

A New Acoustic Emission Wireless Monitoring System; An Experimental Validation of Bearing Condition Monitoring

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ABSTRACT

Bearings are reliable mechanical components which are designed according to known factors and should operate for their designed life. Nevertheless, in practice, various factors such as environmental and operating conditions may significantly reduce their service life, hence application of condition monitoring to bearings could achieve greater reliability. Condition based maintenance (CBM) systems are currently the main maintenance strategy for many applications due to their effectiveness in reducing maintenance costs and increasing reliability. However, trustworthy monitoring techniques are required to support the operation of the CBM system in tracking the condition of the bearing system; two methods are widely used: acoustic emission (AE), and vibration analysis. This work presents a novel AE wireless monitoring system (AEWMS) for rotating machinery which is able to provide a decision support feature using an intelligent approach to overcome any false alarms that may occur. It has been evaluated on an automotive bearing application, but could be adapted to monitor the behaviour of other transmission systems including those in aircraft, wind turbines, and industrial machinery. The study describes the design and operation of the online AEWMS and demonstrates its ability to detect bearing defects.

KEYWORDS: Bearing Failure, Predictive Health Monitoring, Wireless Monitoring, Acoustic Emission, 'Easy AE'

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INTRODUCTION

Damage to bearings can occur as a result of factors such as faulty mounting, faulty lubrication, foreign material or water in the bearing, inaccuracies of the shaft or housing seating, vibration, the passage of electric current, and fatigue processes [1]. Any of these factors can cause damage to the raceways or rolling elements and in many situations surface micro-cracks or even complete failure can result. The focus of the current work is to develop the capacity to detect early damage to the bearing elements due to the above factors before it progresses to final failure. However, it is important to make this process wireless and easy to accomplish, especially if it will be used on a regular basis and with more than one system. A volume of published work has described successful vibration monitoring systems, however the majority of these focus on the requirements of such systems; firstly to get a good vibration measurement and secondly to achieve the correct signal processing algorithms [20, 21, 22]. The author previously introduced a successful measuring

system for gearing systems based on vibration, acoustic emission (AE), and online oil debris analysis (ODA) [2, 3, 4, 18, 19]. This paper studies the ability to achieve a new wireless monitoring system for bearings using only one monitoring technique, AE analysis, and to perform this process remotely which could lead to generalizing the use of such systems for rotating machinery. The monitoring of AE is a powerful technique that can be applied to a range of applications involving non-destructive testing. The concept behind AE monitoring is that all solid materials reveal a degree of elasticity which allows them to spring back and release strain when the effects are removed. This release of elastic energy generates an elastic wave which propagates through the surface and can be detected as an AE event [5]. AE is defined as "a transient elastic wave generated due to a rapid release of strain energy within or on the surface of a material caused by structural fluctuation in/on solid material under mechanical or thermal stresses" [6]. The frequency range of AE signals is from 20 kHz to 1 MHz and for metallic objects is usually between 100 kHz to 300 kHz.

which can be measured by high frequency sensors (Piezoelectric sensors are the most sensitive type of AE sensors) attached to the structure's surface through a thin layer of coupling agent, such as silicon grease, oil, or glue [5]. Two types of mounting that can be used with the AE sensors; magnetic mounting and tapped hole mounting [7]. Murray et al [7] highlighted the influence of the type of sensor mounting on the sensor output. Usually with any mounting method, a pencil test is used to check the quality of the coupling or to evaluate the attenuation of the AE over the path according to the ASTM standard E976 [5].

The application of AE to health monitoring is based on the detection and analysis of acoustic waves radiating from sources such as crack initiation, crack propagation, and friction [6]. The main advantage found in using AE techniques in machinery monitoring is that less effort is required to extract the monitoring features compared to vibration analysis; however, the main disadvantages are the signal attenuation over distance and across interfaces [8] and the dependence on oil temperature during gear fault detection [9].

Several studies have focused on using AE for bearing fault detection. Cole and Bradshaw [10] looked at the use of AE RMS signal levels to diagnose problems in bearings; Johnson [11] studied the ability of AE to detect failure signatures in bearing elements and developed an ultrasonic condition-based monitoring system; and Al-Ghamd and Mba [12] studied the ability to monitor seeded defects introduced to the bearing outer race, where testing showed that the AE RMS increased when the defect size increased. Li and Li [13] successfully detected of bearing outer race seeded defects using two AE extracted features based on short-time signal processing techniques. Furthermore, Jamaludin et al [14] and Elforjani et al [15] successfully detected the damage of slow-speed rolling element bearings. The possibility of using the AE signal energy to monitor and diagnose early faults in machine condition was successfully introduced by Al-Balushi and Samanta [16]; and Thota et al [17]. The authors concluded that it was possible to detect horizontal conveyor bearing failures using AE energy level feature [17]. However, although these studies demonstrated the great advantages of using AE in bearing monitoring, they neither provided a wireless monitoring solution to avoid the use of slip rings to transmit AE signals from rotating parts, nor validated their systems on real applications. These deficiencies are remedied in this work.

DESIGN AND IMPLEMENTATION OF AN AEWMS; AN 'EASY AE' WIRELESS MONITORING SYSTEM

The 'EASY AE' is a low cost AEWMS that has been developed for this research work, and is capable of on-line monitoring, automatic measurement, and analysis. Also, any changes in the bearing condition and degradation during operation can be identified. The advantage of developing the

'EASY AE' system arises from its ability to enhance online analysis methods for AE technique to provide reliable information about the system's condition. This paper introduces the hardware and the software parts of the system including the results of the online monitoring of the bearing system.

The hardware part of the 'EASY AE' system consists of the 16-bit NI wireless data acquisition card, which can stream data up to 250 kS/s, and the Vallen ASCO-P acoustic signal conditioner unit. The AE signal is delivered by the AE sensor to the ASCO-P unit. The signal is amplified by a low noise preamplifier, and then filtered by a band-pass filter (100-300 KHz) to reject undesired frequency components. The AE signal is then rectified and a logarithmic conversion obtained to provide two outputs. The first is the AE average signal level (AE_{ASL}) using a smoothing low pass filter, and the second is the AE peak amplitude (AE_{APK}) using a peak stretcher module. Signals are then acquired continuously and transmitted to the base unit using an IEEE 802.11b/g (Wi-Fi) wireless communication interface (frequency range 2.412-2.462 GHz). The system can send the data from a range up to 30 m for indoor measurements and 100 m for outdoor operation as long as the line of sight of the wireless signal is provided. The system can also provide Ethernet cabling measurements up to a distance of 100 m. The 'EASY AE' system hardware block diagram is shown in [Figure 1](#).

The software part of the 'EASY AE' system was developed in the NI LabVIEW environment to provide continuous online system monitoring for the AE_{ASL} and AE_{APK} AE features. These features were then processed using several algorithms and logged continuously in order to build up the data history, including the real time monitoring and transient analysis monitoring. During which, blocks of 4000 discrete samples were continuously received at the base unit and analysed after scaling at 40mV/dB [5]. [Figure 2](#) illustrates the analysis, feature extraction, and data logging processes of the received batch of samples of the AE_{ASL} and AE_{APK} AE features at the base unit.

EXPERIMENTAL TEST RIG

A vehicle front axle mechanism (shown in [Figure 3](#)) has been used in this ongoing research. The mechanism comprises a front axle driven passenger car which includes wheel bearing (double row ball bearing). The mechanism is driven by the car engine through a hydrodynamic transmission. A mounting device has been manufactured to install the AE sensor at the end of the axle shaft and to clamp the 'Easy AE' system to the rotating wheel as shown in [Figures 4](#) and [5](#). After starting the engine and engaging the hydrodynamic transmission. The test is run under controlled conditions, where a wheel left is used to lift the wheel under test from the ground and the wheel speed is kept constant at 190 rpm (20 km/hr for a wheel diameter of 0.56 m) and the wheel is in a free rolling condition with no external load applied ([Figure 6](#)).