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Laser based measurement for the monitoring of shaft misalignment

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ABSTRACT

This paper presents a method for real-time online monitoring of shaft misalignment, which is a common problem in rotating machinery, such as the drive train of wind turbines. A non-contact laser based measurement method is used to monitor positional changes of a rotating shaft in real time while in operation. The results are then used to detect the presence of shaft misalignment. An experimental test rig is designed to measure shaft misalignment and the results from the work show that the technique can be used for the monitoring of both offset and angular shaft misalignment, which will have applications in the condition monitoring and maintenance of various types of rotating machinery.

1. Introduction

When performing maintenance on machinery, the following techniques are common: (1) run to failure where a piece of equipment must fail before any maintenance is performed; (2) preventative (or periodic) maintenance where maintenance is based on the length of the operating period, using criteria such as the mean time to failure (MTTF) measurement for the machine; (3) predictive maintenance where the operating condition of the machine is monitored to identify the need for repairs through data analysis and diagnosis [1].

Predictive maintenance strategies have led to the need for machinery condition monitoring. Condition monitoring can be defined as monitoring the physical parameters associated with the operation of the machine, such as vibration, temperature or pressure, to determine the operational condition of the machine. Improvements in maintenance strategies have economic benefits through improved production and less downtime, as well as indirect benefits through the need for fewer spare parts [2]. Examples of previous research on condition monitoring for rotating machines use vibration sensors for the monitoring of bearings to identify shaft rub and shaft misalignment [3], fault diagnosis using the empirical mode decomposition method [4] and acoustic noise measurements to predict the remaining useful life of a machine [5].

A typical application of condition monitoring for rotating machines is in wind turbines [6], specifically in offshore wind turbines, due to inaccessible locations [7], which may be expensive or difficult to access, with variable operating conditions. The drive train of the wind turbine consists of typically, a low speed shaft (on the rotor side), a gearbox, and a high-speed shaft (on the generator side) as well as support bearings, one or more couplings (between the shaft and the gearbox) and a mechanical brake [8]. A study [9] showed that 25% of the operational expenditure for an offshore wind farm is for operation and maintenance activities so any improvement in monitoring, leading to a reduction in maintenance costs, could eventually drive down the cost of energy.

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2. Shaft misalignment

A shaft is an essential part of the rotating machine; it is used to transmit power and motion. A common problem (estimated to cause over 70% of vibration problems [10]) in rotating machinery is shaft misalignment. Shaft misalignment occurs when the centre lines of rotation of two (or more) machinery shafts are not in line with each other [11]. This increases axial and radial forces on bearings, seals and couplings, increasing the amount of wear in these components, leading to an increase in vibration in the machine and bearings, it also increases bending of the shaft, increasing the risk of shaft failure and reducing the amount of power transmitted through the shaft [12]. Even if initially, or after adjustment, the shaft is aligned, during operation various factors such as thermal growth, piping pressure and foundation movements will alter the alignment [13].

Previous work on shaft misalignment monitoring has mainly been focused on looking at the vibration response. Arebi et al. [14] developed an on-line misalignment monitoring system using a wireless accelerometer mounted directly to the shaft, to measure the acceleration due to vibration. Work in rotor-dynamics shows that shaft misalignment caused by rotor imbalance leads to synchronous vibrations (frequency of vibration at twice the shaft speed) [15]. Dewell and Mitchell showed that the response to a misaligned coupling contained vibration frequencies of two times and four times the rotation speed [16], Xu and Marangoni also showed vibration frequencies at multiples of rotation speed [17,18]. Patel and Darpe [10] describe a drawback in using vibration monitoring to monitor for shaft alignment, as shaft damage, shaft stiffness and the type of coupling used can also affect vibration response. Shaft misalignment should cause vibration in both the connected machines, if it is only on a single machine, this could indicate other problems such as a cracked case [19]. As well as using vibration measurements, analysis of the motor current has been applied to shaft misalignment monitoring, Chaudhury and Gupta [20] and Verma et al. [21] used spectral characteristics of the stator current to identify shaft misalignment, Thomson and Fenger used motor current signature analysis to identify faults such as misalignment [22]. Similarly to the work on vibration measurements, Bossio et al. showed that angular misalignment has an effect on current at frequencies of two times the rotation frequency [23].

As well as measuring the response of the motor (current) or shaft (vibration) directly, indirect methods have been used to identify shaft misalignment. Rameshkumar et al. investigated the effect of misalignment on "coast down time" (time between the power cut off and the machine stopping rotating). They found that as shaft misalignment increased, the coast down time decreased, due to the increased power loss caused by the shaft misalignment and increased torque on the bearings [24]. Strain gauges have also been used to measure the presence of misalignment on turbine rotors [25] and to measure the increased gear loading caused by shaft misalignment [26]. Fulzele et al. used an optical sensor to measure shaft vibration by measuring the fluctuation of reflected light from the shaft [27]. Various methods have been developed to model or predict shaft misalignment; Sekhar and Prabhu used Finite Element Method (FEM) modelling to investigate the effect of coupling misalignment on the vibration response of a rotor-bearing system [28]. Cho and Jeong [29] and Fang et al. [12] used principal component regression (PCR) and partial least squares (PLS) to predict shaft parallel and angular misalignment. Yang and Tavner used empirical mode decomposition to reconstruct shaft orbit measurements to identify shaft misalignment [30].

Monitoring of shaft alignment during operation is needed as an effective tool in maintenance. A survey on rotating machinery in industry [31] showed that fewer than 10% of 160 machines examined were within acceptable shaft alignment, also 30% of a machine's down time is due to poor alignment [32]. Shaft misalignment consists of three types [33]:

(1) Offset where the two shafts are on two separate parallel centerlines (Fig. 1a).
(2) Angular where the two shafts are coaxial but at an angle to each other (Fig. 1b).
(3) In reality, shaft misalignment would be a combination of both of these effects (Fig. 1c).

Offset misalignment affects power consumption more than angular misalignment and the components of misalignment are additive irrespective of whether they are horizontal or vertical [31]. The process of shaft alignment is the positioning of the shaft centre lines of the driver machine and driven machine to create collinear shafts, where the rotational centre lines of the coupled shafts are parallel and intersect (like a single shaft), this is accomplished through either shimming or moving the machine.

To measure the amount of shaft misalignment, the following methods are commonly used:

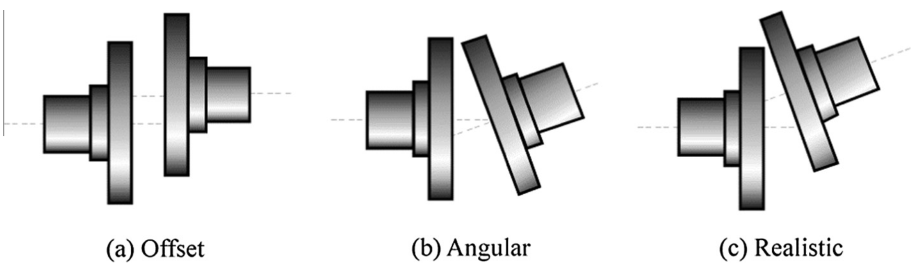

Fig. 1. Types of shaft misalignment.