Damage detection of a composite bearing liner using Acoustic Emission.

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Abstract: Self-lubricating bearings are widely used within the aerospace industry and are commonly found, for example, in the pitch control assembly of a rotorcraft. Due to their high importance the components located within such systems are marked as critical parts and therefore the monitoring of their current health state is of great value. The bearing liner which provides the sliding surface between inner and outer races is a Polytetrafluoroethylene (PTFE) and glass fibre woven composite. Low friction coefficients are achieved via the deposition of PTFE third-body particles, which occupy the valley-features at the roughness scale on the non-conformal sliding surfaces. As these third-bodies form, the woven matrix composite surface layers containing PTFE are consumed up to a point where only the structural reinforcing glass fibres are present, resulting in a higher coefficient of friction and accelerating the wear process. 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.

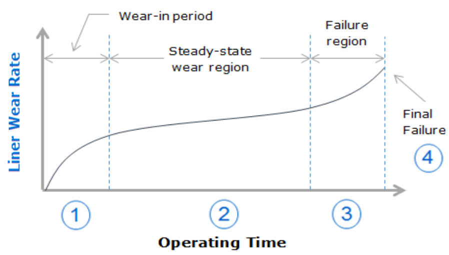

Figure 1 - Three stages of wear during the lifetime operation of a dry-lubricated plain journal bearing.

Introduction: Self-lubricating bearings have a finite life wholly dependent on the quantity of dry-lubricant available within the contact zone **[1]**. Contamination of the bearing's sliding surface and extreme environmental conditions cause these types of bearings to function inefficiently, leading to a fast consumption of the PTFE composite, since a transfer layer may never be achieved and the wear process may in turn never reach equilibrium. Fig. 1 shows the typical stages of wear of self-lubricating bearings from installation to failure. Currently the aerospace industry relies on regular service/inspection intervals to estimate the current health state of the bearings. The aims of this research is to develop a robust damage detection technique utilising AE in combination with temperature readings in order to confidently detect damage. AE 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 caused by phenomena 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]**.

Experimental Procedure: To allow the gathering of useful data within a practical frame, a test rig with accelerated wear conditions had to be developed. The concept had to combine the features of fast data gathering with repeatability and reliability and was achieved by the use of coupon testing instead of whole bearing tests. 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 steel counterface which is heat-treated and super-finished to replicate the bearing inner-ring. The resulting line contact leads to 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

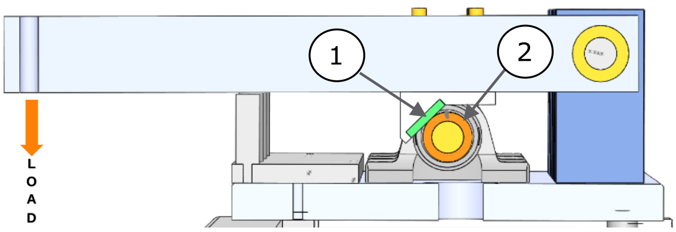

Figure 2 - Side View of test arm. (1) Composite Sample, (2) Reciprocating Counterface.

counterface was driven via a crank mechanism by an electric motor. The contact pressure at the line contact is provided by suspending weights from the loading arm to which the sample is attached as shown in Fig. 2. The test conditions were based on the SAE Aerospace Standard 81819which requires a 5Hz oscillatory motion of reciprocating angle ±10°, 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 determined by conducting an attenuation study from sample to sensor using a Hsu-Nielsen source as a pseudo damage mechanism. The sensor location with the highest amplitude reading was chosen. 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, four samples were under test simultaneously.

Experimental Results: Via the use of a Fast Fourier Transform on the raw waveforms (each 1 s long), the data was transposed into the frequency domain in order to investigate the relationship between signal frequency content and wear. 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 AE activity lay in the lower frequency range between 0 and 250 kHz.

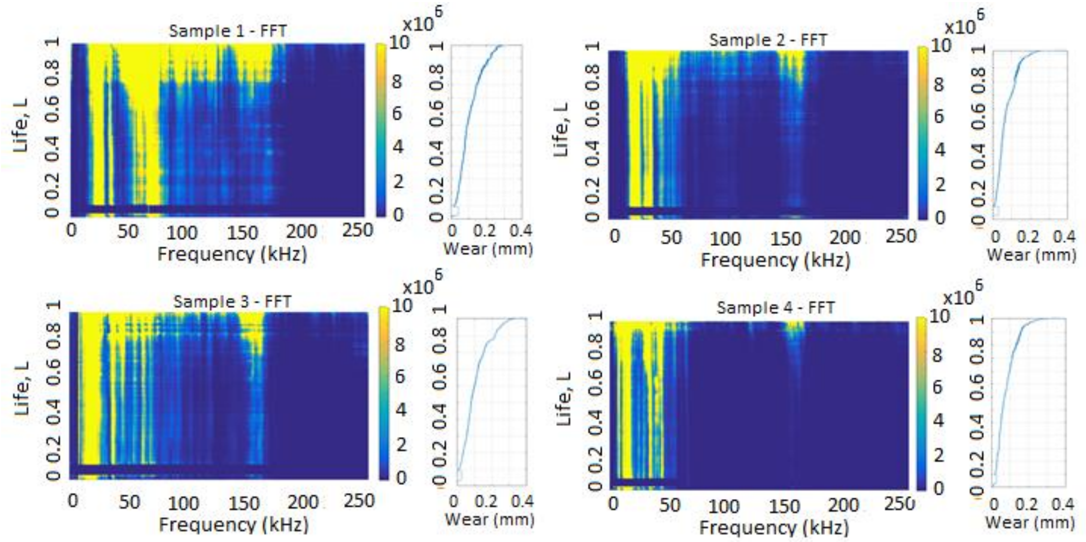

Figure 3 - FFT of Samples 1-4

It can be seen from Figure 3 that there exists a strong relationship between the wear depth (or wear stage) of the liner material and the energy amplitudes recorded throughou the test itself. As the wear depth reaches approximately 0.2mm, the structure of the self-lubricating composite liner is such that the glass fibre rich region starting to come into contact with the counterface. During this period it is thought that the cracking of the glass fibres causes these high energy bands to occur along with wider broadbands seen in the 150-250 kHz region. Currently the aerospace industry replaces bearings at around 0.125mm wear depth in order to avoid unwanted maintenance intervals. By using AE signal procssing techiques such as the ones described above to detect the transition to end of life wear, this wear depth can be potentially increased up to 0.2mm which will allow the bearings to increase their safe-flying lifetime by a further 30%. Further tests have been planned using a simplified pin on disk rig to validate fully the relationship between wear depth and AE energy production.

[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.