The Evaluation of Micro-Pit Life with the DBR method for Rolling-Sliding Contact

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Abstract

In this study, we evaluate the effect of supplied oil quantity and contact bulk temperature on micro-pitting life using two-roller contact machine. To quantify the failure rate of damaged surfaces of micro-pitting occurrence, the DBR (Dark and Bright Ratio) method was effectively implemented for observing not a sudden occurrence of macro-pitting but the transition of micro-pitting growth. The failure criterion is set as 4% micro-pitting on contact surfaces, which is adopted from precedent researches. The change of surface damaged area was measured by an optical microscope and calculated by the use of dark and bright ratio of test specimen pictures taken by optical microscope. The optimum oil quantity was determined to obtain the minimum oil quantity with no change in bulk temperature despite of increasing the supplied oil quantity. In conclusion, the influence of supplied oil quantity and contact bulk temperature on micro-pitting lifetime and the surface contact strength by the S-N curves of failure rate are quantitatively reported and expressed as empirical formulas.

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Keywords: Micro-pit life, S-N curve, surface strength

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1. Introduction

Micro-pitting is a Hertzian fatigue phenomenon that affects many wind turbine gearboxes as well as a compact automobile transmission etc., and it affects the reliability of the machines. With the increasing dependency on renewable energy and the strong tendency of lightweight design despite requiring high capacity, mechanical reliability is recently an extremely important issue that around three methods are widely used to detect pits by the vibration, the depth, the size of pits. The contact pressure distribution and subsurface stress contour maps along the whole contact zone indicate the realistic subsurface damage distribution which correlates well with the experimental observations of micro-pitting in depth[1]. According to the failure criterion which is normally 4% pitted area on one tooth flank of the pinion, a Weibull distribution is assumed and the load cycles for 50%($L_{50}$) failure probability are reported because of the large scatter of pitting life values for the pitting failure life[2]. The limits concerning possible reduction of lubricant quantity in gears without detrimental influence on the load carrying capacity by the failure criterion to 4% pitting on one flank and 1% pitting on all flanks[3]. When pits of the size about 0.5mm were observed on any tooth flank, the test run was stopped and the pitting sizes are measured using scanning electron microscope after the experiments[4]. When it comes to AE signals by the vibration, it has demonstrated that seeded gear defect detection with AE is fraught with difficulties and the reasons have been presented, which was aimed to investigate some of the drawbacks detailed and establish if the technique is relatively robust for natural wear detection on gears[5].

In periodically detecting micro-pitting on surfaces after contacting, initial micro-pits on the run-in stage get to grow and have conglomerated during pre-test so that the transient behavior of micro-pitting growth from infancy to the a sudden emergence of macro-pitting can be more meticulously observed by adopting DBR technique to quantitatively calculate the size of micro-pits on contact surface than aforementioned methods.

In this study, we present the method, which is the way of calculating the size of micro-pits which has conglomerated on the photo taken through optical microscope compared to SEM to quantitatively evaluate the influence of oil quantity supplied and bulk temperature on micro-pitting life and surface strength on contact surface.

2. TEST SPECIMENS, APPARATUS AND PROCEDURES

![Test equipment (TE74)](image1)

![Surface roughness of gear flank](image2)
The TE74 two roller machine is used for the study of contact fatigue of materials under the condition of rolling and sliding as shown in Fig. 1. Two roller specimens are mounted to the upper shaft and the lower shaft respectively with the independent motor driven under the control of different speeds. The Oil quantity in inlet has been constantly controlled to be injected into contact surfaces with ambient temperature maintained as in a given condition.

The bulk temperature of oil supplied right after contacting has been measured in real time using k-type thermocouple. The pitting life test in two roller machine has been performed by maintaining oil temperature at 90°C in both oil inlet and ambient temperature as in actual operating conditions.

Table 1. Specification of Actual operation

<table>
<thead>
<tr>
<th>Operating parameter</th>
<th>Operating condition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Oil quantity supplied</td>
<td>Splashed type (none)</td>
</tr>
<tr>
<td>Ambient temperature</td>
<td>90°C</td>
</tr>
<tr>
<td>Stress for safe design</td>
<td>1.6 GPa</td>
</tr>
<tr>
<td>Actual roughness</td>
<td>0.6 um</td>
</tr>
<tr>
<td>Actual rms roughness</td>
<td>0.8 um</td>
</tr>
<tr>
<td>Rotational speed</td>
<td>2000 rpm</td>
</tr>
<tr>
<td>Slip ratio</td>
<td>5%</td>
</tr>
</tbody>
</table>

As described in Table 1, we applied this operating conditions to a rolling and sliding contact for assessing surface strength considering oil quantity supplied under the specific conditions such as rotational speed, slip ratio, roughness, stress for safe design, the quantity and temperature of oil injected to contact surfaces as well as ambient temperature.

When it comes to surface profiles, the roughness as well as the rms roughness of two roller specimens have been elaborately finished to be respectively 0.6um and 0.8um as equivalently as under the condition of gear surfaces which can be dominatively affecting film parameter related to film thickness in Elasto hydrodynamic lubrication and boundary lubrication by repeatedly measuring 3D Stylus surface profilometer.

In Fig. 3 the distribution of contact pressures in in the lower and upper specimen, for an example as in Table 2, is presented when the normal load is 5400N which can be calculated through contact analysis of semi-infinite solid based on influence function[6], for adding it up to the maximum of 3Gpa of two roller machine while oil quantity has been increased to 80ml/min or 200ml during run-in stage with operating conditions satisfied as mentioned in Table 1.

Therefore, the optimum oil quantity supplied into contact surface can been determined to obtain the minimum oil quantity with no change in bulk temperature which can be automatically controlled despite of increasing the supplied oil quantity as observed in Fig. 2.

After analyzing the design variables and operating conditions of gear and pinion given in the field, the 5 percent of slip ratio in two roller machine for micro-pitting fatigue test can be applied on the basis of the average of slip ratio in the line of action in the same as performed in actual mating gears.
For making a standard of judgment by a failure criterion for surface strength, Dark/Bright ratio (DBR) is effectively implemented to confirm damage rates of micro-pits on contact surfaces. The specimens have been taken by an optical microscope at regular intervals on the experiment to calculate the damaged area by using the pixels of micro-pits on the microscope photo.

The position of contact which has an elliptical shape as shown in Fig. 5 is to be taken through microscope by a size of contact width in the axial direction through contact analysis and the other loads are calculated to perform in fatigue test.

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**Table 2. Specification of Test Condition**

<table>
<thead>
<tr>
<th>Stress (GPa)</th>
<th>Load (N)</th>
<th>Contact Width (mm)</th>
<th>Oil quantity (ml/min)</th>
<th>Rotation (rpm)</th>
<th>Slip ratio (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>3.0</td>
<td>5400</td>
<td>3.3</td>
<td>80/200</td>
<td>2000</td>
<td>5</td>
</tr>
<tr>
<td>2.5</td>
<td>3070</td>
<td>2.9</td>
<td>80/200</td>
<td>2000</td>
<td>5</td>
</tr>
<tr>
<td>2.0</td>
<td>1600</td>
<td>2.3</td>
<td>80/200</td>
<td>2000</td>
<td>5</td>
</tr>
<tr>
<td>1.5</td>
<td>750</td>
<td>1.7</td>
<td>80/200</td>
<td>2000</td>
<td>5</td>
</tr>
</tbody>
</table>

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The 50 percent of major semi-axis width in elliptical contact taken by microscope is analyzed to be the 90 percent of maximum of Hertzian stress in shown in Fig. 4. The damaged surface periodically taken by microscope photo is determined to get to the failure criterion by observing the growth of micro-pits up to 4% on either of two roller surfaces [3].

The transient of micro-pits growth have been more quantitatively observed from infancy to a conglomerate before macro-pitting than the other ways of detecting the behavior of micro-pits by AE signals or the depth as shown in Fig. 6.

3. Results

The Failure rate is presented on damaged surface of micro-pits in inlet oil supplied at 200ml/min at each maximum of Hertzian stress in Fig. 7 and at 80ml/min in Fig. 8, and then S-N curve is presented as empirical formulas that the Failure rate of the micro-pitted surface supplied at 200ml/min is lower than that of the micro-pitted surface at 80ml/min and the surface strength at 200ml/min is higher because bulk temperature increase is lower by about 10°C as shown in Fig. 9.

After calculating film thickness is about 85nm to 140nm at 80ml/min and 200ml/min, The film parameter(\( \lambda \)) is evaluated to be 0.15 to 0.2 to indicate that the regime of lubrication is boundary lubrication, which increased friction may continue increasing with decreasing the film thickness[7]. The S-N curve including film parameter(\( \lambda \)) is also expressed as empirical formulas in Fig. 10.
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CONCLUSIONS

In this paper, The influence of supplied oil quantity and contact bulk temperature by considering film parameter to determine micro-pitting lifetime through the DBR method and the surface contact strength by the S-N curves of failure rate are quantitatively reported and expressed as empirical formulas.

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References


