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 that can be installed on trains in operation to monitor the track with higher frequency. We have developed a track material monitoring device and a body-mounted track measurement device that uses the inertial mid-chord offset method (IMOM) as devices to monitor the condition of track material and track irregularity respectively, and we are testing those installed on the MUE-Train test train running on commercial lines. For the track material monitoring device, we have also developed a track material monitor function that automatically judges abnormalities of the track material. And for the body-mounted track measurement device that uses IMOM, we have confirmed that measurement accuracy at lower speeds could be improved using the device in conjunction with the differential method.

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

1 Introduction

Track that supports railway cars is exposed to repeated train running load, advancing deterioration of tracks. Thus, it is important to correctly identify the status of deterioration by inspections and to carry out repairs at an appropriate timing. At JR East, we measure dynamic displacement (track irregularity when train load applied) by electric and track inspection cars (East-i) every three months. Material deterioration is periodically inspected by track patrolling on foot and mechanically by inspection devices. With track irregularity for example, when track irregularity exceeds the specified threshold (standard for repair), we estimate the timing for repair based on past experience and car body vibration inspection data to conduct systematic repair. But, even at locations where measurement results have not reached such a threshold, track irregularity may rapidly progress due to factors such as condition of the ballast and roadbed. In such cases, urgent repair is needed. 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 to conduct frequent monitoring of the track condition and automatically judge any abnormalities found, aiming for improvement of inspection accuracy and track reliability, and thereby safety as well. Those devices will allow accurate identification of track conditions at any time 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 (Fig. 1). 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, of which prototypes were installed on the MUE-Train test train. It will also cover the status of work towards practical use of the devices.

Fig. 1 Innovation of Track Maintenance by Frequent Inspections

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). 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.

Fig. 2 Examples of Track Material Abnormalities

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2.1 Configuration of the Track Material Monitoring Device

The developed track material monitoring device 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). Fig. 3 shows sample images taken by each recording device.

Fig. 4 shows the configuration of the prototype underfloor unit. Taking into account installation on trains in operation, we made the prototype of dimensions that allow it to be installed under the floor. It has a line sensor camera, a profile camera, a laser projector and LED lights inside.

2.2 Running Test Using MUE-Train

In order to check the accuracy of the track material monitoring device that will eventually be installed on trains in operation, we installed a prototype device on a MUE-Train in January 2012 (Fig. 5), conducting data collection tests with that.

Fig. 6 shows examples of abnormalities of track material that were automatically judged and detected. Grayscale images are used to detect cracks of fishplates and metal flows at glued-insulated joints, and range images are used to detect missing or loose rail fastenings and displaced rail pads.

Fig. 7 is an example of abnormality judgment using a range image. In this figure, the lighter part is more elevated and darker part is less elevated. The top surface of the rail is not recorded this time, however. The cross section of the area indicated by the dashed line is shown in the lower image. For example, bolt looseness can be detected by using the fact that height changes when bolts loosen as shown in the figure. Past running test results confirmed that such grayscale images and range images could be recorded at speeds of up to 120 km/h.

Fig. 8 is an example indicating a shifted rail pad in the judgment result graph. The X-axis is the section kilometrage per 1 km lot and the Y-axis is the number of shifted pads. The range or grayscale images can also be displayed by designating the kilometrage.
and twist) from trains in operation so that the progress of track irregularity can be accurately identified. Present electric and track inspection cars are large and complex because rail displacement sensors are directly installed to each bogie and the cars need onboard processors. Consequently, devices for the present track inspection cars cannot be installed on trains in operation without modification. To install measuring devices that include onboard processors to trains in operation, the device configuration had to be simplified and necessity of onboard processors installation eliminated. We thus selected the track measurement device that uses IMOM developed by the Railway Technology Research Institute (RTRI) as a way to achieve that.

3.1 Overview of the Track Measurement Device that Uses IMOM

As shown in Fig. 9, the measurement unit has components such as an accelerometer, a fiber optic gyro, and a two-axis rail displacement sensor. This device first measures acceleration at the car body. By integrating that acceleration, it calculates its own absolute displacement by the inertial measuring method and also measures relative displacement between the rail and the device using a two-axis rail displacement sensor. Track irregularity can be obtained by calculating the difference between the absolute displacement of the device and the relative displacement. Fig. 10 illustrates a comparison of present measurement by the asymmetrical chord offset method and measurement by IMOM.

3.2 Measures to Improve Measurement Accuracy for Practical Use

Previous research\(^1\) has confirmed the consistency between results of IMOM measurement and measurement using present track inspection cars in high-speed running (30 km/h or faster, Fig. 11). Practical-level reproducibility accuracy in repeated measurements has been confirmed as well. On the other hand, IMOM measurement has a known issue in terms of practical use whereby measurement accuracy is reduced in low-speed running (30 km/h or slower) because appropriate acceleration is not obtained at low speed. We thus adopted the differential method\(^2\) to complement accuracy in low-speed running. The differential method is a method where rail displacement is measured by adjusting the angle based on the values of the rail displacement sensors at two measurement points and the values of a gyro. In this development, we examined a method where the measurement results of IMOM and the differential method are mixed and calculated according to speed range, and we produced a prototype measurement device. As shown in Fig. 12, the prototype was installed on MUE-Train in January 2012 and running tests carried out.

Table 1 shows the reproducibility errors of measured values in the running tests. We set a target for the standard deviation of the reproducibility error in repeated measurements (σ) to be within 0.5 mm for conventional lines. The standard deviation of the prototype device that combines IMOM with the differential method was smaller than that of the device that uses IMOM only. This indicates accuracy improvement; however, standard deviation was still over 0.5 mm in some sections.

We will keep looking at performance and characteristics of gyros and study reduction of reproducibility errors, aiming to achieve satisfactory practical accuracy.
In actual operation, it is necessary that measurement can be remotely started and finished from track maintenance technology centers. Furthermore, the system needs to have a function for real-time onboard judgment and transmission of that judgment data to the centers and offices concerned. This is necessary because immediate operation control or track repair would be required if a critical value that could affect safe and stable transport is measured.

4.1 Development of Remote Control Technology

In measurement using trains in operation, measurement has to be started and finished from track maintenance technology centers. We thus added a function to enable remote control and recording for both of the track material monitoring device and the track measurement device that uses IMOM. That enabled remote control from technology centers, eliminating necessity of start/finish operation at rolling stock depots and other field sites.

4.2 Development of Real-time Judgment Function

In the development of the track material monitoring device up to fiscal 2010\(^1\), we assumed processing would be done at the wayside due to limitations in data processing capacity. However, information on critical failures such as significant track displacement, broken fish bolts and damaged fishplates that can seriously affect train operation should be transmitted in real-time to track maintenance technology centers concerned so as to minimize transport disruption time. We thus developed a function to enable real-time onboard judgment for measurement items that can seriously affect safe and stable transport.

5 Future Outlook

With a view to full-scale deployment of the devices, we plan to conduct test measurement using actual trains in operation and perform final checks. We are also proceeding with development for connection of current monitoring devices and the INegrated Train communication/control network for Evolvable Railway Operation System (INTEROS). By connecting with INTEROS, various train data (line name, line type, route, wheel diameter, etc.), most of which is manually input at present, can be obtained. Reducing input errors and reflecting operation change information without fail will contribute to improvement of operability and measurement reliability.

As mentioned above, we achieved wireless remote control and developed a function for real-time onboard judgment of items affecting safe and stable transport, and we aim to install those on actual trains in operation. As of fiscal 2012, development was at the stage of final check and adjustment for actual introduction. Work in that final stage includes verification of field operability, tests using trains in operation, and building a framework for inspection with the measurement devices.

6 Conclusion

We have developed for the track material monitoring device a function to automatically judge abnormality of track materials using grayscale and range images. For the body-mounted track measurement device that uses IMOM, we have developed a measurement device that can be used in conjunction with the differential method, which looks to solve the issue of improving measurement accuracy in low-speed running.

Much cooperation from RTRI was received for development of the body-mounted track measurement device that uses IMOM. And we thank all who have lent their assistance.

Reference: