Paper: ASAT-14-182-RS

14th International Conference on
AEROSPACE SCIENCES & AVIATION TECHNOLOGY,
ASAT - 14 – May 24 - 26, 2011, Email: asat@mtc.edu.eg
Military Technical College, Kobry Elkobbah, Cairo, Egypt
Tel: +(202) 24025292 –24036138, Fax: +(202) 22621908

A New Acoustic Emission Remote Sensing System; An Experimental Validation of Automotive Wheel Bearing Condition Monitoring

Ahmed Onsy*

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 types are widely used: acoustic emission (AE), and vibration analysis. This work presents a novel AE remote sensing system (AERSS) 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 AERSS and demonstrates its ability to detect bearing defects.

Keywords: Bearing Failure, Predictive Health Monitoring, Remote Sensing, Acoustic Emission, Wireless Monitoring, 'Easy AE'.

1. 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 remote and easy to accomplish, especially if it will be used on a regular basis and with more than one system. A load of published work over the past years concluded successful vibration monitoring systems; however the majority of them spoke about the requirements of such systems to firstly get a good vibration measurement, secondly achieve a correct signal processing algorithms. The author previously introduced a successful measuring system for gearing systems based on vibration, acoustic emission (AE), and online debris analysis (ODA) [2-4].

* Egyptian Armed Forces, Email: phd_student_2006@yahoo.com .

This paper studies the ability to achieve a new remote sensing system for bearing 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 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].

Several studies have focused on using AE for bearing fault detection. Cole and Bradshaw [7] looked at the use of AE RMS signal levels to diagnose problems in bearings; Johnson [8] 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 [9] 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 [11] successfully detected of bearing outer race seeded defects using two AE extracted features based on short-time signal processing techniques. Furthermore, Jamaludin et al. [11] and Elforjani et al. [14] successful detected the damage of slow-speed rolling element bearings. Thota et al. [13] concluded that it was possible to detect horizontal conveyor bearing failures using AE energy level feature. However, although these studies demonstrated the great advantages of using AE in bearing monitoring, they neither provided a remote monitoring solution to avoid using of slip rings to transmit AE signals from rotating parts, nor validated their systems on real applications. These deficiencies are remedied in this work.

2. Design and Implementation of Remote Monitoring System for Bearings; An 'EASY AE' Monitoring System

The 'EASY AE' is a remote sensing AE system 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 robust 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 using the AE_{ASL} and AE_{APK} AE features, including the real time mode and transient analysis. Blocks of 4000 discrete samples were continuously received at the base unit and analysed after scaling at 40mV/dB [5], theses features were then processed using several algorithms and logged continuously in order to build up the data history. 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.

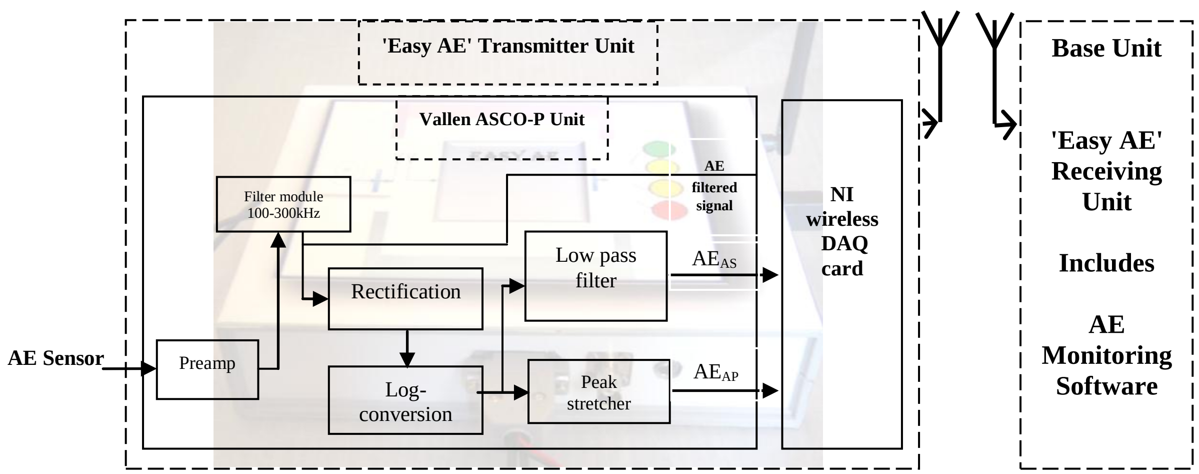

Figure 1, 'Easy AE' measurement system

3. 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 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).

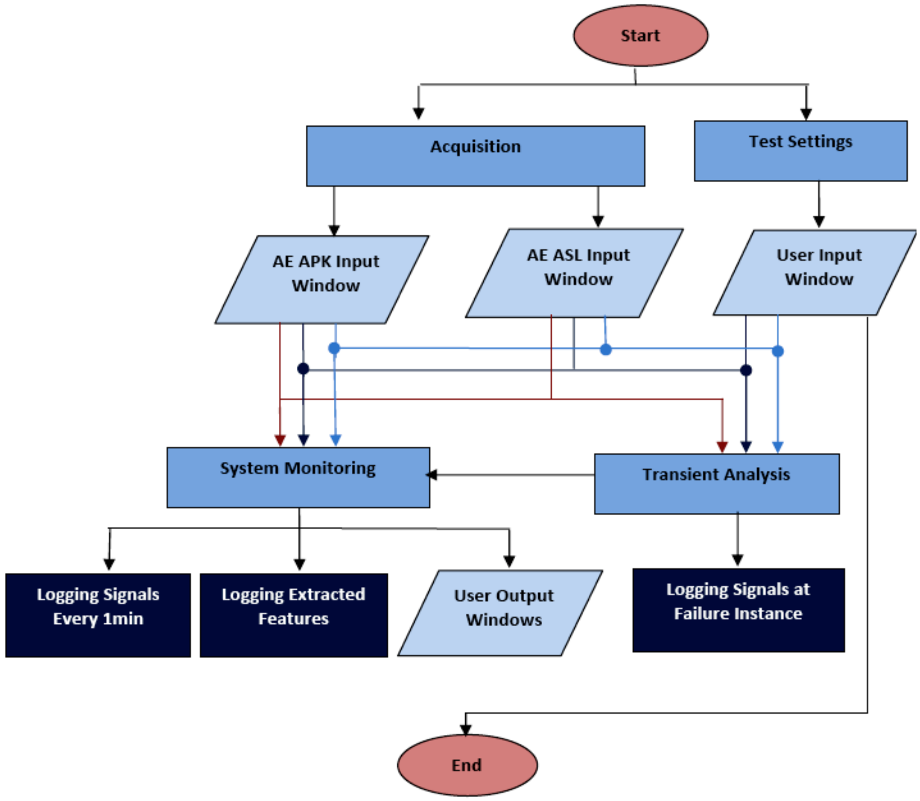

Figure 2, 'Easy AE' system analysis software

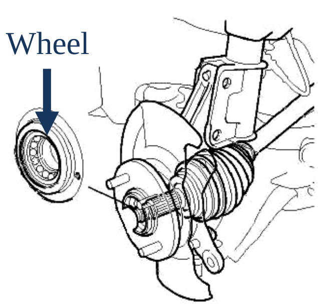

Figure 3, Front wheel bearing mechanism, [10]

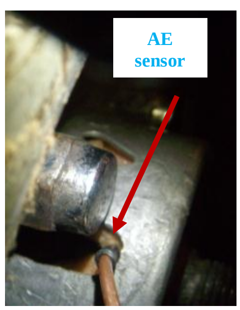

Figure 4, AE sensor installed at the end of the axle shaft

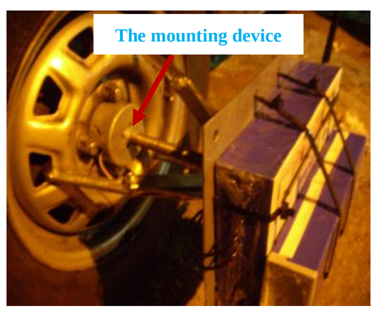

Figure 5, The mounting device used to mount the AE system on the wheel.

Figure 6, Easy AE system in operation, while the wheel is in free rolling condition

4. System Validation

The system validation comprises three tests for healthy, in-service, and faulty bearings that are working in real applications such as automotive wheel bearing. It is designed to assess the operation of the Easy AE remote sensing system in detecting bearing failures at early stage, and to investigate its ability to provide information to users about its status. The test was achieved by first measuring a faulty wheel bearing already run for more than $50x10^3$ km, using several runs for validation, and then this bearing was replaced with a new one and the same test repeated several runs. The new wheel bearing let to operate in service till it reached about $20x10^3$ km of its service life, then it retested after which. All the three tested were carried out at the same wheel speed (190 rpm), and the AE_{ASL} system output was selected to be the comparison feature.

During the test of the new bearing, the system computed the AE_{ASL} feature to less than 25dB, whereupon the AE_{ASL} reached 55.5dB during testing of the faulty bearing. Also, the AE_{ASL} signature of the new bearing was compared to the in-service bearing at the same running conditions, and it was found that the AE_{ASL} increased from about 25dB to 33.5dB as shown in Figures 6 and 7. By inspecting the faulty bearing raceways, it is evident that this increase of the AE_{ASL} feature of about 20dB is attributed to the severe wear found in the outer raceway, occurred in two locations: the first is macro-pitting in the middle of the outer raceway, and the second is uneven wear at both sides of the bearing outer raceway, as shown in Figure 8.

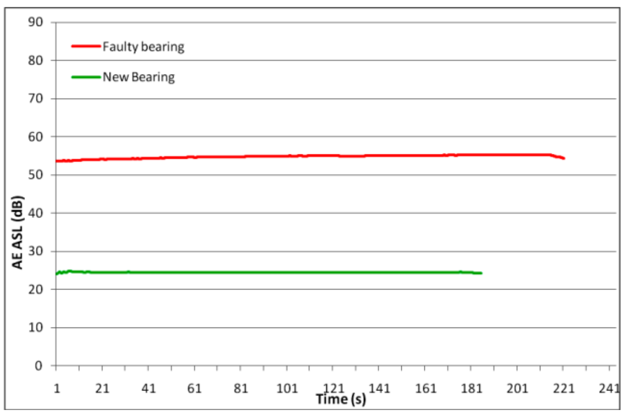

Figure 6, Monitoring the AE_{ASL} (dB) during the testing of new and faulty bearing using the 'Easy AE system.

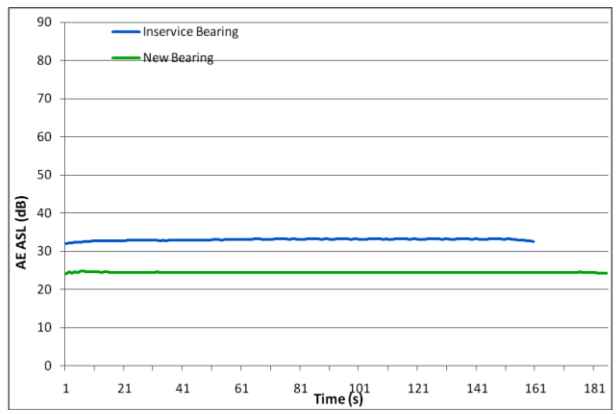

Figure 7, Monitoring the AE_{ASL} (dB) during testing of new and in-service bearing using the 'Easy AE 'system.

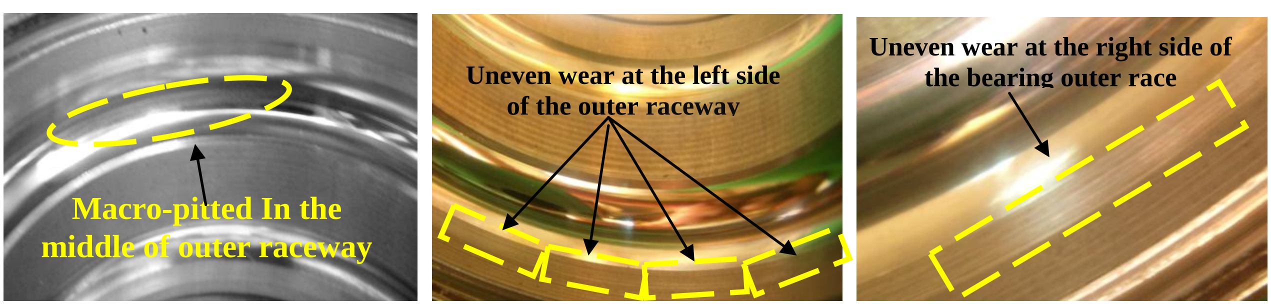

Figure 8, Faulty bearing outer race

Conclusions

The study has presented a new cost-effective acoustic emission remote sensing system that was able to detect different conditions of wheel bearings and clearly identify its condition using only one AE sensor placed on the drive axle shaft. The AE average signal level was selected to indicate the condition of the bearings. The change in the measured AE_{ASL} feature was successfully correlated to the type of wear failure found. The type of failures identified can be considered as a common failure in most bearings, and its monitoring is of main interest for many applications. The system solved a major problem for application those sensing points are far from acquisition and analysis point. The 'EASY AE' monitoring system has been experimentally validated on an automotive application. The prognostic information provided by the system was considered sufficiently accurate and demonstrated the robustness of the information provided by the system. The system is being developed for use on rotating machinery, but can be adapted for other applications such as structural monitoring. Further publication will follow to discuss the software and the intelligent part of the system. Also, shows the system results during the evaluation of the progression of failure.

References

[1] SKF (1983) Bearing Maintenance and Replacement Guide Catalogue 3600 E.

[2] ONSY, A., BICKER, R., SHAW, B. A., ROWLAND, C. W. & KENT, T. (2008b) Monitoring Bending Fatigue Failure in Helical Gears Using Acoustic Emission, Vibration, and On-Line Oil Debris Analysis: A Comparative Study. *Proceedings of the Fifth International Conference on Condition Monitoring & Machinery Failure Prevention Technologies,* UK, Edinburgh, 1108-1118.

[3] ONSY, A., BICKER, R., SHAW, B. A., ROWLAND, C. W. & KENT, T. (2009) Intelligent Health Monitoring Of Power Transmission Systems; An Experimental Validation. *Proceedings of the 2009 Conference of the Society for Machinery Failure Prevention Technology,* USA, Dayton, Ohio, 499-518.

[4] ONSY, A., BICKER, R., SHAW, B. A., (2010) Intelligent Diagnostic Health Management Of Power Transmission Systems: An Experimental Validation. *International Journal of COMADEM,* Vol.13 (2) pp. 46-58, ISSN 1363-7681.

[5] VALLEN–SYSTEM GmbH (2004) Acoustic Emission Signal Conditioner ASCOP-P User Manual, man402E.

[6] TAN, C.K., IRVING, P. & MBA, D. (2005) Diagnostics and Prognostics with Acoustic Emission, Vibration and Spectrometric Oil Analysis For Spur Gears: A Comparative Study. *Insight: Non-Destructive Testing and Condition Monitoring,* 47, 478-480.

[7] COLE, P. & BRADSHAW, T. (2004) AE Signals From Process Monitoring. *Physical Acoustics Ltd, DGZfP-Proceedings BB 90-CD, Lecture 36.*

[8] JOHNSON, J.E. (2005) *Identifying Common Ultrasonic Predictive Failure Signatures in Bearing Elements for the Development of an Automated Condition Based Ultrasonic Monitoring Controller*, M.Sc. Thesis, East Tennessee State University, USA

[9] AL-GHAMD, A.M. & MBA, D. (2006) A Comparative Experimental Study on the Use of Acoustic Emission and Vibration Analysis for Bearing Defect Identification and Estimation of Defect Size. *Mechanical Systems and Signal Processing,* 20, 1537-1571.

[10] HONDA MOTORS Co. (2005) Honda Civic Front Knuckle/Hub/Wheel Bearing Replacement Technical Note.

[11] LI, C. J. & LI, S.Y (1995) Acoustic emission analysis for bearing condition monitoring. *Wear* 185, 67-74.
[12] JAMALUDIN, N., MBA, D., & BANNISTER, R. H. (2001) Condition monitoring of slow-speed rolling element bearings using stress waves. Proc Instn Mech Engrs Vol 215 Part E.
[13] THOTA, S., VANKAMAMIDI, S., MUTHIREDDY, R., WAYNE, S. & QI, G. (2008) Detection and Analysis of Horizontal Conveyor Bearing Failures Using Acoustic Emission Technique. AEWG-51 & International Symposium on AE, Memphis, USA.
[14] ELFORJANI, M. & MBA, D. Acoustic Emissions Observed from a Naturally Degrading Slow Speed Bearing and Shaft COMADEM 2010.