of each rotor bearing – from the computed modal frequencies and mode shapes of the unconstrained rotor and from a measured FRF matrix of the transfer functions relating the dynamics at all support locations of the constrained rotor. The main idea of this method is to exploit a dynamical formulation that relates the unconstrained system to the constrained system. The unconstrained system is represented by means of the transfer functions computed by the finite element method, whereas the constrained one is represented by the measured transfer functions at the supports. The presence of noise in the measurements of transfer functions, as well as almost nodal values in the mode shapes, lead to ill-posed inverse problems. The proposed formulation allows a better regularization of the inverse problem through filtering techniques, namely using singular values decomposition (SVD) of the relevant formulation matrices. Inverse problems of the type addressed here are typically solved through iterative formulations in a nonlinear fashion, and solved using optimization methods. However, these methods become time consuming when the number of the identified parameters increases. Moreover, convergence to a suitable solution is not guaranteed. Therefore, a transformed linear formulation is rather used to find solutions of the inverse problem. Another advantage of the proposed approach is that it does not imply an experimental identification of the constrained modes of the system, which can be delicate in practice. Instead, it is rooted only on transfer function measurements.

As a first step to the problem addressed, this paper presents identification results obtained using realistic simulated data for a model of an electricity generator shaft, under non-rotating conditions. In order to illustrate the satisfactory behavior of the approach, a parametric study is performed to determine the sensitivity of the identification procedure to measurement noise.

2. Theoretical model

2.1. Description of the proposed approach

The structure is composed of a multiple spans rotor, supported by ball bearings, connected to a fixed structure as shown in Fig. 1. As a first step, we consider that the structure is unconstrained, meaning that boundary conditions at the supports are not taken into account. Then, the frequency transfer function matrix $\mathbf{H}_{\mathbf{U}_{ij}}(\omega)$, which relates the excitation at location i to the response at location j, is given in terms of the assembled matrices from the Finite Element model as:

$$\mathbf{H}_{\mathbf{U}}(\omega) = \left[-\omega^2\mathbf{M} + \mathrm{i}\omega\mathbf{C} + \mathbf{K}\right]^{-1} \tag{1}$$

where **M**, **C** and **K** are the structure mass, damping and stiffness matrices, respectively. If the supports are considered as localized additional mass, stiffness and damping constraints, then the frequency transfer function matrix $\mathbf{H}_{\mathbf{C}}(\omega)$ of the constrained system can be given by: