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Condition Monitoring of Railway Track Using In-service Vehicle*

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Abstract

This paper summarizes the development of a portable track-condition-monitoring system for easy installation on in-service vehicles. In this system, rail irregularities are estimated from the vertical and lateral acceleration of the car body. The roll angle of the car body, calculated using a rate gyroscope, is used to distinguish line irregularities from level irregularities. Rail corrugation is detected from cabin noise with spectral peak calculation. A GPS system and a map-matching algorithm are used to pinpoint the location of faults on tracks. Field test using in-service vehicle was carried out to evaluate the developed system. The results show that the condition of rail irregularity and rail corrugation can be estimated effectively.

Key words: Railway, Track, Condition Monitoring, Fault Detection, Noise, Vibration, Spectrum Analysis, Diagnostics, Corrugation

1. Introduction

Condition monitoring of railway tracks, vehicles are essential in ensuring the safety of railways [(1)]. For this purpose, condition monitoring system of railway track using in-service vehicle has developed [(2)-(5)]. In-service vehicles equipped with sensors and GPS systems can act as probes to detect and analyze real-time vehicle vibration and signaling systems while running. They may also dramatically change the current style of rail maintenance, thus contributing to the establishment of safer transport systems. Such trains are known as probe vehicles (Figs. 1 and 2) [(6)].

The probe vehicles can change the current maintenance style to a focus on locations regarded as essential maintenance areas, utilizing data acquired by real-time monitoring of actual vibration together with positional information obtained by GPS. Monitoring based on information obtained by in-service vehicles may enable the detection of impairments at an early stage, thus contributing to the revitalization of local railways by making maintenance tasks more efficient.

We developed a method to detect track faults from the acceleration measured in the car body using discrete wavelet-based multi-resolution analysis (MRA). This technique detects faults by decomposing the measurement signal into an approximation component of low

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frequency and a detailed component of high frequency [(6)-(9)].

In this paper, the development of condition monitoring system of railway track from cabin vibration and acoustic noise, which is easily equipped in in-service vehicle, is described.

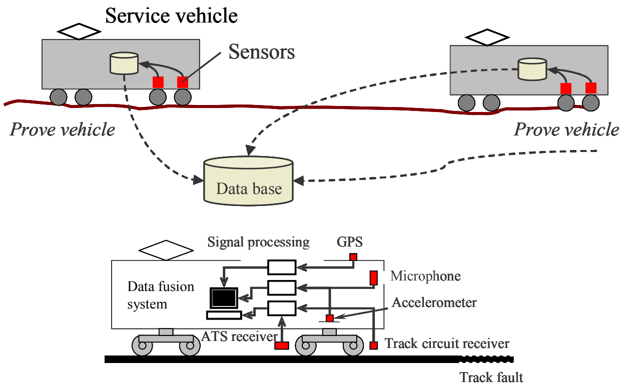


Fig. 1 Condition monitoring of railway by probe vehicle system

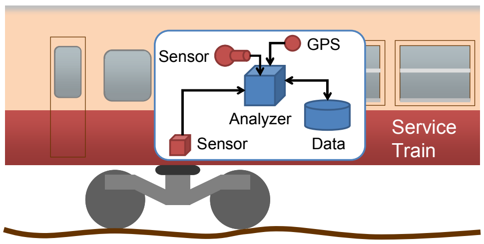


Fig. 2 Probe system

2. Detection of track irregularities from cabin vibration

Several kinds of track fault can be detected by measuring bogie acceleration [(2)-(5)]. However, the ability to track faults from within the cabin will make track condition monitoring much easier. As the distinctive signals of track faults are hidden in the natural frequency of car body vibration, signal processing of acceleration measured in the cabin is necessary to detect such faults.

We carried out simulation studies using SIMPACK, a multi-body dynamics code, to determine the feasibility of detecting track irregularities from car body vibration directly. Figure 3 shows the SIMPACK model used in the simulation study.

Figures 4 and 5 show car body vertical acceleration, lateral acceleration and roll angle with the vehicle running on a track with irregularities in the vertical, lateral and roll directions, respectively. Figure 5 shows that the car body acceleration and roll angle can be used to detect track faults.

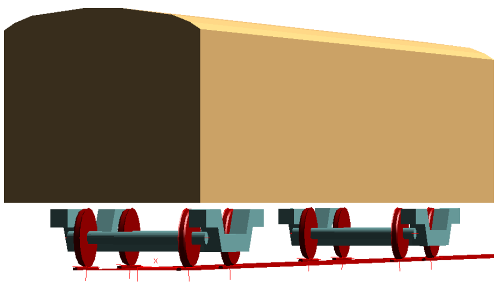


Fig. 3 Full vehicle model

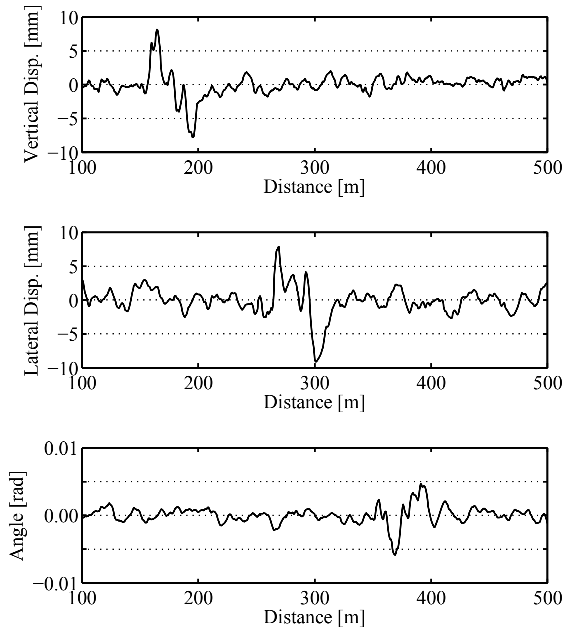


Fig. 4 Track irregularities

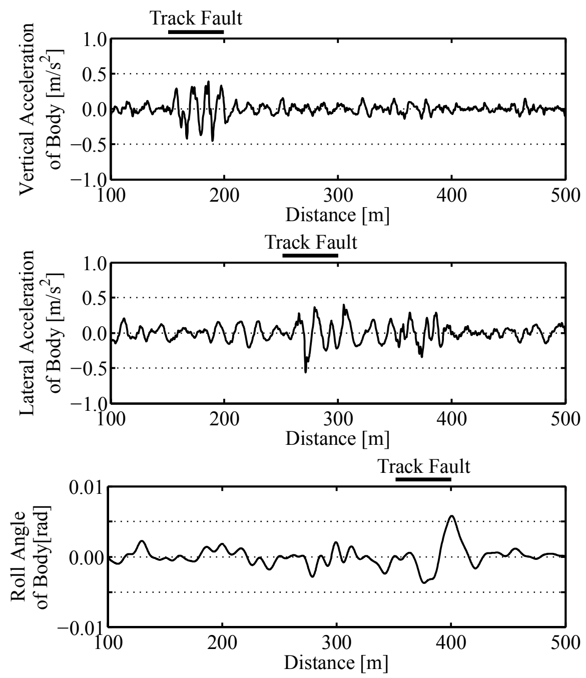


Fig. 5 Responses of vehicle car body

3. Detection of corrugation from cabin noise

One type of track fault is corrugation, a phenomenon in which cyclic wear patterns with wavelengths of a few centimeters to 10–20 cm form on railheads, as shown in Fig. 6. Corrugation on sharp curves in railways poses particularly serious problems. Exacerbation of the phenomenon causes remarkable noise and vibration and leads to rail impairment, making it an important consideration in track maintenance.

Steps should be taken to ensure that the measurement of high-frequency vibration components using an accelerometer is accurate (such as ensuring that the unit is securely attached to the cabin floor). We therefore developed a method to detect corrugation using the cabin noise that is uniquely generated when trains run on rails with such defects.

Fig. 6 Example of rail corrugation

In this method, spectra are obtained using a short-time Fourier transform of cabin noise data. Peak heights of remarkable frequencies in the spectra together with the corresponding frequencies are calculated in real time, and their time-related changes are evaluated (Fig. 7). Corrugation can be detected by simpler measurement with this method using just a microphone in the cabin. In an experiment on a commercial railway line, we confirmed that the extent of corrugation can also be diagnosed using this method.

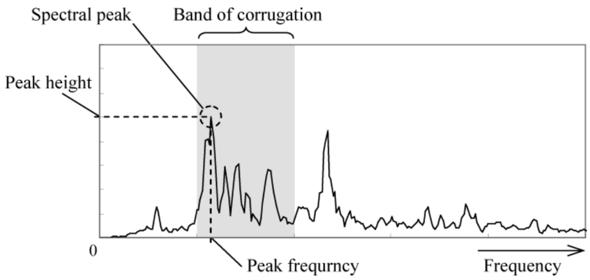


Fig. 7 Detection of corrugation from cabin noise

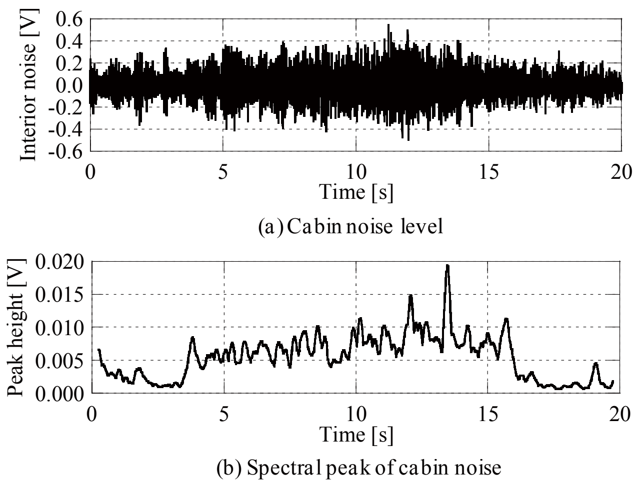


Fig. 8 Cabin noise measured at in-service vehicle and its spectral peak

Figure 8 presents the results of corrugation detection from cabin noise. Figure 8(a) depicts the noise level of a relatively small corrugation section (the hatched part) with a wave height of 0.1 to 0.2 mm, indicating that the corrugation section could not be detected by cabin noise. In contrast, spectral peak values (Fig. 8(b)) were elevated in the corrugation section, suggesting that early-stage corrugation could not be detected by the noise level alone but could be detected successfully using the spectral peaks.

4. Onboard sensing system

We developed a portable onboard sensing system for in-service vehicles to enable simple diagnosis of tracks on a commercial line [(6), (10)]. Figure 9 shows the configuration of the sensing system developed. Figures 10 and 11 show the exterior and interior view of the system.

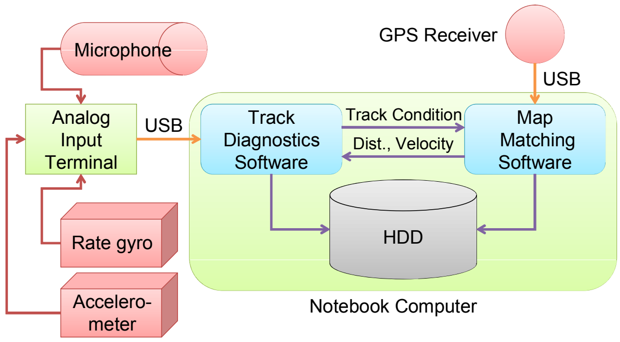


Fig. 9 Configuration of probe system

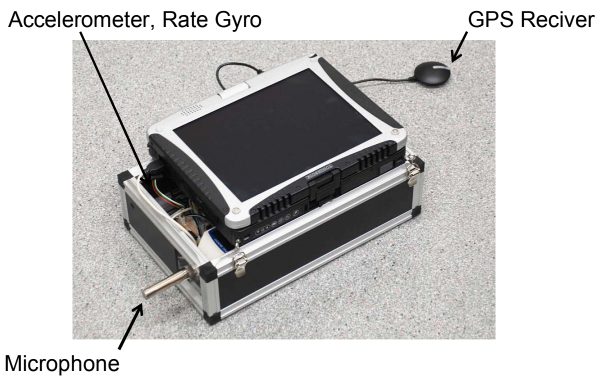


Fig. 10 Portable probe system

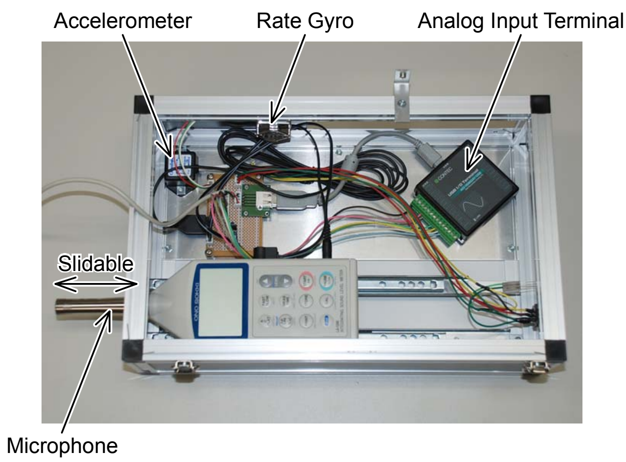


Fig. 11 Interior view of probe system

It consists of a noise meter to detect corrugation, accelerometers to detect track irregularities, a rate gyroscope, a GPS receiver to detect position, a computer for analysis, and an analog input terminal to enter the signals from each sensor into the PC. The signal output from each sensor is converted into a digital signal by the analog input terminal, and is entered into the computer.

Positional information acquired by the GPS receiver is also input into the computer. The PC not only estimates the current position and velocity based on this information from the GPS receiver and acceleration signals from the acceleration sensor, but also estimates the track condition by processing the signals from each sensor and displays the results in a time sequence in the present position on a screen. Data obtained by signal processing is also recorded onto an HD drive and utilized for detailed diagnosis of the track status in off-line analysis.

5. Field test

A method to estimate car body vibration from track displacement has been created as an index for use in controlling track irregularities. The technique estimates riding comfort by calculating car body vibration, and evaluates track status more effectively by obtaining the response characteristics of the car body from field tests (Fig. 12). Figures 13 and 14 show the real-time monitoring of track conditions in the field test.

Fig. 12 Field test

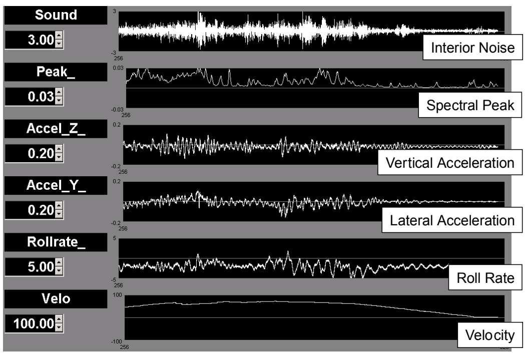


Fig. 13 Real time monitoring of track condition

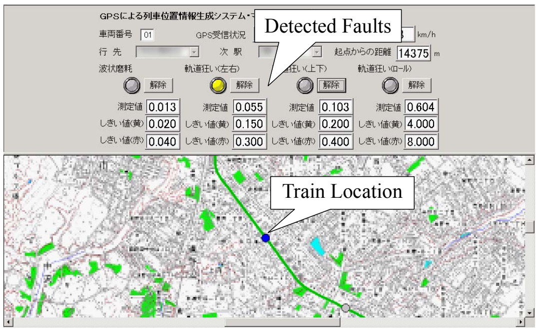


Fig. 14 Real time fault detection of track

The response characteristics of a car body to track irregularities may vary depending on conditions such as factors specific to vehicles, running velocity and loading; however, track irregularities can be roughly estimated by evaluating the RMS value of car body acceleration with time. We can also distinguish irregularities in track alignment from those in level alignment using a rate gyroscope.

Figures 15, 16 and 17 present the results of measurement with a vehicle running at 75 km/h in a straight section. The horizontal axis indicates the distance from the origin as obtained by GPS.

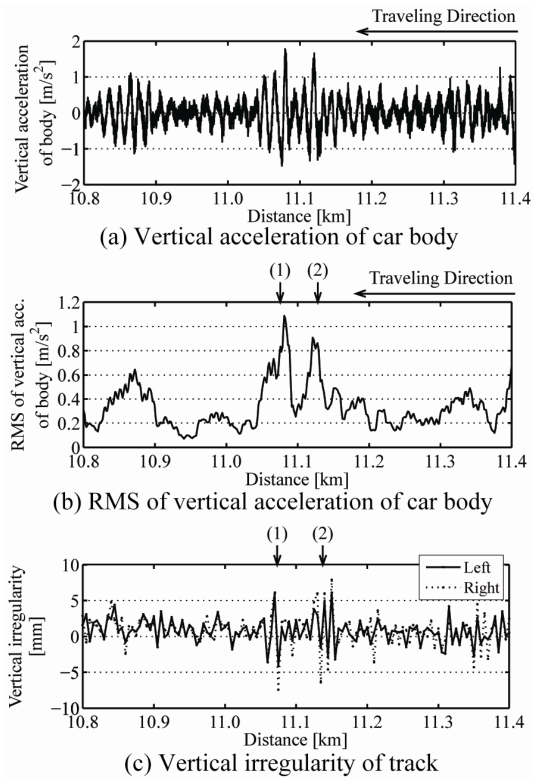
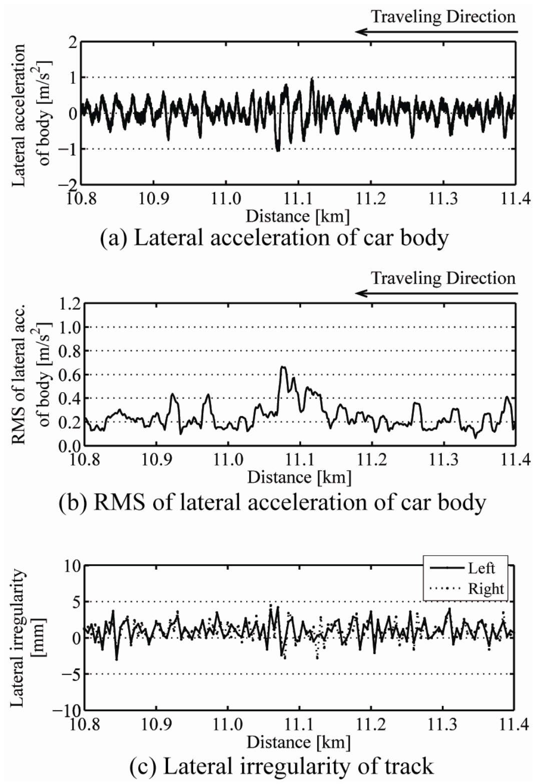


Fig. 15 Vertical acceleration of car body and vertical irregularity of track

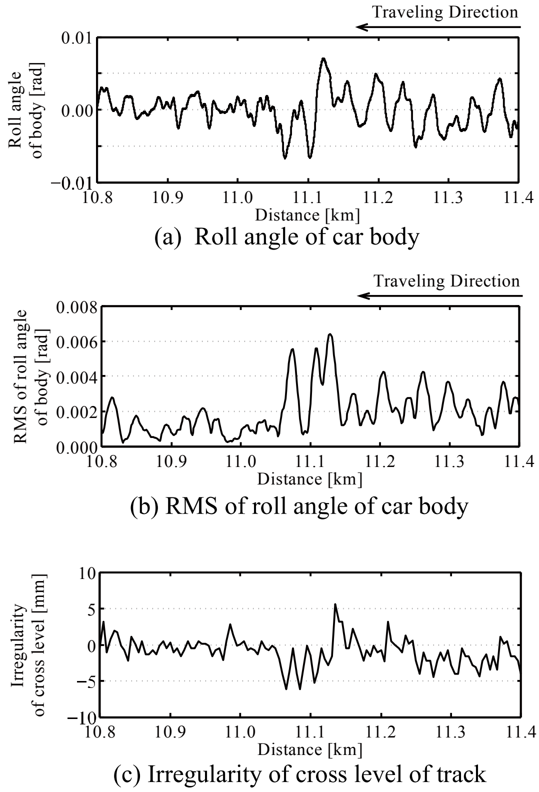


(a) Lateral acceleration of car body

(b) RMS of lateral acceleration of car body

(c) Lateral irregularity of track

Fig. 16 Lateral acceleration and lateral irregularity



(a) Roll angle of car body

(b) RMS of roll angle of car body

(c) Irregularity of cross level of track

Fig. 17 Lateral acceleration and lateral irregularity

Figures 15 and 16 show the relationships between vertical and lateral acceleration, its RMS value and irregularities in track alignment. Such irregularities were demonstrated by expressing displacement toward the left in the direction of movement. The large RMS value of vertical acceleration corresponds to the large irregularities of track.

Figure 17 shows the relationships between roll angle, its RMS value and irregularities in level alignment. The roll angle is obtained by integrating the roll rate as measured by a rate gyroscope. The RMS value of the roll angle was high at around 11.1 km (Fig. 17(b)), which corresponded to a location with large irregularity in level alignment (Fig. 17(c)).

It is also near the peak of the lateral acceleration RMS (Fig. 16(b)). Based on these findings, we consider it possible to detect track irregularities and positions by using the RMS of normal tracks as a standard and setting a threshold.

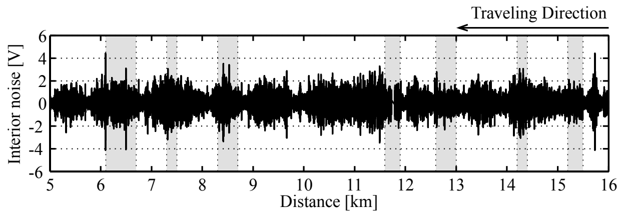


Fig. 18 Cabin noise

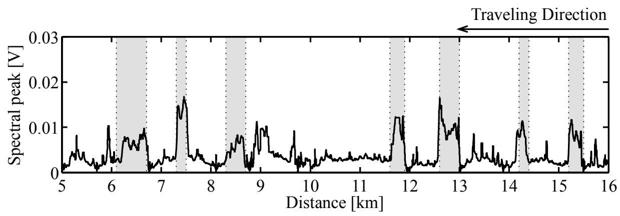


Fig. 19 Spectral peak of interior noise

Figure 18 shows the noise level measured in the cabin and the results of corrugation detection using spectral peak is shown in Fig. 19. The gray parts in the figure indicate areas where corrugation was observed. It is demonstrated that the corrugations are successfully detected by the proposed method using cabin noise.

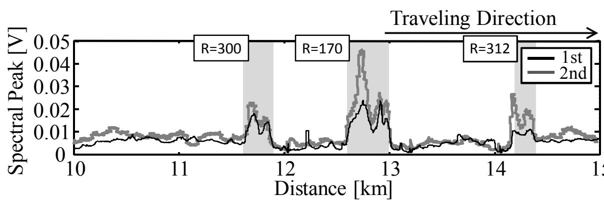
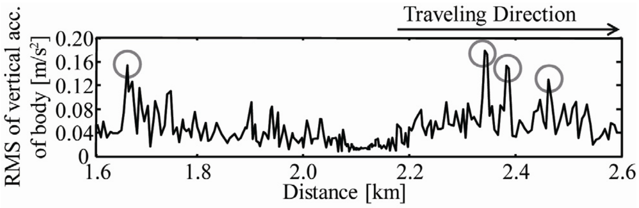


Fig. 20 Condition monitoring of corrugation

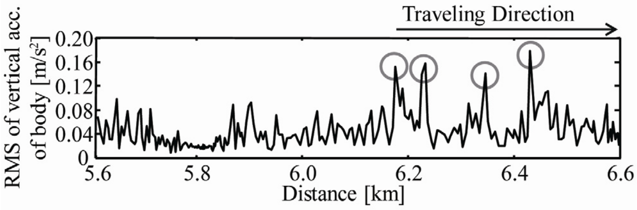
Figure 20 shows the spectral peak observed in two different time, 29/10/2007 (indicated as 1st) and 24/06/2008 (indicated as 2nd) for estimating condition of corrugation. It should be noted that the spectral peak increased at the curve of R=170m and R=312m. This implies that the corrugation grows largely in those sections.

6. Track condition monitoring in a local-line

We measured a track condition in a local-line with in-service vehicle. Figure 21 present the results of the RMS value of car body vertical acceleration. The horizontal axis indicates the distance from the origin obtained by GPS. Sections where the RMS value was especially high are marked with circle. After the measurement, we carried out the wayside investigation for the marked sections.



(a) RMS of Vertical Acceleration (1.6km - 2.6km)



(b) RMS of Vertical Acceleration (5.2km - 6.2km)

Fig. 21 RMS of vertical acceleration of car body

Figure 22 shows the result of wayside investigation. As a result of the investigation, the loose sleeper was observed in all sections whose RMS value was high. The loose sleeper is the phenomenon that inter-space appears between rail and ballast. It is well known that the loose sleeper causes serious problems on track.

(a) Loose Sleeper (2.3km)

(b) Loose Sleeper (6.4km)

Fig. 22 Wayside investigations

7. Conclusion

This paper summarizes the development of a portable track-condition-monitoring system for easy installation on in-service vehicles. It consists of a noise meter for detecting corrugation, accelerometers for detecting track irregularity, a rate gyroscope, a GPS receiver for detecting position, a computer for analysis, and an analog input terminal for inputting signals from each sensor to the computer.

The roll angle of the car body, calculated using a rate gyroscope, is used to distinguish line irregularities from level irregularities. Rail corrugation can be detected from cabin noise with spectral peak calculation. A GPS system and a map-matching algorithm are used to pinpoint the location of faults on tracks.

A field test was conducted using a commercial line in cooperation with a railway operating company. Track irregularity was detected by vertical and lateral acceleration measured while the vehicle was running, and corrugation was detected by spectral peaks of cabin noise.

Track condition was displayed on a route map in real time together with information of the location based on the position information obtained by GPS. The field results show that the condition monitoring of railway track using in-service vehicle is possible with the developed probe system.

A track condition monitoring was carried out in local-line using the developed system. The results show that the track faults can be easily detected using the developed system.

Acknowledgements

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