DYNAMIC HEALTH MONITORING OF METAL ON METAL HIP PROSTHESES USING ACOUSTIC EMISSION

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Abstract

Hip joint replacement enters a new era of fitments for younger people and the survival time of the joints are forecasted to increase. The main advances are the reintroduction of the improved metal on metal hip replacement and resurfacing techniques to avoid stress shielding. This combination is now competing for the gold standard achieved by the Charnley's low-friction arthroplasty device (stainless steel on polymer). Wear is one of the major factors that determine the life span of reciprocating surfaces. Acoustic Emission (AE) is a technique that may help to understand what the contributing factors are that may improve the survival times of the joints. This paper shows the initial investigation of the AE responses, obtained from the final stages of the life cycle testing of the **M**etal **o**n **M**etal **Hi**p **P**rostheses (MOMHIP) on a five station hip simulator. The results show that the real time AE monitoring over a short period during the final phase of a 3 million wear cycle correlated with post surface topography and volumetric changes of the MOMHIP's.

Introduction

The present established method of estimating the life span of a hip replacement joint is by a hip simulator rig [1] The walking gait and its forces [2] are simulated and fatigued by typically 3 million cycles, whilst weighing and measuring the joint every 0.5 million cycles. Also the coefficient of friction of one joint is measured during the fatigue test. The mode of lubrication in the hip joint can then be indicated from a Stribeck diagram, by plotting the measured friction value against the Sommerfeld dimensionless parameter (x axis), see figure 5

The mode of lubrication plays an important role in the wear characteristics of the hip joint

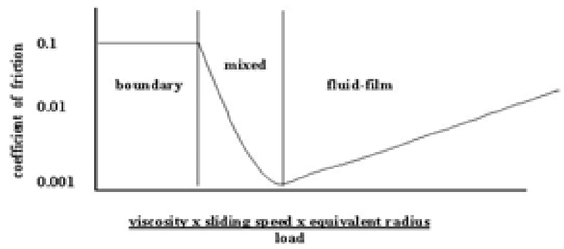

Figure 5 Stribeck diagram

Operating in the boundary lubrication mode i.e. with no pressure built up in the lubricant, the load is carried by the surface asperities of the bearing's ball and cup. Operating the hip joint in the boundary region will produce the largest wear condition. For zero wear the joint interface should run in the fluid-film or hydrodynamic lubrication region, but this would require continuous high sliding velocity as present in engine journal bearings. It is generally accepted that the hip joint will run in the mixed lubrication region where the load is carried by the lubricant and the interacting asperities. After the initial bedding in period there may a portion of the gait cycle when the joint operates in the fluid-film lubrication region. Debris from the fallout of the damaged asperities is a secondary cause of wear as the debris contaminates the lubricant.

AE is a passive technique i.e. it detects stress waves from a material or structure as a result of the forces applied to the material or structure. Piezo-electric sensor attached to the surface of the material or structure convert the mechanical energy into electrical energy for graphical interpretation of the stress waves. The stress waves can be divided into two frequency bands to emphasise the difference between vibration and AE monitoring. Vibration sources, e.g. impact activates of a roller bearing can produce a signal frequency of between 20 to 100kHz (below 20kHz the frequency is termed audio) This signal is a mechanical response of the bearing's cage to the impact of the balls, whilst AE from a crack front is the materials response to the strain energy applied to the structure. An AE's signal frequency response from a plastic deformation source will extend above the 100kHz. The more brittle the mechanism, the higher frequency response it will have. The upper level of the AE frequency response is in the region of 1MHz. Also the attenuation properties of the material increase with frequency, this effect will restrict the distance the stress wave can travel through the material to the AE sensor.

Applications where vibration/AE signals are monitored and utilised in industry are a) machine health monitoring of bearings in motors, pumps and transport systems b) abrasion signals fed to a closed control loop of a grinding machine c) sliding/contact activity for the production testing of computer hard discs d) tool tip wear.

Miettinen [3] showed that in monitoring rolling bearings, when the rotational speed is doubled the AE pulse rate rises about two times as much as the AE level when the bearing load is doubled. It would be normal to see an increase in activity (either vibration or AE) in proportion to the speed but it is not explained how the proportion can be compared to AE v load. Also [3] showed that the influence of the % of contaminants on the AE signal was apparent, although the size and hardness was an influencing factor.

A simple resistivity technique was used by Smith [4] to detect surface contact or separation in a lubrication study, although the actual lubrication regime suggested was derived from the lambda ratio (lubricating film thickness to surface roughness). The other part of the study [4] confirmed that larger the size of the diameter resulted in a better regime of lubrication and hence a lower wear rate.

AE was shown by Mechefske [5] to have a systematic relationship with the wear rate on a tribometer with a steel ball sliding on a steel disc. An anti wear additive reduced the AE activity.

The aims of the research is to correlate the AE activity to the wear mechanisms of metal on metal hip joints when operating on a hip simulator and to determine the lubrication regime in real time by AE techniques.

Experiments

The position of the sensors on the five station wear rig is shown in figure 1

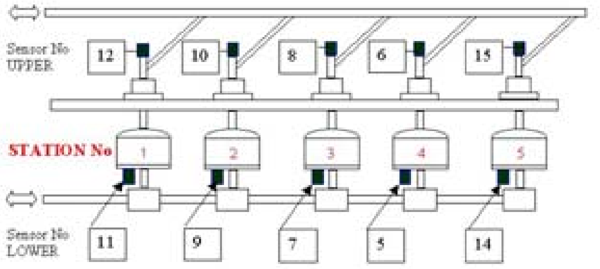

Figure 1 Showing sensor position on upper and lower sections on the 5 station wear rig

The 15 channel AE equipment model AMSY4 and AEP4 40dB pre-amplifiers were manufactured by Vallen GmbH and the sensors P15 by Pancom. The P15 sensor's are resonant at 150kHz and the AMSY4's bandwidth filter is 100 to 850kHz

Attenuation trials showed that the transmission of the signal between the upper shaft (passing through a roller bearing) to the MOMHIP joint was inhibited by >50dB. The majority of this attenuation was due to the polypropylene support coupler see figure 2.

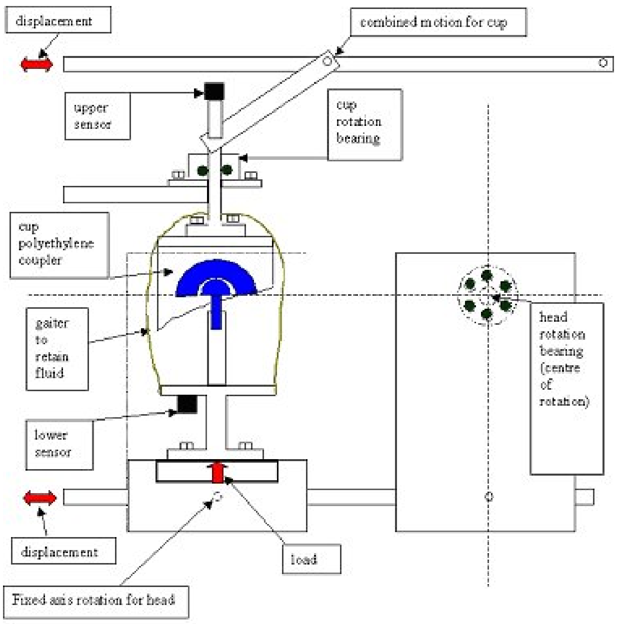

Figure 2 Showing cross section of arthroplasty of the wear rig

Although this high attenuation rules out linear location of the source of the signal its does in fact isolate the upper and lower sensors to provide zonal discrimination. Therefore the lower sensor would not detect any noise generated by the upper roller bearing due to the attenuation across the MOMHIP's polypropylene cup support. Figure 3 shows a snap shot over 200 cycles of the wear rig by the sensors on the lower section of the rig. The activity at station 2 distinctively shows a multi-mechanisms pattern as compared to the other stations. Further magnification of the time period to 2 cycles in figure 4 with gait cycle overlaid, shows that station 2 has two repeating signals of 57 and 66 dB amplitude, separated by 50mS at each cycle (of period of 0.9 second = gait cycle). This activity could be indicative of some extraordinary repetitive mechanism affecting the wear on the ball joint. This observation correlates with higher volumetric wear of the MOMHIP on station 2 [6]. Also subsequent visual inspection of the MOMHIP from station 2 clearly showed a wear line.

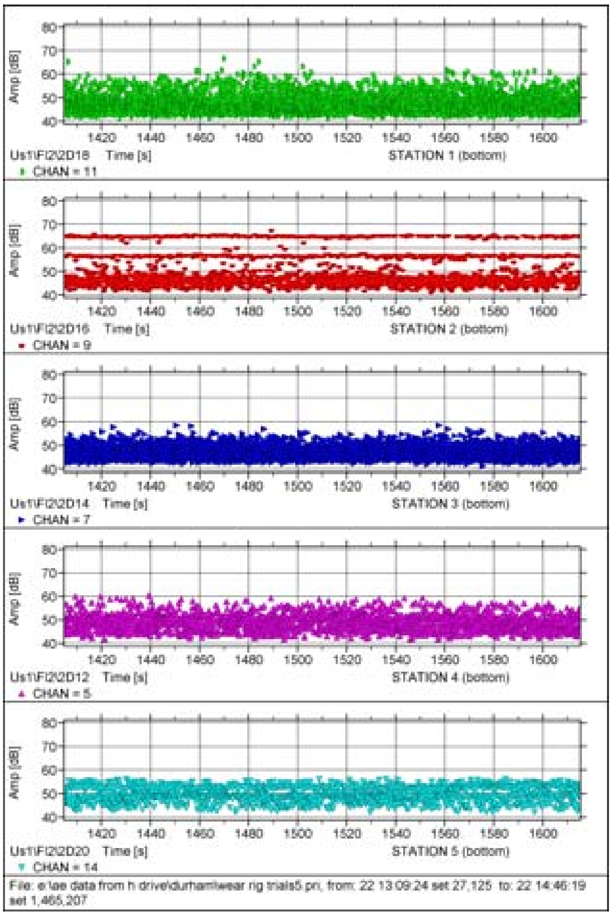

Figure 3 AE v time for 200 cycles on 5 station wear rig

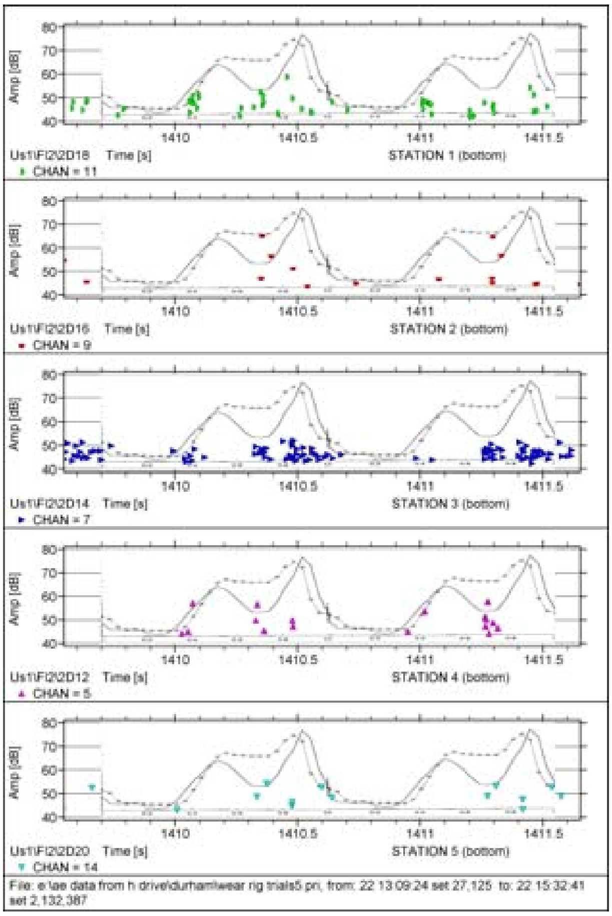

Figure 4 AE v time for 2 cycles on 5 station wear rig

Conclusion

It has been shown that AE can be applied to monitor the various active mechanisms of MOMHIP's on a hip simulated wear test rig.

The repetitive AE signals monitored on station 2 correlated with the out of line wear reported as compared with the remaining 4 stations.

Further analysis is required to synchronise the recorded AE activity with the cup and head displacements and the load cycle.

The materials research group are developing a wear-investigating rig, which will be based on the single bearing pendulum action.

References

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