Abstract

This paper deals with a new detection system of signs before the wheelclimb derailment for a railway vehicle running at low speed. A new system detects abnormal signs all the time before the derailment using MEMS (micro-electro-mechanical system) sensors of automobiles mounted on the vehicle practically and effectively. Vehicle state variables are measured by sensors mounted on the vehicle, and this system detects abnormal states before derailment using real-time data measured and a detecting algorithm for distinguishing derailment or not. First, a concept of the derailment detection system is explained. Second, the effectiveness of proposed detection algorithm was examined by a 1/10 scaled vehicle experiment. Finally, the effectiveness of proposed detection algorithm was examined by a real bogie experiment.

Keywords: railway vehicle, wheelclimb, derailment detection, safety, experiment

1. Introduction

One of the most important assignments for railroad technology is a safety against derailment accident. To improve railroad safety, many researches about derailment have been shown from several aims. The researches of derailment are classified into mainly three fields. First field is a research of derailment mechanism [7], [8]. The second field is investigations of safety assessment for derailment [9]. The last field is derailment detection [10], [11]. For realizing derailment detection system, measurement systems and determinable algorithms of derailment have been practically developed. These detection systems are fundamentally based on measuring impact at a derailment accident. On the other hand, a wheelclimb derailment in low speed which is focused in this research relatively takes time. This kind of derailment has possibility to take some kind of measures before derailment accident. Therefore, a concept of our new derailment detection system is to detect the derailment accident by abnormal behavior of a wheelclimb-beginning.

The purpose of this research is to establish a detection system that predicts wheelclimb derailment at low speed and informs a derailment danger. To put the detection system into practical use, it is important to keep inexpensive cost. Therefore, MEMS acceleration sensors and MEMS angular velocity sensors employed in automobiles are used to construct the detection system in this research. And, some of the authors constructed the new derailment detection algorithm through a 1/10-scale model experiment [6]. The achievement showed that the proposed algorithm was able to detect the wheelclimb derailment before occurring derailment accident.

This paper deals with a new derailment detection system which detects abnormal wheelclimb before a derailment at a low speed. First, a concept of the derailment detection system is explained. Then, features of sensors used in this research are introduced and a derailment detection algorithm is explained. Second, a 1/10 scaled vehicle experiment is introduced. The derailment detection algorithm was constructed by the scaled vehicle. The In this paper, a detection result is shown. Finally, a real bogie experiment is introduced.
2. New Derailment Detection System

2.1 Concept of New Derailment Detection System

In this section, the concept of a non-conventional derailment detection system is developed. The new derailment detection system for a railway vehicle detects abnormal vehicle signs before derailment. Vehicle state variables are measured by the sensors mounted on the vehicle. The concept of this system is shown in Figure 1. This system detects the abnormal states before derailment by using real-time measurement data on the vehicle. Where $V$ is the running velocity, and $\dot{\theta}(t)$ is the pitch angular rate of the truck frame, and $\dot{\phi}(t)$ is the roll angular rate of the truck frame, they are measured any time during driving, and where $\Theta_{CR}(V)$ is the peak threshold of the pitch angular rate of the truck frame, and $\Phi_{CR}(V)$ is the integral threshold of the roll angular rate of the truck frame in integral time $\Delta t(V)$. This system detects abnormal states before the derailment using real-time measurement data on the vehicle. If these variables exceed given threshold levels, the system determines that the vehicle is in an abnormal state before the derailment, and sends an alarm to the drivers cab. Sensors which have important roles in this system are detailed in the next section.

![Figure 1 Derailment Detection System in Early Signs](image)

2.2 Sensors for the Proposed Detection System

The measurement apparatus in the detection system includes micro electromechanical systems (MEMS) accelerometers, angular rate sensors, a data log, batteries, and displacement laser sensors. The MEMS accelerometers in the study have been widely installed on cars for ascertaining vehicle movement in electronic stability control (ESC) or anti-lock braking systems (ABS). It consists of sensor elements, which detect the speed, and application specific integrated circuits (ASICs), which convert the speed information into electronic signals as shown in the Fig. 2. In addition, the system is composed of silicon micro processors, which provide small size, high sensitivity, high accuracy, and strong structure, and, in particular can be readily mass produced.

![Fig. 2 MEMS accelerometer](image)  ![Fig. 3 Angular rate sensor](image)

Fig. 3 shows the elements of an angular rate sensor which has a balanced H-shaped resonant sensor consisting of a tuning fork gyroscope made from a piezoelectric material, usually quartz. The tuning fork is made to vibrate electromechanically. A crystal tuning fork is characterised by its small size, low...
cost, high sensitivity, and high accuracy and it can be used in wide range of temperatures with no calibration. It is packaged with the accelerometers in this research.

2.3 Proposed Detection Algorithm

The proposed detection algorithm and the sensing method for detecting derailments were proposed using the derailment results of the numerical analysis and the experiments with 1/10-scale model. Basically, the detection algorithm in the previous study needs to take into account the following:

- By whatever means possible, the derailments should be detected under all experimental conditions.
- Error detection caused by the rail joint should be avoided.

The two types of checking in the detection algorithm are proposed as follows:

- Peak check (Check1): the threshold for judgement is classified according to the running velocity and determined by the minimum pitch angular rate for derailment input under the remaining experimental conditions.
  \[
  \dot{\theta}(t) \geq \dot{\theta}_{cr}(V) \tag{1}
  \]

- Integral check (Check2): the threshold for judgement is classified according to the running velocity, and determined as the integral of the roll angular rate, during an interval of time \(\Delta t(V)\), with regard to the running velocity after the start of the wheelclimb under the remaining experimental conditions.
  \[
  \dot{\Phi} \geq \dot{\Phi}_{cr}(V), \quad (\dot{\Phi} = \frac{1}{\Delta t(V)} \int_{\Delta t(V)}^{t} \dot{\Phi}(t)dt) \tag{2}
  \]

All thresholds are determined depending on the running speed, and they should be preset in the railway vehicles before driving. Both the peak check of the pitch angular rates of the truck frame and the integral check of the roll angular rate of the truck frame are considered simultaneously, and an algorithm is proposed as shown in Fig. 4. It is able to distinguish between whether a wheelclimb derailment is occurring or not and excludes the rail joint effect. If both of them are over the threshold at the same time, the warning will work, and ways can be considered to prevent the derailment in advance.

3. Experiment of 1/10 Scaled-vehicle

The detection algorithm was constructed by the experiment of a scaled vehicle. In this chapter, the experimental equipments and experimental results are explained. The experiment was performed at the Chiba Experiment Station at the Institute of Industrial Science, the University of Tokyo. The experimental equipment is shown in figure 5. A 1/10-scale railway vehicle which was based on the common commuter train was built (figure 6). The derailment detection algorithm was constructed by using this experimental setup. The sensing devices which are explained in the former chapter were mounted on the each gear boxes, each bogies and wagon. Dynamic behaviors until the wheel-climbing...
derailment are realized by using a wheel-climbing device (figure 7).

Fig. 5 Layout of 1/10 scaled track

Fig. 6 1/10-scale railway vehicle with measurement apparatus

Fig. 7 Wheel-climbing Device
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It was found to be possible to detect an abnormality before the wheelclimb derailment in all the derailment experimental conditions using the proposed algorithm, which is verified as follows. Taking the data of the pitch and roll angular rate of the truck frame and one of the all experimental conditions, “0.9 m/s, 1st(left), 10 mm, 1 revolution”, for example, the results are shown in Fig. 9(a) and 9(b). In Fig. 9(a), the upper and lower lateral line represents the magnitude of threshold for the peak check on the pitch rate of the truck frame, and in Fig. 9(b), the roll rate of the truck frame is used for the integral check. The integral check with different integral times, 0.2 [s], 0.5 [s], and 1.0 [s] are shown in Fig. 9(c), 9(d) and 9(e). The lateral line represents the magnitude of the threshold for the integral check on the roll rate of the truck frame. A longer integral time for the integral check results in improved rejection of rail joint interference. However, the longer integral time delays the early detection of a derailment and
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counters the goal of achieving an early warning. In Fig. 11(c), the smallest integral time (0.2 s) found, which excluded the effects of rail joints and gave the earliest possible warning of a derailment, was 0.2 [s]. Some signal magnitudes exceeded the threshold before flange top running started. However, during this time period, because the pitch angular rate of the truck frame did not exceed the threshold of the peak check, no alarm was generated. The circles in the figure indicate where the derailment was positively detected, and the warning worked at that time. In other words, both the peak check and integral check exceeded the determined threshold at the same time, and both gave warning before the assumed derailment would have occurred. Therefore, the algorithm for detecting signs of a derailment excluding the effects of rail joints was verified for all experimental conditions.

4. Experiment of Real Bogie

The real-scale wheel-climbing experiment was performed to verify our derailment detection algorithm in the facility of the University of Tokyo. In this experiment, an actual bogie and a test course which has a constant sharp curve (R=48.5m) were used, shown in figure 4 and figure 5. The wheel-climbing state was created by running on the wheel-climb device. The device was installed along an outside rail of a wheel-climbing span, and a wheel of the outside rail was lift up by the device. The figure 6 shows wheel-climb running state.

4.1 Experimental Field

The test track, shown in Fig. 10, which was constructed by Institute of Industrial Science, the University of Tokyo at Chiba Experiment Station in 2007 was used for the experiment. This is the first test track belonging to university in Japan. It also will be part of comprehensive experiment fields for transport system such as ITS. The features of the test track are as follows.

- Curve radius is set to 48.3m with the assumption of imitating tight curving for LRT.
- 1435mm gauge which is the international standard gauge is used.
- For derailment prevention, derailment prevention rail is set in inner rail side.
- Equipments for measurement from the ground exist during constant curve.
- Place for the test track is paved with asphalt in order to be used for campus road and experimental road.
- The test track also will be a part of comprehensive experiment fields for transport system such as ITS.

The specification of the test track is introduced in the table 1. The wheel-climbing experiment was performed by using the constant curve area.

| Table 1. Specification of the Test Track | Fig.10 Overview of the Test Track |
A truck frame 'FS-509' which was donated from the Keihan Railway Company to the University of Tokyo was used in this real-scale experiment. The overview of the truck frame is shown in fig.11. The specification of the truck frame is introduced in the table 2.

![Fig.11 FS-509 Bogie](image)

<table>
<thead>
<tr>
<th>Specification of the FS-509 Bogie</th>
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<tbody>
<tr>
<td><strong>Length [mm]</strong></td>
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<tr>
<td><strong>Width [mm]</strong></td>
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<tr>
<td><strong>Height [mm]</strong></td>
</tr>
<tr>
<td><strong>Wheelbase [mm]</strong></td>
</tr>
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<td><strong>Weight [kg]</strong></td>
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4.2 Overview of Real-scale Wheel-climbing Experiment

The length of experimental area is 8m in the test track. The experimental area is constructed by a climbing part (3m), a highest part (3m), and a declination part (2m), in figure12. In the fig.12, the experimental area is shown by the red line. The bogie was running from the right end to the left direction in the fig.12. For the wheel-climbing experiment, the bogie was towed by a truck (figure13). The abnormal behavior before the derailment is expressed in the derailment is expressed in the climbing part.
4.3 Wheel-climbing Device

In this section, a wheel-climbing device is explained. The test track has the sharp curve. Therefore the bogie has a large angle of attack when the bogie runs on the curve. The fig.14 shows the overview of the angle of attack. Therefore, the wheel-climbing device was designed by using the angle of attack. The device makes only the front axle lifted up. A detail of the device is shown in fig.15. The device was consisted of the four parts; a base part, a slope base, a spacer, and a 6kg rail. The 6kg rail worked to lift up the wheel. And the 6kg rail was mounted on the slope base which inclination was designed from the rotation of the wheel during the climbing. The device was set up in the side of the right rail, shown in the red line of the fig.14. By using the 6kg rail which was thinner than flange gap of the second axle, the only right wheel of the first axle was lift up by the wheel-climbing device.
4.4 Measuring System

As the measuring devices, MEMS acceleration sensors and MEMS angular rate sensors which were explained former section were used. Six-axis measuring devices which are constructed by the acceleration sensor and the angular rate sensor were installed near to the center of the truck frame. Three-axis acceleration sensors were mounted on the four axle box. By using these sensors, the abnormal behavior before the derailment was measured. Moreover, laser sensors were mounted on the guard iron to measure the climbing amount, and the running speed was measured by the wheel pulse.
One of the experimental results is shown in fig.20. The bogie speed 3.5 km/h is the lowest speed in the experiment. The climbing up area is between the two blue solid lines. The bogie reached to the climb-up area at 76 second. The fig20(a) shows the climb-up amount. The fig20 (b) shows roll angular rate at the center plate, and the fig20(c) shows pitch angular rate at the center plate.

In order to detect abnormal state before derailment accident, the detection algorithm has to separate an abnormal sign in a wheel-climbing from a disturbance in a normal running. Therefore, physical values which are used in the proposed algorithm are checked in this section. The pitch angular rate and integrated roll angular rate which were measured in the experiments are plotted and max values of both the normal running and the during wheel running are plotted in the figure 21. The figures show that the proposed algorithm is possible to separate the wheel-climb running from the normal running in the each running speed. The results showed an effectiveness of the derailment detection algorithm in the real scale experiment.
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(a) Vertical Displacements

(b) Pitch Angular Rate

(c) Roll Angular Rate on the Center Plate

(d) Integrated Roll Ang. Rates on the Center Plate

Fig. 20 Measured Data (V = 3.5km/h)

Fig. 21 Relationship between Velocity and Pitch Angular Rate

Fig. 22 Relationship between Velocity and Integrated Roll Angular Rate
5. Conclusions

This paper dealt with a new derailment detection system which detects abnormal wheelclimb before a derailment at a low speed. First, a concept of the derailment detection system was explained. Second, the effectiveness of proposed algorithm was examined by the 1/10 scaled vehicle experiment. Finally, the effectiveness of the algorithm was examined by the real bogie experiment.

References