STATISTICAL DAMAGE DETECTION IN A STATIONARY ROTOR SYSTEMS THROUGH TIME SERIES ANALYSIS

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Abstract — A novel approach to detect damage in stationary rotating systems excited by unbalance and stochastic forces is presented. The methodology is based solely on output time series measured at the bearings stations. The method deals with the application of auto-regressive models and statistical modeling for the linear prediction of damage diagnosis. The results showed that the approach is suitable for practical applications.

Keywords — damage detection, rotor systems, AR-ARX models.

I. INTRODUCTION

The analysis and monitoring of machines play an important role in modern industries due to economical, equipment availability, and safety reasons. Farrar et al. (2005) stated that in-service failure corresponds to 20-40% of all losses in engineering sector, mainly in petrochemical industry. And rotating components are presented in the majority of the machines usually found in industries as, for example, pumps, compressors, fans, turbines, etc. Hence, the monitoring and maintenance of this kind of equipment – the rotating machines – is a crucial issue in any industrial plant.

Several technical standards adopt the root means square (RMS) values (DIN 45666, for example) and/or the overall vibration value (ISO 10816) as damage-sensitive index in rotor systems (NBR 10082, 1987). Unfortunately, in some cases, these features are contaminated by the unavoidable experimental errors or dynamical effects. To overcome these facts, the spectral analysis can be performed, but the results are highly dependent on the human experience (Mitchell, 1993).

Another more elaborated approach for damage detection is the use of mathematical models, which can be generated numerically, using the finite element methods and/or experimental, obtained through modal analysis. Based on these models, different strategies are described in the literature to identify a damage as, for instance, correlation analysis (Eduardo, 2003); model updating by using optimization methods (Castro et al., 2005); state observers based methods (Melo and Lemos, 2004), etc. It is worth noting, however, that model-based assessment approaches are usually computationally intensive and requires a quite accurate model of the rotor system.

The present paper addresses the damage detection problem of a rotor system. The methodology is based on an AR-ARX model, as described by Sohn and Farrar (2001), who used this procedure for structural application. The main idea is to use the one-step-ahead error prediction as damage-sensitive index. Large prediction error comparing to the actual measurement will occur if the system presents accumulated damage (Silva et al., 2007).

This paradigm has successful applications for gear fault detection comparing with wavelet analysis and resonance demodulation (Wang, 2003). The partitioning of this damage-sensitive feature in healthy or damaged state is made in this paper by using two different statistical modeling. The first one is the ratio between the residual errors (Sohn and Farrar, 2001). The second one is based on limits control constructed by statistical process control (Silva et al., 2005). The performance for both threshold values determination are compared and discussed. Tests are made in a rotor system with different damage patterns. The capability to reach good diagnostic based solely in response measurements is demonstrated.

Additionally, the procedure proposed is not based on the human knowledge and experience, as is the case in the classical spectral and/or RMS analysis.

II. DAMAGE-SENSITIVE FEATURE

Initially, it is considered signals, \(z[k]\), measured from the undamaged rotor system (healthy state) in \(N\) environmental conditions, always running in stationary condition. In order to obtain all signals with zero sample mean and standard deviation equals to one, these time series must be standardized, as given by the following expression:

\[
x[k] = \frac{z[k] - m(z)}{s(z)},
\]

where \(x[k]\) is the standardized signal at the \(k^{th}\) time instant, \(m(z)\) and \(s(z)\) are, respectively, the mean value and standard deviation of the \(z[k]\) sequence.

The first phase of the methodology is devoted to the construction of an AR model, with order \(p\), for each \(x_i[k]\), \(i = 1, 2, ..., N\). The AR\((p)\) model can be written as:

\[
A_p(q)x_i[k] = e_i[k],
\]

where \(e_i[k]\) is the error between the \(i^{th}\) measured signal and the output from the prediction model. \(A_p(q)\) is the \(i^{th}\) polynomial in the delay operator \(q^{-1}\). The coefficients of the AR model can be found by the Yule-Walker equations (Wang, 2003), while the polynomial order, \(p\),