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Development of a Method of Continuously Detecting Transverse Cracks in Rail Heads




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Transverse cracks (squats) occurring in rail heads are usually managed by ultrasonic detection from the rail top surface using an angle probe or by ultrasonic transmission detection where probes are placed on the gauge face and field face of the rail head. However, when there are defects such as large horizontal cracks or head checks on or under the rail surface, or when there is some deformation of the rail head due to wear and the like, those interfere with ultrasonic waves, resulting in insufficient defect detection. At the same time, to find internal defects that develop in a certain length of rail, it is also desirable in terms of improving detection efficiency to continuously detect such defects while moving in the direction longitudinal to the rails. In light of that situation, we have developed a new defect detecting device. The developed new device can continuously detect transverse cracks regardless of the rail head condition by using phased array technology where two probes send and receive ultrasonic waves at the upper fishing surfaces (underside of the rail head).

●Keywords: Rail, Squat, Transverse cracks, Ultrasonic defect detection, Phased array

1 Introduction

Rail defects are currently managed mainly by ultrasonic rail defect detection. Detecting and managing transverse cracks caused in rail heads is particularly important because they may affect transport. In general, a transverse crack branches off from a horizontal crack called a squat as shown in Fig. 1 and develops toward the bottom of the rail.

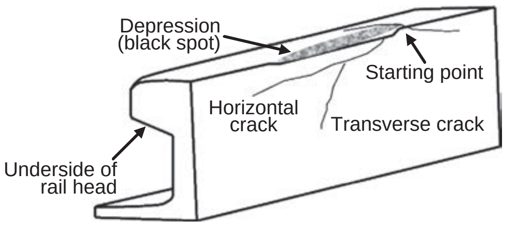

Fig. 1 Forms of Squat

In on-site ultrasonic defect detection, transverse cracks are sometimes difficult to detect because of damage on or under the rail surface (head checks or horizontal cracks) or rail head deformation due to wear. There was also a need for longitudinal continuous detection. In light of those, we have developed a rail defect detection device that detects defects from the upper fishing surface of the rail head (hereinafter, "underside of the rail head") using phased array technology.

2 Issues in Current Defect Detection Method

If a horizontal crack is located on top of a transverse crack in defect detection from the rail top surface using an angle probe (incidence angle of 70º) as shown in Fig. 2, that horizontal crack interferes with the ultrasonic waves, causing incorrect measurement of the depth of the transverse crack. In some cases the transverse crack is judged to be deeper than it actually is due to multiple reflection of the ultrasonic waves. An ultrasonic transmission detection method as shown in Fig. 3 has thus been used in recent years. While this method is not affected by horizontal cracks, it is difficult in this method for ultrasonic waves to penetrate the rail head when wear or other deformations prevent probes from contacting firmly.

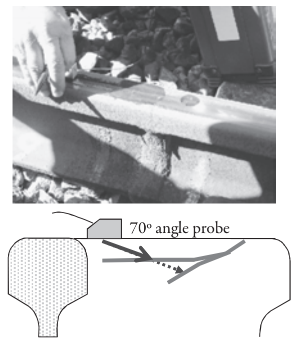

Fig. 2 Angle Beam Method from Rail Top Surface

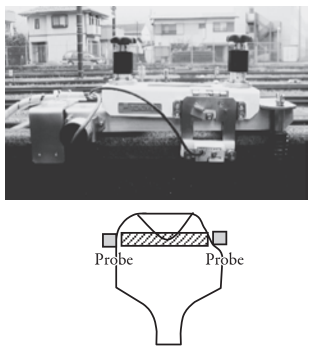

Fig. 3 Ultrasonic Transmission Method from Sides of Rail Head

In light of those issues, the Technical Center devised a method of reflecting from the underside of the rail head using two probes as shown in Fig. 4 as a method where transverse cracks can be found regardless of the condition of the rail head surface or the rail head deformation. We also developed a defect detection device that uses that method.[1] With that method, an operator manually scans the longitudinal position and the angle to the rail head of the probes to detect echoes reflected from the surface with a transverse crack. Based on the ultrasonic beam path length and the angle of each probe, the depth of the crack is worked out.

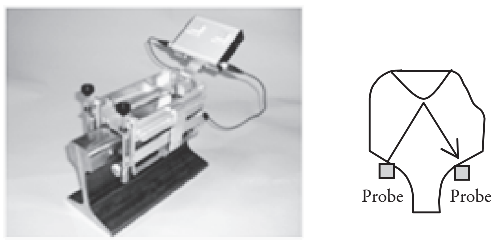

Fig. 4 Defect Detection Using Reflection from Underside of Rail Head

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The three methods (ultrasonic detection using an angle probe, ultrasonic transmission detection, detection using reflection from the underside rail head) also have further issues other than those mentioned above in that repeated scanning is needed to find the deepest part of a crack and that detection accuracy is dependent on the skill of the operator.

3 Features of Phased Array Technology

3.1 Areas Where Phased Array Technology Is Applied

As a method to allow continuous and broad detection of defects in rail heads while moving longitudinally along the rails, we investigated the applicability of phased array to rails.

Medical ultrasonography such as sonographic imaging devices for viewing children in the worm is an example of a well-known type of ultrasonic defect detection device (ultrasonic test instrument) using phased array. For industrial use, phased array devices were developed and their production started in the 1980s. With an advantage in being able to handle complex shapes, they are used for inspection and maintenance of energy plant systems and for quality check of steel production lines.

With rails, phased array devices are used to for tasks such as detecting defects in the production line as an method to improve the rail production quality assurance system.[2)] In this case, however, probes are fixed while rails move to detect any pinhole-like production defects. The phased array defect detection device we have developed is the first attempt at moving the device itself in on-site rail defect detection to measure defect size.

3.2 Principles and Terms of Phased Array Technology

In usual ultrasonic detection, each probe has a single element to send and receive ultrasonic waves. In phased array detection, however, a probe has multiple elements and excites each element with a time lag to control the direction of the main ultrasonic beam. Fig. 5 is an illustration of this concept. Scanning with ultrasonic waves in a fan-like pattern is called sector scanning. That allows instantaneous detection of a wide area, and it thus can eliminate the need of repeated manual scanning to detect the deepest part of the transverse crack as explained in section 2.

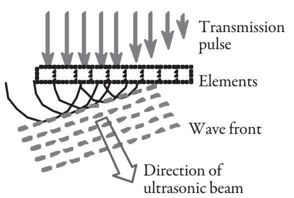

Fig. 5 Conceptual Image of Ultrasonic Beam

In the development, we first confirmed that almost the entire rail head could be scanned at a sector scanning angle of 60°. Then, after confirming the effectiveness of detection of rail transverse cracks with two probes from the underside of the rail head by different detection methods, we commenced development of the new detection device.[3)]

As phased array has not been standardized, we use the terms described in reference document 4). Table 1 shows some of the terms.

Table 1 Phased Array Terminology

Term	Description
Phased array	Formation of ultrasonic beams by controlling through electronic circuits the phase (time) of sonic waves emitted from multiple elements. For incoming signals, incoming signal waves are formed by controlling the phase of the incoming signals.
Array probe	An array probe is a probe composed of multiple (usually more than eight) elements. It is usually used connected to a phased array defect detection device.
Element	Elements that compose an array probe.
Electronic scanning	The general term of a method of scanning with ultrasonic beams while electronically switching elements of an array probe.
Sector scanning	A method of scanning where the direction of ultrasonic beams is changed by controlling the drive timing (phase) of individual elements of an array probe.

4 Overview of Continuous Detection Device for Transverse Cracks in Rail Heads

4.1 Device Structure

Fig. 6 shows an overview of the device. Operators control the device with a PC set on top of the device. Drive wheels are run at a constant speed by a motor while the device is supported by hand. A transmitter and receiver probe is placed on each side of the rail head as shown in Fig. 7.

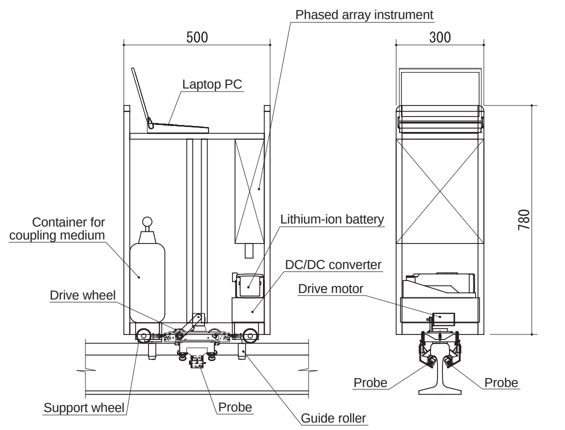

Fig. 6 Overview of Device Structure

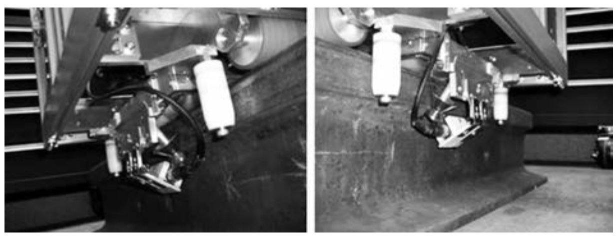

Fig. 7 Photos of Probes

Due to the placement of the probes, the device cannot detect defects at points such as alumo-thermic welds, rail bonds, fishplates, expansion joints, and level crossings. The direction that the device moves (detecting direction) is the same as the train running direction as transverse cracks develop in that direction. Fig. 8 is a photo of actual detection using the device.

Fig. 8 Actual Defect Detection

4.2 Characteristics of the Device

4.2.1 Probes

The detector has a transmitter probe on one side and a receiver probe on the other side at the underside of the rail head, and those probes receive by the double probe method the reflection echo from a defect.

Table 2 shows the specifications of the array probe. Sector scanning is performed at +/-30º (at a fan-shaped scanning angle of 60º). Fig. 9 shows the scanning zone.

Table 2 Array Probe Specifications

Item	Description
Frequency	3 MHz
Number of elements	10
Element length and width	10 × 0.6 mm
Gap (interval between elements)	0.1 mm
Refracting angle	50º
Probe outer dimensions	20 mm × 40 mm

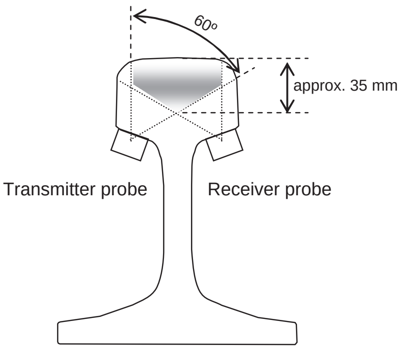

Fig. 9 Scanning Zone in Rail Head

4.2.2 Scanning Mode and Operation

The continuous detection device for transverse cracks in rail heads is operated using a PC set on the device. With the PC, operators can drive and stop the device as well as change the scanning mode and check the size of transverse cracks. On the conditions setting screen, scanning mode selection, line name, inbound or outbound line, left or right rail, and the like are input. Three modes of scanning are available: primary, secondary, and test continuous scanning modes. The primary continuous scanning mode is for detecting presence of transverse cracks while moving fast. The secondary continuous scanning mode is for detailed checking of the depth of transverse cracks detected in the primary continuous scanning, and the test continuous scanning mode is for detecting while checking the waveform.

(1) Primary Continuous Scanning Mode

In the primary continuous scanning mode, the movement speed is selected from 0.5 km/h, 1.0 km/h, or 2.0 km/h. At any speed, sector scanning is longitudinally performed at 5 mm pitch. Fig. 10 shows an example of the PC screen at scanning. When an echo exceeding the set threshold value is detected, the device plots the area at the rail profile on the screen. In the event that a transverse crack is ascertained, operators further can identify the deepest part of the crack by designating the area with the cross cursor to read that depth.

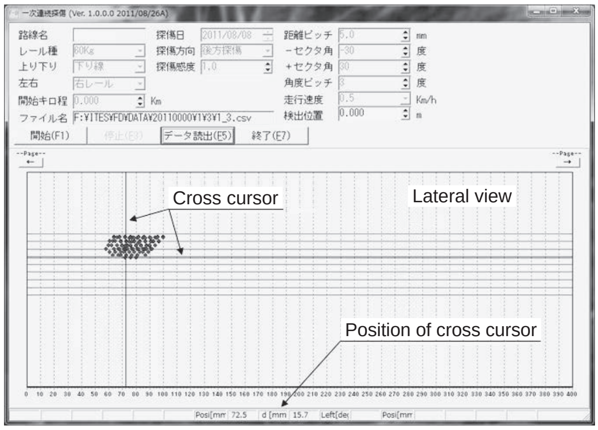

Fig. 10 Sample Screen for Primary Continuous Scanning Mode

(2) Secondary Continuous Scanning Mode

This mode is for checking the depth of transverse cracks in detail. In this mode, the movement speed is selected from 1 mm/sec., 2 mm/sec., or 5 mm/sec., and the sector scanning pitch is set to 1 sec., 2 sec., or 5 sec. Unlike with the primary continuous scanning mode, the width of the transverse crack can be read at the rail cross section on the screen in addition to depth as shown in Fig. 11.

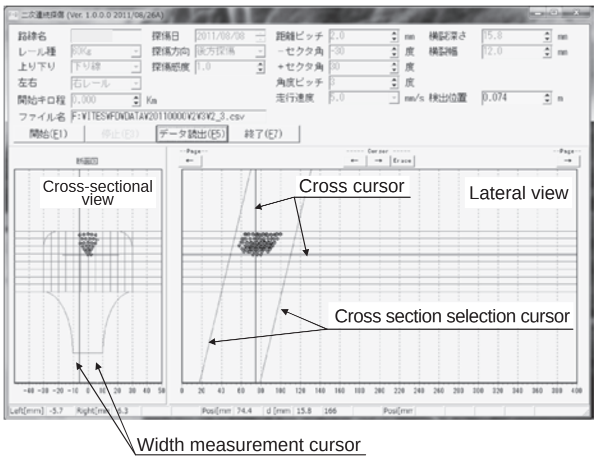

Fig. 11 Sample Screen of Secondary Continuous Scanning Mode

5 Transverse Crack Scanning Results

5.1 Artificial Crack Scanning Results

We tested the device using test rail pieces with artificial transverse cracks that simulated squats (crack depth 10 mm, 15 mm, 20 mm, and 25 mm). The scanning results in secondary continuous scanning mode are shown in Fig. 12.

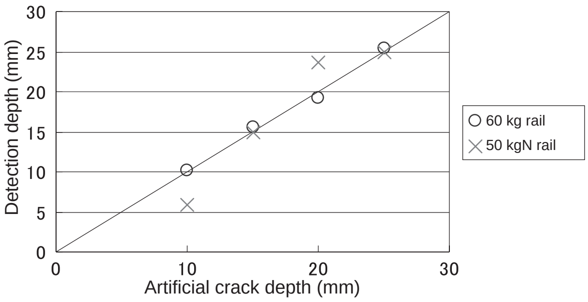

Fig. 12 Example of Detection Results

5.2 Scanning Results of Actual Crack on Commercial Line

The device detected a transverse crack of a depth of 10.3 mm on a rail of a commercial line. Fig. 13 shows that scanning image. To check the actual state of the defect, we cut the rail longitudinally (Fig. 14). The detected crack is in the circle shown in the figure. As cracks are scanned from the underside of the rail head in this method, the depth of the crack is calculated based on the dimensions of a new rail and indicated as a value including the wear depth of the rail head. The measured depth including the wear of the deepest part was 10.2 mm (approx. 8 mm when excluding the wear), equal to the results detected by the device. Even though the angle from the rail top surface of the transverse crack was approx. 30º, which is about a half of usual angle of a transverse crack that has progressed, the device could successfully receive the reflected echo.

Fig. 13 Detection Results

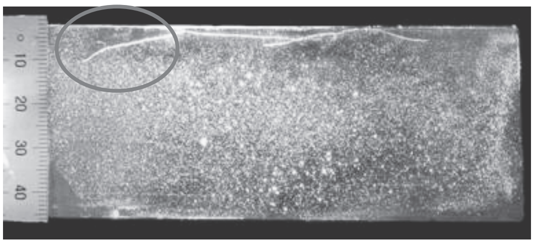

Fig. 14 Cross Section of the Scanned Rail

5.3 Performance Limits of the Device

When using the developed device, users have to keep in mind the following in preparation and when checking results.

(a) As the probes run along the underside of the rail head to send and receive ultrasonic waves, dirt and rust on the scanning surface must be removed before scanning.
(b) The larger the sector scanning angle is (at locations such as the ends of the fan shape of ultrasonic scanning), the lower the efficiency of ultrasonic wave reflection becomes, causing lower scanning accuracy.
(c) The more distant from the center of the rail cross section a transverse crack is, the lower the efficiency of ultrasonic wave reflection becomes, causing lower scanning accuracy. This is because the probes are fixed at the same position on the left and the right sides of the rail.
(d) Due to the features of this method, the device cannot detect horizontal cracks.
(e) Glycerin paste is used as the coupling medium.

6 Conclusion

Using the double probe method from the underside of the rail head with phased array technology, we developed a detection device that can solve the issues of the current angle beam and ultrasonic transmission methods and also continuously detect defects in the longitudinal direction to the rails. The device also enabled continuous and efficient detection and detection at locations where detection had been difficult.

With understanding of the performance and advantages of current methods and this device, we believe that better and more efficient on-site defect detection and rail defect management will become possible. We are therefore planning to further make use of the features of phased array technology for research on a defect detection system that can obtain various data on the shape of transverse cracks.

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