Development of an Evolution Type Train Protection System to Prevent Secondary Accidents

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In order to reduce the consequences of primary railway accidents such as a train derailment, overturning, and collision, it is vital to prevent secondary accidents which may occur with oncoming trains.

Previously in Japan, the crews at the site of primary accidents used fusee signals to prevent secondary accidents. Since 1986, the crews have used “Train Protection System” (Train protection alarm signals sent directly to oncoming trains by radio) to warn trains approaching accident sites. This system has proven to be highly effective, and is utilized by railways nationwide. To send the protection alarm, however, a button should be pushed by the crews manually.

Now, we have been developing a much superior system to prevent secondary accidents by triggering the alarm automatically when the accident occurs. This system will ensure passenger safety even in the instance that the crews are unable to take immediate protective measures against an oncoming train.

1 History of Train Protection

In the case of train derailment or collision with obstructions, it is necessary to stop any oncoming trains promptly. This is to prevent a serious secondary accident such as further derailment or head-on collision with oncoming trains. “Train Protection” is a term meaning to stop oncoming trains to prevent the secondary accidents.

In the early years of Japanese railway system, the train protection was carried out manually. The steps of the measures are listed below. (Figure 1)

1. When the train stops, the crews step down from the train, light a “Portable Fusee Signal” and put it at a position that could be seen easily from oncoming trains. (about 600 m far from the stopped train)
2. The crews try to turn an electric signal red by short-circuiting a relating track.

The prototype for the train protection was designed in Great Britain, birthplace of the railroad in the 19th century. Afterwards, various improvements were added, and the train protection as mentioned above was conducted in Japan until the 1980s.
However, the train protection by hand had become unrealistic as the number of trains increases.

A multiple derailment collision occurred at Mikawashima Station on the Joban Line on May 3, 1962. (Figure 2) Following a freight train passed a red signal and derailed, other two oncoming trains intruded into the freight train because there was no time to set the train protection devices. After this accident, the fusee signal was installed on the roofs of all the crews' cabs as a countermeasure. It could light and smoke a signal and sound an alarm by a drawstring.
In the latest train protection system, a radio signal is also used.

Figure 2: Mikawashima Accident

2 Nationwide Introduction of Train Protection System

Nowadays the train protection system (Figure 3) with the radio signal is used in the entire network in JR East. When the crews confront an emergency scene such as detection of an obstruction on the track or a train derailment, the crews should send emergency stop radio signals to oncoming trains by pushing a

Figure 3: Train Protection System

train protection button in the driver’s cab. If the emergency radio signals reach other trains, alarm beeps will sound in the driver’s cab of the oncoming trains. If the crews in the oncoming train hear the sound, s/he should stop the train immediately and cannot start to drive it again without permission by the authority of train operation. Because the communication between operation staffs and the crews is necessary to lift the ban, a train radio system is needed. Thus, the train protection system was introduced throughout Japan in 1986 when the train radio systems were arranged to all trains.

3 Development of an Evolution Type Train Protection System

3.1 Amagasaki Accident

In a train derailment accident in Amagasaki occurring in April, 2005, the train protection system was not adequately performed, although a secondary accident did not occur fortunately. Neither the driver nor the conductor of the derailed train was able to use the train protection system. It seems that the conductor in the last car pushed the train protection system button when the derailment occurred. However, it was necessary to switch the power supply of the system to the emergency position. Because the power supply was not changed, the train protection radio was not sent. A train approaching the accident site was informed about the accident not by the train protection system but by the observation of abnormal shakes of the catenary near the crash site by a crew, and he stopped the train in time.

Thus, from the Amagasaki accident we learnt of the necessity of the securing power supply in an emergency and the necessity to send the train protection radio automatically.

3.2 Development of a New System

Our company started the development of the evolution type train protection system to prevent secondary accidents from the lesson of the Amagasaki accident. The new system can trigger the train protection radio automatically if the train derails, overturns or intrudes with something. The most important device in the new system is a device that detects collision, derailment, and overturn (Hereafter, it is called the detection device). The device detects the vibration of the rolling stock and the state of the inclination from the acceleration data acquired with the acceleration sensor in this device. When the acquired acceleration exceeds a threshold, it detects abnormality. The detection devices target four events, head-on collision, side collision, derailment, and overturn. The device informs the crews which event is detected, and sends the train protection radio to other trains automatically. (Figure 4)

Head-on Collision and Side Collision:
Collision is detected by large impact acceleration generated by the collision.

Derailment:
Derailment is detected by unusual vibration in vertical direction in the rolling stock.

Overturn:
Overturn is detected by the continuous decrease of acceleration in the vertical direction.

In order to prove the stiffness, less maintenance, and low cost of the device, the system is simplified and miniaturized by judging abnormality only with the acceleration sensor.

3.3 Point of Development

The train protection system is set up in the driver's cab where it is most convenient for the crews to send radio signals in case of emergency. After a collision occurs, especially a head-on collision, the front part of the front-most rolling stock may be wrecked, and there is a possibility that the detection devices and the train protection system are destroyed. The time that it takes to acquire the acceleration data, to judge the abnormality, and to trigger the alarm should be shortened as much as possible. The detection device and the train protection system should trigger an alarm before these are destroyed by the collision or power supply is cut off. By simplifying the algorithm of the judgment, the judgment time can be shortened, and this system made it possible for an oncoming train to properly transmit the train protection radio quickly.
Moreover, the detection device can transmit the information of an abnormality to two train protection systems set up in both the first and last rolling stocks. Even when the detection device and the train protection system equipped at the head of the train are destroyed by a head-on collision, it is possible to avoid secondary accidents by the emergency stop radio signals sent from the train protection system at the tall end of the rolling stock. In the rolling stock of our company, when the train protection system is not able to obtain a regular power supply, it can keep sending the radio signals with a spare battery.

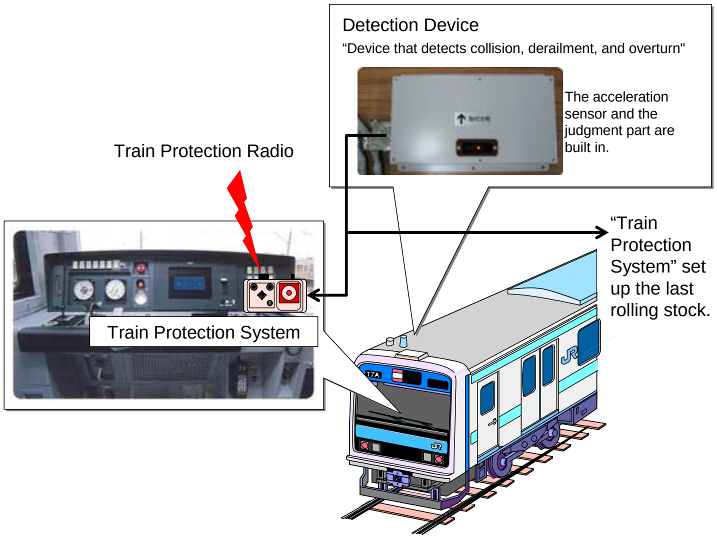


Figure 4: Detection Device and Train Protection System

3.4 Judgment Logic

3.4.1 Judgment of Head-on Collision

When the head part of the train collides, the detection device measures a back and forth vibration and the impact that acts on the body with a built-in acceleration sensor. When the acceleration exceeds 10.0 G after over 40 Hz vibrations are removed by the low-pass filter, it is judged a head-on collision. There is a possibility that the first rolling stock is destroyed in an extremely short time in case of a head-on collision, and the detection device is destroyed. Therefore, all processes from the acquisition of the acceleration data and the output of the judgment result should be made as short as possible in the head-on collision. The detection device judges the acquired acceleration data compared with the threshold at each 5 milli-seconds cycle (200 times per one second). The threshold is decided from the result of some experiments and simulations of collision.

(1) Impact Acceleration Analysis That Uses Collision Simulation

In order to understand how much impact acceleration exists when an automobile collides with the head part of a train, we analyzed the impact acceleration by using the collision simulation. We get the simulation result when the head part of the train, E231 (a commuter train in our company), collides with object that corresponds to four kinds of automobile respectively (large-scale dump truck, truck, car, and mini type car) at 60 km/h in speed. We measure the acceleration at the seven places in the head part of the train as shown in Figure 5. For all four automobile types, the acceleration at the upper side behind driver’s cab exceeded 50.0 G. Moreover, in the another experiment in that a train collides with a wall, the impact acceleration at the body center of gravity exceeds 10.0 G, and that at other parts such as sides and roofs of the driver’s cab are high enough.

(2) Examination of Impact Acceleration When a Train Is Connected With Another Train

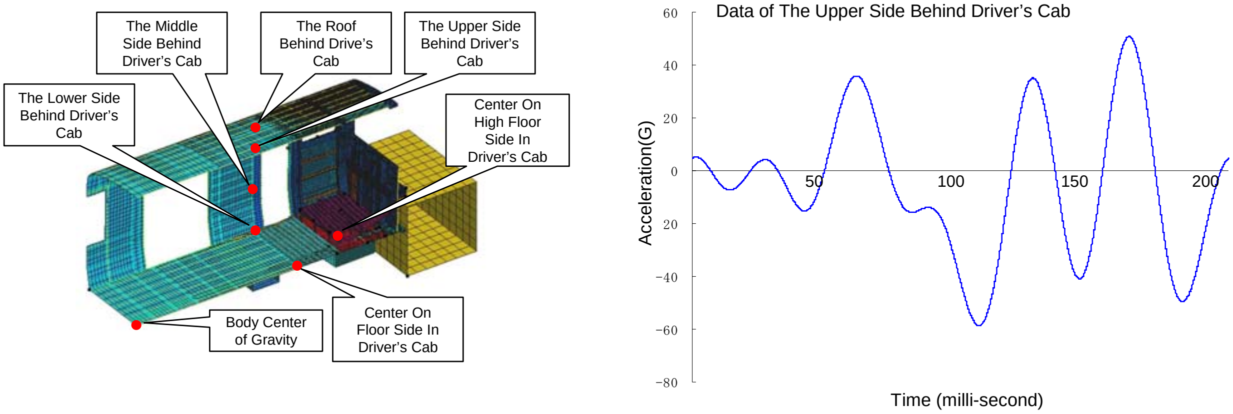


Figure 5: Collision Simulation

It is required that the detection device does not mistake the usual acceleration of the rolling stock for an accident when the train is operated normally. One may assume that the highest impact acceleration is obtained when a train is connected with the other in normal operation. For two types of rolling stocks, locomotive and electric, we measured the acceleration on the dashboard, at the floor and at the upper part of a wall in driver's cab when a train is connected with the other at 5 km/h. (Figure 6) As the results of the measurement, we obtain 0.5 G in a locomotive car and 0.3 G in an electric car as the maximum acceleration. We confirmed that these results are lower enough than the threshold.

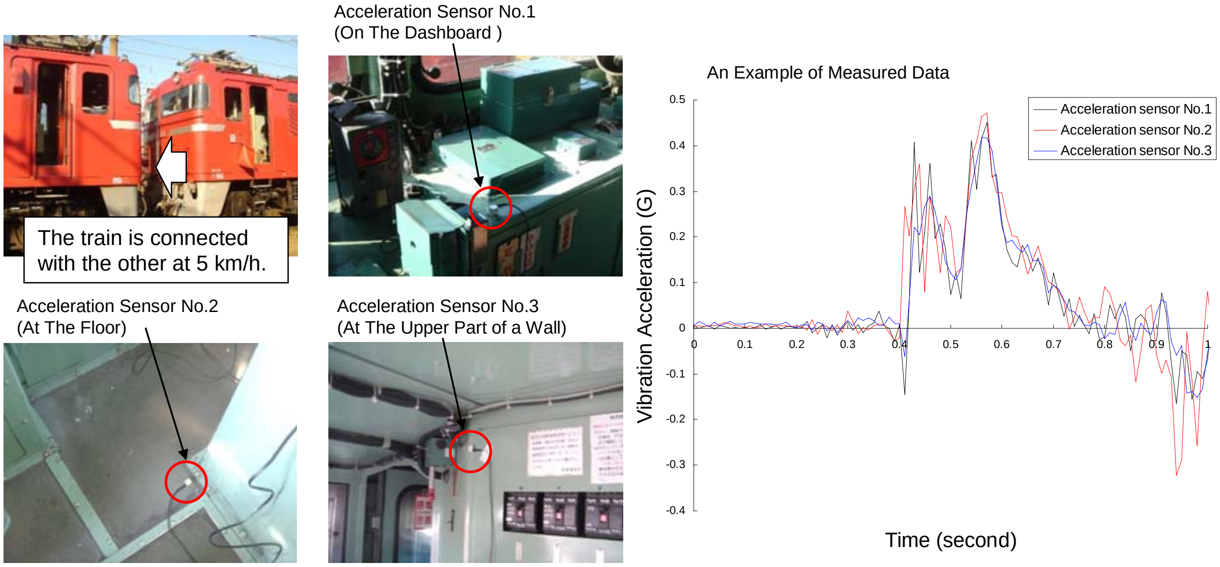


Figure 6: Examination of Impact Acceleration When a Train Is Connected with Another Train

3.4.2 Judgment of Side Collision

The detection device can be also used to detect a side collision. The detection device measures horizontal vibration and impact that act on the body with a built-in acceleration sensor. When the acceleration exceeds 3.0 G after over 40 Hz vibrations are removed by a low-pass filter, it is judged the side collision. As well as a head-on collision, the detection device compares the acceleration data and the threshold every 5 milli-seconds. It is required that the detection device does not mistake the impact of closing doors for the side collision. Measuring the impact acceleration of the closing doors, we confirmed the detection device does not mistake the closing doors for the side collision.

3.4.3 Judgment of Derailment

When a train derails, it might be followed by secondary accidents such as turning over to sideways, and colliding with the bridge girder, the platform, and the oncoming train. When a derailment occurred at Naka-Meguro Station in 2000, the middle part of the derailed train collided with an oncoming train because it had not stopped at once after the derailment. We developed a “derailment detection device” to detect the occurrence of derailment in 2001. The derailment detection algorithms are also used in the detection device.

The derailment detection device informs the driver of the derailed train the occurrence of the derailment immediately. This has been already introduced into a new train, E331, in Keiyo Line in 2006.

The device was developed so that it can detect derailment with high reliability at low cost.

Therefore, the derailment detection device should have a simple judgment algorithm. In fact, we considered three simple algorithms and confirmed the reliability of these algorithms by running tests for over 20,000 km and by derailment tests at low speed. The algorithms that can detect the derailment is as follows. (Figure 7)

Judgment Method 1:

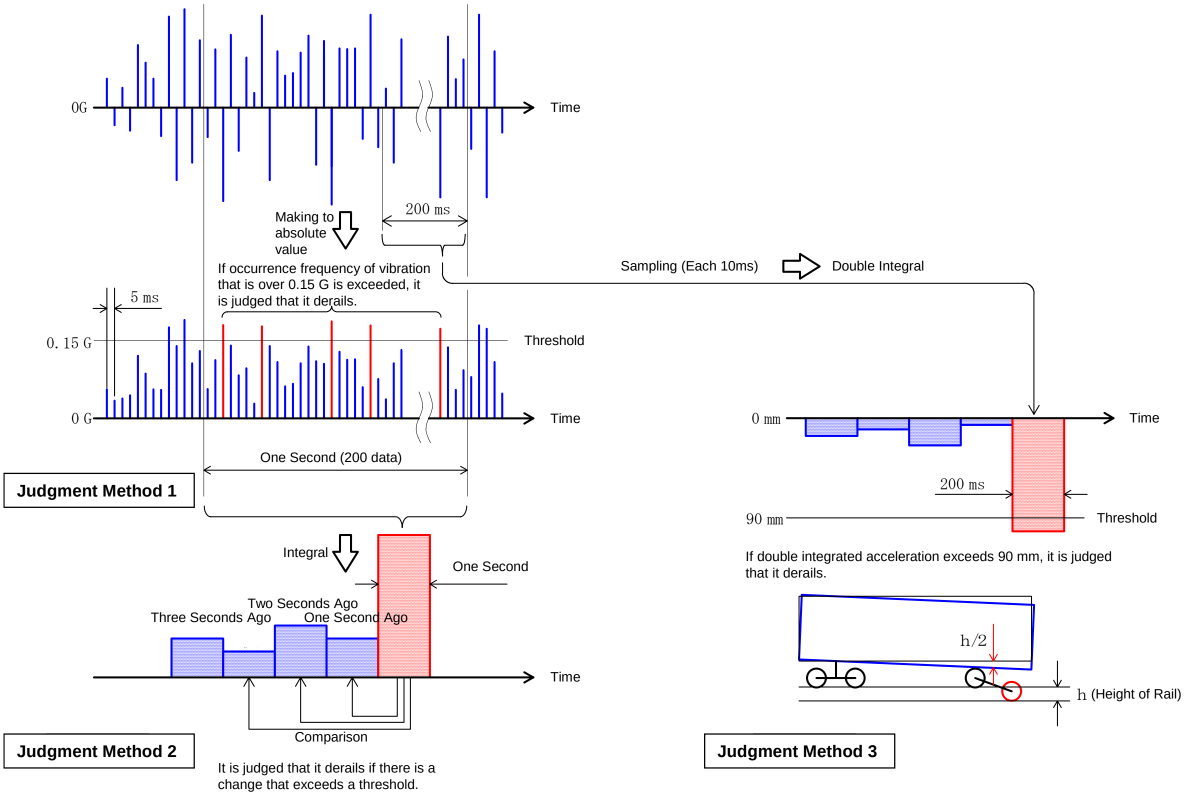
If the size of amplitude of the vibration of acceleration exceeds 0.15 G and its occurrence frequency exceeds 20 times per one second, the devices make a judgment of derailment.

Judgment Method 2:

The absolute value of the vibration is added up for one second, and if the amount of the difference from the previous sum value exceeds a certain level, the devices make a judgment of derailment.

Judgment Method 3:

If the double integrated value of the acceleration for a 200 milli-seconds exceeds 90 mm that corresponds to the height of a rail, the devices make a judgment of derailment.



If occurrence frequency of vibration that is over 0.15 G is exceeded, it is judged that it derails.

If double integrated acceleration exceeds 90 mm, it is judged that it derails.

It is judged that it derails if there is a change that exceeds a threshold.

Figure 7: Method of Judging Derailment

In general in Japan, a train car is designed to reduce particular vibrations whose frequencies are between 6 Hz and 20 Hz, because people perceive the vibration of this frequency band clearly. In order to make the vibration of derailment prominent, we used a band-pass filter that can extract vibrations between 6 Hz and 20 Hz.

The derailment detection device was set up in the prototype train (Advanced Commuter Train) from 2002, and examined in various conditions. As a result, we could confirm the derailment detection device does not misjudge in usual running.

3.4.4 Judgment of Overturn

One may think that these are two kinds of overturn forms. One is an overturn caused by the centrifugal force when the train is running in the curve at over speed. The other is an overturn caused by outside force such as crosswind and downdraft. We select a train type whose center of gravity is lowest in our properties, and investigate the limit angle at that the train cannot straighten up if the train leans accidentally. The limit angle can be understood by reduction of the acceleration that is observed with a vertical acceleration sensor. If the reduction of the acceleration is less than -0.114 G for over 300 milli-seconds, the devices judge it as overturning.

4 Schedule for The Future

As we mentioned above, we developed the detection device that can judge collision, overturning, and derailment, and the train protection system that can send alarms to oncoming trains, and could confirm the validity of the devices by some experiments and simulations. In addition to that, we are planning to set the devices in some trains in service and to check the behavior of them, in order to secure the reliability of the devices. After the pilot running, we intend that the detection device and the train protection system will be introduced to trains nationwide.