Measurement 80 (2016) 190–200

Contents lists available at ScienceDirect

Measurement

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

Bearing diagnosis using proximity probe and accelerometer

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ARTICLE INFO

Article history:
Received 9 July 2015
Received in revised form 10 November 2015
Accepted 14 November 2015
Available online 22 November 2015

Keywords:
Proximity probe
Rolling element bearing
Diagnosis
Time Synchronous Averaging

ABSTRACT

Employing multiple sensors that generate different physical parameters from the measured system to monitor its health increases the diagnosis reliability. In the present work, bearing diagnosis capabilities of proximity probes are explored by exploiting its advantages and alleviating its shortcomings using appropriate signal processing of the raw time domain data. A Time Synchronous Averaging based method is proposed for processing of the data acquired by proximity probes and its benefit is illustrated on test bearings. Simultaneous synchronous data is acquired with the help of proximity probes and accelerometer during a life test as the defect is naturally induced and progressed with time. The proximity probe is shown to perform better diagnosis for inner race defect compared to accelerometer due to a direct transmission path for this defect. The use of proximity probe can effectively supplement the information from accelerometer and improve the accuracy of bearing diagnosis.

1. Introduction

A rolling element bearing is one of the most critical components in industry with broad range of applications, both in terms of size and criticality of machine. Bearings are used from a drawer of furniture to cryogenic turbo pump in space application. In the manufacturing industry, failure of a bearing can cause downtime, and production losses due to downtime of the machines may be enormous. Apart from production losses, bearing failure has several indirect losses [1] including inferior quality components (responsible for increased warranty costs). Depending on the product, warranty cost may vary from 2% to 10% of the price of the product. Additionally, due to increasing competitiveness in the industry, the warranty duration provided by various companies is also being extended [2]. Based on the criticality of the application, at times, failure of the bearing may result in catastrophes. In some cases, e.g. cryogenic turbo pump, automotive and aviation industry applications, failure of the bearing can claim loss of lives [3]. Therefore, a robust diagnostic system is required for the bearing health assessment.

Vibration data based condition monitoring is considered best among several available methods (acoustic, stress waves, wear debris, and temperature) [4]. A number of review papers [5–8] discuss bearing diagnosis using vibration data. Methods of increasing the robustness of a system include independent parallel systems that introduce redundancy in the system, in turn making them more reliable. A parallel system ceases to perform only when all the individual systems fail simultaneously. Therefore, the reliability of the overall system increases as the number of components in parallel is increased [9]. Inclusion of independent alternate sensors for bearing diagnosis is similar to introducing parallel branches for bearing diagnosis. Due to this reason, application of multiple sensors for bearing diagnosis is beneficial as it increases the reliability of bearing diagnosis. Systems, wherein the diagnostic decisions are based on the multitude of information acquired from multiple types of sensors are likely to make better judgment, even if one of the sensors malfunctions.

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http://dx.doi.org/10.1016/j.measurement.2015.11.029
0263-2241/

Multisensor data fusion is similar to the capability of living organisms on reaching a decision by integrating complementary information from various sensory data such as sight, sound, smell, taste, and touch. Most of the multisensor data fusion techniques endeavor to achieve this capability of living organisms [10]. Multiple sensors introduce redundancy in the bearing diagnostic system making it more robust. Multiple sensors sensing different physical parameters from the measured system increase reliability of the system significantly since the possibility of all sensors malfunctioning simultaneously is remote. Multisensor data fusion has three types of architectures for fusion of information [10] (i) data level fusion; (ii) feature level fusion; (iii) decision level fusion. In decision level fusion, initially each sensor performs a decision based on its data and finally the decision of the various sensors is fused. However, before using the multiple sensor data for fusion, the choice of sensor should be based on its effectiveness in detecting changes in condition of the bearing. In the present work, proximity probe and accelerometer are used for bearing diagnosis, in particular, the exploration of proximity probe for its usefulness in bearing damage detection.

A proximity probe is a non-contact type probe, which acquires the vibration data in displacement mode. The vibration of the rotor supported by the bearings under investigation is acquired as it spins with given rotational speed. Anomaly with any of the components of the rolling element bearing generates vibratory response of the rotating shaft. Proximity probes are generally used to detect common rotor faults such as unbalance, bend, misalignment, rub, bow, and crack [11–13]. However, usage of the proximity probe is not so common in the diagnosis of bearing faults, as the physical parameter measured by proximity probe is displacement. High frequency components are difficult to detect accurately as the associated displacement amplitude are much smaller than the corresponding acceleration amplitude. This limits the higher frequency components measured by the transducer. There are other issues such as compensation due to shaft surface undulations; however, these can affect higher frequency information more, than the frequencies associated with bearing characteristics frequency for shafts operating at low-moderate speed. In addition, the dynamic range is limited for proximity probe compared to accelerometers. These issues have precluded the use these probes in contrast to piezoelectric accelerometer that is superior from the point of view of ease, dynamic range and high frequency performance. However, the use of new proximity probe with much superior sensitivity and dynamic range coupled with a proposed signal processing approach that involves removal of shaft frequency and harmonics, the present work explores the bearing fault detection based on accelerated life test data.

The experimental time-domain vibration data acquired by proximity probes comprise shaft frequency and its several harmonics. The frequency spectrum of typical bearing signal in practice is noisy and at times, it is difficult to spot bearing defect frequencies and its harmonics. For removing the shaft frequency and its harmonics from the spectrum of the acquired data, a Time Synchronous Averaging (TSA) based method is proposed. The TSA is used predominantly for the cases, where a particular periodic signal is needed to be separated from the other periodic/non-periodic signals and noise [14–16]. The TSA is utilized frequently for the gear diagnosis [17–19] for separating the intended gear vibration signal from the vibration generated by other components and noise present in the desired data. In the present work, initially a TSA based method is proposed to isolate components related to bearing defects. The methodology is applied on vibration data acquired from a known healthy and defective bearing. Application of the method proposed in bearing defect identification is shown. The proposed methodology helps in extracting the defect frequency information for bearing diagnosis. In addition, a comparison of the FFT spectra of both sensors is presented to compare their relative ability to diagnose different types of defect.

The next section gives details of the specification of the sensors used and the experimental set-up for accelerated life test. Section 3 discusses the method used for the signal processing of the data acquired from the proximity probe. Section 4 presents application of the methodology on experimental datasets along with comparison of the FFT spectra of the data acquired from accelerometer and proximity probe. Major conclusions drawn from this study are discussed in Section 5.

2. Details of sensors and experimental setup

The accelerometer used is B&K make 4514-002 that has accuracy within amplitude of ±10% for the frequency range of 1 Hz to 10 kHz, sensitivity of 500 mV/g with measuring range ±10 g peak. The proximity probe is Micro Epsilon make U05 model based on eddy current technique that has frequency range from 1 Hz to 25 kHz, static resolution of 25 nm with measuring range of 0.5 mm. The sensors are much more sensitive with sensitivity of 20 V/mm compared to 8 V/mm sensitivity of the commonly used proximity probes in practice.

Acceleration is second time derivative of displacement. For a sinusoidal signal, displacement of a point with time can be written as:

$$d(t) = d_0 \sin(2\pi f t) \quad (1)$$

where $d(t)$ is the displacement at a given time t and d_0 is the amplitude of the signal and f is the frequency (in Hz) of the vibration. The second derivative of the displacement giving acceleration $a(t)$ may be written as:

$$a(t) = -4\pi^2 f^2 d_0 \sin(2\pi f t) \quad (2)$$

Therefore, the amplitude of the acceleration A takes the following form:

$$A = 4\pi^2 f^2 d_0 \quad (3)$$

As an example, for a displacement value of 1 mm, the value of acceleration is $0.004f^2g$ (taking $g = 9.81\ \text{m/s}^2$). In wind turbines, maximum shaft speed goes up to 40 rpm (0.67 Hz) [20], bearing characteristic frequencies are likely to be well within 10 Hz. For a bearing defect frequency of