Use of Acoustic Emission to Determine the Lubrication Conditions in Simulated Gear Contacts

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Abstract

This research investigates the use of Acoustic Emission (AE) measurement to monitor the lubrication conditions in simulated gear tooth contacts. It is experimentally shown that a strong correlation between lambda value (an indicator of the lubrication regime) and the AE exists, and that for a constant speed a simple empirical relationship exists between them. This benefits those seeking to use AE for condition monitoring of gears.

Introduction

Gear tooth contacts often operate in a mixed lubrication regime. In this, the load is carried partly by a lubricant and partly by direct asperity interaction between opposing surfaces. The lubrication regime can be characterised by the lambda ratio: the ratio of the equivalent smooth surface film thickness to the RMS surface roughness. This value is an important indicator of the likely wear rate and possible failure of two surfaces in contact. A practical method by which it can be monitored in critical components is sought, AE measurement may offer this. AE are transient high frequency elastic waves generated by the deformation of a material. Researchers have shown that asperity interactions in moving contacts are a significant source of AE [1]. However, the experiments have tended to be highly idealised, such as pin on disk tests, or involve only coarse comparisons between 'healthy' and 'damaged' surfaces [2]. This research explores, in detail, the correlation between the AE and the lambda value for a contact simulating that of production gears.

Test Method

Rig. Experimental measurements were made on a power recirculating twin disk rig. On this, an elliptical contact is made by radially loading two crowned disks of identical geometry. The ellipse has a ratio of four to one and the minor axis is aligned with the slide / roll direction. The disks are axially ground to produce a finish with a lay and roughness equivalent to that of production gears. The contact is lubricated with an extreme pressure oil. The oil temperature, load, rotational speed and slide to roll ratio of the disks can be varied to produce different lubrication conditions. The rig allows for in-situ, repeat position, profile measurements using a portable Taylor Hobson profilometer. The disk temperatures are measured using thermocouples embedded 3 mm under the contact surface. Two PAC Pico transducers measure the AE from the contact. One, the rotating sensor, is clamped to one side of the fast disk and is connected to the acquisition system using a slip ring. The other, the static sensor, is fixed next to, but not touching the other side of the fast disk, the sensor is coupled to the disk by an oil film and is connected directly to the acquisition system.

Test Procedure. For this work a quasi-stable surface roughness was used. This was achieved by running-in the test disks under a more severe lubrication regime than was subsequently tested. The contact load was kept constant at 1460 N (a maximum Hertzian contact pressure of 1.2 GPa), as was the slide / roll ratio at 0.5 (3 slow disk revolutions for every 5 of the fast disk). The lubrication conditions were modified by variation of rotational speed and oil temperature. Five fast disk speeds were tested: 300, 500, 1000, 1500 and 2000 rpm. For each, the oil temperature was slowly increased from ambient to over 100°C. The AE were sampled every 25th fast disk revolution for a period of one revolution. The surface roughness of each disk was measured on the centre line at three positions in-between each of the five speeds tested. The lambda value was calculated using the CDDT formula [3].

Results and Discussion

Figure 1 shows the results from the RMS roughness measurements. There is no significant change in the mean values over the test series. This indicates that there was minimal surface modification after the initial run-in and validates the use of a constant roughness value in the lambda calculation.

Figure 2 shows the AE from the rotating sensor vs the lambda ratio for each of the five speeds tested. The AE signal has been band-passed between 150 and 300 kHz as this range was found to show the greatest sensitivity to changes in the lubrication conditions. For each speed it can be seen that as the temperature increases the lambda value decreases. This is due to increased asperity contact as oil viscosity, and consequently the film thickness, decreases. As the lambda value decreases the AE amplitude increases approximately exponentially (note the log-log scale of Figure 2). For each speed tested the AE is sensitive to the lambda ratio and a simple empirical relationship exists. The effect of speed on AE, as demonstrated by other researchers [3], is clearly evident: Higher speeds result in higher amplitude AE independent of the lambda ratio. Further analyses of these results have explored the possibility of an empirical relationship between AE, lambda and speed.

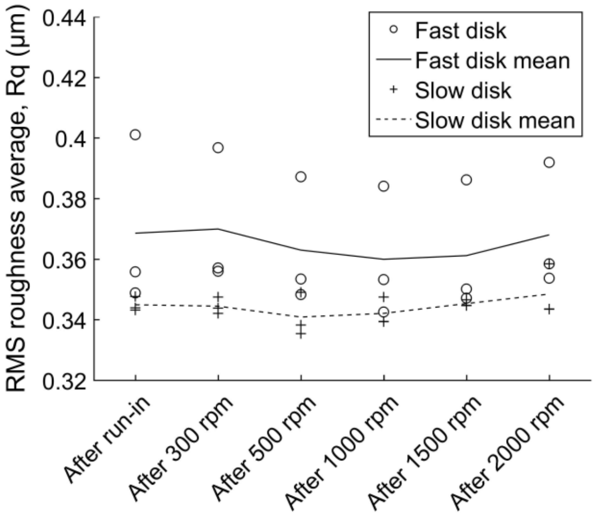

Figure 1. Disk roughness after initial run-in and each speed subsequently tested.

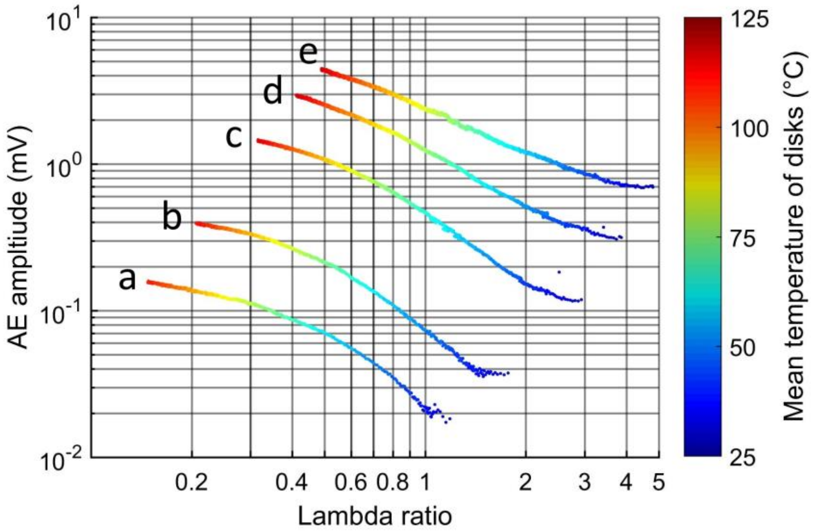

Figure 2. AE from the rotating sensor band-passed between 150 - 300 kHz vs. the lambda ratio. Fast disk speed: a) 300 rpm. b) 500 rpm, c) 1000 rpm, d) 1500 rpm, e) 2000 rpm.

Conclusion

This research has shown that, for a simulated gear tooth contact with a stable surface roughness, the AE is dependent on the lambda ratio. Furthermore, a simple empirical relationship exists for constant speed applications. This work will provide a useful starting point for developing a more general relationship between AE and the contact conditions.

References

[1] Fan, Y., Gu, F. and Ball, A., 2010. Modelling acoustic emissions generated by sliding friction. Wear, 268(5), pp.811-815.

[2] Eftekharnejad, B. and Mba, D., 2009. Seeded fault detection on helical gears with acoustic emission. Applied Acoustics, 70(4), pp.547-555.

[3] Chittenden, R.J., Dowson, D., Dunn, J.F. and Taylor, C.M., 1985, February. A theoretical analysis of the isothermal elastohydrodynamic lubrication of concentrated contacts. II. General Case, with lubricant entrainment along either principal axis of the Hertzian contact ellipse or at some intermediate angle. In Proceedings of the Royal Society of London A: Mathematical, Physical and Engineering Sciences (Vol. 397, No. 1813, pp. 271-294).