Electrical pitting of grease-lubricated rolling and sliding bearings: a comparative study

S Raadnui\(^1\) and S Kleesuwan

Faculty of Engineering, King Mongkut’s University of Technology North Bangkok (KMUTNB), 1518 Pibulsongkram Road, Bang-Sue, Postcode 10800, Bangkok, Thailand

Email: srr@kmutnb.ac.th, s_raadnui@yahoo.co.uk

Abstract. The electrical pitting of grease-lubricated rolling and sliding bearings were tested. Subsequently, various conclusive findings arose from the tests. The various tests included testing for: typical wear modes and mechanisms, wear debris morphology, the results of various experiments, the results relating to experiments undertaken at temperatures and the typical bearing worn surfaces. Using different techniques, this study methodically assessed the effects of electrical currents and mechanical parameters combined with grease-lubricated rolling and sliding bearings. The grease-lubricated bearings were tested using the AC field. Typical characteristics or morphologies of electrical pitting wear particles were observed. In addition, the electrical pitting wear regimes, which corresponded to the respective physical responses, such as bearing housing temperatures, worn surfaces and the morphology of wear debris were anticipated. Thus, from the experiments undertaken, different wear regimes were revealed. These were dependant on the test parameters. Each stage produced wear particles, which were supported the belief that morphology had taken place at each stage.

1. Introduction

When voltage differences are generated between the shaft and the bearing housing due to a dissymmetrical effect, current passes through the very thin lubricating film located between the shaft and the sliding bearing. This effect, induced by the rotor and stator arrangement, intentionally or accidentally applied to the shaft (possibly caused by a build up of particles, charged lubricant, or charged belts). The current then produces sparks, arcing, and the subsequent melting of the bearing surface. This phenomenon is known as electrical wear; or, “pitting”. Thus the deterioration of the lubricant is accelerated; and, conversely the bearing life is reduced due to the heat generated and an instantaneous temperature rise when the bearing is exposed to an electrical current. To support these findings, several studies have been investigated and used to assess the formation of electrical pitting from the lubricant bearings [1 to 4]. Considerable experiments and test previously undertaken have been devoted to the examination of the physical, chemical, and mechanical phenomena responses when subjected to the varying stages of electrical pitting wear. The identification and clarification of electrical of sliding bearing electrical pitting wear particles has not been thoroughly investigated until now. Whilst it is known that electrical sparks or erosion continues to be a major contributing factor of premature rolling and sliding bearing failures on a motor, a major challenge has been the ability to diagnose the causation at an early stage. Proper maintenance can be planned in advance to prevent...

\(^1\) To whom any correspondence should be addressed.
catastrophic failures. The use of modern electrical apparatus in fault finding, such as, oscilloscopes could assist in diagnosing electrical erosion, but it would prove impractical, expensive, and time consuming [5]. Therefore, the specific purpose of this paper is to provide the reader with a detailed and systematic study for diagnosing electrical erosion utilization of wear debris, specifically, “typical wear debris” found in used grease samples from electrical pitting rolling and sliding bearing wear tester.

2. Experimental works

Electrical pitting wear tester, as used in this research, is shown in Figures 1 to 3. A load was applied mechanically in relation to the specific “dead weight”. The bearing housing used was equipped with a type “K” thermocouple. The purpose of the thermocouple was to monitor the increase in temperature throughout the entire test. Grooved ball bearings, a single row deep (designation type-6202-ZZ), were used throughout in the case of rolling element bearings. This is because of the ease and flexibility it provided to the tester during testing. The bearings were made of AISI 52100 bearing graded steel. On the other hand, sliding bearings used in the tests were Babbitt bearing materials (62% Cu, 34% Zn, 3% Pb, 0.25% Fe, 0.11% Ni and 0.3% Al). All bearings were lubricated with the same amount of standard NLG1 consistency, No.2, multi-purpose grease, which consisted of mineral base oil with lithium soap-based thickener. The rotating shaft was driven continually at 1450 rpm by an electric motor, with its motion transmitted by a V-belt. An AC voltage was used during testing the bearings, so that the current could flow through the test bearing. The voltage was manually controlled by using an auto-transformer.

![Diagram of bearing electrical pitting wear tester](image-url)

**Figure 1.** A sketch of bearing electrical pitting wear tester.
Figure 2. Bearing electrical pitting bearing wear tester.

Figure 3. Circuit diagram of current control for the bearing electrical pitting wear tester (\(R_A\): System resistance, \(R_E\): Asperities’ Resistance & \(R_F\): Lubricating film’s resistance).

Thirty six experiments using the “Design of Experiments” (DOE), as shown in Table 1, were carried out under various conditions of load, applied current, and test duration. Combinations of all
conditions were used. At the end of each test, the tested bearing was collected for further analysis. This included examining worn surfaces and analysing the wear debris. The data gathered was analysed further to evaluate the effects of input parameters, if any. Similarly, contour plots were plotted showing the bearing housing temperature as output response.

**Table 1. Electrical pitting wear parameters.**

| Level | Load (N) | Current (Amp.) | Test Duration (Minute) |
|-------|----------|----------------|------------------------|
| 1     | 20       | 0              | 20                     |
| 2     | 100      | 40             | 40                     |
| 3     | -        | 80             | 60                     |

3. Results and discussion
It is clear from the contour plots and the surface plots (the response surface plots from Figures 4 to 7), that increasing the current and test durations significantly, increased the bearing housing temperature. This was due to higher energy used and longer periods of electrical arcing or sparking electrical discharge. Increasing the load at 20 N and 100 N did not significantly increase the output parameters. From the above statistical and quantitative data as analysed, namely, the contour plots and the surface plots, we can see that, in general, increasing current and test duration increased bearing housing temperature, but increasing the applied load did not significantly increase the response parameter.

![Contour Plot of Housing Temp. (°C) vs CURRENT (Amp.), TIME (Min.)](image-url)

**Figure 4.** Contour plot of bearing housing temperature vs. current and test duration (sliding bearing)
Figure 5. Contour plot of bearing housing temperature vs. current and test duration (rolling bearing).

Figure 6. A surface plot for rising of housing temperature during the tests (sliding bearing).
Figure 7. A surface plot for rising of housing temperature during the tests (rolling bearing).

Figure 8. Worn surfaces of sliding bearings.
Closer examinations of the worn surfaces of the test bearings and the wear particles generated during a series of tests were carried out. Some typical worn surfaces of the inner ring raceway appearances are shown in Figures 8 and 9. The first stage or “mode” appeared as a grey/dull worn surfaces: micro craters, due to the electrical discharge phenomenon. The second stage is directly related to “macro-craters”, this is known as “micro pitting”. The reason why these patterns appear is because of the combination of electrical arcing effects and mechanical stress due to the rougher surface of the rolling and sliding bearings, which in turn are due to the electrical sparking effect from the first “mode”. The final “mode” is the more severe electrical pitting wear mode, where large amounts of “macro pitting” are present. The final mode represents a critical stage in testing both for sliding and rolling bearings. Analysis of the worn surface and wear debris were undertaken simultaneously. Typical electrical pitting wear debris characteristics are shown in Figures 10 to 12.
The findings as explained above can be supported with the results shown in Figure 13. It is obvious from the figure that the bearing housing temperature has been significantly influenced by the test duration and the applied current used both rolling and sliding bearings.

**Figure 11.** Spherical wear debris and sliding wear debris.

**Figure 12.** Spherical wear debris and sliding wear debris.
Figure 13. Sliding and rolling bearing housing temperature rising vs. variation of test duration and applied current.

From the data gathered and analysed from the various “test runs”, it can be deduced that electrical current “leakage” was the most likely cause for the bearing temperature to increase. This type of damage would seem to indicate that electrical current has passed through the bearings. The craters and welding beads (black spherical particles) were the result of electrical discharges. In normal to mild electrical pitting wear mode, between the microscopic peaks or “asperities” that are always found in worn surfaces of both rolling and sliding bearings.

Where there is a “bottleneck” and a spark then penetrates a fully developed lubricating film (via the Elasto Hydro-Dynamic (EHD) and Hydro-Dynamic (HD) lubricating stage of rolling and sliding bearings, respectively), this effect, makes the adjacent surface to briefly experience a melting effect. In the mixed friction range; Boundary to Mixed film lubricating regime; or, stage, where metal to metal contact occurs, this results in the affected surfaces becoming temporarily fused together. They are then immediately broken apart by the rotation of the shaft. In both cases, material also separates from the surfaces. The material immediately then solidifies and forms welding beads. The result is that some of the beads are then mixed in with the grease. The remaining beads are deposited on the metal surfaces. Inevitably, craters and welding beads can be flattened and smoothed as the rolling elements (rolling bearing) and the shaft (sliding bearing) continue to pass over them.

Where a perpetual flow of current exists, the thin layers, this causes a melting and solidifying process. This process is repeated and continues to take place over a period of time. Regardless of whether a bearing was exposed to low or high alternating currents, the resulting changes observed were always the same; that is: a dull appearance with grey marks (micro pitting) on the rolling and sliding bearing surfaces. “Macro pitting”, refers to the washboard patterns that develop along the worn
surface in a rotational direction. The main consequence of the flow of electric current and arcing when the rolling and sliding bearing move, resulted in wear to the bearing surfaces. This was due to the removal of “fused metals”, in the form of black. Thus, the result was that “micro pitting” (or pitched mark) and crater burns had occurred. Following this, the “micro pitting” was “roughened” and the mechanical wear was then accelerated. Additionally, the now “liberated” electrically induced ferrous particles at intense heat showed that this causes the degradation and oxidation of the grease and, subsequently, the grease losses it’s purity. The consequence of this deterioration in the condition of the grease is that the grease gradually deteriorates its ability to lubricate effectively and severely results in (sliding) wear particles being produced.

4. Conclusion
Test bearings were exposed to various electrical arcing regimes (or stages). The degrees of the regimes were: normal, mild, and severe pitting regimes. The damage, which resulted, to both the worn raceway and wear debris respectively, was observed using microscopic analysis. The tests, and findings of these various tests (of which many were made) conclude that these experiments and tests are a good point and source for further investigative research, specifically dealing with electrical current damage in rolling and sliding bearings regarding the formation of wear debris, prognostics for the lifetimes, under specific electrical regimes, and the production of “pitting” patterns. To summarize:

1. The major pitting of the electrically eroded worn bearing surface is caused in the first regime of the arc discharge. Also, when there is an increase in the duration of testing, the pitting increases significantly.

2. The test results, photographs, and charts as reflected in this paper serve to demonstrate the power of wear debris as analysed. This assists in the condition monitoring of grease lubricated rolling and sliding bearings.

3. The major differences between sliding contacts and rolling contacts are the problems related to wear during extended period of test duration. Good conduction and such sliding characteristics produce surface changes like loss of surface finish, transfer of material from softer (sliding bearing) interacting metal surface at the contact interface.

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