On the use of Acoustic Emission as an aid to understanding of lubricated contacts in tribological systems

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1. Introduction

Acoustic Emission (AE) has been long established as a sensitive tool for detecting damage and failure in engineering structures, where sensors are used to detect the elastic stress waves originating from crack growth, impact damage, plastic deformation and other failure mechanisms [1]. It is a useful tool capable of detecting failure at an earlier stage than more conventional monitoring techniques, and offers much potential insight into conditions in tribological contacts [2,3].
This paper examines the sensitivity of AE to mixed lubrication conditions, with a view to evaluating the suitability of the technique for monitoring heavily loaded concentrated contacts in power transmission gear systems where roughness scale fatigue phenomena such as micropitting are a problem. It then discusses the results of using AE to monitor bearings, highlighting some of the challenges which must be overcome to enable its adoption as a condition monitoring tool.

2. Disk machine experiments in mixed lubrication conditions

A carefully controlled set of experiments were conducted using a power-recirculating twin disc test rig designed to investigate EHL contacts under typical gear conditions, using a mineral-based fully formulated gear oil [4]. Contact conditions (kinematics, load and lubricant temperature) were controlled in order to operate at a range of lubrication conditions from full film elastohydrodynamic lubrication (specific film thickness or lambda ratio > 3) to heavily mixed lubrication conditions (lambda ratio << 1). The test rig used axially-ground test disks with an Ra of approximately 0.4 μm. The approximately perpendicular orientation of roughness to the rolling/sliding direction was designed to mimic the conditions found within gear contacts. The rig was fitted with Acoustic Emission sensors, one mounted on the faster-rotating disk, and the other mounted close to the side face of the same disk, with a jet of oil providing acoustic coupling. An experiment was conducted where the rig was run at a fixed slide/roll ratio of 0.5, and a maximum Hertzian contact pressure of 1.2 GPa. The disk speeds and lubricant supply temperatures were varied in order to control the specific film thickness, with five particular fast disk speeds from 300 to 2000 rpm used.
The raw AE signals were band-passed in the region 150 to 300 kHz, as initial examination of the signals showed that AE activity in this frequency range varied with specific film thickness. Figure 1 shows the amplitude of the AE within this range.

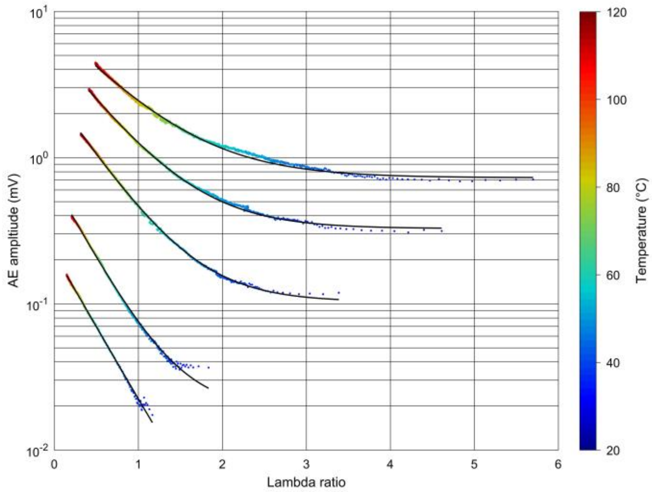

Figure 1: *Band-passed AE signals collected at five different fast disk operating speeds (from bottom, 300, 500, 1000, 1500, 2000 rpm), shown as a function of specific film thickness*

Each line within the figure shows data collected at a particular speed, with the lowest speeds producing the lowest AE amplitudes. There is a clear dependence of the AE within this frequency range on contact conditions – as the lambda ratio is decreased below 3, there is a significant increase in the AE signals. However, at full film conditions, the AE levels appear to reach asymptotic values. Experiments with superfinished surfaces (Ra < 0.1 μm) showed much reduced AE activity in this frequency range under the same operating conditions. This demonstrates that these signals are generated by asperity interactions within the contact occurring under mixed lubrication conditions. As the asperities pass through the EHL contact, they are cyclically loaded and unloaded many times during their traverse of the contact. This produces a variation in sub-surface strain energy within the contact, leading to the generation of Acoustic Emission. The technique also showed much promise as a tool to study contact levels during the running-in process and subsequent micropitting failure of the surfaces [5].

3. Experiments with Rolling Element bearings

A second test rig, shown in Figure 2, was capable of loading a 20mm bore cylindrical roller bearing up to and beyond its rated load, and was used to investigate the generated of AE within rolling element bearings.

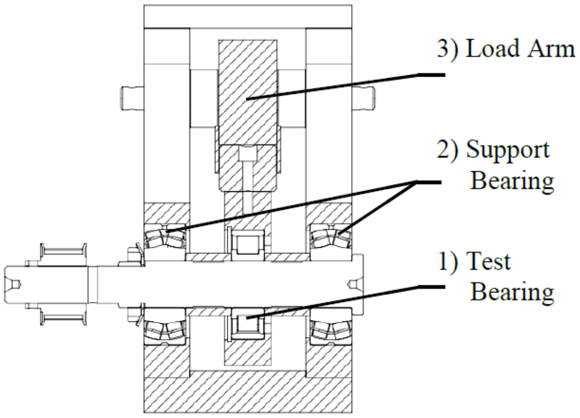

Figure 2: *Schematic of bearing rig test head*

Initial work with the test rig concentrated on the identification of seeded outer-race defects using Acoustic Emission [6]. Further work to characterise the effects of bearing operating condition on the generation of AE during normal operation demonstrated the sensitivity of AE to the bearing speed and load [7]. Other workers [8,9] have shown the application of AE to bearing monitoring, with many workers using seeded defects or grossly overloaded test conditions.

A life test was performed, with the bearing initially loaded at 3.24 kN and rotating at 5980 rpm. After 280 hours of operation, the load was increased to 5.2 kN, and then at 1680 hours the load was further increased to 6.2 kN. The speed remained constant throughout the test, which was stopped after a total of 110 days. Figure 3 shows the variation of RMS AE signals recorded by a sensor attached to the test bearing housing, over the duration of the test. Figure 3 also shows the fatigue damage found on the surface of one of the bearing rollers when inspected after the test. It can be seen that, at approximately 79 days, there is a sharp increase in the AE generated by the bearing, thought to be associated with the formation of the roller damage. However, analysis of the frequency content of the signals showed the RMS increase to be caused by widespread increase of energy levels within the signal rather than by the introduction of new frequencies which may be associated with the damage. This was different to previous work [6, 7] which showed, under more accelerated test conditions, clear influence of defects and failures on the frequency content of the signal.

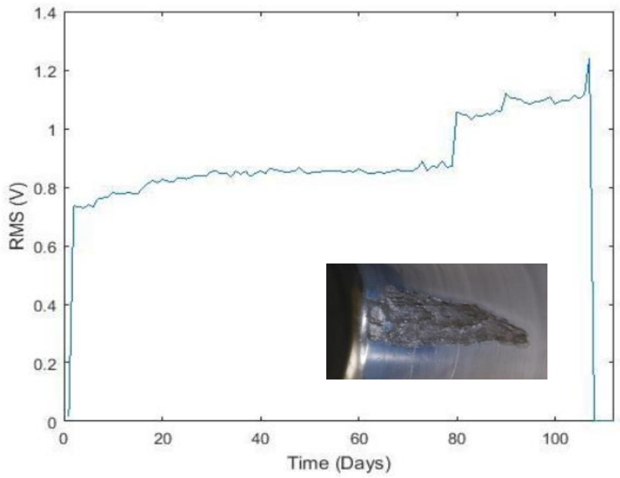

Figure 3: *RMS AE levels during bearing life test*

The authors' work on bearing monitoring with AE clearly demonstrates the difficulties in extrapolating from seeded defect or accelerated life tests, to more realistic operating conditions.

4. Conclusions

- A range of tests have been conducted using disk machine and bearing tests to investigate the sensitivity of AE to operating conditions and failure in tribological contacts.
- It was possible to identify the frequency content of the AE signal associated with asperity interaction in mixed lubrication contacts, with AE responding to a reduction in the specific film thickness.
- AE was also used to monitor bearing tests, with an extensive bearing life test under realistic operating conditions highlighting the ability of AE to detect damage within the bearing.

5. References

[1] Hase *et al.*, *Wear*, 292-293, 144-150, 2012.
[2] Tan & Mba, *J. Nondestruct. Eval.*, 24(1), 11-28, 2005
[3] Vicuna, *Applied Acoustics*, 77, 150-158, 2014.
[4] Clarke *et al.*, *Trib. Int.*, 93, 709-716, 2016.
[5] Hutt, Clarke, Evans, *Trib. Int.*, 2017 In Press, DOI: 10.1016/j.triboint.2017.11.011
[6] Cockerill *et al.*, *J. Phys. Conf. Ser.*, 628, 012074
[7] Cockerill *et al.*, *J. Eng. Tribol.*, 230, 1377-1388, 2016.
[8] Al-Ghamd & Mba, *Mechanical Systems & Signal Processing*, 20(7), 1537-1571, 2006.
[9] He *et al.*, *J. Vibration & Acoustics*, 131, 061012-1, 2009.