

Bearing Premature Failure Study

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Abstract

The mining industry is heavily reliant on conveyors to transport its product. The extreme environments they operate in place a significant volume of potential contaminant in the vicinity of the bearings that support them. The labyrinth seals employed are not an effective protection. The higher than predicted bearing failure rates prove this. The shut-downs resulting from the failures are extremely costly for companies needing continuous production. The goal of this project is to find the mechanism that allows the contaminant to pass through the length of the labyrinth and the internal cavity into the bearing. Once the mechanism is understood a solution to the issue can be devised. To achieve this objective a test rig has been modified to better examine the phenomenon. It has undergone significant modifications to improve the results it produces. Currently it is examining a potential mechanism identified in the literature review. While the extent of the testing has been limited at the time of submission, the results so far have been positive. If the results continue to reinforce current data then a strong link between viscosity gradients and particle migration will be established.

1. Introduction

Conveyors are a critical component in the mining industry. They are involved in all stages of the mining process and their reliability is a significant issue (Mazurkiewicz, D. 2008). Mining operations are typically in very dusty environments which is not ideal for bearings such as those used on the conveyor pulleys. Higher than expected failure rates are experienced in these bearings due to the ingress of particles (Brittan 2011). These failures are extremely costly to the CEED Client and the industry in general.

In 2010 BHP Billiton engaged the UWA CEED program to investigate how despite the labyrinth seals being employed, contaminant was still managing to penetrate and damage the bearings. This project will be a continuation of that work.

A large portion of last year's project was the construction and use of a test rig. The purpose of the rig was to investigate possible particle entrance and migration mechanisms. There are a number of issues with the rig which will need to be resolved to accomplish meaningful results (Brittan 2011). The apparatus in its current form is a metal shaft rotating in a Perspex sleeve. O-Rings on either side of the shaft trap the grease in the cavity as the rig operates. Using an actual labyrinth is not practical so the rig acts as a simplification of that environment.

SKF conducted a study investigating the migration of particles in grease close to the contacts of lip seals (Baart et al 2011). While the paper was relatively brief, it formed the basis of the mechanism to be tested. It identifies four effects that need to be considered in the design of an

experiment investigating particle migration in grease. Of those four only two are relevant to the scale of this project. They ensure the hydrodynamic forces are dominant relative to other potential forces. The importance of Brownian motion must be insignificant relative to the hydrodynamic forces. This is determined by the Peclet number (Snijkers et al 2009). The other consideration is the significance of the particle inertia relative to the viscous forces acting on it. The Reynolds number of the particle determines this (Snijkers et al 2009).

The overall goal of the study was to qualitatively explore what affected the direction of particle migration. A large viscosity gradient resulted in migration towards the lip seals contact point. A large Weissenberg number resulted in the reverse being observed (Baart et al 2011). It did acknowledge significant work still needs to be done to explore the phenomenon. The intention of this project is to expand this field beyond simple lip seals by qualitatively investigating the same effects on the labyrinth seals.

One limitation of the study applicable to this project was it only investigated lip seals. A large portion of this projects work has gone into adapting the method, theoretical work and scale in Baart, Lugt and Prakash's (2011) work for use in the area of labyrinth seals. In lip seals the viscosity gradient is created by a pressure differential as the contact point is approached. Equation 1 shows the relationship between dynamic viscosity and pressure while Equation 2 shows its relationship with temperature (Stachowiak 2011).

$$\eta_P = \eta_0 e^{\alpha P} \quad \text{Equation 1}$$

$$\eta_T = a e^{b(T-c)} \quad \text{Equation 2}$$

Whilst Baart, Lugt and Prakash (2011) essentially investigated the effects of a pressure gradient, this study will seek to manipulate temperature to achieve the required viscosity gradient. It is an entirely plausible situation in reality. Big bearings with large loads like the conveyor pulley bearings run much hotter than their surrounding environments (Detweller 2007). Such conditions would result in a temperature gradient along the length of the labyrinth seal.

2. Experiment Redesign

Several measures were taken to fix the problems of last year's test rig. Parts had to be acquired from different sources and several workshops were utilised to put it together. The modifications are summarised here in the sequence that they were initiated.

2.1 Shafts

The Perspex shaft from last year was not straight and forced the grease out from the sleeve. As a result the rig could only be run for a few seconds before all the grease was extruded. To resolve this issue a machined steel shaft was constructed to create a constant 2mm clearance along the length of the cavity. This closely resembles a real labyrinth seal. While the shaft was significantly straighter, it was also somewhat heavier than its predecessor resulting in a much larger load on the 500W motor.

2.2 Seals

The increased straightness of the shafts did improve the grease retention but it was still escaping the sleeve. The analysis of the video revealed the inertia of the grease was the cause. On the side where the moving grease had to work against gravity it took the path of least resistance. While it was no longer being pushed out by the shaft, there was nothing stopping it from sliding out the sides of the sleeve as there were no seals trapping the grease in.

An external company was consulted on how to best seal the system utilising industrial seals. Grooves were machined into the shaft for O-rings to run. The O-rings provide an even pressure across the circumference with a relatively low pressure on the shaft. The sleeve is also only loosely supported by the clamps. This allows the O-rings to centre the axis of the sleeve to the axis of the shaft and ensure even pressure across the seals.

2.3 Motor

The new seals have significantly more pressure at the contacts. Testing them was not possible with the 500W motor installed last year. It was not powerful enough to turn the shaft at any more than a few RPM. As a result an 800W version of the motor was acquired. It had the same dimensions and mounts so swapping was not a problem. It works with the current 24V supply but this does not result in any extra power to the shaft. At present a 12V deep cycle lead acid battery is in series with it to provide the extra power.

2.4 Speed Controller

The components in the speed controller were no longer adequate to handle the new electrical loads. Several components blew and had to be upgraded. The new parts over compensate for the current needs so should further power increases be required the controller will be ready.

3. Method

3.1 Application of Grease and Particles

A small volume of grease is applied around the shaft. Only just enough is used to thinly cover the entire surface of the shaft. This provides a surface for the zinc particles to attach as they are sprinkled onto the shaft. The particles are then mixed into the grease.

The sleeve is slid over the first O-ring, across the grease mix to the point just before it makes contact with the second O-ring. The remaining air is forced out by pumping grease into the nipple. Once all the air is removed the sleeve is slid over the O-ring and lightly clamped.

3.2 Heat source

To achieve a viscosity gradient a heat source is being placed at one end of the shaft. The heat dissipates through the length of the shaft creating a heat gradient. Equations 1 and 2 show that provided the pressure is constant over the length of the sleeve a viscosity gradient will result.

A baseline test has been conducted without the heat source. The purpose of this test was to establish whether the rig was working as expected and ensure there were not any other factors that could affect the viscosity of the grease.

3.3 Test Apparatus Operation

Once the test rig is set up the motor is operated at approximately 100 to 200 rpm for 45 minutes. On regular intervals the temperatures of the sleeve, shaft, bearings, coupling and motor are monitored. The sleeve and shaft temperatures are measured to determine the thermal gradient experienced by the grease. The other components are monitored to ensure there is no overheating.

3.4 Data Collection and Analysis

After testing is complete the sleeve is removed carefully to ensure no grease moved. Samples are collected from five equally spaced locations along the shaft. These are placed between slides and compressed so the sample is one particle thick. These are placed under a digital microscope. Four photos are taken of each sample and analysed in ImageJ.

4. Results and Discussion

4.1 Particle Distribution without a Heat Source

Data was collected without a heat gradient to determine if there were any other factors that could affect particle migration within the test rig environment and establish a baseline.

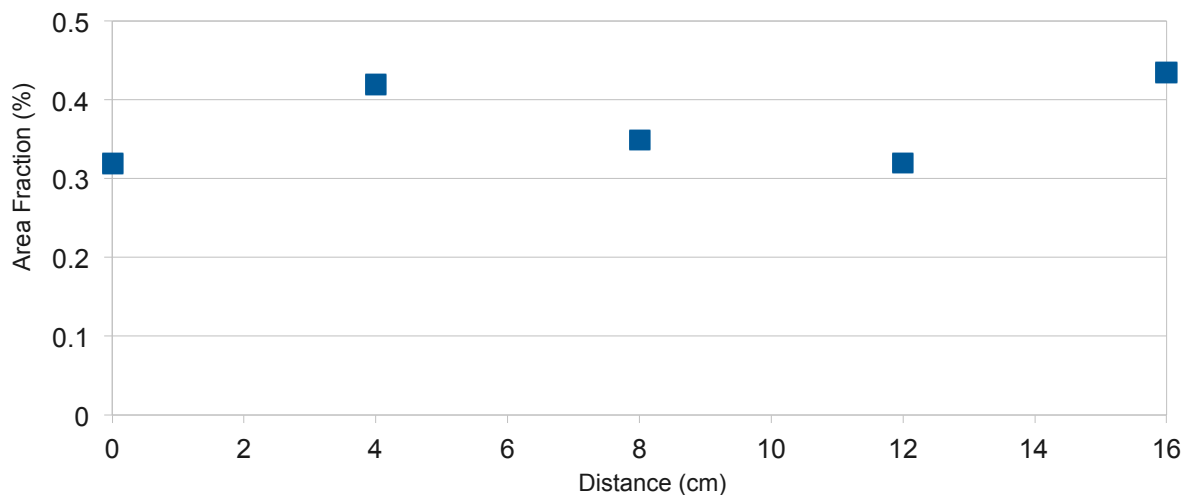


Figure 1 The area fraction at each location in the baseline test results

The Area Fraction is the area taken up by particles expressed as a percentage of the total area in the image. It was used as the primary measure of particle density throughout the study because it removed much of the human error involved in collecting the data.

The distribution in the non-heated test was fairly consistent across the length of the sleeve. There were no obvious discrepancies in any of the other data collected during this test. The results were consistent with the expectations for the baseline.

4.2 Heat and Viscosity Gradient

With the heat source active the temperatures were measured on the sleeve and metal shaft. The average minimum and maximum temperatures experienced by the grease at either end of the sleeve were 34 and 45 degrees respectively. The gradient between them was very linear.

The corresponding viscosities were determined using the ASTM chart for viscosity (Stachowiak 2011). It was assumed that there were no other factors like pressure effecting viscosity. As such the focus should be on the gradient in viscosity rather than its value.

4.3 Particle Distribution with a Heat Source

The second test was conducted with the heat source introduced. More particles were used to increase the density making the analysis easier and more accurate. It also enabled the effects to be viewed while the rig was in operation. After the second test was complete there was a clear build up of particles on one side.

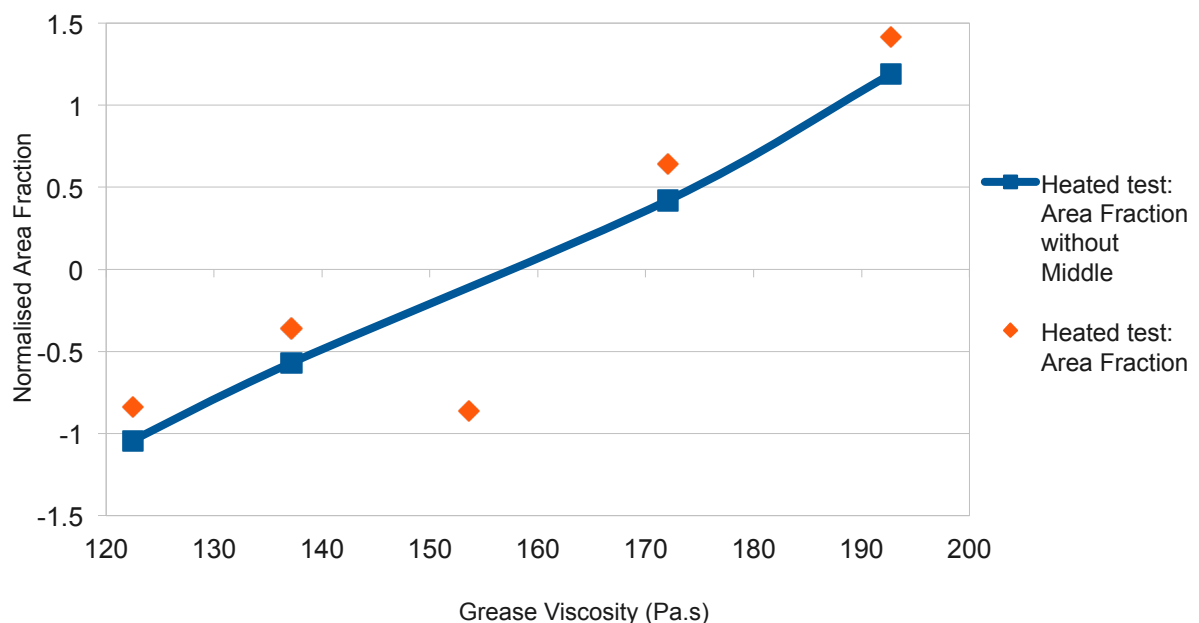


Figure 2 The normalised results from the heated test

Figure 2 contains the particle distribution as a function of grease viscosity. The analysis backs up the visual observations. The side of the sleeve with the particle build up had the larger Area Fraction and this value decreased along the length of the sleeve. The correlation coefficient between the area fraction and dynamic viscosity along the sleeve is 0.893.

The density in the middle seems quite out of line with the other locations given the linearity of these results. It is worth noting that the grease nipple protrudes into the cavity between the sleeve and shaft at this point and could be affecting the results here. An air bubble was observed behind the nipple for the duration of the operation. Further investigation of this is required if the anomaly continues to appear in the data. If the middle location is removed the correlation coefficient increases to 0.998.

4.4 Relation to Previous Work

The study by Baart, Lugt & Prakash (2011) outlined some conditions to be met in order for the hydrodynamic forces to be dominant on the particles. The grease and particles used in this experiment comfortably met these requirements.

The direction of particle migration was of particular importance. Provided temperature was the only variable effecting viscosity they travelled into the more viscous grease. If this grease was used in the labyrinths the result would suggest the particles would be ejected. However the grease used in this experiment is not the same as the grease used in the labyrinths. Whether the two greases have different characteristics like shear thinning properties or Weissenberg Numbers will have serious implications on the direction the particles migrate (Baart et al 2011). While there is not enough information available to determine whether they will behave in a similar manner, the grease specifications suggest they won't.

4.5 Conclusions and Future Work

The highest priority is to conduct more tests to verify the results obtained so far and ensure the test apparatus is producing repeatable results and to reinforce the data already collected. Testing will continue after the submission of the paper. The issue of the grease currently being tested not being in use on the actual seals complicates this. While there is a need to verify the current results, BHP Billiton requires findings which will help them identify the exact mechanism allowing the particles through their seals. Testing many different types of grease could become a long term objective to determine which direction particles will travel in each.

Provided the results from future tests continue to provide a similar set of outcomes the findings will help provide qualitative predictors of particle migration in labyrinth seals and other similar systems. This would influence grease selection decisions to ensure more reliable sealing solutions and bearing longevity.

5. References

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