DIAGNOSTIC TECHNIQUE OF ABNORMALITIES IN BALL BEARINGS WITH AN ULTRASONIC METHOD

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Abstract

The sensitive and quantitative measurement method will be important to evaluate the lubrication condition and to predict the remaining bearing life-time. Observations of the size and number of damage or wear particle, and the fluctuation of the ball load are useful for the quantitatively evaluation of operation abnormalities in a ball bearing. The vibration and AE (Acoustic Emission) method are usually used as the effective diagnostic technique. However, it is difficult to detect those items individually by these methods. Then, the ultrasonic technique was attempted to use as a semi-quantitative measuring method for sensing these quantities. Ultrasonic wave pulses are entered into a bearing housing from an ultrasonic probe attached to the outside of the housing. Those pulses are partially reflected from the interface between the housing and the outer ring of the bearing. Because of the different acoustic impedance between the solid-to-solid contact and the contact with an intervening gas or liquid layer, the height of the reflected echo depends on the real contact area or on the local contact pressure at the interface. In a normal condition, the height of the filtered echo pulses produces smooth, nearly sinusoidal peaks corresponding to passages of the balls. Semi-quantitative evaluation of abnormality becomes possible on the basis of the observation of magnitude and frequency of the echo height fluctuation. Diagnosis of bearing abnormality was performed as a standard of evaluation in size, fluctuation velocity and mode of echo height fluctuation. Then algorithms for the judgment of those abnormalities were added in diagnostic software, and abnormal width or fluctuation rate of ball support load were evaluated semi-automatically. As a result, the measurement of model indentation with 0.3mm width added to inner ring and the quantitative evaluation of growth of an indentation were enabled.

1. Introduction

In recent years, the ratio of rolling contact fatigue by the internal crack started from an internal non-metallic inclusion has been decreased. On the other hand, flaking of the surface origin induced by indentation in a raceway surface becomes a serious problem in maintenance of a rotary machine which operates under the mixed lubrication region.

Therefore, the observation of the degradation process of bearing with the deterioration of the lubricating condition is important for the prediction of accurate bearing life. It is necessary to evaluate the lubricating condition and to detect the sign of life limit in early stage of damage of ball bearing. In particular, estimation of size and quantity of the damage parts and observation of variation rate of ball load may become effective. Therefore, sensitive and quantitative measurement method to improve the evaluation accuracy is necessary.

The vibration method is usually used as an effective diagnostic technique. The AE method is also expected with becoming an effective measuring method, if noise counterplan and signal processing technology are improved. In addition, observation of the wear particles by using ferrography and particle counter, which has been performed frequently in plant, is known as effective method. However, quantitative measurement of the flaw size, quantity of flaw parts and the fluctuation of ball load is difficult by these methods described above.

Then ultrasonic technique is used to measure the indentation size. In case of this study, the height of echo reflected from the interface between housing and outer ring of bearing depends on the load supported with a ball [1]. Degree of damage can be evaluated from local drop of echo height with reduction of a ball support load when ball contacted with a flaw.

For universal use, the software including the algorithm to diagnose bearing abnormality was made, and measurement of the indentation having 0.5mm and 0.32mm in width which attached on the inner ring surface of ball bearing was tried.

2. Evaluation target for diagnosis and example of measurement method

The reduction of bearing life with flaking induced by indentation becomes a serious problem, since frequently solid contact occurs under the mixed lubrication condition. Therefore, analysis of deterioration process is necessary to predict accurate bearing life limit.

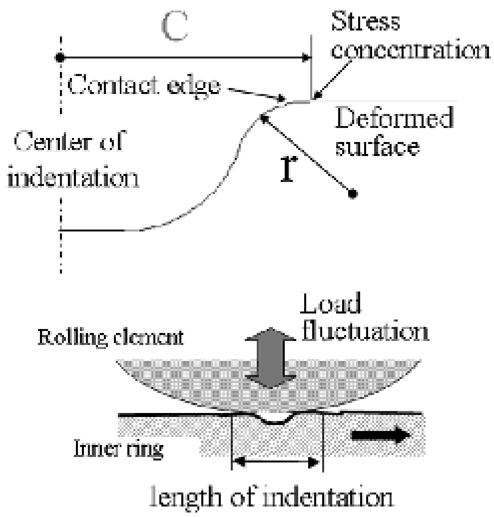

Figure 1: Diagnosis items for indentation

Fig.1 shows the evaluation items which becomes important for the improvement of prediction accuracy of operation conditions in ball bearing with indentation on a surface of raceway. As the flaw on a surface is able to progress to severe flaking, in-situ and quantitative evaluation of the indentation length and the quantity of damage part becomes important. In addition, the fluctuation of the ball load seems to influence a life of bearing, too. Therefore, it is necessary to evaluate it quantitatively. Father more, information of the wear particle which exist between orbital plane and rolling element is also important, because the intervened wear particle affect the formation of indentation. Then, sensitive and quantitative measurement methods for sensing those items are necessary.

Table 1: Detection method of abnormality

Diagnosis items		Vib.	A.E.	U.T.
Indentation	Number	△	◎	○$^{+}$
	Shape	×	×	○$^{+}$
	Load fluctuation	○	○$^{+}$	○$^{+}$
Particle	Number	△$^{-}$	◎	○$^{+}$
	Shape	×	×	○$^{+}$
	Load fluctuation	○	○$^{+}$	○$^{+}$
Discrimination		△$^{-}$	△	◎
Sensitivity		○	×	◎$^{+}$

Table 1 shows some example of detection method for operation abnormality defined with some indexes, such as a number, shape, load fluctuation, discrimination of particle or flaw, described in the table. The vibration method is usually used as a effective diagnostic technique of rolling bearing abnormality, because a measurement technique and analysis are established and operation is simple. A.E. method is also expected with becoming effective measuring method, if noise counterplan and signal processing technology are improved. However, it is difficult to measure plural indexes individually by using the vibration and A.E. method.

Then ultrasonic technique is applied for semi-quantitative evaluation of abnormalities in a ball bearing. As the height of the echo depends on the real contact area formed at the interface, it is possible to discriminate the particle or flaw [2] [3]. However, it is not discussed here.

3. Measurement principle

There are roughness and waviness on machined surface. The boundary surface has been composed of slight solid contact part and thin aerial layer, when dried two surfaces contacted each other. The part of ultrasonic waves transmitted from ultrasonic probe is reflected in proportion to difference of acoustic impedance of solid and air and to non contact area. Then first reflected echo height h shown in Fig.2 is observed on the display of ultrasonic flaw detector. Reflected echo height h is lowered, since the solid contact area is larger and the contact pressure in high sound pressure region is higher [4].

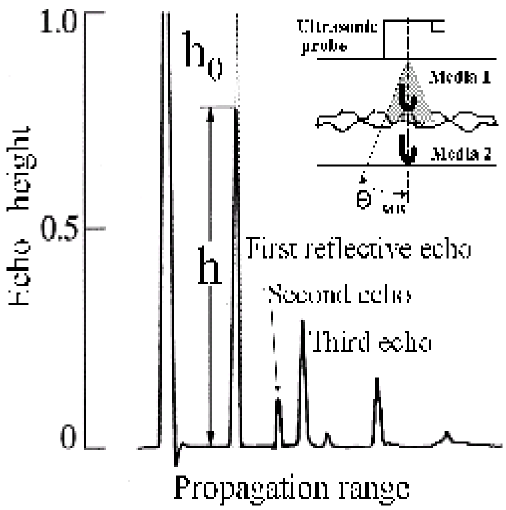

Figure 2: Measurement principle

First reflected echo height h changes by characteristic and mounting condition of the probe and effect of diffusion and scattering of the acoustic wave in propagating route. For excluding these effects, the contact condition is evaluated by the value (h/h_0) which was standardized by echo height h_0 in the condition that two surfaces were perfectly separated [5] [6].

4. Observation of operating state

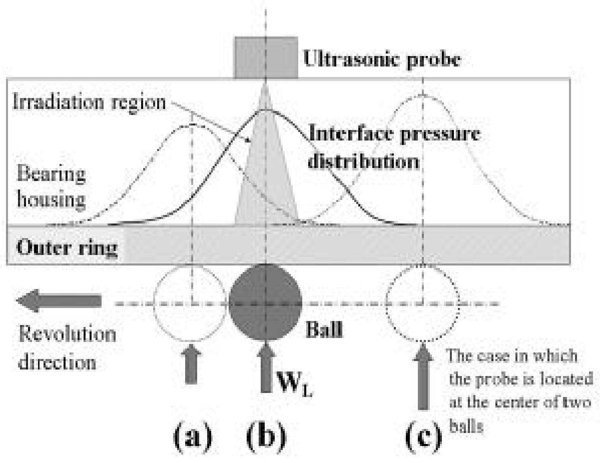

Figure 3: Observation principle of operation state

The example of applying the measurement principle described above to the observation of operating state of the ball bearing is shown in Fig.3. In this study, the change of the first reflective echo height from contacting surface between outer ring of ball bearing and bearing housing is observed. In case of the ball bearing, the load added to the shaft is supported by the ball in the loading side.

Therefore, the pressure of contacting surface is the highest at the position of the ball [7], and it gradually decreases in both sides of the ball, it is shown in Fig.3. Then, the pressure in Fig.3(c) lowers most, since it is in the position where two balls of the neighbors are equal from the sound axis of the probe. And then, the echo height in this case is the highest, and h_0 is shown. On the other hand, the echo height lowers to h in case of Fig.3(b) in which the ball exists near the sound axis.

In this paper, operating state is evaluated by echo height ratio H $\{=(1-h/h_0)\times100)\}$ of which the correspondence between pressure of contacting surface and echo height is easy. Namely echo height ratio H is a scale which means a transmission level of ultrasonic waves. Therefore, H in the condition that the ball has separated from the sound axis is low. And, H in the condition in which the ball exists on the sound axis shows the highest value.

By the way, the waveform of observed H repeats only the smooth fluctuation when the bearing without the damage is normally operated. However, the load supported by the ball fluctuates instantaneously when the ball pass through a damage part. Therefore, the reflectivity of the ultrasonic waves also changes as shown in Fig.4, since the pressure of the contacting surface near the sound axis is influenced by them. Then, the detection of abnormality using the ultrasonic method becomes possible, because the sudden fluctuation is superimposed on the continuous smooth waveform [1].

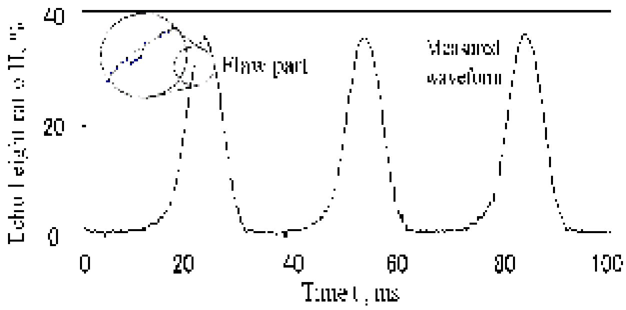

Figure 4: Example of phenomena of H

5. Experimental equipment and conditions

Fig.5 shows the outline of the experimental equipment. In the experiment, deep groove ball bearing which had 70mm pitch diameter was used. The bearing was installed into the steel housing so that the center of width was located on beam axis of the probe, where the pressure of a fitting surface has maximum value. Then, the normal load of 40KN was applied to the bearing, and rotational speed in these tests was set to 500 rpm.

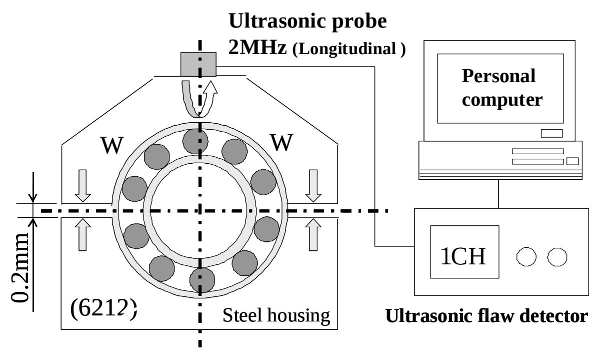

Figure 5: Outline of experimental equipment

Operating condition of test bearing was examined by 2MHz longitudinal wave probe, piezoelectric element diameter is 10mm, attached to the outside of the steel housing by sound adhesives. Repetition frequency of pulse of ultrasonic flaw detector was set to 10KHz, and the data was gathered in every

100 μs by A/D converter with using the developed software.

Fig.6 is the geometry of model damage added to the inner ring by Vickers indenter. In particular, depth of indentation in case of 0.32mm width was about 3.5μm almost same with a real damage.

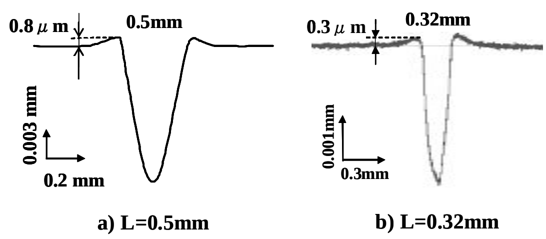

Figure 6: Geometry of model damage

6. Indexes for judgment of abnormality and flow of software

Three indexes shown in Fig.7 were defined to specify the abnormal part. Index 1 is the fluctuation ratio of support load by a ball, index 2 is the intensity of impact when a ball came in contact with an indentation, and index 3 shows the change of gradient in echo height ratio H.

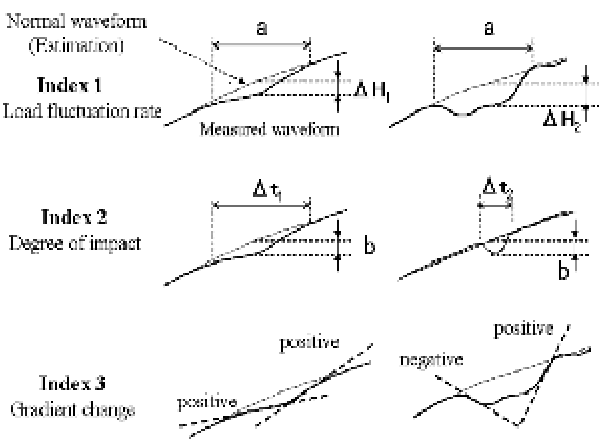

Figure 7: Indexes for judgment of abnormality

The length of indentation and the load fluctuation were estimated in a step shown in Fig.8. At first, abnormal part was specified based on magnitude of each indexes shown in Fig.7, and the final abnormal part was assigned by a combination of each provided indexes. In the diagnosis treated here, the points in which all indexes exceed a threshold were taken as abnormal part.

The neighboring waveforms were extracted after determining abnormal part, and a normal waveform was estimated by least square method. The difference ΔH between estimated normal wave form and measured wave form was calculated, and width of indentation L and decreasing ratio of ball support load, $\delta H_M = \Delta H_M / H \times 100$ %, were evaluated (Fig.11 is an example).

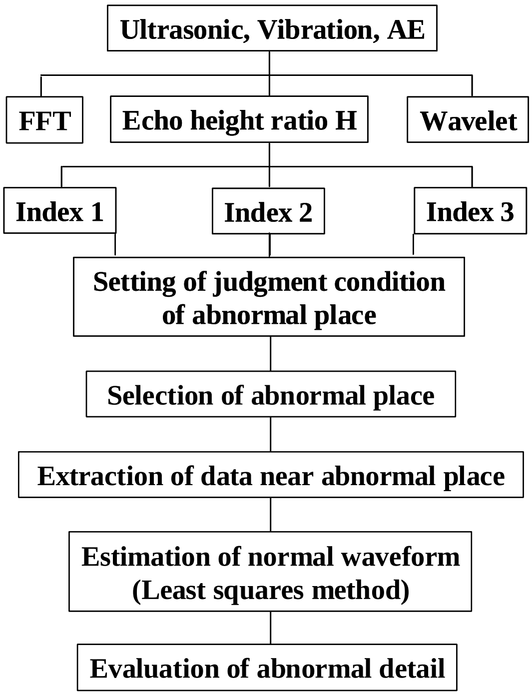

Figure 8: Flow of diagnostic procedure

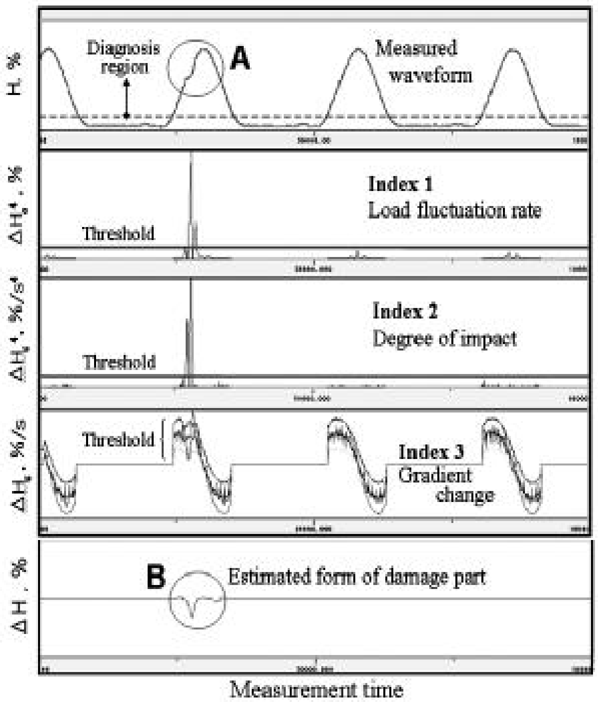

Figure 9: Example of real processing data

Above-mentioned step was applied to all data, and abnormal details were evaluated quantitatively. As the time-current characteristic was taken too much to carry out these activities by manual operation, algorithm for the judgment of abnormalities was added in diagnostic software. However, there was little data of the fatigue test evaluated by this software, and a correct threshold with each index could not be determined automatically. Then each threshold was set low, and candidate of abnormal parts were elected by software, and data of the neighborhood were extracted automatically, and abnormal parts were decided by visual inspection. Therefore, it was semiautomatic abnormal diagnostic method, but a diagnosis time was able to be considerably shortened by automatic detection of the candidate of abnormal parts.

An example of real processing data is shown in Fig. 9. In the region where an echo height ratio was low, accurate evaluation of the damage was difficult because a ball locates at the outside of ultrasonic irradiation region. Then the diagnosis was performed only in the region where the echo height ratio H exceeded a threshold as shown in the upper stage of Fig.9. In this example, obtained results were almost same with index 1 and index 2, and the gradient of H in index 3 was also reduced suddenly at the same point. Therefore, the points in which all of these indexes exceeded the threshold were identified as abnormal points, and data of H in region including the neighborhood was extracted.

On the other hand, normal waveform was estimated by using the least square method which treated the echo height data except the data in abnormal region. The difference between those waveforms is shown at lower stage of Fig.9, and the detail is in Fig.10.

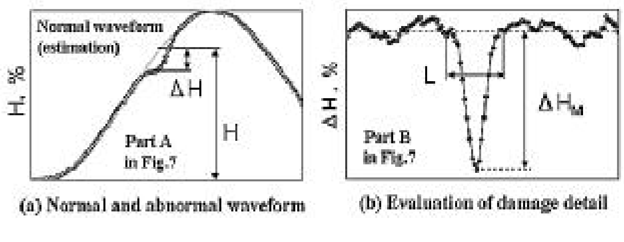

Figure 10: Evaluation example of detail of damage

7. Evaluation of indentation width and decreasing ratio of ball support load

Evaluation result of the abnormal details for the model damage of 0.5mm width is shown in upper stage of Fig.11. Width of indentation estimated from echo height was about 0.55mm and was almost same with added indentation width. The lower stage in same figure shows a real geometry of indentation measured after an experiment. The measured indentation width was about 0.57mm, and its geometry denoted by solid line accords with the variation of H shown by plot point.

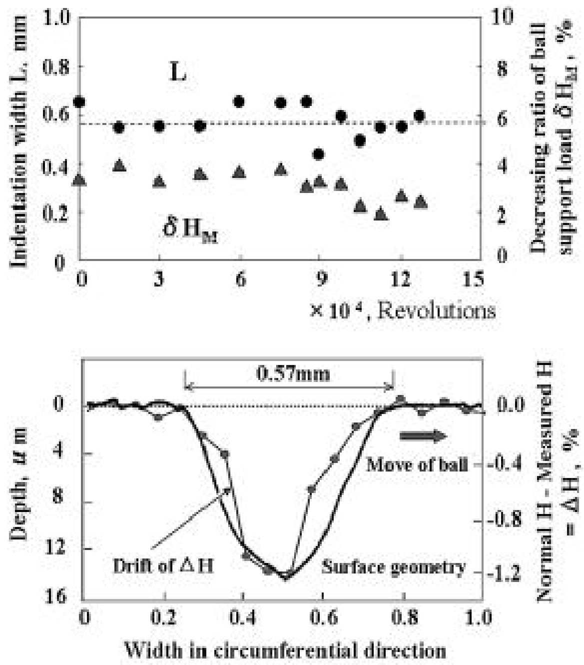

Figure 11: Evaluation result of abnormality

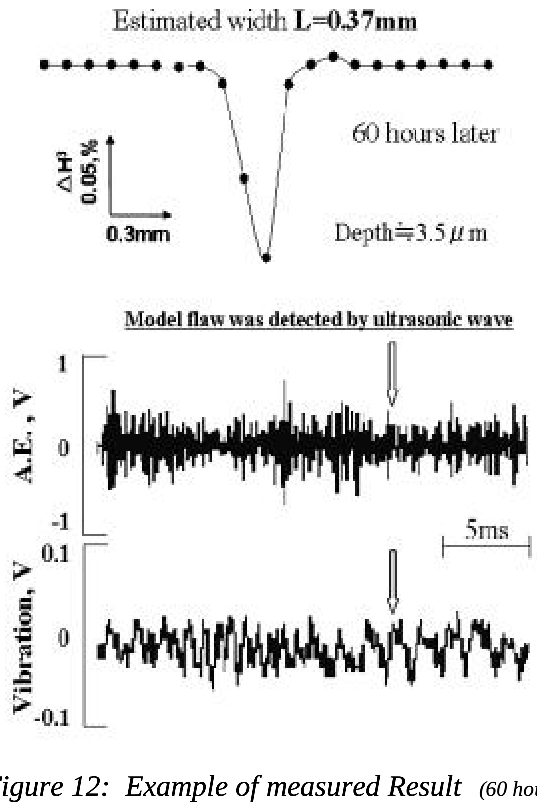

Figure 12: Example of measured Result (60 hours)

Result of a measurement for indentation of 0.32mm width is shown in Fig.12 and Fig.13 together with a result of the vibration and A.E..

Indentation width estimated from echo height variation in early stage of experiment was 0.37mm and was almost same with indentation width shown in Fig.6(b) attached by Vickers indenter. However, in a vibration and A.E. wave form measured at the same time, the significant variation was not observed as shown with arrow.

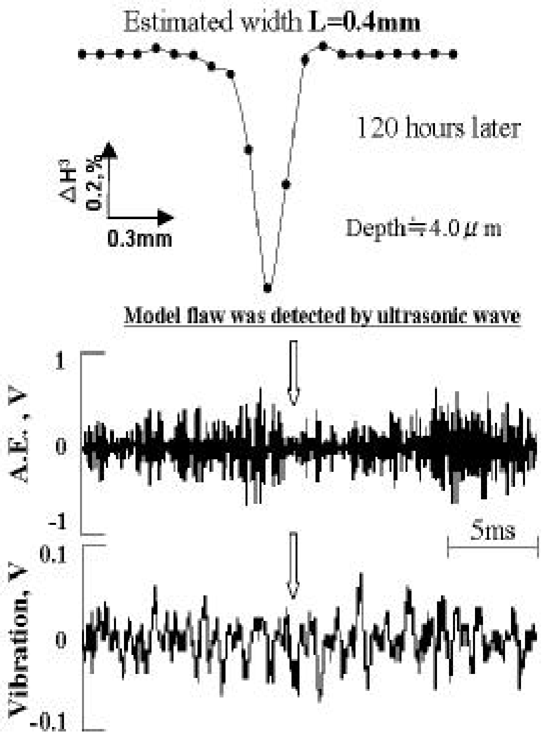

Figure 13: Example of measured Result (120 hours)

Result after 120 hours passed since an experiment began is shown in figure 13. Since the indentation had been progressed during 60 hours, indentation width estimated by ultrasonic method, about 0.4mm, was slightly wide compared to the result shown in figure 12, and echo height fluctuation ΔH^3 increased up to quadruple of initial value. These results suggest the possibility that can evaluate deterioration process of bearing quantitatively.

8. Conclusions

The ultrasonic technique was used for semi-quantitative evaluation of the bearing operation abnormality. Three indexes, the fluctuation ratio of support load by a ball, the intensity of impact when a ball came in contact with an indentation, the change of gradient in echo height ratio H, were defined to specify the abnormal part.

For universal use, those algorithms for the judgment of abnormalities were added in diagnostic software, and abnormal width or fluctuation rate of ball support load were evaluated semi-automatically.

As a result, it became possible to estimate the width of the small and shallow indentation having a geometry almost same with real damage.

9. References

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