Development of Compact Size Onboard Device for Condition Monitoring of Railway Tracks*

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Abstract

This paper summarizes a new development of a compact size onboard device for condition monitoring of railway tracks followed by a former development of a portable onboard device. Track irregularities are estimated from a vertical and lateral acceleration and roll rate of a car body. 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. The device is driven by Li-ion battery for 6 hours or outside power source. Accelerometers, rate gyroscope and GPS were redesigned to give higher performance. One can add a microphone outside if a condition monitoring of rail corrugation is necessary. Collected data are usually kept in an inside un-volatility memory (SSD) or a SD card. Communication unit transfers the collected data to a data server via cellular phone. The compact size onboard devices provide regular monitoring of tracks for sustaining railway system with securing safety.

Key words: Railway, Track, Condition Monitoring, Maintenance, Safety, Vibration, Diagnostics

1. Introduction

Condition monitoring of railway tracks is essential in ensuring the safety of railways (1). Preventive maintenance is important for avoiding risks in railways. An inspection of railway tracks should be done with high frequency. However, the inspection with a track inspection car is limited to use in local lines.

In order to solve this problem, condition monitoring system of railway track using in-service vehicle has been 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 track maintenance, thus contributing to the establishment of safer transport systems. Such trains are known as “probe vehicles” (Fig.1) (6),(7).

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 portable onboard device to realize probe vehicles. \(^{(8)}\)

![Fig. 1 Condition monitoring of railway by probe vehicles](image)

In this paper, at first the result which the caution needed section is specified for by previous report \(^{(9)}\) is shown. Then, a long-term measurement examination is enforced about the point attention section, and assessed about the track maintenance done between that. Next, the compact size onboard device which improved the performance of the portable onboard device was developed with university and company. It explains about the outline of the compact size onboard device that stability improvement and facilitate the operation is done for railway operator.

2. Condition monitoring of tracks using onboard sensors

2.1 Detection of track irregularities from cabin vibration

A change in a form of the longitudinal direction of the track is said as track irregularities. Track irregularities promote the deterioration of the track, and increase the risk of the derailment. Because of that, it is one of the most important inspection items.

Track irregularities can be roughly estimated by evaluating the RMS value of car body acceleration with time. We consider it possible to detect track irregularities by using the RMS of normal tracks as a standard and setting a threshold.

In this method, track conditions are obtained using a short-time RMS value of car body acceleration. The short-time RMS value is calculated using following equation.

\[
RMS(t) = \frac{1}{N} \sum_{i=1}^{N} x(t)^2
\]

Track irregularities to detect are level, alignment and cross level; the measurement value which copes with it is vertical acceleration, lateral acceleration and roll angular velocity respectively.

2.2 Detection of corrugation from cabin noise

Some measures should be taken to ensure accurate measurement of high-frequency vibration components using an accelerometer, e. g., it should be attached tightly to the cabin floor. A method was therefore invented to detect corrugation using cabin noise that is uniquely generated when trains run on rails with corrugation.

In this method, spectra are obtained using a short-time Fourier transform of cabin noise data. Peak heights of specific frequencies in the spectra together with the corresponding frequencies are calculated in real-time, and their time-related changes are evaluated \(^{(10)}\).

3. Condition monitoring of tracks with portable onboard device

3.1 Portable onboard device

A portable onboard sensing system was developed for an in-service vehicle to enable
simple diagnosis of tracks on a commercial line \(^{11}\). Figure 2 depicts components of the sensing system developed. It consists of a microphone for detecting corrugation, accelerometers for detecting track irregularity, a rate gyroscope, and 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 signal output from each sensor is converted into a digital signal by the analog input terminal and input into the computer. The sampling frequency of the measured data is 1 kHz. RMS values are calculated using Eq. (1) with \(N=8\).

Position information acquired by a GPS receiver is also inputted into the computer. The computer not only estimates current position and velocity based on the position information from the GPS receiver and acceleration signal from the acceleration sensor, but it also estimates track condition by processing the signal from each sensor and displays it in time sequence in the present position on a screen. Data obtained by signal processing is also recorded on a hard disk drive and utilized for detailed diagnosis of track status by off-line analysis.

![Configuration of portable onboard device](image1)

![Condition monitoring of tracks using portable onboard device](image2)

**3.2 Condition monitoring experience in local lines**

A method for estimating car body vibration from track displacements has been created as an index for controlling track irregularities. This method estimates riding comfort by calculating car-body vibration and evaluates track condition more effectively by obtaining response characteristics of the car body. Figure 3 shows a condition monitoring of tracks using a portable onboard device in a local line.

Long term condition monitoring of railway tracks has been carried out in local lines where the track irregularity is significant. Figure 4 shows a comparison result of two measurements with a time interval of 15 days. It should be noted that the two measured wave forms are almost the same and the significant peeks due to the track irregularities can be seen at the same location.

![Comparison of RMS of vertical acceleration in first and second runs](image3)

Fig. 4  Comparison of RMS of vertical acceleration in first and second runs (left) and condition of track where a significant peek was observed (right).
3.3 Evaluation of track maintenance

(1) Tamp down with a multiple tie tamper

In early January 2010, track maintenance works for whole line was made by a multiple tie tamper. Measured vertical acceleration RMS of car body before the track maintenance (December 12, 2009) is shown in Fig. 5 and after the track maintenance (January 13, 2010) is shown in Fig. 6. In general, a track condition is not good enough if a high RMS value is observed. A decrease in RMS value was confirmed after the maintenance by a tamping machine. Among them, RMS value of the places where it exceeded 0.3 m/s² has significantly reduced.

![Fig. 5 RMS value of car body (December 2009)](image)

![Fig. 6 RMS value of car body (January 2010)](image)

A half years later from the track maintenance (July 28, 2010), RMS values were evaluated again. A result is shown in Fig. 7. Figure 7 indicates that the maintenance work is not good enough to keep the RMS values in low level.

![Fig. 7 RMS value of car body (July 2010)](image)

(2) Ballast supplement and tamp down

An additional maintenance work was planned after the evaluation of RMS values obtained by a portable onboard device. The additional maintenance work was made with a ballast supplement and tamp down. The vertical acceleration RMS of car body after the additional track maintenance (November 1, 2011) is shown in Fig. 8 and a result of a half year later from the additional track maintenance (May 20, 2012) is shown in Fig. 9. It can be seen that the maintenance work was successful because we can not see any remarkable differences in those.

![Fig. 8 RMS value of car body (November 2011)](image)

![Fig. 9 RMS value of car body (May 2012)](image)

A long term condition monitoring of railway tracks was carried out for a place where the track irregularity was significant. Figure 10 shows a result for 3 years monitoring. Vertical acceleration of car body was collected by the portable onboard device for two runs. A speed difference in first and second runs was corrected using nominal train speed. It can be clearly seen that the first track maintenance is less effective than the second one and the track condition has been stable after the additional maintenance work.
4. Development of compact size onboard device

4.1 System configuration

The portable onboard device is a prototype device built up with general purpose modules. Therefore reliability of an operation is not enough as a commercial product. In addition to this, a trained measurement staff is needed to collect measurement data. A main concept of new device which is applicable for long term condition monitoring of tracks should be:

1) Much more compact than former device,
2) Full automatic data collection with a single switch operation,
3) Data transfer via cellular phone.

Figure 11 depicts components of the sensing system developed. This device is composed of processing unit, power unit, sensor unit and communication unit. Some pieces of software were unified in processing unit, and reliability of the system is greatly improved. The sampling frequency of the measured data is 820 Hz. RMS values are calculated using Eq. (1) with N=8.

The device is driven by Li-ion battery or outside power source. Accelerometers, rate gyroscope and GPS were redesigned to give higher performance. MEMS (Micro Electro Mechanical Systems) based accelerometers with anti-aliasing filter (cut-off frequency: 330 Hz) were chosen. One can add a microphone outside if a condition monitoring of rail corrugation is necessary. Collected data are usually kept in an inside un-volatility memory (SSD) or a SD card. Communication unit transfers the collected data to a data server via cellular phone.

Figure 12 shows an exterior view of the compact size onboard device. A built-in sensor unit is attached the device body. The body of the device is designed to avoid the additional vibration due to the car-body oscillation. It also has a function to keep it in horizontal plane. Newly developed devices fits in A4 size paper, and weigh about 2.8 kilograms. Full automatic data collection for 6 hours is possible by only pressing power switch.
4.2 Comparative experiment of devices

Two devices, former and newly developed device, were used in a local railway line (Fig. 13) and collected data were compared. And, zero point adjustment is being carried out by post-processing to the measured data. Vertical acceleration RMS obtained from newly developed the compact size onboard device is shown in Fig. 14, and from former portable onboard device is shown in Fig. 15.

As the data are obtained under the same condition, one expects that a result should be the same. They have good agreement in wave form but RMS values are very different. Those differences can be seen only in the accelerometer.

4.3 Calibration of accelerometers

A comparison was made between the newly developed device and correctly tuned accelerometer to calibrate accelerometers in the device. A vibration test was made using a vibration testing machine with correctly tuned accelerometer. A sinusoidal vibration (amplitude: 50[mm], frequency: 0.7[Hz]) were applied to the device for vertical and lateral direction on the vibration testing machine.

Measured vertical acceleration is shown in Fig. 16, and measured lateral acceleration is shown in Fig. 17. A high frequency vibration is appeared in the measurement due to a characteristic of the vibration testing machine. As they are identical, the newly developed device can be used without calibration.
But, one can realize that the calibration of accelerometer is necessary to use the data collected by former device. Figure 18 shows a result of former device with accelerometer calibration. The result shows that they are almost identical. It should be noted that a new threshold value should be set when we keep the condition monitoring using the compact size onboard device to evaluate railway tracks.

5. Future prospects

The most important change in the way of thinking for track maintenance is the collected data is not only used for keeping current maintenance index, but also used for sustaining railway system with securing total safety. Thus, the prove vehicle can be considered to be used for quality reforming in track maintenance, not be a simple alternative of a track inspection car. The compact size onboard devices provide regular monitoring of tracks every day. Condition monitoring network using onboard devices can collect a huge amount of track data by regular monitoring. Collecting data in one place is more efficient than leaving it to many local lines independently. It is necessary to construct an organization that can utilize the collected data for track maintenance effectively. Figure 19 indicates the example of an organization for track maintenance.
6. Summary

This paper summarizes a new development of a compact size onboard device for condition monitoring of railway tracks followed by a former development of a portable onboard device.

Condition monitoring experience in local lines showed that the collected data obtained from onboard device is effective for diagnoses of track condition. They also can be used for evaluating a quality of maintenance work. But, it is necessary to set up a threshold again depending on a measurement line, a measurement vehicle.

A newly developed device can collect the data of car body vibration automatically and transfer to the monitoring center via cellular phone for track diagnoses. The compact size onboard devices provide regular monitoring of tracks. We can collect a huge amount of track data by regular monitoring. It is necessary to construct a diagnostic system that can utilize the collected data for track maintenance effectively.

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References