Study of Condition Monitoring for Track Irregularity and Track Materials using Commercial Test Car

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Abstract

To improve reliability and efficiency of track inspections, we have been developing track monitoring systems which can be installed on trains in commercial use with the aim of conducting frequent monitoring of track condition and automatically judging any abnormalities found. We developed a track material monitoring device and a body-mounted track measurement device using inertial mid-chord offset method (IMOM) to monitor the condition of track material and track irregularity respectively, and we are continuously testing those installed on the test train running on conventional lines. This paper contains an overview of the track material monitoring device and reports the verification of the track material monitor function that automatically judges abnormalities of the track material using range images. We also give an overview of the body-mounted track measurement device using IMOM and the results of test measurement using that device.

1. Introduction

Track that supports railway cars is exposed to repeated train load and the elements, advancing irregularity and deterioration of tracks. Thus, it is important to identify correctly the status of irregularity and deterioration by inspection and to carry out repairs at an appropriate timing. Fig. 1 shows the usual track maintenance method employed by JR East. The horizontal axis shows time, and the vertical axis shows track irregularity. We measure dynamic displacement (track irregularity with train load applied) by track inspection cars (East-i) every three months along conventional lines. Inspection for irregularities and material deterioration is periodically made on foot and mechanically with 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 its threshold may remain constant and result in extremely inefficient repair work.

We have been developing track monitoring systems which can be installed on trains in commercial use with to conduct frequent monitoring of the track condition and automatically judging any abnormalities found. Those devices allow accurate identification of track conditions so repair work can be made at the optimal timing. We expect use of those devices will result in the achievement of more accurate and efficient maintenance. Early detection of predictive signs of failures and early action such as train operation control and transmission of information to other trains when failures are detected will be made possible as well. Furthermore, automation of visual inspection will reduce manual work.
We developed a track material monitoring device and a body-mounted track measurement device using IMOM to monitor the condition of track material and track irregularity respectively, and we are continuously testing those installed on the multipurpose experimental train called “MUE-Train” running on conventional lines [1]. MUE-Train is a test train converted from former Keihin-Tohoku line 209 series cars to be used to test and develop new technology for use on future trains. As the result of running test for the track material monitoring device, we confirmed that elevation information can be collected to an accuracy of 1 mm at up to 110 km/h. This paper contains an overview of the track material monitoring device and reports the verification of the track material monitor function that automatically judges abnormalities of the track material using range images. For the body-mounted track measurement device using 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. Then, it gives an overview of the device and reports the results of measurement under conditions differing from the past and data transmission by remote control from the ground station.

2. Track material monitoring device

The 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, track reliability will be improved and labor for periodic inspections and foot patrols reduced.

![Fig. 2: Examples of track material abnormalities](image)

2.1 Configuration of the track material monitoring device

The track material monitoring device consists of two recording devices: 1) a gray-scale 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 of the vicinity of the rails (three-dimensional images). We are planning to mainly use range images for automatic judgment of abnormalities of track materials for 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 the 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.
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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 components for one of the two rails. It is 1,020 mm wide (in the direction of sleepers), 775 mm tall and 976 mm deep (in the direction of rails), and weighs approximately 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 the cabin unit via cables.

Fig. 3: Underfloor unit configuration (for one of two rails)

2.2 Overview of the data collection tests using MUE-Train

We 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 to develop a function to automatically judge abnormalities using range images. Fig. 4 shows how the device is installed. The MUE-Train is a seven-car train set, and this device is installed to car No. 7 under the floor on the end nearest to car No. 6.

Fig. 4: MUE-Train and installed device

Fig. 5 shows 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 the rail was 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 confirmed that elevation information as shown in the figure can be collected to an accuracy of 1 mm at up to 110 km/h, the maximum speed of MUE-train [1].

Fig. 5: Range image of track materials
2.3 Inspection system for automatic judging of track material 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. Fig. 7 shows a system function conceptual diagram. Table 1 shows the function list of the system. Inspection of the first step targets missing rail fastenings, loose rail fastenings, shifted rail pads and missing fish bolts.

Fig. 6: Inspection system

![Inspection system](image)

Fig. 7: System function conceptual diagram

![System function conceptual diagram](image)
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Table 1: Function list

<table>
<thead>
<tr>
<th>Function</th>
<th>Processing</th>
</tr>
</thead>
<tbody>
<tr>
<td>(a) Operator handling</td>
<td>Specification of inspection data, section, inspection item and parameter through Graphical User Interface.</td>
</tr>
<tr>
<td>(b) Access to track material database</td>
<td>The material type of the specified criteria is recognized from the track material database.</td>
</tr>
<tr>
<td>(c) Inspection processing command</td>
<td>Data is divided kilometer to minimize inspection processing time, through concurrent processing.</td>
</tr>
<tr>
<td>(d) Display the results of judgment</td>
<td>Judgment results are displayed in a list or by graph. The range or grayscale image is displayed by designating kilometerage.</td>
</tr>
<tr>
<td>(e) Trend analysis</td>
<td>Trend graph shows comparisons with past inspections.</td>
</tr>
<tr>
<td>(f) Reinspect</td>
<td>The parameter is changed and the inspection started again.</td>
</tr>
</tbody>
</table>

Fig. 8 shows the judgment processing flow. The inspection processing first searches the rail position as pre-processing, and adjusts it to a standard position. Next, the relative position of each type of track material can be specified from the rail position and searches for each type’s area. The type and/or existence is judged using the material’s shape registered beforehand. Next, the amount of characteristic (for instance, height of the upper surface of rail fastening) corresponding to each inspection target is calculated. The threshold is set to the calculated amount, and automatically judged.

![Fig. 8: Judgment processing flow](image)

The list or graph displays judgment results on the main display as in Fig. 6. The range or grayscale images can also be displayed on a sub-display by designating the kilometerage. A trend graph can also show chronological changes.

2.4 Function confirmation tests

To confirm the function of the inspection system, the track material monitor function that automatically judges accuracy of abnormalities was verified through running test along conventional lines. Fig. 9 shows the range and grayscale image of the missing rail fastening which was detected. It was able to be automatically detected using the range image. Fig.10 shows false detection. We verified that it is difficult to judge parts covered with an example of grass, ballast, cables, etc.
Table 2 shows the result of the test that simulates a loosened rail fastening. Fig. 11 shows the amount of loosening in the fastening. In the test, the amount of loosening was defined as the difference between the lower side and top of the spring. From the table, it was also confirmed that the amount of loosening tends to grow with the increase of the value of looseness measured. Some differences can be seen in Table 2. The reason for the lack of uniformity in values is thought to be due to the difference in the position of measurement of the top of spring and/or the way the spring has been installed. Data will continue to be accumulated in order to consider a threshold to judge the amount of loosening.

Table 2: Test results of loosened rail fastening

<table>
<thead>
<tr>
<th>Test sites</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Measurement value using a ruler</td>
<td>25.0</td>
<td>21.0</td>
<td>21.0</td>
<td>19.0</td>
<td>19.0</td>
</tr>
<tr>
<td>Measurement value using the monitoring device</td>
<td>24.7</td>
<td>24.9</td>
<td>21.5</td>
<td>17.3</td>
<td>22.9</td>
</tr>
</tbody>
</table>

Fig. 11: The amount of loosening in the fastening
Fig. 12 shows an example of the range and grayscale image of the gap of the rail pad. Some of the amounts of the gap were changed and the gap of the rail pad was examined. Detection accuracy improves with increasing size of the gap, although with smaller gaps some cases of false detection were noted. Data will continue to be accumulated in order to consider a threshold to judge the shifted rail pad.

![Range image](a) Range image ![Grayscale image](b) Grayscale image

**Fig. 12: Examples of detected shifted rail pad**

We could also automatically detect the missing fish bolt in Fig. 13. The detection results were verified for each inspection above. As a result, prospects for application of automatic judgment function using the range image are favorable.

![Range image](a) Range image ![Grayscale image](b) Grayscale image

**Fig. 13: Examples of detected missing fish bolt**

### 3. Body-mounted track measurement device using IMOM

The body-mounted track measurement device using IMOM frequently measures track irregularity (longitudinal level, alignment, gauge, cross level and twist) from trains in commercial use and accurately identifies the progress of track irregularity. Present track inspection cars are large and complicated because rail displacement sensors need to be installed near each bogie. Consequently, devices cannot be installed on trains in commercial use. To install measuring devices to trains in commercial use, they had to be downsized. We thus selected the track measurement device using IMOM developed by the Railway Technology Research Institute (RTRI) as a way to achieve that downsizing [2,3].

#### 3.1 Overview of the track measurement device using IMOM

The track measurement device using IMOM 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). The difference of the displacement of the device and the relative displacement is calculated to find track irregularity (mid-chord offset irregularity that is normally used for track inspection). The characteristic of IMOM was understood by combining characteristics of the inertial measuring method and mid-chord offset method to avoid the problem of the inertial measuring method is that the
waveform is distorted by high-pass filtering process for stabilizing the double integration of acceleration.

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 using IMOM is an external device, so such disassembly and assembly is not needed.

3.2 Development of a body-mounted track measurement device using IMOM

Bogie-mounted track measurement devices using IMOM (installed on the bogie frame) have already been used by the Kyushu Shinkansen [4]. 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. 14 shows the detailed configuration of the measuring unit. It is 1,440 mm wide (in the direction of sleepers), 445 mm tall and 320 mm deep (in the direction of rails), and weighs approximately 170 kg. The unit 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.

3.3 Overview of running tests using MUE-Train

In order to check the measurement accuracy and durability of the body-mounted device, we installed the device on the MUE-Train and have been carrying out test measurements on major lines in the greater Tokyo area. Fig. 15 shows the installed device. This device is installed to car No. 7, near the bogie on the side closer to car No. 6. As of January 2011, at a running distance of about 15,000 km (not including deadheads), there have been no notable problems with the device.
3.4 Reproducibility accuracy of repeated measurement

As reported in [1], regarding the reproducibility accuracy of repeated measurement, a level of accuracy sufficient for practical use was reached on tests over simple curve. For this report, we have verified accuracy in reproducibility over more complex alignments, based on measured nine times in three days on the same section at 10‰ downhill gradient, veering right-left-right.

Fig. 16 shows the waveform of 10-m chord longitudinal level irregularity and Fig. 17 that 10-m chord of alignment irregularity. The $\sigma$ 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. 16, 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. 17, sufficient accuracy is achieved here too. The accuracy does not depend on speed here either.

![Fig. 16: Reproducibility of 10-m chord longitudinal level irregularity waveform in repeated measurements](image1)

![Fig. 17: Reproducibility of 10-m chord alignment irregularity waveform in repeated measurements](image2)

3.5 Data transmission via remote control measurement

Having operators board a vehicle in order to carry out tests can prove to be costly. Therefore, we have developed a wireless system which can start/stop the device and send data via remote control.
through communication between the device on board and a ground station. For it, we developed a monitor to relay the status of the device (start and stop of testing, etc), and a function to transmit data. Data relayed includes track irregularity and kilometerage. By adding this function, we now collect data automatically and relay it to a remote PC at a ground station. Fig. 18 shows the display on the computer screen. As seen in the figure, it is possible to find spots which exceed the value set for repair work.

![Measurement condition](image1)

![Measurement situation](image2)

Excess of standard for repair

Remarks column

**Fig. 18: Examples of the display on the remote PC**

4. Conclusions

We have developed for the track material monitor a function to automatically judge abnormality of track materials using range images and confirmed the function through running test along conventional lines. As a result of test, prospects for application of automatic judgment function using the range image are favorable. For the body-mounted track measurement device using IMOM, we have confirmed that the device has practical accuracy by checking the reproducibility accuracy in repeated measurements. We have also developed a wireless system which can start/stop the device and send data via remote control between the device on board and a ground station.

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 commercial use, we will also go forward with development particularly on downsizing the unit.

5. Acknowledgments

This study was partly supported by the Kawasaki Heavy Industries, LTD. We thank all who have lent their assistance.

References


