Available online at www.sciencedirect.com
ScienceDirect
Journal of Sound and Vibration 316 (2008) 331–347
JOURNAL OF SOUND AND VIBRATION
www.elsevier.com/locate/jsvi

Localization and quantification of vibratory sources: Application to the predictive maintenance of rolling bearings

X. Chiementin[a,*], F. Bolaers[a], L. Rasolofondraibe[b], J.-P. Dron[a]

[a]GMMS, Groupe de Mécanique Matériaux et Structures, University of Reims Champagne-Ardenne, BP 1039, 51687 Reims Cedex 2, France
[b]CReSTIC, Centre de Recherche en Sciences et Technologies de l'Information et de la Communication, University of Reims Champagne-Ardenne, BP 1039, 51687 Reims Cedex 2, France

Received 6 July 2006; received in revised form 18 February 2008; accepted 19 February 2008
Handling Editor: C. Morfey
Available online 3 April 2008

Abstract

Among the methods which make it possible to establish a diagnosis on the operating condition of a mechanism, the vibratory techniques seem very promising and are booming. The signals collected by accelerometers are the result of a mixture of various sources each of which corresponds to operation of a component. The diagnosis and monitoring of each component require the determination of the contribution of each source in the signal collected. The objective of this work is to use and optimize the techniques applied to the inverse problems with the aim of quantifying the contribution of each source in the obtained mixture, more particularly, the sources which are characteristic of a damaged element. However, the inverse problems are generally unstable. These instabilities are often related to the errors of measurement or the parasites contained in the signals and require methods of stabilization. This paper proposes a methodology, based on the restitution of the sources. Thus, the methodology ensures the detection and the localization of a defect of a component by the optimization of the position of a limited number of sensors. Two approaches are then proposed: the numerical approach which employs an updated numerical model of the studied structure and the experimental approach based on the correlation between the position of the sensors and the modal parameters of this same structure. The experimental validation of this methodology is carried out on a casing made up of two bearings.

1. Introduction

Predictive maintenance by vibratory analysis makes it possible to increase the productivity and to improve one's performance in terms of reliability, availability and security. This procedure of analysis implements the techniques related to the dynamics of the structures and the signal processing [1,2]. Three levels of analysis are currently used: (i) the monitoring carried out with global indicators, that makes it possible to observe possible drifts of the level of vibrations, (ii) whose diagnosis is aimed at locating a damaged component and (iii) monitoring of the quantification of variation of the failure severity. The vibratory signals resulting from piezoelectric accelerometers represent the response of the structure to various excitations caused by the various

*Corresponding author.
E-mail address: xavier.chiementin@univ-reims.fr (X. Chiementin).

0022-460X/$ - see front matter
doi:10.1016/j.jsv.2008.02.029

mechanical components. Thus, the aim of our work is to define the contribution of each excitation source in order to quantify its severity. The separation of the sources starting from the measured signal requires the use of inverse problems. However, the inverse problems are ill-posed problems in the sense of Hadamard [3]; they are unstable during the inversion. Many works have studied the inverse problem for the indirect force measurements. We can distinguish two main categories: the first one using mathematical methods and the second one taking into consideration physical phenomena.

The mathematical tools are generally combined with the use of a large number of sensors [4,5]. These sensors give rise to a mixture matrix whose singular value decomposition (SVD) offers a very interesting mathematical base [6]. Within the framework of the vibrations, a first method, described by Powell in 1984 [7], consists in cancelling the lowest singular values considered like noise. Romano [8] decided to reject the singular values lower than 10% of the highest singular value. Elliott [9] and Thite [10] define the threshold according to the level of the uncertainties of the measurements. A second method consists in regularizing these values. This method was implemented by Nelson in 1998 [11] within the field of the indirect measurements of forces, and recently by Kim [12] and Thite [10]. Hansen [13] proposes a method based on the visualization of the solution norm according to the residue. This function forms an L whose corner corresponds to the optimal regularization parameter (the L-curve principle), while Golub [14] proposes a performance index based on the coherences between the measurements, the generalized cross validation (GCV) principle. However, according to Lanczos [15], *A lack of information cannot be remedied by any mathematical trickery*. This statement proves that the regularization methods allow to stabilize the problem but they skew the inversion. Even if the regularization parameter is determined, these regularization methods can delete a source.

The tools, which use the physical phenomena, are inspired by the dynamic structures. Powell [7] shows that two physically very close excitations generate similar deformations, particularly at low frequencies. This fact makes the inversion unstable because of a dependence between the column vectors of the matrix. Fabunmi [16], Hilary [17] and then Desanghere [18] define the existence of a link between the modal analysis of the structure and the number of the determinable sources at a narrow band of frequency. They highlight that the number of modes participating in the response of the structure must be equal or superior to the number of sources. In particular, the restitution of the frequencies close to the resonance frequency is impossible because only one eigenmode governs the structure, and this is all the more true as the structure is lightly damped. Thanks to these remarks, Lee [19], then Hadjit [20], made a measurement selection which allowed to stabilize the inversion. Lee [19] proposes a method based on the maximization of the norm of an undersquared matrix obtained by the SVD. Hadjit [20] defines a new criterion to select the responses by considering the provision of independent information deduced from the matrix of Fischer. Leclère [5] implements a strategy of weighting of the mean squares based on the importance given to each response. It is thus possible to decrease the importance of some vibratory responses positioned on vibration bellies, and to increase the importance if the sensors are positioned on vibration knots. Other works studied the restitution of the frequencies close to the resonance frequency. Lee [19] proposes to add an oscillating system to shift the resonance frequency. This system modifies the structure: consequently, it modifies the resonances. However, this modification can be very important, and it can significantly modify the required sources. Another procedure, implemented by Mas [21], is based on the damping of the structure. Indeed, a damped structure has less acute resonance peaks, which improve the stability.

This paper is inspired by these works, in order to implement the restitution of the sources related to the damage of one or several components. However, some of the points are different from the previous studies. The nature of the quantities to be restored are "accelerations", whereas the previous studies propose the restitution of the forces. The reasons are that restored accelerations can be compared to measured ones and that the measured quantities and the quantities to restore have the same order of magnitude. Then, we wish to use a limited number of sensors and to optimize the restitution in narrow bands of frequencies around characteristic frequencies of bearing defects. The objective is not to increase the *quantity* of the information but the *quality* (given by the sensors). The previous studies have implemented a selection among several sensors but they did not propose a mathematical model to optimize the position of the sensors. They describe only some principles (a global repartition, to avoid a vibration knot). This is why this work determines a relation between the modal parameters and the position of the observations giving place to conditioning maps. These maps define the positions of the sensors. This relation avoids using the regularization methods which