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Track Monitoring using Trains in Operation




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Inspections of track are currently done periodically by means such as use of track inspection cars and track patrolling on foot. To improve reliability and efficiency of such inspections, we have been developing track monitoring systems which can be installed on trains in operation and monitor the track with higher frequency. We developed a track material monitoring device and a body-mounted track measurement device that uses inertial mid-chord offset method (IMOM) as devices to monitor the condition of track material and track irregularity respectively, and we tested those installed on the MUE-Train series 209 test train running on conventional lines. At the same time, we also developed a track material monitor function that automatically judges abnormalities of the track material using range images. Moreover, we have confirmed that the developed body-mounted track measurement device that uses IMOM has accuracy required for practical use by verifying reproducibility accuracy in repeated measurements and consistency with measurement results from present track inspection cars.

●Keywords: Track monitoring, Range image, Inertial mid-chord offset method (IMOM)

1 Introduction

Track that supports railway cars is exposed to repeated train running load and to the elements, advancing irregularity and deterioration of tracks. Thus, it is important to correctly identify the status of irregularity and deterioration by inspections and to carry out repairs at an appropriate timing. Fig. 1 shows the usual track maintenance method employed by JR East. The horizontal axis is time, and the vertical axis is track irregularity. We measure dynamic displacement (track irregularity when train load applied) by track inspection cars (East-i) every three months. Irregularity and material deterioration are periodically inspected by track patrolling on foot and mechanically by inspection devices. Usually, when track irregularity exceeds the specified threshold (standard for repair), we estimate the timing for repair based on past experience and data to conduct systematic repair. But, even at locations where measurement results has not reached such a threshold, track irregularity may rapidly progress and troubles may occur before the next inspection due to factors such as condition of the ballast and roadbed. In other cases, track irregularity that has reached the threshold may remain constant and result in extremely inefficient repair work.

JR East has been developing track monitoring systems which can be installed on trains in operation with an aim of conducting frequent monitoring of the track condition and automatically judging any abnormalities found. Those devices will allow accurate identification of track conditions so repair work can be done at the optimal timing. We expect use of those devices will result in being able to achieve more accurate and efficient maintenance. Early detection of predictive signs of failures and early actions such as train operation control and information transmission to other trains when failures are detected will be made possible as well. Furthermore, automation of visual inspection will reduce manual work.

This article will give an overview of the track material monitoring device and the body-mounted track measurement device that uses IMOM as track condition monitoring devices. We will also report on the running test results of those devices installed on the MUE-Train series 209 test train.

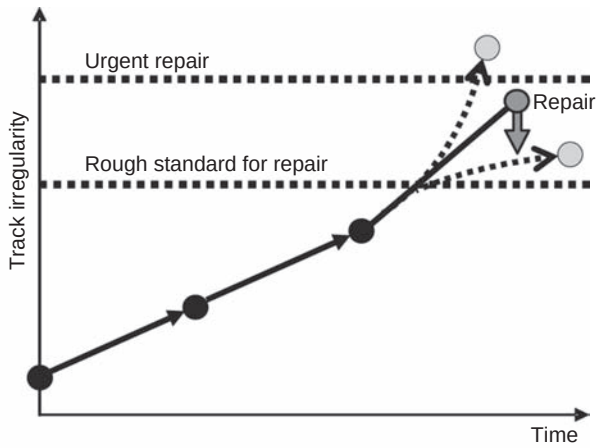

Fig. 1 Traditional Track Maintenance Method

2 Track Material Monitoring Device

A track material monitoring device records images of track materials such as fish bolts and rail fastenings to automatically judge abnormalities (Fig. 2). Devices that record images of the track materials using a line sensor camera or other imaging device have already been put into practical use in Japan and other countries. However, there are not many examples of functions for automatic judging of track material abnormalities. If such abnormalities can be automatically recorded and judged frequently, reliability of the track will be improved and the labor for periodic inspections and foot patrols reduced.

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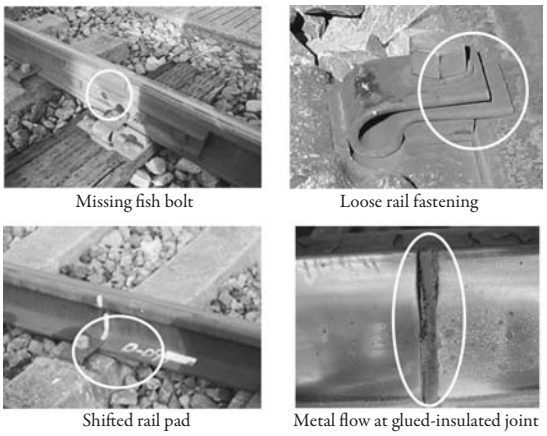


Fig. 2 Examples of Track Material Abnormalities

2.1 Configuration of the Track Material Monitoring Device

The track material monitoring device now under development consists of two recording devices: (1) a grayscale image recorder (line sensor camera) to take photos (two-dimensional images) of the track material, and (2) a range image recorder (profile camera) to obtain elevation information around the rails (three-dimensional images). We are planning to mainly use range images for automatic judgment of abnormalities of track materials in this development. With this monitor, a laser slit projector and a profile camera are combined for high-speed and continuous recording of the cross sectional shape in light sectioning measurement to acquire range images of the track surface. The brightness value of each pixel in range images corresponds to distance from the camera. So, if the rail fastenings and bolts can be identified in range images, elevation information can be obtained and missing or loose materials detected and judged.

Fig. 3 shows the configuration of the underfloor unit of the monitoring device. As the unit in this figure is just for testing, it consists only of the components for one of the two rails. Its dimensions are 1,020 mm width (in the direction of sleepers), 775 mm height and 976 mm depth (in the direction of rails), and the weight is approx. 250 kg. The unit has a line sensor camera, a profile camera, a laser projector and LED lamps inside. Data from the underfloor unit is transmitted to on the cabin unit via cables.

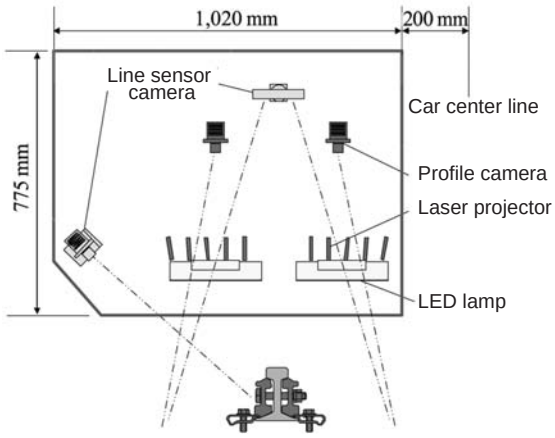


Fig. 3 Underfloor Unit Configuration (for one of two rails)

2.2 Overview of the Running Tests Using MUE-Train

We have installed this monitoring device on the MUE-Train and have been carrying out data collection tests on the Tohoku (Utsunomiya) and Nikko lines since January 2009. The purpose of that was to check the accuracy of the track material monitoring device and to develop a function to automatically judge from range images missing bolts or loose fastenings. Fig. 4 shows how the device is installed.

The MUE-Train has a seven-car train set, and this device is installed to car No. 7 under the floor on the side closer to car No. 6. A cover for the monitor is also attached to MUE-Train to protect against flying ballast.

Fig. 4 MUE-Train and Installed Device

2.3 Running Test Results

Fig. 5 is an example of a range image around the rails. In this figure, the lighter part is more elevated and darker part is less elevated. The top surface of rail is not recorded this time, however. The cross section along the dashed line is shown in the lower image. Based on the recording results obtained so far, we have confirmed that elevation information as shown in the figure can be collected to an accuracy of 1 mm at up to 110 km/h, max. speed of MUE-train.

The following figures show examples of automatic judgment of track materials abnormalities. We have developed a function to automatically judge abnormalities whereby the aforementioned range image data is input into an inspection system (Fig. 6) to automatically detect any abnormalities through judgment processing. Missing rail fastenings and shifted rail pads as shown in Fig. 7 can be indicated on the inspection result graph by kilometerage, and a trend graph can show aging changes (Fig. 8). The range or grayscale images can also be displayed by designating the kilometerage.

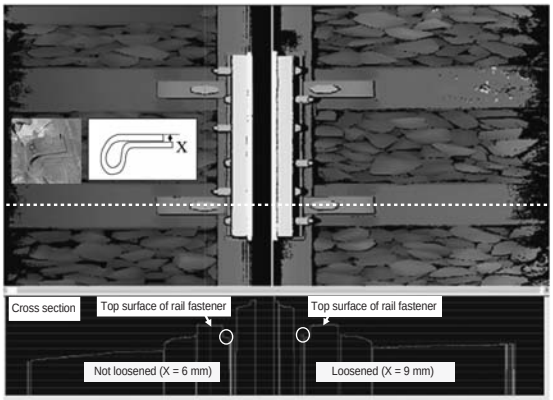
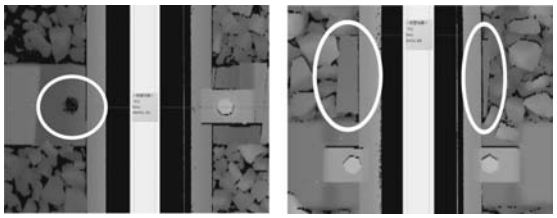


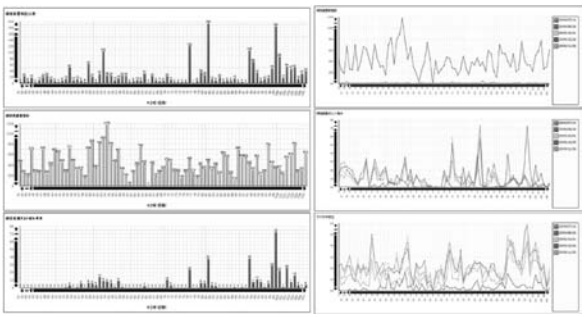
Fig. 5 Range Image of Track Materials

Fig. 6 Inspection System



Missing rail fastening　　Shifted rail pad

Fig. 7 Examples of Range Images



Result graphs　　Trend graphs

Fig. 8 Examples of Judgment Result Graphs

3 Body-mounted Track Measurement Device that Uses IMOM

The body-mounted track measurement device that uses IMOM frequently measures track irregularity (longitudinal level, alignment, gauge, cross level and twist) from trains in operation and accurately identifies the progress of track irregularity. Present track inspection cars are large and complex because rail displacement sensors need to be installed near each bogie. Consequently, devices cannot be installed on trains in operation. To install measuring devices to trains in operation, they had to be downsized. We thus selected the track measurement device that uses IMOM developed by the Railway Technology Research Institute (RTRI) as a way to achieve that downsizing.

3.1 Overview of the Track Measurement Device that Uses IMOM

This device measures acceleration at the car body. By integrating that acceleration, it calculates its own displacement (inertial measuring method) and also measures relative displacement between the rail and the device using a laser (two-axis rail displacement sensors). Track irregularity can be obtained by calculating the difference between the displacement of the device and the relative displacement.

It is possible to downsize and lighten the device and reduce its cost from the present one that occupies a single car since track irregularity is determined by measurement at a single point.

Furthermore, present track inspection cars need to have components that are installed together with the axle box removed at inspections in rolling stock depots. And those components have to be reinstalled after inspections. In contrast, the track measurement device that uses IMOM is an external device, so such disassembly and assembly is not needed.

3.2 Development of a Body-mounted Track Measurement Device that uses IMOM

Bogie-mounted track measurement devices that use IMOM (installed on the bogie frame) have already been used by the Kyushu Shinkansen. Such devices have dimensional constraints, however, so it is difficult to install them on some types of bogies. We thus developed a device that is a body-mountable device (installed under the car floor) with fewer constraints on where it can be attached.

In this case, the device is somewhat distant from the rail; thus, necessitating a wider measurable range, resulting in the possibility that foreign objects might also be caught within its range. It is therefore important to make improvements so the objects being measured can be properly ascertained and so processing is fast.

The body-mounted type device consists of a measuring unit (under floor), a control unit, a PC for data processing and recording and a power supply (on floor). Fig. 9 shows the detailed configuration of the measuring unit. The measuring unit dimensions are 1,440 mm width (in the direction of sleepers), 445 mm height and 320 mm depth (in the direction of rails), and the weight is approx. 170 kg. It has an accelerometer, an optical fiber gyroscope, a two-axis rail displacement sensor and an arithmetic circuit inside. Data from the measuring unit is transmitted to the control unit on the car floor via optical fiber cables.

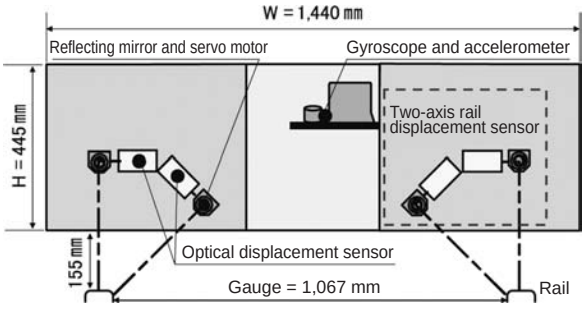


Fig. 9 Measuring Unit Configuration

3.3 Overview of Running Tests Using MUE-Train

In order to check the measurement accuracy of the body-mounted device, we installed the device on the MUE-Train and carried out test measurements on major lines in the greater Tokyo area. Fig. 10 shows the installed device. This device is installed to car No. 7 of MUE-Train, near the bogie on the side closer to car No. 6.

Fig. 10 Installed Body-mounted Device

3.4 Reproducibility Accuracy of Repeated Measurement

We have verified accuracy in repeated measurements on the same section. Fig. 11 shows the waveform of 10-m chord longitudinal level irregularity and Fig. 12 that 10-m chord of alignment irregularity, both measured nine times in three days on the same section. The σ values in the figures are the standard deviations of reproducibility errors of each waveform, with the waveforms at the top of each figure as the standard. The target standard deviation of reproducibility error in repeated measurements is smaller than or equal to 0.5 mm for conventional lines.

As shown in Fig. 11, all of the reproducibility errors of 10-m chord longitudinal level irregularity are less than 0.3 mm, and sufficient accuracy is achieved. That accuracy does not depend on speed. The reproducibility error of 10-m chord alignment irregularity is a maximum of 0.41 mm as shown in Fig. 12, sufficient accuracy is achieved here too. The accuracy does not depend on speed here either.

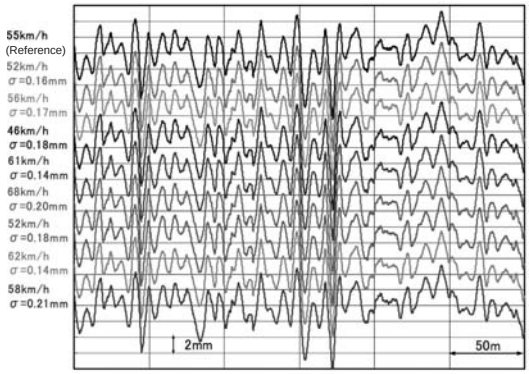


Fig. 11 Reproducibility of 10-m Chord Longitudinal Level Irregularity Waveform in Repeated Measurements

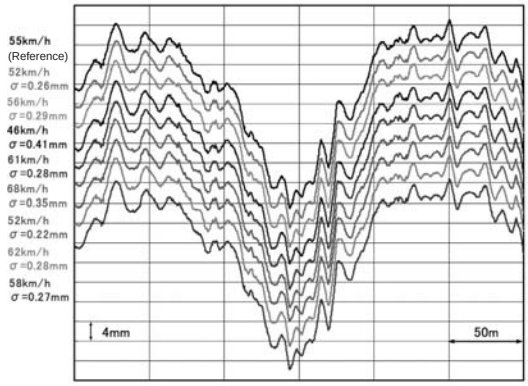


Fig. 12 Reproducibility of 10-m Chord Alignment Irregularity Waveform in Repeated Measurements

3.5 Verification of Consistency with Results by Present Track Inspection Car

Next, we verified the consistency by comparing measurement results by the present track inspection car and results by this device. Fig. 13 shows the waveforms of 10-m chord longitudinal level irregularities for each result in the upper part and the waveforms of 10-m chord alignment irregularities in the lower part. The waveform by this device was measured three days after measurements by the car. The running speeds at both measurements were almost the same at approx. 60 km/h.

In 10-m chord longitudinal level irregularities, the waveform of the device is identical to that of the car. As for 10-m chord alignment irregularities, both shape and amplitude correspond roughly to each other's waveforms, though small differences in detail can be seen due to difference of detection method and the rail side positioning.

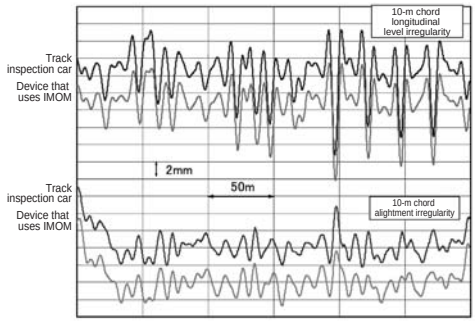


Fig. 13 Comparison with Results by Track Inspection Car

4 Conclusion

We have developed for the track material monitor a function to automatically judge abnormality of track materials using range images. For the body-mounted track measurement device that uses IMOM, we have confirmed that the device has practical accuracy by checking the reproducibility accuracy in repeated measurements and the consistency of measurement results with those by present track inspection cars.

Running tests to confirm the reliability and durability of the devices are set to continue in the future. And with an aim of equipping the devices to trains in operation, we will also go forward with development particularly on downsizing the onboard unit, wireless data transmission and remote control technology.

Much cooperation from the Track Geometry & Maintenance Laboratory of RTRI and from related manufacturers was received for this development. And we thank all who have lent their assistance.

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