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Evaluation Method of Bearing Steels using High Frequency Ultrasonic Testing†

1. Introduction

Bearings are key parts in many types of machinery, including automobiles. Extended life under cyclic loading (rolling fatigue life) is required in bearing steels used as materials for bearings. From an early date, JFE Steel Corporation has conducted research and development aimed at extending the life of bearing steels[1].

In order to extend bearing steel life, it is necessary to discover the optimum manufacturing conditions by evaluating fatigue life under various manufacturing conditions. However, because of the long duration of rolling fatigue life tests, considerable time is required before the test results are available, and this had been the controlling factor for improvement efforts.

Therefore, for rapid evaluation of life characteristics, JFE Steel developed a new technique for evaluating inclusions in steel, which are the point of origin for fatigue cracks, by using a high frequency ultrasonic testing method.

2. Evaluation Method

In a study of inclusions, which are the cause of rolling fatigue cracks, it has been reported that even microscopic inclusions with a size of approximately 10 μm or smaller may become a point of origin for cracks[2]. Therefore, a method which makes it possible to detect microscopic cracks is required in an evaluation method for inclusions in steel. On the other hand, evaluation of inclusions in a large 3-dimensional volume is necessary in order to improve evaluation accuracy. To meet these requirements, JFE Steel studied an evaluation method using ultrasonic C-scan testing[3].

Figure 1 shows a schematic diagram of the ultrasonic C-scan testing method. This is a technique in which defects are detected in a certain range (detectable area) in the depth direction while performing 2-dimensional scanning of the probe along the surface of the specimen. **Photo 1** shows a photograph of a measuring device using ultrasonic C-scan testing.

As a distinctive feature of ultrasonic testing methods, including ultrasonic C-scan testing, detection performance, detection speed and the detectable area differ greatly depending on the ultrasonic probe used. Here, the following equations show the relationship between beam diameter b and detection depth l, and the probe frequency f, transducer diameter D and focal distance F[4].

$$d \propto \frac{F}{f \cdot D}$$

$$l \propto \frac{F^2}{f \cdot D^2}$$

From these equations, it is not possible to satisfy both improvement of detection performance by reducing the beam diameter and an increase in the detection depth. Thus, it is necessary to select the probe corresponding to the intended purpose. Since the priority in

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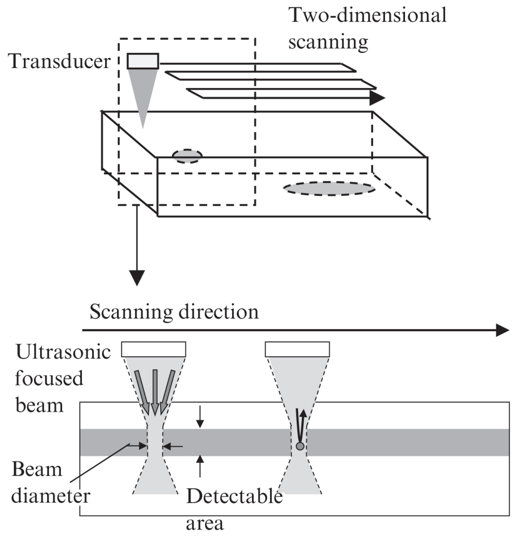

Fig. 1 Schematic diagram of ultrasonic C-scan testing

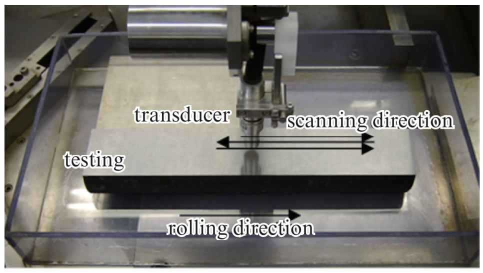

Photo 1 View of ultrasonic C-scan testing

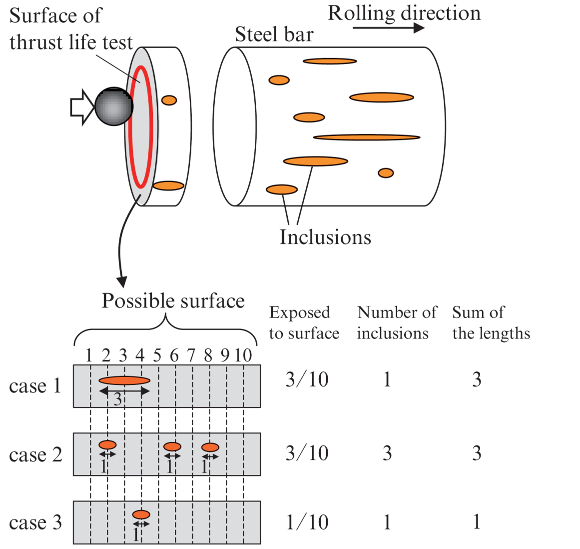

Fig. 2 Concept of evaluation by summing indicated length

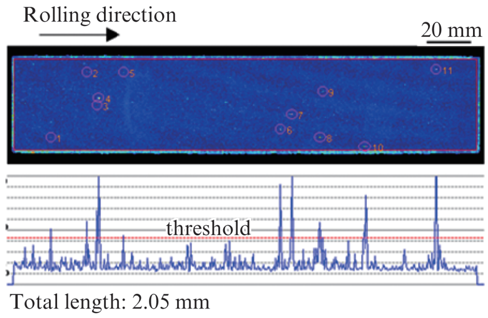

Fig. 3 Evaluating all of the testing area

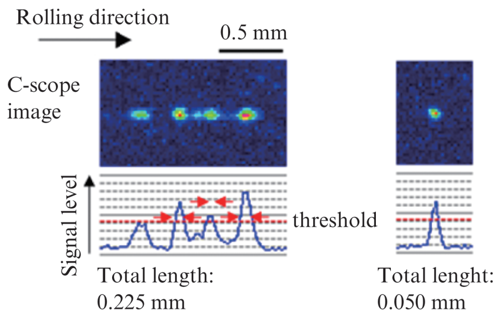

Fig. 4 Examples of inclusion images

this evaluation method is detection performance for microscopic inclusions, a high convergence probe with a frequency of 50 MHz or more and beam diameter of 100 μm or less was mainly used. The immersion method[5] was used as the coupling method.

For analysis of the signals obtained by ultrasonic C-scan testing, the following evaluation method was developed, considering the fact that the probability that an inclusion will be exposed near the bearing rolling surface changes according to the length of the inclusion in the material rolling direction. That is, the material rolling direction length is calculated for regions (indicated regions) in which a signal exceeding a predetermined threshold is obtained, the sum of the indicated lengths is then calculated by adding the rolling direction lengths of the various indication regions, and the result is output as one main item in the evaluation results. Since this evaluation value is considered to correspond to the probability that an inclusion will be exposed near the rolling surface of an actual bearing product, as shown in **Fig. 2**, good correspondence with rolling fatigue life can be expected.

3. Examples of Evaluation

Figure 3 shows the result of ultrasonic C-scan testing and evaluation by this method. As shown in the figure, the evaluation is performed by obtaining the sum of the indicated lengths by adding the indicated lengths of all of the inclusions detected in the detectable area. It is possible to evaluate flaw detection in this wide range in a time of approximately 0.5 to 2 h (depending on the conditions) per 10 000 mm^2. At this time, the detection depth is several 0.1 mm to 1.0 mm (determined by the probe used), and detection of 10 000 mm^2 corresponds to a detection volume of several 1 000 mm^3 to 10 000 mm^3.

Figure 4 shows examples of images of individual microscopic inclusions detected by ultrasonic C-scan testing, and the results of individual evaluations of those inclusions. It can be understood that the inclusions on the left side in Fig. 4 are elongated in the material rolling direction, and as a result, the sum of their indicated lengths is larger than that of the spotted inclusion in the image at the right. Thus, in addition to evaluating the detection surface as a whole, a detailed evaluation of individual inclusions is also possible. These can be analyzed, and the results can be reflected in improvements in manufacturing conditions.

Figure 5 shows a comparison of the results of an evaluation of high cleanliness bearing steel by this technique, and the results of a rolling fatigue life test (thrust life) of that bearing steel. For comparison with the newly-developed technique, the figure also shows a comparison of the result of evaluation of part of the same bearing steel using an optical microscope and fatigue life by the conventional method. According to the comparison of fatigue life by the two methods, a good correlation cannot be seen between the evaluation by the optical microscope and fatigue life in the high cleanliness bearing steel evaluated in this study. (At a glance, there appears to be a positive correlation, but this is unreasonable, as fatigue life would increase as the size of the inclusions becomes larger.) In contrast, a correlation can be seen between the evaluation by the

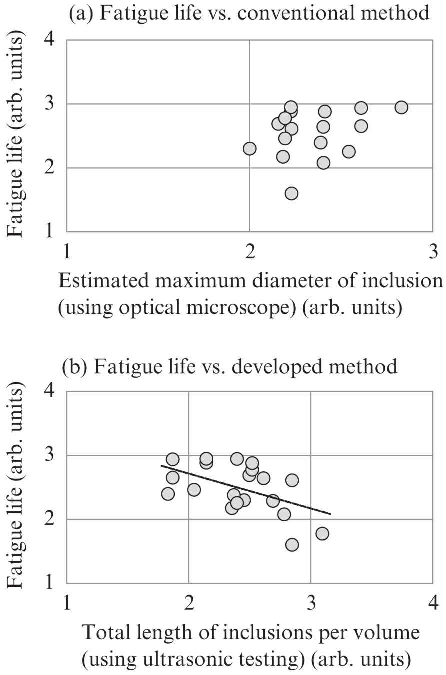

Fig. 5 Comparing fatigue life with evaluated results of conventional method and developed method

technique developed in this research and fatigue life. From this, it can be understood that the developed technique is an effective evaluation method for high cleanliness bearing steels.

4. Conclusion

Microscopic inclusions affect the fatigue life of bearing products. In order to evaluate microscopic inclusions in bearing steel, a technique in which the total indicated length of inclusions in the detection volume was developed by using high frequency ultrasonic C-scan testing. A good correlation between evaluations by this technique and the results of the rolling fatigue life test was obtained. In the future, JFE Steel will work to further extend the life of bearing steels by accelerating efforts to further improve product cleanliness and fatigue life based on quick evaluations of bearing steels by the newly-developed technique.

References

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