Damage detection of a PTFE liner matrix composite through the use of Acoustic Emission.

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Abstract: Self-lubricating bearings are widely used within the aerospace industry and are commonly found in the pitch control assembly of rotorcraft and, as such, are critical parts due to their importance within the system. The dry lubricant present within these bearings acts as a consumable material which occupies the troughs of the inner race therefore forming a smooth sliding surface between inner and outer race via the deposition of third body particles. For this research the liner material is in the form of a woven composite, consisting of Polytetrafluoroethylene (PTFE) as the dry-lubricant and glass fibres as the reinforcing material, cured in a resin matrix. A cylinder-on-flat oscillating wear test bench developed within Cardiff University allowed for the gathering of physical data including temperature and Acoustic Emission (AE) signals during an accelerated wear test of the liner material. A radial load of 2.5 kN and oscillation frequency of 5Hz were applied to replicate typical operating conditions within a pitch control system. Frequency analysis techniques were carried out on the AE data, successfully identifying the transition from healthy contact into the failure region.

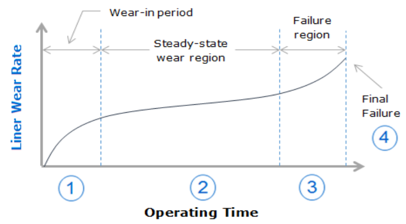

Figure 1 – Three stages of wear during the lifetime operation of a dry-lubricated plain journal bearing

Introduction: Self-lubricating bearings have a finite life wholly dependent on the quantity of dry-lubricant available within the contact zone **[1]**. Both contamination of the bearing and extreme environmental conditions cause these types of bearings to cease functioning in the absence of the lubricating agent (PTFE); when metal to metal contact is reached. Fig. 1, explains the stages of wear of self-lubricating bearings from initialisation to failure. Currently the aerospace industry relies on regular service/inspection intervals to determine the condition of the bearings. It is hoped that a robust damage detection technique can be developed utilising AE in combination with temperature readings in order to confidently detect damage. The AE phenomenon is described as the release of transient elastic waves when a solid releases strain energy from within its internal structure when subjected to external stresses. Such changes are said to be caused by phenomenon such as crack formation and propagation, plastic deformation due to subjected loads, and microstructural changes in certain materials **[2]**. In the case of damage, these waves travel through the liner matrix and metal components of the system and result in a surface displacement which can be recorded using piezoelectric sensors **[3]**.

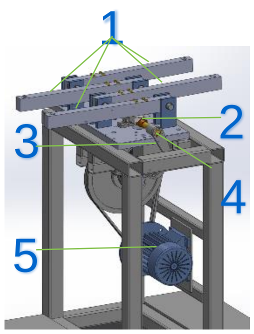

Figure 2 – Isometric view of test rig showing: 1) Loading arms 2) Sample holders 3) Counterface shaft 4) Oscillation drive crank 5) Electric motor

Experimental Procedure: In order to gather useful data for the failure diagnostics of the liner material, an experiment was set-up on a Cardiff University-developed test bench. The particular test bench does not facilitate whole bearings, but instead focuses on coupon testing. The coupons consist of a rectangular metal backing onto which the liner matrix is adhesively bonded and cured. In turn the flat sample comes into contact with a cylindrical heat-treated and super-finished steel counterface which provides a line contact between sample and counterface, which results in accelerated wear due to the contact being less conformal than the real bearing contact. To provide the reciprocating motion required in order to simulate flight conditions, the counterface was located on a main shaft which reciprocates with the aid of a crank arm driven by an electric motor. The contact pressure at the line contact is provided by suspending weights which are attached to the arm where the samples are located as shown in Fig. 2. The SAE Aerospace Standard 81819 was consulted when determining the oscillatory motion, reciprocation angle and load. A 5Hz oscillatory motion of reciprocating angle ±10° must be used, along with a contact pressure between 10-20 MPa. For the detection of AE signals a piezoelectric R15S sensor was used in series with a 40db pre-amplifier. The sensor location was chosen by conducting an attenuation study from sample to sensor using a Hsu-Nielsen source as a pseudo damage mechanism, indicated by the letter 'S' in Fig. 3. The sensor location with the highest amplitude reading was chosen a nd this is represented by sensor location (3) in Fig. 3. An adhesive Loctite silicone gel was used for bonding the sensor onto the preferred location, and to provide effective coupling between sensor and surface. For temperature and wear measurements, type J thermocouples and LVDTs were used respectively. Due to the versatility of the test bench, more than one sample can be tested at a time and therefore for the purpose of this experiment, two samples were under test simultaneously.

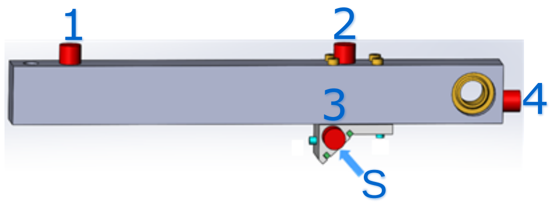

Figure 3 – Sensor locations investigated during attenuation test

Experimental Results: Via the use of a Fast Fourier Transform on the raw waveforms, the data was transposed into the frequency domain in order to detect patterns which could be viewed as signs of damage. A general analysis was carried out over the whole frequency range of the Mistras Physical Acoustics (MPA) R15S sensor and found that the areas of interest lay in the lower frequency range between 0 and 200 kHz. Fig. 4, shows how the total power within 50 kHz frequency bandwidths over this range changes as the wear test enters a destructive region.

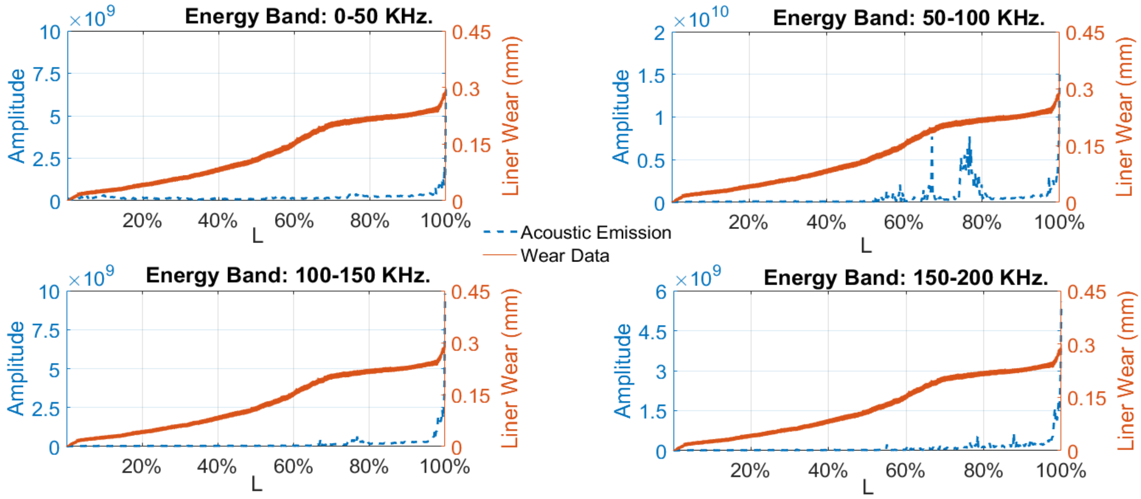

Fig. 4 – Power & Wear Depth vs Liner life 'L' of 50 kHz bands

The main area of focus regarding the AE data is in the region of transition of the liner matrix, from the PTFE to the glass fibre region, where glass fibre breakage occurs. In a typical liner this occurs when the wear depth reaches a value of approximately 0.2 mm. It is therefore interesting to note that as this region is reached, the power amplitude of the AE data is greatly increased due to an increase in energy being released and this could potentially be linked to structural damage of the liner matrix. Using this technique, a non-intrusive prognostic method of damage detection is possible regarding self-lubricating bearings.

[1]. Lancaster, J. K., "Accelerated wear testing of PTFE composite bearing materials" Technical Report 78046, pp. 1-16, 1978.
[2]. Huang, M. et al., "Using acoustic emission in fatigue and fracture materials research" JOM, vol 50, pp. 11, 1998.
[3]. M. Weavers, "Listening to the sound of materials:acoustic emission for the analysis of material behaviour" NDT&E International, vol. 30, pp. 99-106, 1997.