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A Study for the Installation of a Door Catch Detection Device using a Laser Sensor

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Abstract

To prevent accidents in which customers' luggage gets caught in the door of a train, we have developed a door catch detection device using a laser sensor with even higher detection accuracy in addition to the existing door-trap detection function of vehicles. In this study, we confirmed the basic characteristics of the developed device and examined the installation method of it through a short-term installation test on a vehicle. Then, we installed the device in a commercial vehicle to verify its detection performance in operation. We also conducted a test using a doll to start the vehicle with an object wedged in the door.

Keywords: safety, door catch, drag, detecting device, platform, human damage accident

1 Introduction

When customer's luggage or other items are caught in the door of a train (hereinafter, referred to as "door catching") and the train starts (hereinafter, referred to as "door dragging"), the customer or other customers on the platform may be injured, resulting in a train accident with personal injury. To prevent such accidents from occurring, trains must be equipped with a function to detect door catching and dragging.

In the existing trains of East Japan Railway Company (JR East), the occurrence of the door catching is detected by the switch that is pushed in when the train door is completely closed. However, if an object less than 20 mm thick is wedged in the door, the switch may be pushed in while the rubber at the end of the door (hereinafter, referred to as "door rubber") is deformed, making it difficult to detect the door catching. To improve the door catching detection function, JR East has been developing devices that can detect door catching though objects less than 20 mm thick are wedged in the door and can also detect door dragging[1].

Among the door catching and dragging detection devices under development, the device using a laser sensor has little impact on existing door functions when it is installed additionally and has been used by several other railway companies. However, differences in train body widths exist between the vehicles of JR East and other railway companies that have already adopted the sensor. Part of the width of the JR East's train body is designed wider, while the width of other railway companies' train bodies are uniform. So, it is necessary to consider the installing position of the laser sensor and adjust the projection position of the laser light in order to install it in the JR East's actual vehicle.

In this study, we first confirmed the basic characteristics of the door catching detection device using a laser sensor, and then installed the laser sensors on two doors of a vehicle on a trial basis for about one month to verify the detection performance and to consider the installing position of it. In addition, to verify the detection performance in the event of door catching or dragging, we conducted a test using a doll with an object wedged in the door and start the vehicle.

2 Basic characteristics of the device

2.1 Detection methods

Figure 1 shows the equipment configuration of the door catching detection device using a laser sensor. A laser sensor is installed at the center position above the door, and a laser beam is projected downward near the door rubber to detect objects wedged in the vehicle door.

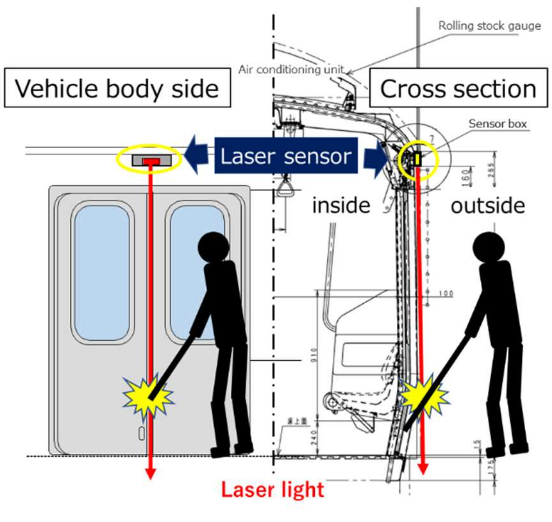


Figure 1: Equipment configuration

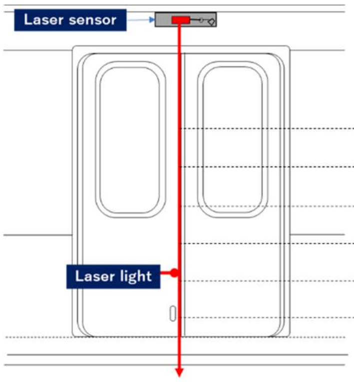
2.2 Basic characteristics

To confirm the basic characteristics of detection by a laser sensor, a box containing a laser sensor was installed at the center position above the door on the side of the vehicle (hereinafter, referred to as "side position"). We verified the detectable thickness of wedged objects and detectable width from the center of the door. Also, we examined the projection position of the laser light.

(1) Detectable thickness of wedged objects
We used five different thickness of boards (2,5,6,7,11 mm) to confirm the detectable thickness of wedged objects. Each board was wedged in the door, each at six different heights (100, 300, 600, 1000, 1200, 1500 mm from the vehicle floor).

Figure 2 shows the results. At a height of 600 mm or more from the vehicle floor (near the laser sensor installation position), it was possible to detect objects 2 mm or more in thickness. Even at height of 100 mm from the vehicle floor (furthest distance from the laser sensor installation position), objects with a thickness of 11 mm could be detected.

While it is difficult to detect objects of less than 20 mm in JR East's actual vehicles, the laser sensor can detect thinner objects.



Hight from the vehicle floor [mm]	Detectable minimum thickness [mm]
1500	2
1200	2
1000	2
600	2
300	5
100	11

Figure 2: Results of detectable thickness of wedged objects

(2) Detectable width from the door
Here, we verified the "width" as the detectable range from the center position of the vehicle door. The detectable widths were verified for six heights (100, 300, 600, 1000, 1200, 1500 mm from the vehicle floor). We measured the detectable width by moving a board in the direction of the rail, which is the direction of the train is moving, and in the direction of the railroad tie, which is perpendicular to the rail. To check for variations due to the installation conditions of the laser sensor, we examined the width at two vehicle doors (door A and B in Figure 3).

Figure 3 shows the results. The detectable widths in the rail direction were less than 5 mm at a floor height of 1000 mm or higher, which is close to the laser sensor, while the widths increased to about 12 mm at a floor height of 600 mm or lower. This is thought to be since the laser light projection range increases as it moves away from the laser sensor. On the other hand, the detectable widths in the direction of the railroad tie were found to be 0 to 5 mm regardless of the floor height, indicating that there is not much spread.

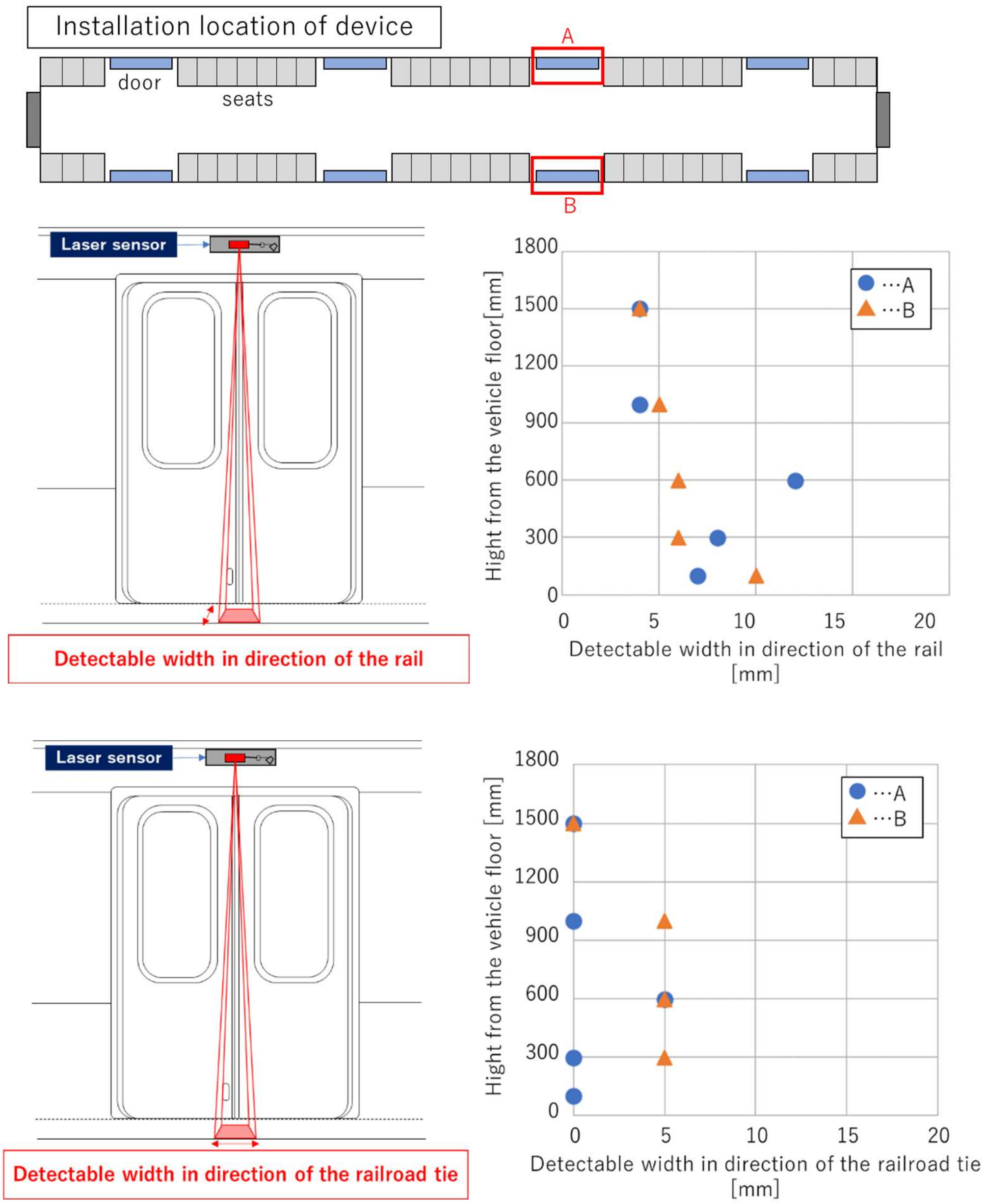


Figure 3: Results of detectable width

(3) Projection position of laser light

The following two situations can be considered as possible causes of unwanted detection when using the door catching detection device with a laser sensor.

a. Widened part of the vehicle body gets into the detectable range

b. Customers and luggage on the platform get into the detectable range

Considering the detection performance verified in the previous section, we decided to set the projection position of the laser light in the space between the vehicle body and the platform to avoid unwanted detection.

2.3 Short-term installation test

To verify the detection performance of the laser sensor when installed on actual train, the detecting devices were installed on two doors of a train of the E231 Series running on the Chuo-Sobu Line, and a test was conducted for about one month. The laser sensor was installed on the “side position”, and the projection position of laser light was set in the space between the vehicle body and the platform. The detection range was set from the vehicle floor to the laser sensor installation position. In addition, the laser light was always projected to figure out whether there was a required/unwanted detection while the train was running on the business line or when it passed through the washing equipment.

(1) Detection performance for structures
It was confirmed that structures such as station platforms and turnouts are not unwantedly detected. This is thought to be since a certain amount of space is secured for vehicles by clearance gauge, and the probability of those structures blocking the laser lights projected in the range close to the vehicle body is low.

(2) Detection performance in operation
No door catching or dragging events occurred during the test period, but some detection records were identified. It is considered that the objects were present in the detection range of the laser sensor due to water and detergent on the vehicle body during cleaning operation, maintenance workers and drivers passing near the vehicle body, and other factors. To avoid these unwanted detections, we decided to impose operating and driving conditions for activation of laser sensor. Although there was no detection due to weeds during the test period, we also imposed conditions such as not activating the laser sensor while the vehicle is in motion, since weeds could grow and be detected depending on the time of year and the environment.

2.4 Installing position of laser sensor

Figure 4 depicts the installation position of laser sensors. Left side of Figure 4 shows the installation position of “side position”, which is the position of the laser sensor up to the previous section. In the case of the “side position” installation, the dimensions of the laser sensor itself are less restricted because it is installed on the side of the vehicle body. However, it was necessary to install a new sensor box to store the laser sensor and drill a hole in the side of the vehicle body to install the electric cable. There were also restrictions on maintenance work, such as the need to set up scaffolding outside the vehicle when adjusting the projection position or replacing the laser sensor in the event of a malfunction.

To solve the above issues, we considered installing the laser sensor at the position shown on the right side of Figure 4 (hereinafter, referred to as “doorway frame position”). In this installation method, the laser sensor is installed inside the vehicle door header, and a laser light projection port is provided on the vehicle door entrance frame. Although there were restrictions on the dimensions of the laser sensor body due to the existing devices installed inside the door header, the selection of a compact sensor made it possible to install the sensor. The installation position of "doorway frame position" also made it possible to adjust the projection position of the laser sensor and replace the laser sensor from inside the vehicle without the need for scaffolding, thus eliminating the restrictions on maintenance work that existed when the laser sensor was installed in "side position". As in the "side position" installation, the laser light was set to project into the space between the vehicle body and the platform in the "doorway frame position" installation.

To compare the detection performance of the installation of the "side position" and the "doorway frame position", the detection performance of various objects caught in the door was verified. Table 1 shows the results. No significant difference in detection performance was observed depending on the positions of the laser sensor.

The laser sensor was installed in "doorway frame position" from then on because it solved the problem of maintenance work and had the equivalent detection performance to that of the "side position" installation.

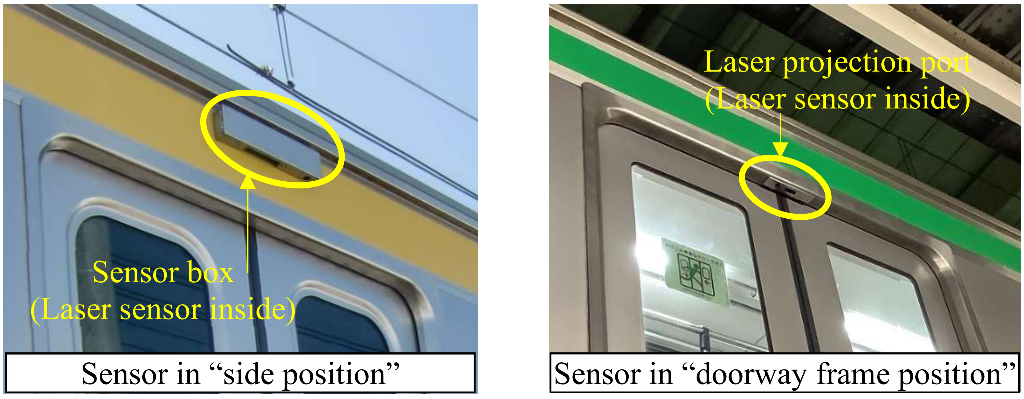


Figure 4: The installation position of laser sensor

Objects	"Side position"	"Doorway frame position"
White cane	++	++
Stick	-	++
Backpack belt	-	-
Strap	++	++
Board	++	++
Clothing	++	++
Umbrella	++	++
Bag	++	++
Hand	++	++

++…detectable
-…undetectable

Table 1: Detection performance of "side position" and "doorway frame position"

3 Long-term installation test

3.1 Methods

To verify the detection performance under the operating environment, the detection devices were installed at 28 doors of a train of the E233 Series running on the Ueno-Tokyo Line and Shonan-Shinjuku Line. The installation positions were the “doorway frame position” considered in the previous chapter, and the test was conducted from February 2023 to January 2024. Information such as whether the detection device detected or not and whether the vehicle door opened or closed was recorded by the control unit, and the image of when the vehicle door closing was recorded by a small camera attached near the laser sensor.

3.2 Results

During the test from February to June 2023, several detection records were confirmed. The detection records were categorized into three cases.

a. Partially caught in clothing or bag (Figure 5 a)
b. Contact from outside of vehicle (Figure 5 b)
c. No object (Figure 5 c)

Case “a” was detected when a passenger in the train was standing near the door due to crowding, etc., and his/her clothes or bag was caught in the door. The detection by the object was confirmed to be normal. When the caught object was pulled inside the train, the detection stopped because there was nothing left to reflect the laser light.

Case “b” was detected when a station attendant checked whether the train door was completely closed from outside the train on the station platform, and his/her hand got into the detection range. In this case, too, the detection by object was confirmed to be normal.

For case “c”, no object reflecting the laser light could be identified, although the detection record was confirmed. This is assumed to be due to the detecting the vehicle body as an object caught in the door due to misalignment of the projection position of laser light or detecting raindrops or dust adhering to the laser projection port. Since these detection case affects transport stability, the projection position of the laser light, its adjustment method, and cleaning of the laser light projection port should be considered.

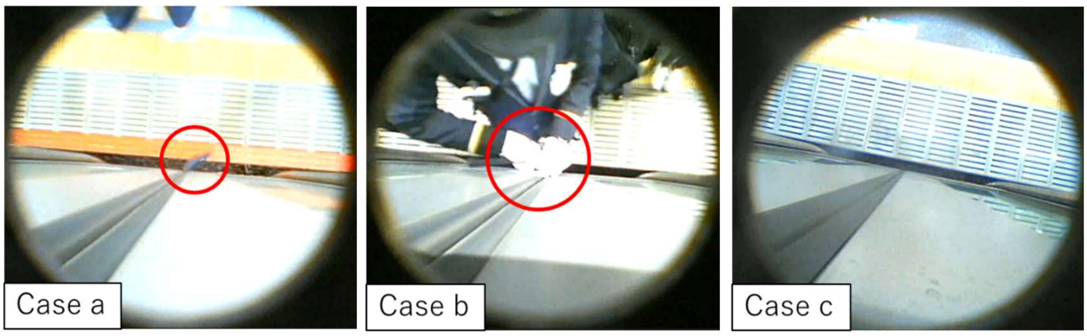


Figure 5: Example of detection records

4 Vehicle start-up test with an object wedged

4.1 Methods

To verify the detection performance in the event of door catching or dragging, we conducted a test using a doll. Specifically, a doll simulating an adult (approximately 60 kg) was made to carry an object and the object was wedged in the door of the train described in “3. Long-term installation test” to confirm the door catching detection performance. From this state, the train run for approximately 10 m to check the door dragging detection performance. Straps, clothing, and bag were selected as the objects.

Before and during the run, the detection information of the detection device was recorded by the control unit, and images during the test were recorded by a small camera installed in the train.

4.2 Results

Figure 6 and Figure 7 show the test when the bag and the strap were wedged in the door, respectively, and Table 2 shows the results of each object.

In the case where the bag was wedged in the door, the doll and the bag were dragged along with it when the train moved. On the other hand, in the case where the strap or the clothing were wedged in the door, both escaped from the door shortly after the train moved and were not dragged.

Regarding detection performance, the detection device could not detect the door catching condition of the strap. This is assumed to be due to the presence of the undetectable range of laser sensor between the vehicle door and the laser light. It is considered that the strap was in this range and therefore could not be detected.

The clothing was detected when it was wedged in the door, but the detection stopped after the train moved, and the clothing had escaped from the door.

The bag was detected when it was wedged in the door. However, after the train moved, it could not be detected in some cases. This is because when the train moved, the objects and the doll were dragged and thus moved relative to the door from their before-start up positions. Therefore, it is assumed that they had moved out of the detection range of laser sensor.

The results show that the door catching detection device using laser sensor is applicable to detect door catching, while it is difficult to detect door dragging. In order to detect door catching events that may lead to door dragging, it is necessary to improve the detection performance by adjusting the projection position of laser light, and more.

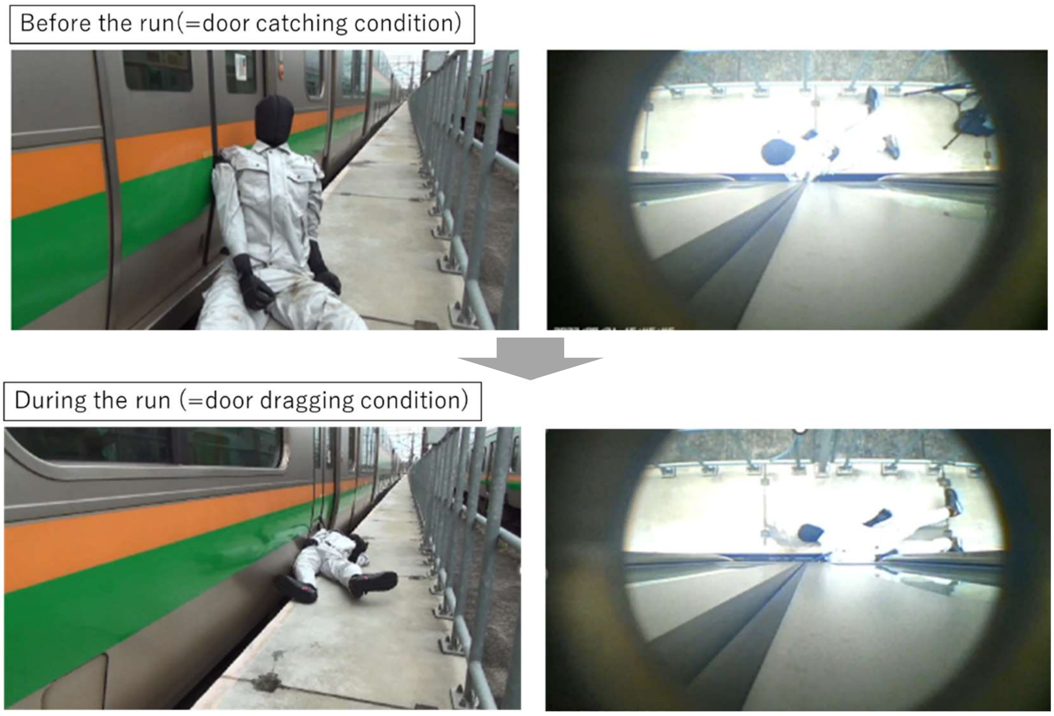


Figure 6: Vehicle start-up test with the bag wedged in the door

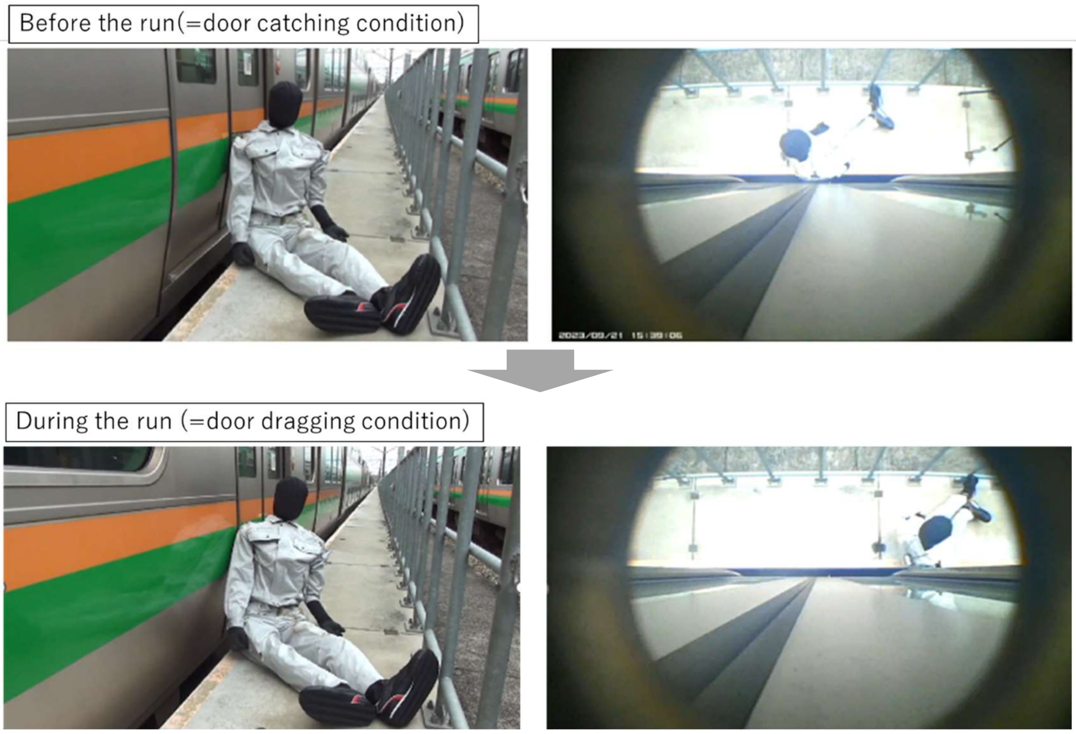


Figure 7: Vehicle start-up test with the strap wedged in the door

Objects	Before the run (=door catching condition)	During the run (=door dragging condition)
Strap	-	/
Clothing	++	/
Bag	+	+

++…detectable +…undetectable in some cases
-…undetectable /…no dragging occurred

Table 2: Results of vehicle start-up test

5 Conclusions

In this study, to improve the door catching detection performance, the device using a laser sensor was installed in actual vehicles on a trial basis, and the following results were obtained.

1) As a basic characteristic, it was confirmed that the laser sensor can detect door catching condition of objects up to 11 mm in thickness. The detectable width in the rail direction increased as it moved away from installation position of the laser sensor. On the other hand, in the direction of the railroad tie, there was no spread in the detectable width regardless of the distance from installation position of the laser sensor. Based on the results of the basic characteristic, the projection position of the laser light was examined.

2) The devices were installed on two doors of a train on trial basis for about one month to verify the detection performance when installed on the actual vehicle. As a result, it was confirmed that unwanted detection was not found on structures such as station platform. On the other hand, since it was confirmed that detection was made during cleaning operations, etc., we decided to impose operating and running conditions on the activation of the laser sensor. Also, in condition of environmental changes such as weeds growth, the laser sensor is not activated while the vehicle is running.

3) To solve the problem of installing the laser sensor at “side position”, which requires the setting of a sensor box and wire holes, we consider installing at “doorway frame position”. Because a compact sensor made it possible to install the sensor inside the door header, and there was no significant difference in detection performance between the “side position” and “doorway frame position” installation, the laser sensor was installed on the “doorway frame position”. This allows adjustment of projection positions of laser light from inside the vehicle, thereby reducing the burden of maintenance work.

4) To verify the detection performance in the event of door catching or dragging, we conducted a test using a doll and start the vehicle. As a result, it was confirmed that the door catching detection device using a laser sensor is applicable to detect door catching, while it is difficult to detect door dragging. To detect door catching events that may lead to door dragging, it is necessary to improve the detection performance in the event of door catching.

References

[1] R. Watanabe, Y. Akasaka, Y. Uchida, K. Matsuhashi, Y. Misu, H. Natsume, H. Murakami, H. Takagi, “Development of door catching detecting device (Special edition paper)”, Technical review, JR East, 70, 47-52, 2023 (In Japanese)