

Bearing Tester Analysis of the Factors in Engine Plain Bearings Seizure

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ABSTRACT

A bearing tester that overcomes the problems of a conventional bearing tester was fabricated and experimental modes were selected in order to clarify factors determining the seizure limit of engine plain bearings. Using this tester, seizure tests were performed on copper-lead bearings with an overlay and aluminum alloy bearings, both of which are used as automotive engine bearings. Bearing hydrodynamics calculation was performed based on the obtained experimental data. These results clarified that the seizure limit for copper-lead bearings with an overlay is determined by the occurrence of plasticity flow of the overlay due to the maximum oil film pressure, and that the seizure limit for aluminum alloy bearings is determined by the minimum oil film thickness.

1. Introduction

Requirements more stringent than ever before have been placed on the plain bearings of automobile engines in recent years, due to such factors as the reduction of friction level, more compact engine sizes, reduced width due to improved crankshaft rigidity for improving NVH, and a reduced amount of lead in the fuel to minimize the burden on the environment.^{(1)~(5)}

It consequently became necessary to clarify the mechanism for bearing seizure in order to identify the parameters for judging the suitability of a plain bearing.

However, since conventional plain bearing testers seem unable to completely break away from the level of a relative comparison of bearing performance, it is necessary to employ a quantitative evaluation in order to enable a design study of bearing suitability. In order to achieve this quantitative evaluation, it was necessary to devise a new type of plain bearing tester and the most appropriate experimental procedure. This report presents the mechanism for seizure as determined by this new bearing tester with the experimental procedure that was used.

2. Overview and Problems with Conventional Bearing Testers

Fig.1 shows a system diagram of a conventional testing system, Fig.2 shows the conventional method for measuring the temperature of the test bearing and sliding parts in the direction of the load, and Fig.3(a) shows the conventional load pattern.⁽⁶⁾

This conventional test employs a method in which the static load generated by hydraulic pressure is applied to a round shaft supported by bearings. The test is stopped when the indicated temperature at the back of the test bearing, or the bearing friction torque, reaches a prescribed value. The

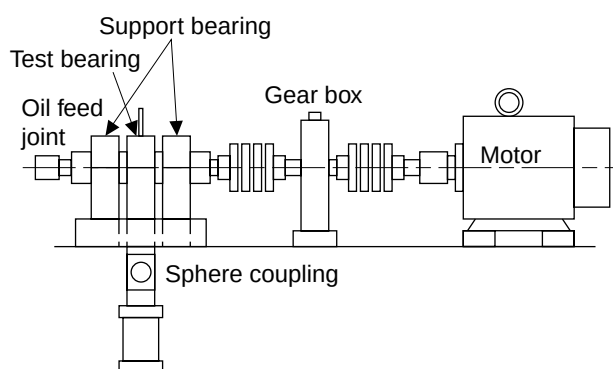


Fig.1 Conventional system of the equipment

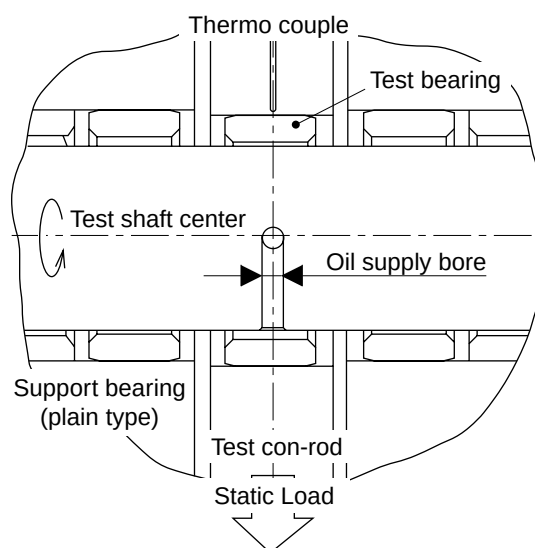


Fig.2 Conventional bearing part

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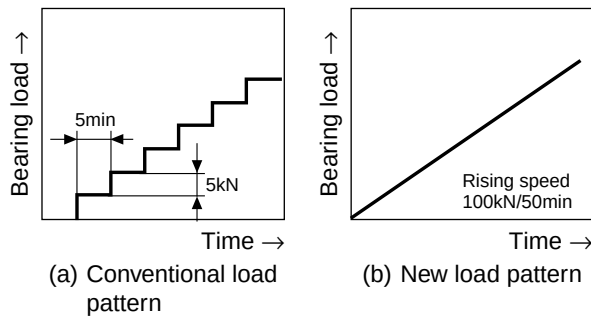


Fig.3 Bearing load pattern

reason for stopping the tester before the bearing has completely seized is to prevent damage to the tester components that would be caused by the sudden stopping torque that is generated when seizure occurs. Problems associated with this testing system are as follows:

- (1) The tester must be stopped at a stage before the bearing completely seizes, despite the purpose of the test being to analyze seizure.
- (2) The temperature of the support bearings has a significant effect on the temperature at the back of the test bearing.
- (3) The method for assessing contact between the shaft and bearing involves only visually examining the bearing contact state after testing.

3. New Bearing Tester for Seizure Analysis

Fig.4 shows a system diagram of the newly devised bearing tester, while Fig.5 illustrates the method used to measure the temperature of the test bearing and load sections.

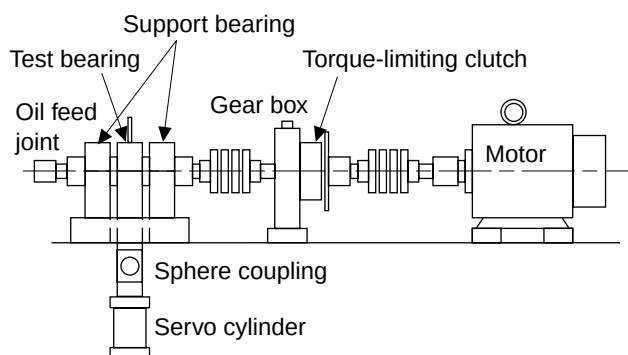


Fig.4 New system of the equipment

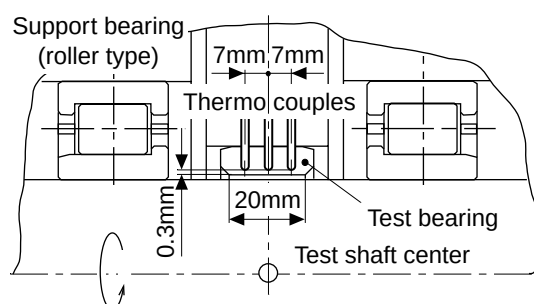


Fig.5 Developed bearing part

This tester has the following characteristics:

- (1) By providing a torque-limiting clutch between the motor and gear box, testing can continue until the bearing has completely seized (until the bearing surface melts or the shaft and bearing seize solid).
- (2) A roller bearing that generates very little heat is used for the support bearings to minimize the effects of the support bearing temperature.
- (3) An additional location for temperature measurement is provided across the bearing width as a method for assessing whether the shaft and bearing are making contact. Contact between the shaft and bearing can be detected by monitoring the temperature balance. In addition, a design is employed in which sheathed thermocouples are embedded in holes at the back of the bearing surface so that the temperature close to the bearing sliding surface can be measured to monitor the phenomena that occur on the sliding surface. The use of this method makes it possible to accurately adjust the shaft inclination without having to view the contact state of the bearing.

Instead of the conventional method of applying a load in steps, a linearly increasing load is applied as shown in Fig.3(b). Since a rapid temperature rise and seizure tended to occur when the load was increased in steps as shown in Fig.3(a), or in other words, since it was determined that the seizure load varied according to the load increment at each step and the time the load was held constant, the load is increased along a linear gradient to avoid the effect of increasing the load in steps.

Fig.6 shows the results of repeatability testing by this method.

Although there is a difference of about 10% in the load during seizure occurrence, the plots during the course of the temperature rise and those of the secondary rise in temperature are nearly identical.

A list of test conditions applied is shown in Table 1.

Tests were conducted on copper-lead bearings and aluminum alloy bearings that are typically used in automotive applications.

The structure of an automotive plain bearing consists of a soft material having outstanding sliding properties supported on a strong backing plate. The sliding materials

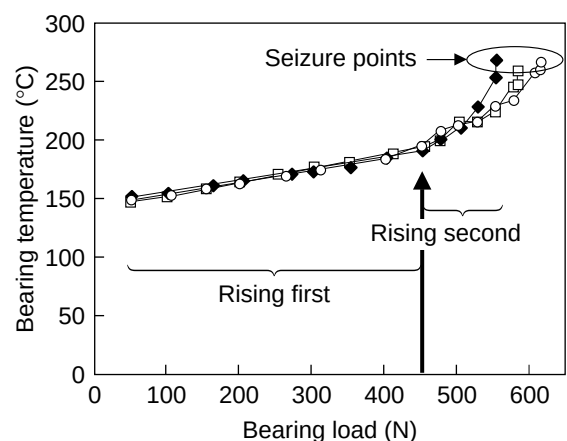


Fig.6 Confirmation test of the repeatability

Table 1 Tested condition

Shaft rotation speed	3000 ~ 6000 rpm
Feed oil temperature	35 ~ 140 °C
Feed oil pressure	300 kPa
Radial clearance	13 ~ 20 μm
Oil SAE grade	10 W-30
Shaft surface roughness	0.8 S (Rmax)
Oil feed method	Shaft feed

can be broadly classified into those made of lead alloy and those made of aluminum alloy, each of these being further classified into several subcategories according to the performance. In contrast to using an overlay of soft lead on the sliding surface of copper-lead bearings to achieve uniformity, many aluminum alloy bearings use a single alloy layer having aluminum as its main component.

4. Results of Seizure Tests for Individual Bearing Materials

4.1. Seizure Characteristics of Copper-Lead Bearings

Fig.7 shows measured results for the sliding surface temperature up to seizure relative to the load for a lead alloy bearing.

Fig.8 is a schematic drawing of the contact characteristics of the bearing surface that were observed when the tester

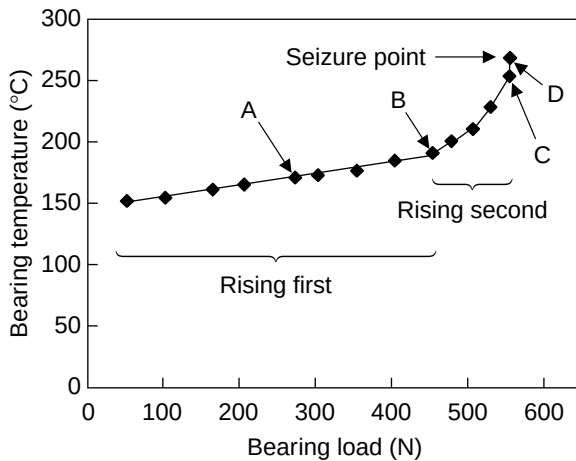


Fig.7 Temperature process of the Pb bearing

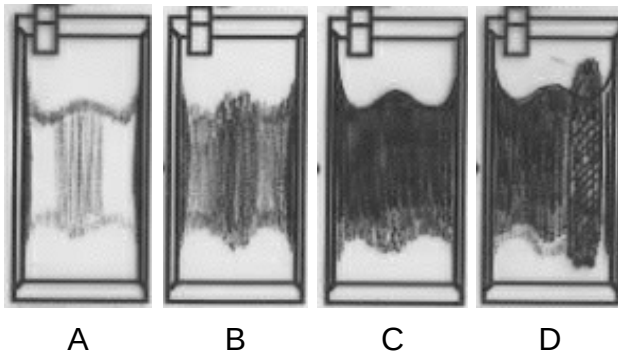


Fig.8 Characteristic of bearing surface of Pb bearing

was stopped at each of the points indicated in Fig.7.

Characteristics at each test point are described next.

A: The state during which the temperature linearly increases: Slight contact is apparent between the shaft and bearing.

B: The state near the end of the linear rise in temperature: Substantial contact occurs overall.

C: The state during which there is a secondary rise in temperature: Although greater overall contact occurs, in contrast to the contact in states A and B which is apparent as scratches both upstream and downstream, plastic flow of the overlay in the downstream contact portion is clearly apparent. This phenomenon occurs prior to reaching the melting temperature of the overlay, and indicates flow due to physical plasticity.

D: The state after the overload torque clutch has operated: Flow occurs due to melting of the overlay.

Based on these findings, over the linear range of the temperature increase, metal contact on the bearing sliding surface progresses, and the temperature increases linearly relative to the load. A secondary temperature rise is then initiated at point B, and plastic flow of the overlay is thought to occur.

Changes in the sliding surface temperature relative to the load are shown in Fig.9 when changing the oil temperature, bearing radial clearance and shaft rotational speed to identify the onset of seizure under the various conditions.

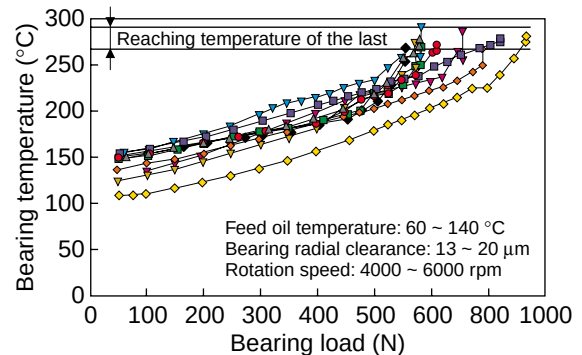


Fig.9 Parametric study of oil temperature, radial clearance and rotation speed on Pb bearing

The measured temperatures were influenced differently by each of these parameters under the same load. Although the load at which seizure occurred is different in each case, the ultimate temperature can be seen to be within a fixed range under all the conditions. This is believed to correspond to the melting point of the surface layer.

4.2. Seizure Characteristics of Aluminum Alloy Bearings

Fig.10 shows the measured results of the sliding surface temperature leading up to seizure of the aluminum alloy bearing. Fig.11 is a schematic drawing of the contact characteristics of the bearing surface that were observed in the same manner as that for the copper-lead bearing.

A: The state near the end of the linear rise in temperature: Substantial contact is apparent throughout, which is

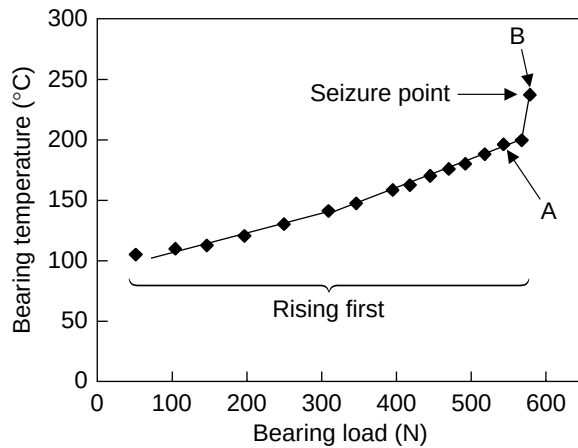


Fig.10 Temperature process of the Al bearing

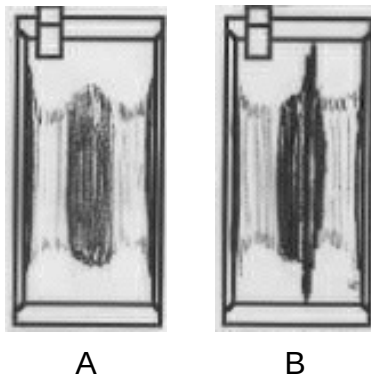


Fig.11 Characteristic of bearing surface of Al bearing

similar to the case of the copper-lead bearing.

B: The state after the overload torque clutch has operated: In contrast to the apparent melting of the surface overlay in the case of the copper-lead bearing, flow occurs due to adhesion of the surface of the aluminum alloy that has been picked up from the area with the vertical scratches at the center.

Fig.12 illustrates the process leading up to seizure when the parameters of rotational speed, oil temperature and bearing radial clearance were changed.

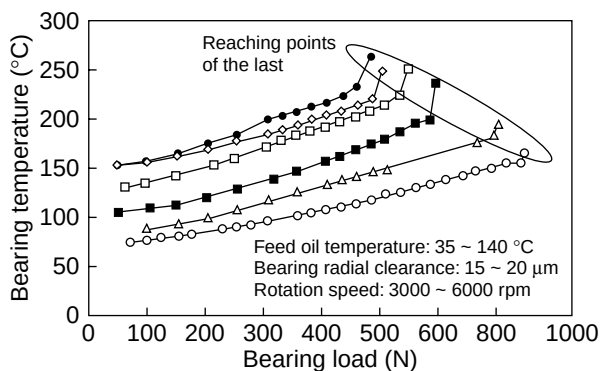


Fig.12 Parametric study of oil temperature, radial clearance and rotation speed on Al bearing

The aluminum alloy bearing was determined to have the following characteristics in comparison with the copper-lead bearing:

1. Seizure occurred immediately after completion of the primary temperature rise.
2. Adhesion within the bearing occurred regardless of the melting point of the aluminum alloy.
3. There was no correlation between the seizure threshold load and the sliding surface temperature.

5. Analysis of the Cause of Seizure

5.1. Calculation Conditions

Bearing hydrodynamic calculations were made using the test conditions as input values (load and sliding surface temperature) to analyze the cause of seizure.

The mobility method⁽⁷⁾ used in rigid body bearing calculations was applied. The shaft oil feed holes, lemon shape and relief shape were not considered in the calculations.

Fig.13 indicates the sampling points for data input into the calculation.

The value at which the temperature started to rise prior to the secondary rise in Fig.13(a) was used for the lead alloy bearing, this value being selected to determine the cause of the secondary rise in temperature.

The value just before the sudden rise in temperature and the onset of seizure was used for the aluminum alloy bearing.

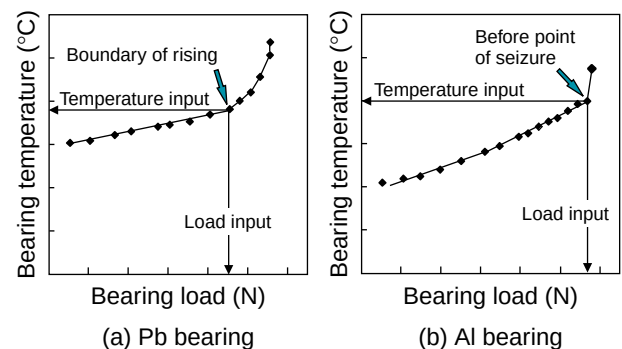


Fig.13 Definition point of calculation

5.2. Calculation Results

Fig.14 shows the results of the bearing hydrodynamic calculations. The graph also shows two types of bearing material. The first is the standard lead alloy material. The second is a lead + indium (Pb + In) material in which the overlay is softer than the standard lead alloy as a result of the added indium.

Table 2 shows the hardness of the bearing surfaces used in these tests.

When the minimum oil film thickness was plotted on the horizontal axis, and the maximum oil film pressure was plotted on the vertical axis, the lead alloy bearing demonstrates a horizontal distribution, while the aluminum alloy bearing can be seen to demonstrate a vertical distribution.

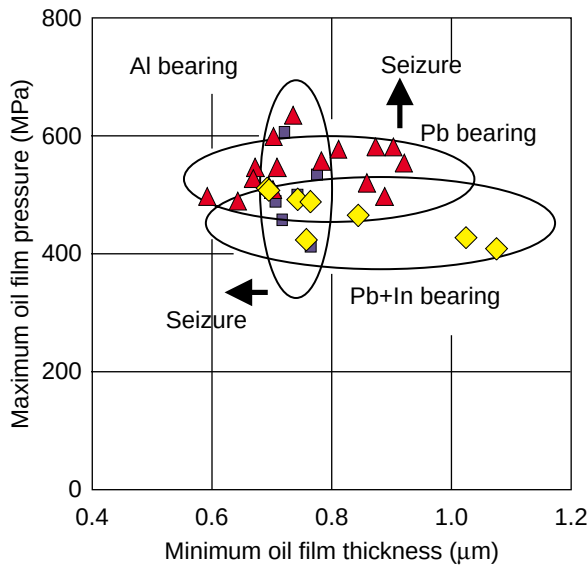


Fig.14 Calculation result

Table 2 Bearing surface hardness

Material	Scale	Value
Pb bearing	HMV10g	13 ~ 17
Pb + In bearing	↑	10 ~ 13
Al bearing	HV5g	42

This indicates that, in the case of the lead alloy bearing, when the maximum oil film pressure becomes excessively high, plastic flow of the overlay occurs, resulting in a secondary rise in temperature that eventually leads to seizure.

In addition, the plastic flow of the overlay at a lower maximum oil film pressure, as with the lead-indium bearing, also serves to support the above-mentioned cause of seizure.

6. Conclusion

One aspect of the mechanism for bearing seizure was quantitatively clarified by solving the inherent problems of conventional bearing testers and improving the test procedure.

1. The plastic flow of the overlay that occurred with the copper-lead bearings material is thought to have led to seizure due to the high oil film pressure that was induced between the shaft and bearing.
2. Since aluminum alloy bearings are not provided with a soft overlay on the bearing surface in the manner of copper-lead bearings, there is a critical limit to the minimum oil film thickness rather than a critical limit to the oil film pressure, and this is thought to lead to seizure.

The demonstration of this critical limit to the maximum oil film pressure over a wide range of oil film thicknesses has been clearly shown to be an indicator for defining the minimum oil film thickness and seizure threshold when designing bearings.

References

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