Wear of Spindles for Spinning

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Abstract

Object: With the aid of flat plates and balls we have made spinning wear tests on the footsteps of spinning spindles equipped with roller bearings. The purpose is to clarify the characteristics of wear caused by total revolutions, load, speed and hardness, and to examine the wear resistance property of the steps.

Test results: Conducted with the use of flat plates and balls (both made of bearing steel SUJ 2) as well as spindles, the wear tests have shown that:
(1) Spinning revolutions and the amount of wear (loss in weight) increase in an almost linear relation.
(2) The relation between the load and the amount of wear is such that the latter tends to increase slightly as the former increases.
(3) The amount of wear tends to increase rapidly with a decrease in the spinning rotation speed. It will help to reduce wear if rotations are speeded up by improving the efficiency of service spindles.
(4) The relation between combinations of various degrees of hardness and the total amount of wear is such that the latter decreases with an increase in the hardness of test pieces, if flat plates have been hardened in a degree reasonable and matching balls approximately HRC 64 in Rockwell hardness.
(5) A step having a well-finished and harder surface reduces the wear of spindle pivots.

Introduction

The wear of the footsteps of a roller bearing-equipped spindle for spinning is characterized by the spinning wear of the pivot. On this characteristic there have been hardly any published studies to date. Only a few studies on the sliding wear of bearing steel have been published [1,2]. Also scarce are published works dealing with the wear of footsteps [3,4,5].

We have tried to investigate the characteristics of the wear of the footstep section. With the aid of flat plates and balls, we have inquired into factors contributory to wear, such as total revolutions, the load and the spinning speed. By using service spindles and a step of improved wear resistance, we have observed the wear behavior of blade pivots.

1. Factors Affecting the Wear of the Footstep Section

1-1. Conditions of Sliding Contact

The maximum sliding velocity \( v_{\text{max}} \) (m/sec) of the outer circumference of the contact circle, and also the maximum contact pressure \( p_{\text{max}} \) (kg/mm) in the contact section of bearing steel, shown in Figure 1, are evaluated on the basis of H. Herts's elasticity contact theory [6], as follows:

\[
v_{\text{max}} = 2\pi a \cdot 10^{-3} \times \frac{n}{60} \text{ (m/sec)} \tag{1}
\]

\[
p_{\text{max}} = 295 \left( \frac{1}{r} - \frac{1}{R} \right)^{\frac{1}{2}} \cdot W^{\frac{1}{3}} \text{ (kg/sec)} \tag{2}
\]

where \( a \): radius of the contact circle

\[
a = 0.0402 \left( \frac{1}{r} - \frac{1}{R} \right)^{-\frac{1}{2}} \cdot W^{\frac{1}{3}} \text{ (mm)} \tag{3}
\]

\( n \): revolutions of the blades (r.p.m.)
\( r \): radius of the pivot (mm)
\( R \): radius of the step (mm)
\( W \): load (kg)

For instance, the maximum sliding velocities of...
Hm 3-37 and Hm 3-17 spindles when they are unfed and yarn-filled are shown in Figure 2. Figure 3 indicates the maximum contact pressure of yarn-filled Hm 3-17 spindles.

The $v_{\text{max}}$ and $p_{\text{max}}$ in both Figures 2 and 3 can be evaluated in their initial rotation stage if the designed values $R$ and $r$ are given. As wear develops and the values $R$ and $r$ change with an increase in revolutions, so the $v_{\text{max}}$ increases in the direction shown by the arrow, while $p_{\text{max}}$ decreases in the direction of the arrow.

Assume, therefore, that the sliding velocity is a factor within the scars of wear and is the total of velocity effects, including those up to $v_{\text{max}} - 0$. Assume also that the contact pressure is the total or average of contact pressures including those up to $p_{\text{max}} - 0$. We can then sum up the wear as the total of pressure effects, including those up to $p_{\text{mean}}$ (at the time of designing) — $p_{\text{max}}$ (after the rotation).

A wide-ranging sliding velocity such as has just been described is peculiar to spinning wear. Therefore, the contact points of the pivot and the step slide over a longer distance in the circumference of the circumferential area than in its center. This means that, all things being equal, the center is subject to less wear.

1-2. Wear Resistance of the Surface

![Fig. 2. Maximum sliding velocities of Hm 3-37 and Hm 3-17.](image)

1-2-1. Roughness, cracks and wrinkles on the surface of the step.

The roughness of the surface affects sliding wear noticeably where pieces of hard steel are used in combination.[7] Meanwhile, it is reported that a lubrication sliding wear test, in which high carbon-chrome steel of a roughness of 0.1 — 0.8 $\mu m$ was used, showed that the lesser the roughness of steel, the smaller the amount of wear[8]. Conceivably, then, the surface treatment of the step can have a bearing on wear.

On the other hand, it is often that slight cracks and wrinkles are found on a rough surface if cold working has been given to the step. It is also probable that cold working affects the condition of wear as adversely as roughness does. It is possible that lapping powder may adversely affect the surface and produce an abrasive wear.

1-2-2. Surface Hardness

From the data [8-11] on the effect of hardness upon the sliding wear we see that the higher the degree of "stabilized hardness," the smaller the amount of wear. There is a difference in the amount of wear between pieces of steel differing only slightly in hardness, as we shall see later. Depending on the condition of heat treatment, inner hardness and especially surface hardness conceivably constitute major factors affecting initial-stage wear.

1-2-3. Effect of lubrication

Normally, spindle oil #60 or Velocite E is used for lubrication. It is quite possible the deterioration

![Fig. 3. Maximum contact pressure of Hm 3-17 (full yarn).](image)
of viscosity or oxidation caused by the exothermic reaction of wear may influence the amount of wear. Accordingly, care should be taken in the choice not only of lubricating oil but also of the method of lubrication.

1-2-4. Movement (oscillation) of blades and vibration-absorption in inserts.

From a practical point of view, spindles are designed to oscillate in a minimum degree and generally used for high-speed revolutions. To reduce wear, therefore, it is necessary that vibration absorption within inserts be complete.

2. Spinning Wear Characteristics of the Bearing Steel

2-1. Method of Testing

Bearing steel SUJ2, whose components are shown in Table 1, was used for our tests. For the convenience of weight-measuring and considering the load condition, flat-plate test pieces 10 × 7 mm were used on the stationary side, and balls 1/4 inch in diameter were used on the spinning rotation side.

To change their hardness, we subjected the flat-plate test pieces to the three methods of heat treatment shown in Table 2, and the ball test pieces to the method of heat-treatment shown in Table 3. Hardness was measured with a Vickers hardness tester (5 kg) and the values were converted into Rockwell hardness (HR C).

The apparatus used for the wear tests are shown in detail in Figure 4. At the upper end of a high-speed rotating spindle (1) a ball (2) was fixed and put into contact with a plate (3) placed above the ball. The plate (3) was put into contact with an arm (5) which was supported by a supporting point (4) and was orthogonal to the spindle. A stationary load (6) was put on the arm (5) at a point just over the plate (3).

A normal weight (393 g) and a heavier weight (653 g) were used to approximate the load to the sliding velocity and the contact pressure at the footstep. The spindle was driven by a belt attached to motor (7) at five different rates of speed, 5,000, 7,500, 10,000, 12,500 and 15,000 r.p.m.

The flat plates and balls, which had been precisely finished, were washed in alcohol, benzene and ether, completely dried, and subjected in dry state to wear tests by the apparatus shown in Figure 4.

The object of the tests was to study the characteristics in dry condition, seeing that the practical condition of the wear of the footstep in lubricating oil is considered a boundary lubrication condition and that the wear is, for the most part, the wear of the sections of contact between metals.

During the tests, one set of test pieces was worn out four or five times and then their loss in weight was measured in a high sensitive balance. The average values were taken as the amount of wear. The tests were made at a temperature of 26—31°C and under a humidity of 70—80%.

2-2. Test Results Reviewed

2-2-1. Relation between the total revolutions and the amount of wear.

Table 1. Components of Test Piece

<table>
<thead>
<tr>
<th></th>
<th>C</th>
<th>Si</th>
<th>Mn</th>
<th>P</th>
<th>S</th>
<th>Cr</th>
<th>Fe</th>
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<tbody>
<tr>
<td>Bearing steel</td>
<td>0.95</td>
<td>0.15</td>
<td>0.50</td>
<td>0.030</td>
<td>0.030</td>
<td>1.30</td>
<td>remain</td>
</tr>
<tr>
<td>SUJ2</td>
<td>-1.10</td>
<td>-0.35</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>-1.60</td>
</tr>
</tbody>
</table>

Table 2. Heat Treatment of Flat Plate

<table>
<thead>
<tr>
<th></th>
<th>Quenching temp. (°C)</th>
<th>Tempering temp. (°C)</th>
<th>Hardness (HRC)</th>
</tr>
</thead>
<tbody>
<tr>
<td>P 1</td>
<td>790</td>
<td>150 (1 hr.)</td>
<td>60.4—61.0</td>
</tr>
<tr>
<td>P 2</td>
<td>810</td>
<td>150 (1 hr.)</td>
<td>61.5—62.1</td>
</tr>
<tr>
<td>P 3</td>
<td>830</td>
<td>150 (1 hr.)</td>
<td>63.3—63.5</td>
</tr>
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</table>

Table 3. Heat Treatment of Ball

<table>
<thead>
<tr>
<th></th>
<th>Quenching temp. (°C)</th>
<th>Tempering temp. (°C)</th>
<th>Hardness (HRC)</th>
</tr>
</thead>
<tbody>
<tr>
<td>B 1</td>
<td>790</td>
<td>120 (1 hr.)</td>
<td>63.9—64.0</td>
</tr>
</tbody>
</table>

Fig. 4. Spin-wear testing apparatus.

Fig. 5. Relation between total revolutions and wear.
Figure 5 indicates a relation between the total revolutions (total running hours) and the total amount of wear, which latter was obtained when the flat-plate test pieces P I and the ball test pieces B I were used at spindle revolutions \( N = 10,000 \) r.p.m. and load \( W = 393 \) g or 653 g. \( w_p \) in the figure indicates the amount of wear of the flat-plate test pieces; \( w_b \), the amount of wear of the ball test pieces.

As shown above, the relation between the total revolutions and the amount of wear (loss in weight) is almost linear. It seems that the initial wear field is almost nil or negligible.

Therefore, if the total revolutions are a definite value of some magnitude, the amount of wear can be used for a comparison of characteristics. When the effect of the spinning rotation speed was observed in later tests, the amount of wear at the total rotation number \( R = 7.5 \times 10^5 \) revolutions was used as a standard of wear. Apropos of Figure 6, the amount of wear per unit of revolutions is calculated approximately as follows:

With \( W = 393 \) g
- Flat plate: \( 8.8 \times 10^{-7} \) mg/rev.
- Ball: \( 7.5 \times 10^{-7} \) mg/rev.

With \( W = 653 \) g
- Flat plate: \( 10.0 \times 10^{-7} \) mg/rev.
- Ball: \( 9.4 \times 10^{-7} \) mg/rev.

As for the debris of wear, our tests showed that a large quantity of red-brown iron oxid powder had been formed. An observation of the wear-scars with the naked eye revealed that the wear consisted of a combination of oxidation wear and mechanical wear, mostly the latter.

2-2-2. Relation between load and amount of wear.

A load similar in contact pressure to the practical footstep shown in Figure 3 was used in an attempt to establish the load-wear relation in two instances, namely, \( W = 393 \) g \((p_{mean} = 64 \text{ kg/mm}^2)\) and \( W = 653 \) g \((p_{mean} = 72 \text{ kg/mm}^2)\).

In these two cases, the flat-plate test pieces P I and the ball test pieces B I were used. Figure 6 shows the amount of wear for total revolutions \( R = 2 \times 10^5, 4 \times 10^5, 8 \times 10^5 \) rev. at spindle revolutions \( N = 10,000 \) r.p.m.

Figure 6 indicates not only the maximum sliding velocity \( v_{max} \) (m/sec) but also the average contact pressure \( p_{max} \) (kg/mm) which are evaluated from the actual measurement of the wear-scars \( 2a \) (mm) in diameter. From Figure 6 it is concluded that the \( v \) and \( p \) change at the same time that the load condition is changed; and that the amount of wear tends to increase slightly with an increase in the load.

Although it may be premature to deduce the load characteristics from these tests in which two loads approximating those in practical use were employed, it seems possible to grasp a general trend in the range of practical use.
2-2-3. Relation between spinning rotation speed and amount of wear.

The flat-plate test pieces P 2 and the ball test pieces B 1 were used to obtain the velocity characteristics for the load \( W = 393 \) g. Figure 7 shows the amounts of wear at the total revolutions \( R = 7.5 \times 10^5 \) rev. for spindle rotation speeds of 5,000, 7,500, 10,000, 12,500 and 15,000 r.p.m.

Figure 7 shows the maximum sliding velocity \( (v_{\text{max}} \text{ m/sec}) \) and the average contact pressure \( (p_{\text{max}} \text{ kg/mm}^2) \) which are evaluated from the actual measurement of the diameter of the wear-scars on the flat plates. It is conceivable that the \( v \) and \( p \) change at the same time, if the spinning rotation speed is changed at a definite load.

The change of the \( v \) is, however, larger than that of the \( p \). As stated in (2) above, the change of amount of wear caused by the change of the \( p \) is slight. It is, therefore, possible to conclude from Figure 7 that the effect produced by the change of the \( v \) is dominant.

As reported in an earlier paragraph, the sliding velocity is a total including the values from 0 to the \( v \) in Figure 7. It shows that the amount of wear of the flat plates and balls tends to increase rapidly with a reduction in the spinning rotation speed. The reason for this tendency cannot be clearly stated, unless the load and velocity characteristics of the wear of bearing steel are defined.

The condition of wear revealed by the wear test referred to in the first paragraph of this section, 2-2-3, is, in our opinion, such that a mechanical wear field is dominant. This opinion is supported by the curves for sliding velocity under 1 m/sec in Figure 8. That figure, which gives the results of a sliding wear test of friction between pieces of ball bearing steel, shows that with each decrease in sliding velocity from 1 m/sec, the amount of wear increases rapidly.

In view of these factors, it deserves special note that a speed-up of service spindles will reduce the wear of footsteps.

2-2-4. Relation between hardness and amount of wear.

With the use of the flat-plate test pieces of different hardness degrees shown in the Figure 2 and the ball test pieces shown in Figure 3, a comparison was made of the wear of three hardness combinations and inquiry made into the question of what degree of hardness, in proportion to the hardness of the service plate pivot, should be given to the step. Figure 9 shows the results of wear tests when the spinning rotation speed \( N \) was 10,000 r.p.m., load \( W = 393 \) g, and the total revolutions \( R = 7.5 \times 10^5 \) revolutions.

The temperature for hardening chosen for our tests was close to the temperature in use for practical purposes, and pieces of the bearing steel were modified in a reasonably small range. Accordingly, the temperature for hardening is in a linear relation to hardness. The values adjusted on the basis of the temperature for hardening are of the same leaning as in Figure 9.

Since it is possible that not only the wear of the step and pivot but also abrasive wear caused by the debris of wear may acceleratively affect the condition of the wear of a service footstep section, it is advisable to choose a combination of hardnesses which will reduce the total \( (w_p \cdot w_B) \) of the amount of wear of the flat plates and balls.

Figure 10 is a co-ordination of the flat plate

![Fig. 8. Characteristic of sliding wear of bearing steel.](image)

![Fig. 9. Relation between hardness and wear.](image)

![Fig. 10. Relation between hardness and total wear.(B1)](image)
hardness within the limits of the tests. It shows that, within the range HRC 60–40 of the flat plates for which B 1 (HRC 63.9–64.0) is used, the $\sigma_p - \sigma_B$ decreases with an increase in the hardness of flat plates. The hardness of the plate pivot being about equal to B 1, we may conclude that the harder the steel a step is made of, the better.

3. Characteristics of the Wear of Blade Pivots

We have successfully obtained the total rotations, load, speed and hardness characteristics from our fundamental tests in which flat plates and balls were used as test pieces. Figure 9 discloses that the total amount of wear lessens if the step is harder than the blade pivot. We, therefore, used a service spindle in our tests. We then observed the effect blade pivots had on wear when hardness (wear resistance property of the step), especially surface hardness, was enhanced and when the finishing of the surface was improved.

3-1. Influence of Difference in Steps on the Characteristics of the Wear of the Blade Pivot

Blades of the same lot (the hardness of the pivots being a definite HRC 64) were used in our tests and two methods of step treatment, A and B (see Table 4), employed. Twenty steps—some treated by method A, others by method B—and 20 pivots of uniform hardness were put to a wear test to see what influence wear would have on the hardness, especially surface hardness, and surface finish of the steps.

As for the hardness measurement of the hardened surface, steps (Figure 11) having flat bottoms were measured with a micro Vickers hardness tester. This revealed, as shown in Table 4, that the test pieces treated by method A were not uniform in the surface hardness of their steps, and that the soft section presented a decarbonized appearance.

The test pieces treated by method B were hard and uniform in surface hardness, while their hardness characteristics (a factor in the wear resistance property) were excellent. As the quenching temperature was, of course, the same, the Rockwell hardness of internal hardness was almost the same and high enough, as stated in Table 4.

In surface finish also, the test pieces treated by method A were very rough, as shown in Figure 12. A microscopic overt observation revealed that the surface of the test pieces treated by method A had micro-cracks and wrinkles, and that the surface of the test pieces treated by method B were smooth and had an even curve.

Into an Hm 3-17 insert having a step treated by method B, we inserted a blade of Nippon Spindle Mfg. Co., Ltd.'s make and ran the spindle on a spindle-rotation tester for 2,000 hours under the load $W = 187$ g—corresponding to the load of a yarn-filled spindle—the rotation number being $N = 14,500$ r.p.m. The lubricating oil used was Velocite E 10 cc. This test showed the amount of the lengthwise wear of the blades given in Figure 14.

The “lengthwise amount of wear” is a value comparatively measured by a 1/1,000 mm-dial indicator on the basis of the conical section of the blade pivot, as shown in Figure 13.

Since it is necessary to deal statistically with the wear phenomena, we used 23 spindles for the inserts of the test pieces treated by method A and 20 spindles for the inserts of the test pieces treated by method B. Figure 15, therefore, indicates their standard deviations.

From the curves in Figure 15 we find that the pivots treated by methods A and B develop about

### Table 4. Step and Its Hardness

<table>
<thead>
<tr>
<th>Treatment of step</th>
<th>Test piece</th>
<th>Surface hardness (MVH 100 g)</th>
<th>Test piece</th>
<th>Internal hardness (HRC)</th>
</tr>
</thead>
<tbody>
<tr>
<td>No. 1</td>
<td>No. 6</td>
<td>772 858 803 488</td>
<td></td>
<td>66.1</td>
</tr>
<tr>
<td>No. 2</td>
<td>No. 7</td>
<td>707 698 690</td>
<td></td>
<td>66.2</td>
</tr>
<tr>
<td>Quenching</td>
<td>No. 8</td>
<td>642 882 870 858</td>
<td></td>
<td>66.7</td>
</tr>
<tr>
<td>in air</td>
<td>No. 9</td>
<td>858 734 464</td>
<td></td>
<td>65.9</td>
</tr>
<tr>
<td>cold working</td>
<td>No. 10</td>
<td>882 689 627 724</td>
<td></td>
<td>66.4</td>
</tr>
<tr>
<td>A</td>
<td>No. 11</td>
<td>888 852 882</td>
<td>No. 16</td>
<td>65.8</td>
</tr>
<tr>
<td>New heat</td>
<td>No. 12</td>
<td>858 847 835</td>
<td>No. 17</td>
<td>66.8</td>
</tr>
<tr>
<td>treatment</td>
<td>No. 13</td>
<td>303 858 835 835</td>
<td>No. 18</td>
<td>65.8</td>
</tr>
<tr>
<td>(bright)</td>
<td>No. 14</td>
<td>847 852 835</td>
<td>No. 19</td>
<td>66.9</td>
</tr>
<tr>
<td>quenching</td>
<td>No. 15</td>
<td>852 835 847</td>
<td>No. 20</td>
<td>66.2</td>
</tr>
<tr>
<td>and new cold working</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

![Fig. 11. Step for measuring hardness.](image1.png)

![Fig. 12. Condition of finishing surface of step.](image2.png)
the same wear trend: the initial wear field characterized by a measurable increase in the amount of wear is seen for about 300 total running hours \((= 2.6 \times 10^8 \text{ rev.})\), after which only a moderate wear field is noticed.

This seems to be a wear trend different from that observed in the fundamental test referred to in chapter 2. It is a reasonable trend, however, if the amount of wear expressed in terms of the loss in weight is replaced with the amount of lengthwise wear.

The test pieces treated by method B were smaller in the amount of wear and smaller in the distribution of the amount of wear than the test pieces treated by method A. This seems to be the result of an improvement in their wear resistance property.

As shown in Figure 10, the total amount of wear of the test pieces treated by method A is larger, if the inclination of the curve is observed. Their wear seems to have been aggravated by the abrasive wear coming from the debris of wear. The inferiority of method A to B in surface finishing seems to have added to the amount of the wear of the test pieces treated by method A.

These results convince us that care should be taken about internal hardness as well as surface hardness, and that the step treated by method B is superior in surface finish.

4. Conclusions

We have looked into the main factors influencing the wear of the footstep section of spindles equipped with roller bearings for spinning. Our spinning wear tests with the use of flat plates and balls (both made of SUJ2 bearing steel) have shown that the amount of wear increases in an almost linear relation to the total rotation number, increases slightly with an increase in weight, and increases rapidly with a decrease in the spinning rotation speed.

This suggests that a speed-up of service spindles through the promotion of their efficiency would reduce wear.

By using three hardness combinations, we investigated what kind of combination could reduce the total amount of wear. It has been established that reasonably hardened steps are preferable to the existing blade pivots. It has also been shown that the steps treated by the new method B, with their improved surface finish and surface hardness, have greater wear resistance property and reduce the wear of the blade pivot.

References

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