Non-destructive sizing method for ball bearing flaking

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Abstract. This paper proposes a new non-destructive method for evaluating the size of the flaking in ball bearing with an electromagnetic sensor. This method focuses on the variation of the magnitude of the characteristic frequency of a defect on the outer race. Through the presence of local maximums and minimums, the length of the flaking is evaluated while the bearing is in operation. The applicability and accuracy of this method is confirmed through several accelerated aging tests. It is shown that the growth of the length of the flaking in ball bearings is linear.
Keywords: bearing defect, flaking, non-destructive diagnosis, electromagnetic sensor

1 Introduction

In power and chemical plants, a lot of rotating machines such as pumps and blowers are used. In those equipments, ball bearings are commonly used for supporting rotating elements such as shafts and reducing the friction between moving and static parts through their mechanical structure and lubrication. When a defect appears in a bearing, friction is increased and the induced heat and vibrations lead to the malfunction of the equipment. It is therefore crucial to monitor the health of bearings to insure the good operation of rotating machines.

In practice, even when a measurement indicates the presence of a defect in a bearing, it does not necessarily mean that a breakdown is imminent and that a repair must be performed immediately. The knowledge of the characteristics of a bearing defect allows deciding when to stop and repair the equipment in a timely and cost effective manner.

This study introduces a new method for evaluating the size of the flaking of ball bearings in operation using an electromagnetic sensor. The results are confirmed experimentally and the characteristics of the growth of the flaking are examined.

2 Principles of electromagnetic sensors[1]-[5]

An electromagnetic (EM) sensor consists of a permanent magnet and a pickup coil wrapped around it. When a conductor moves in the static magnetic field produced by the magnet of the EM sensor, an electromotive force is induced in the conductor and eddy currents are generated. The change of the magnetic field is detected by the pickup coil (Fig.1). The signal measured by the EM sensor reflects the movement of conductors under the sensor. When an EM sensor is placed close to rolling elements, the EM signal shows the displacement of each rolling element.

However, in the present study, bearings are surrounded by a ferromagnetic casing and the magnetic field produced by the EM sensor hardly reaches the rolling elements such as the balls of the bearings. The source of the EM signal is thus mainly the microscopic movements (vibrations) of the casing surface where the EM sensor is located.

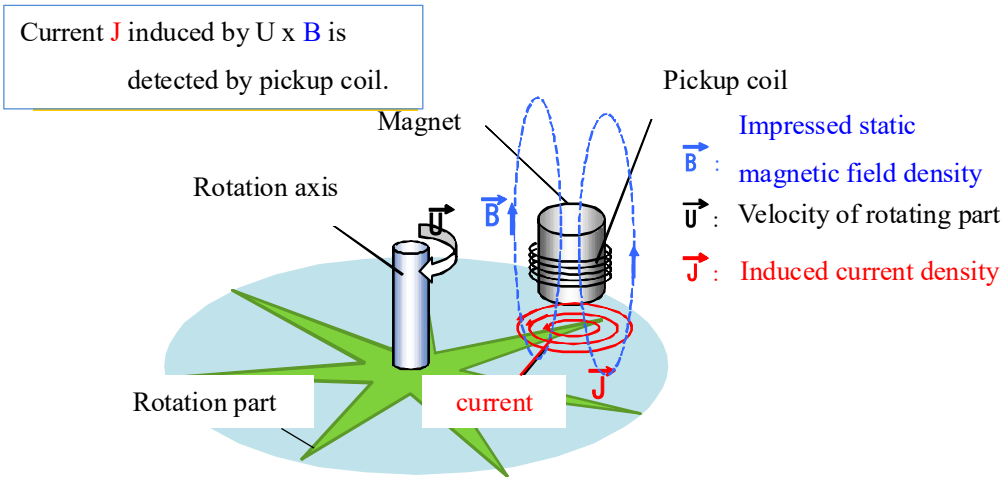
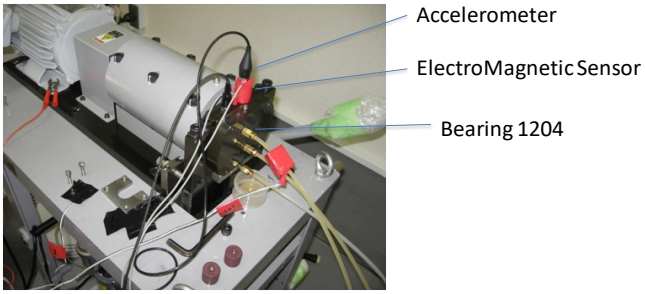


Fig. 1 .The principle of electromagnetic sensors.

3 Experimental Setup

Accelerated aging tests of bearings are performed with several radial loads.(Table 1) The test bearings are self-aligning ball bearing of type 1204 with a system of lubrication by oil circulation. All tests start with a healthy bearing and data are acquired with both an EM sensor and an accelerometer placed on the casing of the bearing. The experiments are stopped once the reading of the accelerometer reaches the value of 5G.



rotation speed	2400 rpm
lubrication	oil circulation
load direction	radial

Fig. 2 . Experimental setup.

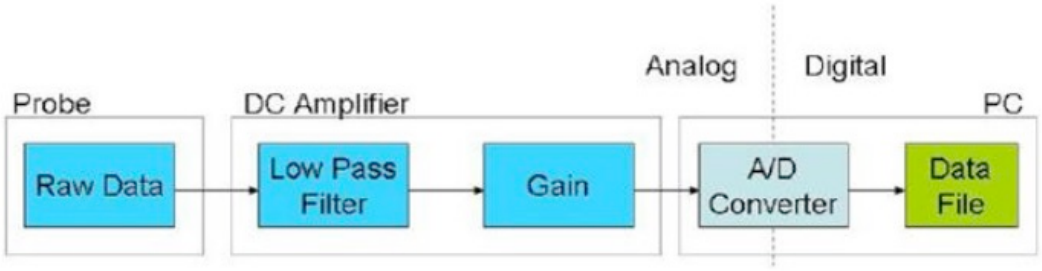


Fig. 3 . Data acquisition system setup.

Table 1 Loading conditions

Test ID	Load (kgf)
1	1200
2	1125
3	1050
4	1050
5	975
6	900
7	825
8	750

4 Sizing Method

When flaking occurs on the outer race of the bearing, a stronger vibration is produced each time a ball passes through the defect. This vibration is periodic and its frequency is called the outer defect characteristic frequency (ODCF). As the size of the flaking increases and eventually reaches a length equal to the distance between two neighboring balls, the periodicity of the vibrations is lost as there is always a ball on the defect that is producing vibrations. There is no more transition between the states “no ball on the defect” and “one ball on the defect”. This causes the ODCF component to disappear from the EM signal. As the length of the flaking continues to increase, the same phenomenon occurs and can be explained in the same manner but this time by considering one additional ball. As long as there is a transition between two states (this time between the state “one ball on the defect” and the state “two balls on the defect”), the ODCF appears in the EM signal. It disappears again when the length of the flaking becomes equal to the distance between three successive balls. By monitoring the magnitude of the ODCF, local minimums will appear each time the flaking has a length that is a multiple the distance between two neighboring balls. Because this phenomenon is linear and continuous, the magnitude of the ODCF component will reach a local maximum between two local minimums.

When this happens, the length of the flaking can be evaluated and will be equal to a multiple of the distance between two neighboring balls added to one half of this distance.

To evaluate the magnitude of the ODCF, acquired signals are band-pass filtered with a narrow band which includes ODCF, then the RMS (Root Mean Square) of signals are calculated.

5 Experimental Results

Outer race flaking occurred in the totality of the eight tests. The size of the flaking was evaluated several times during the experiments and at the end of each experiment. The final evaluated length is compared to the actual size of the flaking as measured on the bearings.

Fig.4 to 6 show some of the experimental results. Each figure shows the variation of the magnitude of the ODCF component during the experiment and a picture of the bearing outer race after the completion of the experiment. The presence of local minimums and maximums can be clearly detected. By using the method described previously, the size of the flaking can be estimated at several points during the experiments (each time a local maximum or minimum is reached). The test bearings have 12 balls on a single race. The angle between two successive balls is thus 30°. In the following, the evaluated length of the flaking is expressed by an angle.

In the case of the experiment shown in Fig. 4, the ODCF magnitude increases significantly after 22 minutes when flaking occurs. After 30 minutes, the magnitude reaches a local maximum and the length of the flaking can be evaluated as one half of the distance between two neighboring balls (*i.e.* 15°). When the first local minimum is reached, the length of the flaking is evaluated to be 30°. At the end of the experiment, the length of the flaking is estimated to be about 45°. This value agrees with the actual measurement of the flaking after the experiment is completed (see the picture of Fig.4).

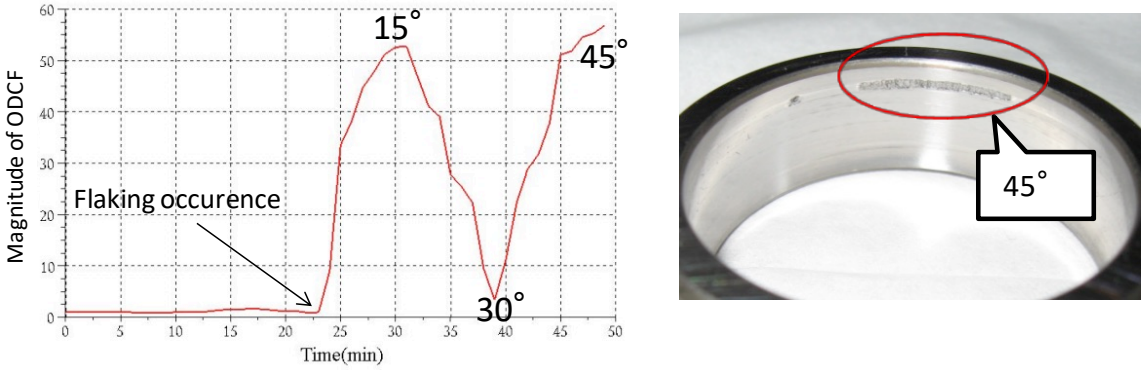


Fig.4. Magnitude of the ODCF and picture of the bearing outer race after the test (Test 1)

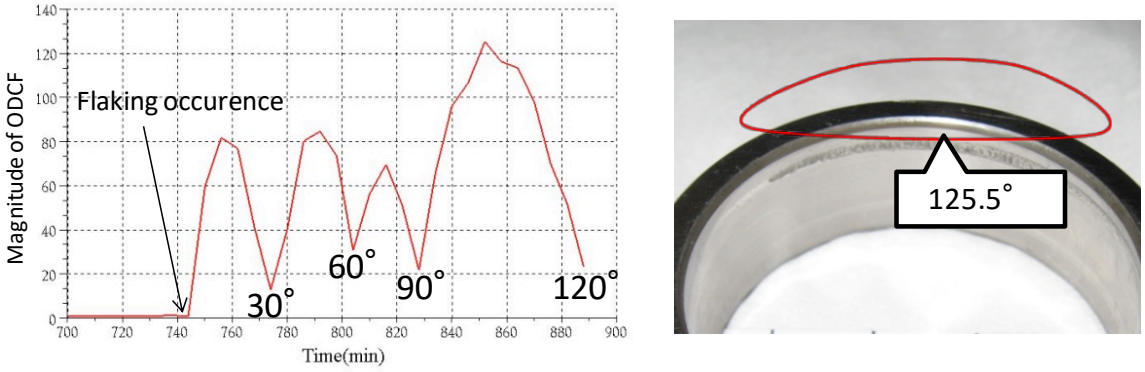


Fig.5. Magnitude of the ODCF and picture of the bearing outer race after the test (Test 2)

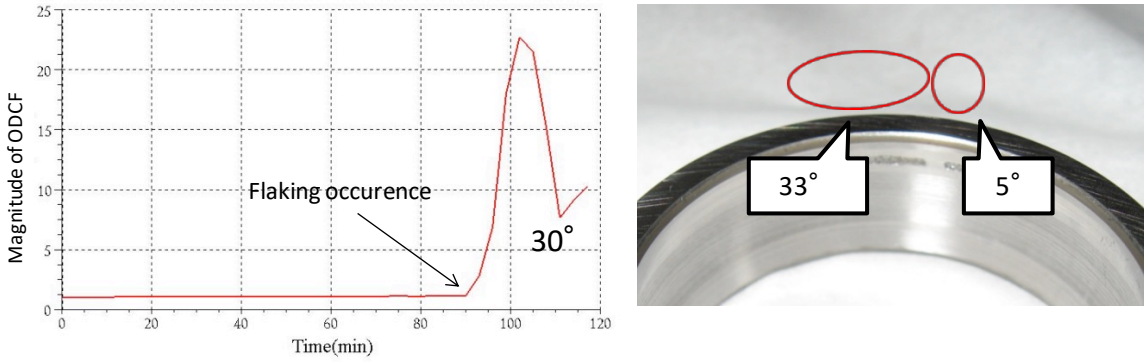


Fig.6. Magnitude of the ODCF and picture of the bearing outer race after the test (Test 5)

Table 2 shows the estimated flaking length and the actual measurement value at the end of each test. A very good agreement is found between the actual length of the flaking measured on the bearing and its evaluated length at the end of each test.

Table 2: Estimated and actual flaking length at the end of tests

Test ID	Estimated flaking length	Actual flaking length
1	=~ 45°	45°
2	> 120°	147°
3	=~ 120°	125.5°
4	=~ 120°	125.5°
5	30°~ 45°	33°
6	=~ 30°	28.5°
7	> 150°	160°
8	> 150	155°

Fig. 7 shows the growth of the length of the flaking depending on the time and the load. The point at the right end of each curve is the actual measurement value of the length of the flaking. The other points are the evaluated lengths of the flaking during the tests. These curves show that the growth of the flaking is linear and does not depend on the load.

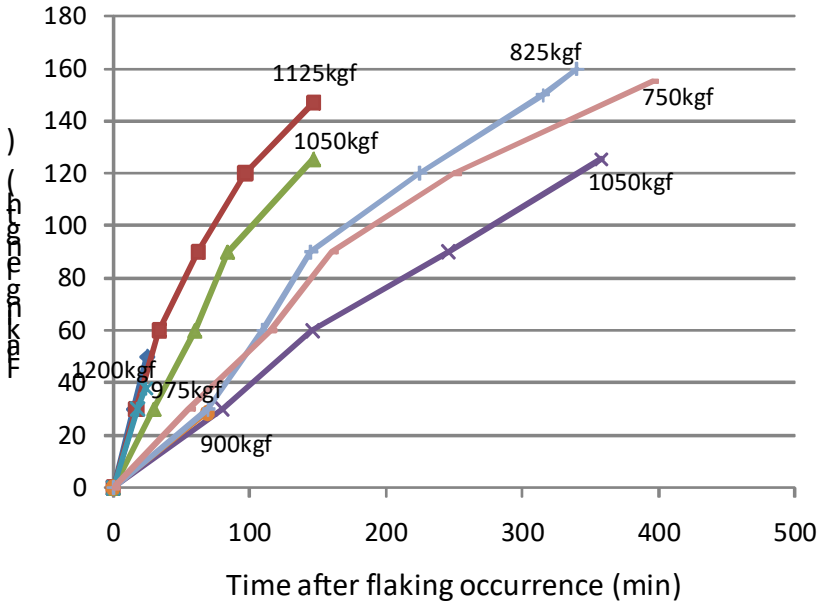


Figure 7: Growth of the flaking depending on the time and the load.

6 Conclusions

A new nondestructive method for evaluating the length of the flaking in ball bearings was presented. This method makes use of an electromagnetic sensor to evaluate the length of the flaking in bearings while they are in operation. The applicability and accuracy of this method was experimentally confirmed by several tests of accelerated aging.

Using this method, the nature of the growth of the flaking was shown to be linear. This finding can be used for estimating the remaining life of bearings from the time flaking first appears.

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