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Detection and monitoring of coupling misalignment in rotors using torque measurements

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Rotor faults such as misalignment, shaft crack, rotor rub, bearing fault etc. lead to high vibration and are major cause of machinery shut down. Misalignment in rotating machinery shafts develops reaction forces and moments at the coupling. Conventionally, misalignment diagnosis is carried through vibration measurements. Especially, the existence of strong 2× component is widely accepted. However, there are other rotor-bearing faults which lead to significant 2× vibrations. Hence distinguishing misalignment is a challenging task using vibration signals alone. In view of these limitations by employing vibrations signals, present study focuses on torque measurements for misalignment diagnosis. Experimental results using torque sensor for different cases of misalignment at different frequency of operation are reported. Fourier and wavelet transforms are used to detect the misalignment fault. The variation of the fault characteristics with respect to time are reported for sampled signals using wavelet transforms. The study shows the possibilities of using torque measurements as useful and additional technique for the detection and monitoring of coupling misalignment.

1. Introduction

Misalignment is a situation in which the input shaft and the output shaft are not in the identical centreline. Misalignment can be classified into three categories namely: parallel, angular and a combination of both. It is very challenging to attain a perfectly aligned condition between two shafts in industrial environment. Even if an accurate alignment is secured, it cannot not be continued for a long duration due to many external effects, like base foundation disturbance [1,2]. Shaft misalignment is a frequently encountered fault observed in large rotor bearing systems like steam turbine shafts, gas turbines shafts and aircraft rotating components, and it is a significant source of vibration. High levels of misalignment may lead to fatigue cracks or rotor to stator rubbing. Therefore, misalignment detection and monitoring is an important objective for successful operation in the industrial scenario. Precise detection of shaft misalignment faults can cut the operation cost and facilitate long and safe operation.

The vibration response of the rotor provides knowledge on operating conditions that are connected to the fault characteristics. However, due to the confusing spectral characteristics of vibration, vibration based misalignment detection lead to less reliability [1]. Usually, it is expected that the existence of misalignment will lead to high vibrations with strong higher harmonics. But, it is reported by Piotrowski [1] that the higher misalignment may lead to decrease of vibrations. In spite, of the above reported observation, a strong 2× vibration component is widely accepted for misalignment fault diagnosis. During misalignment fault diagnosis, vibrations are outcome of several other vibrations sources along with coupling misalignment. Unlike vibration based data, torque data captured from

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misaligned shafts will capture the primary effects of misalignment.

It was practically proved that vibration magnitude varies significantly at 2× and 4× frequencies of operating frequency of the rotating member as the misalignment increases [3]. Also it is reported that the frequencies of forces and moments from misaligned shafts are even multiples of the operating speed of the motor [2,4]. Analysis of other faults with analytical models of rotating systems reported by Hamzaoui et al. [5] also indicated that misaligned shafts generates vibrations such that the magnitude of the 2× operating harmonic frequency component is sensitive to the fault. Sekhar and Prabhu [6] analyzed shaft misalignment in rotor bearing system with a flexible coupling using higher-order finite element model by applying theoretically modeled forces and moments. The effect of harmonic and flexural mode shapes on vibration magnitude is reported. Lee and Lee [7] introduced a dynamic model for shaft misalignment in a rotor-bearing system with roller bearing connected by flexible coupling. A model-based evaluation of defects in frequency domain was reported by [8–10]. Sinha et al. [11] introduced a technique to diagnose the shaft misalignment from a shutdown data in which the shaft misalignment at couplings is assumed to developed steady forces and moments.

A detailed review on different studies on coupling misalignment is presented by Sudhakar and Sekhar [12]. Concluding the observations of shaft misalignment detection in rotor bearing system components as indicated in previous publications, the features of rotor misalignment defect can be seen in vibration magnitude varying at a speed of 2× the shaft operating frequency and the harmonic components. However, these results are concluded using the Fourier-transform based techniques; therefore new harmonics may be useful to generate the analytical response. These harmonics components may not directly indicate the actual misalignment level. The available model-based techniques are based on the linear force assumptions [7]. The vibration caused due to shaft misalignment, may fall into plastic range and may not show linear characteristics. It is not accurate to assume the features of misaligned shafts by using the linear force assumptions. Moreover, the experimental results from vibration responses are normally corrupted with other effects like low signal to noise ratio. It is generally difficult to find the defect characteristics of the responses directly from the actual testing. Traditionally, filters are used to reduce the unwanted noise and retain the actual responses within a interested frequency range. However, the filter parameters like band width and central frequency are to obtained by testing and experience [13]. Many time–frequency techniques are available for analysis signals with non-stationary features.

A brief literature review on wavelet based condition monitoring of rotating systems is presented as follows. Unlike the Short Time Fourier Transform (STFT) approach where the analysis window dimension is constant the CWT based approach allows variable window dimensions during analysis of responses with many frequency components [14,15]. Staszewski [16] reported a state of the art review on fault identification using wavelets transform. Tse et al. [17] evaluated the performance of the wavelet transform based approach and the envelope identifications (EI) methods for roller element bearing defect monitoring. Peng et al. [18] analyzed 3 categories of typical defects: rubbing, oil whirl and coupling misalignment, which are frequently observed in rotor bearing systems, by wavelet based scalograms. Other studies on the rubbing phenomenon in rotor-bearing systems were reported with scalograms and phase spectra [19].

In this paper the Section 1 reviews the two general methods to misalignment detection using vibration based analysis, like Fast Fourier Transform based and continuous wavelet transform based approaches. In Section 2 the details of the experimental arrangement and the data collection procedures are presented, whereas in Section 3 the experimental results using the Fast Fourier Transform approach and Continuous Wavelet Transform (CWT) based approach are presented. In this work an alternative technique based on torque measurements for detecting the shaft misalignment problem of rotating components is proposed. Finally, conclusions are reported in Section 4.

2. Experimental setup

The experimental setup used in this study is shown in Fig. 1 and the physical details of the rotor bearings system are presented in Table 1. The motor with belt driven system drives a shaft coupled torque sensor system. The rotor can be run at different speeds below and above critical speed. A special platform which facilitates inducing desired amount of misalignment in the rotor bearing system is fabricated. Precast channels and flats of this platform hold the bearing pedestal rigidly and to induce misalignment shims of different sizes are introduced. To measure vibrations, accelerometers are placed near bearings in radial direction. The accelerometers employed are precision quartz shear ICP type with sensitivity of 100 mv/g and frequency range 0.5 to 10 kHz. The torque sensor is attached in between the motor shaft and the rotor shaft as shown in Fig. 1. In every measurement both accelerometer and torque sensor outputs are recorded.

Data is sampled in the time domain with sampling of 5000 Hz. A Dewesoft program is used for data acquisition. The schematic representation of the experimental setup (see Fig. 2) presents the sensor, disk and bearing locations.

The torque sensor instrument used in the torque measurements is shown in Fig. 3. Torque sensor used is a RWT310/320 series transducer. Rayleigh Wave rotary Torque (RWT) transducer provides a method of precisely measuring rotary or static torque. The RWT series transducers require no external instrumentation and has its own built in test capability. Its compact size makes it ideal for use in applications where there is little space for any extra equipment. Analog voltage outputs are standard, with current outputs available as an option.

The shaft of the transducer should be connected to the mechanical system on which the measurements are to be made using appropriate couplings (see Fig. 1) so it can rotate freely up to its maximum recommended speed, with relation to the transducers body and bearings fitted. The