Measurement 70 (2015) 47–61

Contents lists available at ScienceDirect

Measurement

journal homepage: www.elsevier.com/locate/measurement

Use of composite higher order spectra for faults diagnosis of rotating machines with different foundation flexibilities

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ARTICLE INFO

Article history:
Received 28 November 2014
Received in revised form 29 January 2015
Accepted 20 March 2015
Available online 27 March 2015

Keywords:
Rotating machines
Flexible foundation
Faults diagnosis
Data fusion
Composite bispectrum
Composite trispectrum

ABSTRACT

It is commonly observed in practise that rotating machines installed at different plant locations often exhibit different dynamic behaviours, due to variations in the flexibilities of their supports. This often makes the faults diagnosis complex from one machine to another machine. In the current study, a similar scenario has been experimentally simulated on a rotating rig with different foundation flexibilities. Also, different faults were experimentally simulated at different machine speeds so as to develop a reliable diagnosis technique that will be suitable for different machine foundations. Recently developed data fusion methods for constructing composite spectrum (CS) and composite bispectrum (CB) for a machine are again applied for faults diagnosis here. In addition, the present study introduces the composite trispectrum (CT) as a new feature for diagnosis. The paper hereby presents the computational concepts of all composite spectra, rig details, data analysis and diagnosis.

1. Introduction

The dynamic behaviours of 'as installed' rotating machines at different locations in a plant and/or in different plants is observed to be significantly different in many cases [1,2]. This is mainly due to different flexibility of the foundation at different places. For instance, two large turbo-generator sets may exhibit different dynamic behaviours as a result of the differences in their foundations [3]. To further enhance clarity, an abstract representation of machine and foundation is shown in Fig. 1, where machines can be identical (for example pump and motor units, identical turbines, etc.), but may have different foundations. It is also important to state that the term rotating machine in Fig. 1 solely refers to the rotor–bearing–motor assembly (including other integral components such as couplings, and discs), that may have been acquired with such a machine from the original equipment manufacturer (OEM), which can be identical for several rotating machines. The foundation on the other hand refers to all machine installations onsite, including structural connections (e.g. piping, bracing, etc.) that can have an influence on the 'as installed' machine dynamics.

Since rotating machines are sometimes subjected to a wide range of operating conditions, which often leads to the emergence of faults that require early and effective diagnosis that will avoid compromising personnel and equipment safety [4]. These factors make the faults diagnosis process complex. This however explains why good prior understanding of the modal parameters and dynamic behaviours of rotating machines play a very vital role in vibration-based faults diagnosis. Perhaps, model-based diagnosis approach [5–11] may prove useful for such cases where foundation dynamics is generally taken into account. However, some of the popular techniques highlighted in research articles [12–15] summarising various

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http://dx.doi.org/10.1016/j.measurement.2015.03.041
0263-2241/

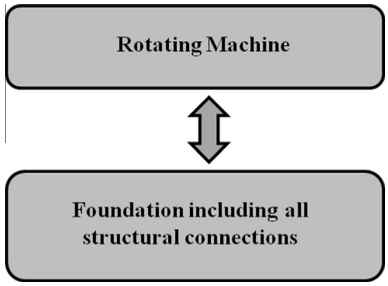

Fig. 1. Abstract representation of rotating machine and foundation.

faults diagnostics and prognostics techniques may or may not be directly applicable for reliable diagnosis when dealing with rotating machines installed on different foundations.

Within the past few decades [16], appreciable research contributions on the application of higher order signal processing techniques for faults diagnosis in rotating machines have been made. This was based on the premise that faults diagnosis using conventional and well-known linear spectral analysis techniques such as power spectrum density (PSD) alone is unable to establish the interactions that exist between frequency components of measured vibration signals when faults occur, due to its lack of phase information [16]. However, these studies have been dominated by the application of the normalised forms of the higher order spectra (HOS), known as the higher order coherences (HOC) [17–23]. Sinha [24] experimentally and theoretically explored the application of HOS (bispectrum and trispectrum) for fault detection on a very simple rotating rig, supported by just two bearings. However, a significant number of industrial rotating machines often posses a more complicated configuration, with more bearings. This therefore triggered further investigation of HOS for the diagnosis of more rotor-related faults on a relatively rigid rotating machine supported by four bearings, at a single [25] and multiple machine speeds respectively [26]. In the latter study [26], it was shown that bispectrum could not adequately distinguish between certain machine conditions (intermittent rotor rubs and healthy conditions) at certain machine speeds, which led to the combination of bispectrum and trispectrum features for a more robust diagnosis. Despite the significant contributions on HOS and HOC, as well as considering the fact that a significant number of industrial rotating machines are mounted on flexible foundations, none of the earlier studies has been geared towards diagnosing faults associated with 'as installed' identical rotating machines with different foundations.

Hence, the current paper aims to simulate an industrial scenario through an experimental rig with different flexible foundations. The impacts of the different foundations on the rig have also been confirmed by conducting modal tests to obtain the modal parameters [27]. Different faults have been experimentally simulated and the observed dynamic behaviours for each fault have been found to be different for the different foundations, and hence the diagnosis features. In this study, the recently developed data fusion technique for computing composite spectra (CS) [28] and composite bispectra (CB) [29] for a machine is used on the present experimental data. Furthermore, the concept of composite trispectrum (CT) for a machine has also been introduced as an additional diagnosis feature, so as to significantly enhance the ability of the proposed technique to discriminate between different machine conditions, owing to the fact that the CT component expresses the relationships between more frequency components in the measured vibration data. The current research effort is based on the development of a reliable and simplified faults diagnosis approach that will be applicable to rotating machines with different foundation flexibilities. The developed method can utilise the diagnosis features for identical rotating machines with different foundations. Several sets of measured vibration data from the rig with different foundations under various experimentally simulated faults at different machine speeds are analysed using all composite higher order spectra. Hence, the paper provides details of signal processing, rigs,

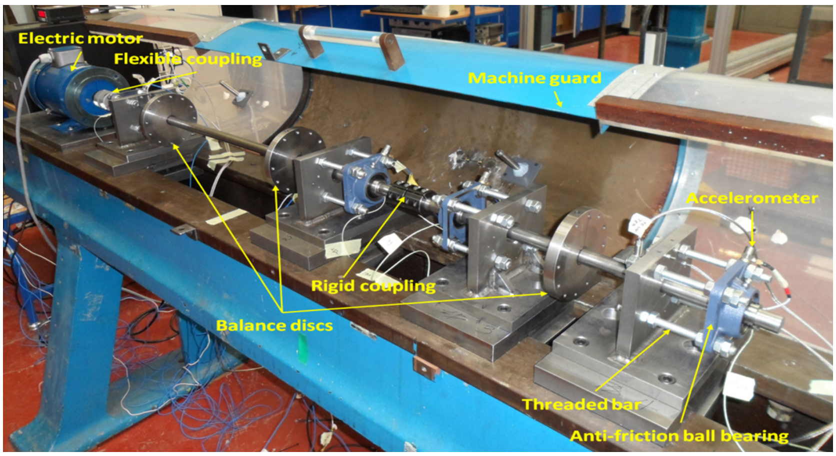

Fig. 2. Photograph of the experimental rig.