Development of a Detector of Foreign Objects Caught in the Doors with Improved Function for Preventing Passenger Dragging Accidents

Rolling stock such as that for commuter trains has safety devices that detect if bodies or baggage are caught in the doors and prevent the train from starting to move in such a case. Since conventional safety devices detect objects using a mechanical switch (door close switch), it is difficult to detect thin objects such as the leg of a stroller or passenger’s clothes. Thus, there is a risk of accidents when passengers are caught in the doors and dragged by the train. In this study, we are aiming to develop a safety device based on completely different principles from former ones to eliminate accidents. This new device can detect objects based on deformation and change of inner pressure of a detection tube at the edge of the doors. We have conducted checks of the detection performance and reliability of the prototype, and we are now seeing a prospect of putting it into practical use.

● Keywords: Caught in doors, Dragged by train, Door close switch, Door stop rubber, Semiconductor micro-differential pressure sensor

1 Introduction

When the doors of a train at the platform close, passengers run the risk of being caught in the doors. If the train starts to move with a passenger caught, it could result in a serious accident where the passenger is dragged by the train. Avoiding such incidents is thus a major issue in safety.

2 Conventional Foreign Object Detection System and Issues

2.1 Changes of Door Structure and Foreign Object Detection System

Fig. 1 illustrates changes of the door engine and the foreign object detection system of commuter train cars of JR East. Older cars operate doors using air cylinders, but modern cars use a door operation method combining components such as an electric motor and ball screws (electric doors).

On the other hand, detection of a foreign object in the doors is done using a method where a push rod attached to the door pushes and ball screws (electric doors).

2.2 Problems of the Conventional Method

Fig. 2 demonstrates the problems with detection by a door close switch. This method involves two structural elements that create detection dead zones, and those hinder detection sensitivity improvement. One cause of the detection dead zone is deformation of the rubber cushion (door stop rubber) at the door edge by foreign objects. Another cause is flexibility allowance (wipe) of the pressing spring at the contact point of the door close switch. Together those cause the width of the detection dead zone to reach approx. 15 mm, which makes it difficult to detect hands or other objects of similar thickness caught in doors.

Recent electric doors determine that something caught in the doors when the door system detects a decrease of the motor speed while closing the doors. In such a case, the door system temporarily reduces the driving torque to make removal of the object easy. This door control method is effective to help passengers caught by rushing for the train; however, thin objects in fully closed doors cannot be detected in this control method. Hence, this method cannot be a solution of the above-mentioned detection dead zone problem.

In light of those circumstances, there is a possibility of accidents that a passenger might be caught in the doors and dragged by the train. And that remains as a safety issue.
3 Foreign Object Detection With the New Principle

3.1 Study of the New Detection Method
The Safety Research Laboratory has studied foreign object detectors for car doors for some time, and has developed a detector of foreign objects in doors that is based on a completely different principle from before (Fig. 3). This detector was originally developed to achieve door control such as that on cars with electric doors to allow removal of foreign objects as soon as possible on older cars with doors driven by air cylinders. Since the detector is able to detect a thinner object than the conventional door close switch, it can be applied to prevention of accidents where a passenger caught in the doors is dragged by the train. Thus, in this development, we are improving that detector from the perspective of preventing passenger dragging accidents, aiming to introduce it to new cars that will be deployed in future.

Fig. 3 Principle of Detection of Foreign Objects in Doors with Door Stop Rubber

3.2 Detection of Foreign Objects by Change in the Inner Pressure of the Door Stop Rubber
Fig. 4 shows the foreign object detection flow with the door stop rubber. When closing doors catch an object, the whole door stop rubber is deformed by the thickness of the object, and the embedded pressure tube (detection tube) is also deformed to decrease the volume. Since the detection tube is sealed, the inner pressure of the tube becomes higher as the volume is decreased. By detecting that change of the inner pressure using a semiconductor micro-differential sensor connected to the end of the detection tube, the foreign object can thus be detected. Hereafter we will call the door stop rubber with an embedded detection tube a “door stop rubber sensor”.

Previous studies have proved that car doors driven with an air cylinder can detect objects equivalent to an approx. 5–6 mm thick plate of 10 mm width and object equivalent to an approx. 15 mm diameter round stick. But, this detection sensitivity is not always sufficient from the perspective of preventing passenger dragging accidents.

Fig. 4 Foreign Object Detection Flow with the Door Stop Rubber

4 Detectability Required to Prevent Passenger Dragging Accidents

4.1 Conditions to be Expected
Fig. 5 shows the most severe (dangerous) situation of passenger dragging accidents that can actually occur. Here, the doors close just after a child gets off a train, with only a bag hanging from a string on the child’s school backpack caught in the doors and remaining inside of the car. As the doors hold only a thin string, even the aforementioned door stop rubber sensor fails to detect it. Furthermore, as the bag is connected at the end of the string caught between the doors, it is impossible to pull the bag out of the doors no matter how strongly the child pulls it. Such a case could have serious consequences if the train starts moving without the conductor or other person noticing the situation.

Fig. 5 Most Dangerous Situation to be Expected

4.2 Setting Targets for Detection Sensitivity
Fig. 6 illustrates the deformation of the detecting tube by a foreign object. In the conventional method, the deformation allowance of the door stop rubber is a cause of the detection dead zone. As shown in the figure, foreign objects directly press the tube if a structure is adopted where a detection tube is embedded at the edge of the door stop rubber. The deformation allowance at the door edge causes a change of the volume and inner pressure of the tube leading directly to detection (Fig. 6), so no detection dead zone will remain.

Fig. 6 Model of Deformation of the Detection Tube by a Foreign Object

The door stop rubber sensor has no mechanical contact points that are another cause of the detection dead zone. Thus, the detection dead zone in this method will be quite small. Fig. 7 shows a magnification image of the edges of the right and left doors with detection tubes. A gap may actually remain between the right and left doors when closed, so that gap will be the detection dead zone. However, it will be as small as approx. 1 mm.

Based on those findings, we have decided to set the following targets for detection sensitivity in this development and to supplement detection by the door close switch with the door stop rubber sensor for safety improvement.
both improvement proposals 1 and 2 could detect the object, while
a plate of 90 mm width and 2.5 mm thickness. The results proved that
the ratio of stable detections in the test where we repeatedly inserted a
shape of the previous door stop rubber and of the improved ones.

5 Development of an Improved Door Stop Rubber Sensor

5.1 Placement of the Detection Tube at the Edge of the Door Stop Rubber

To meet the above-mentioned targets, we have undertaken the
development of an improved door stop rubber sensor. The first
improvement was locating the detection tube to the edge of the door
stop rubber (at the position where the right and left doors contact
each other) at an exposed location to improve detection sensitivity
instead of being embedded in the door stop rubber as in the previously
developed system. Fig. 8 shows a comparison of the cross-sectional
shape of the previous door stop rubber and of the improved ones.

Table 1  Comparison of Detection sensitivity
(with a Plate of 90 mm Width and 2.5 mm Thickness)

<table>
<thead>
<tr>
<th>Height of inserted object (Both the</th>
<th>Number of</th>
<th>Set detection sensitivity (Pa)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Door stop rubber</td>
<td></td>
<td></td>
</tr>
<tr>
<td>mm</td>
<td></td>
<td>29</td>
</tr>
<tr>
<td>300</td>
<td>Turn on</td>
<td>10</td>
</tr>
<tr>
<td>600</td>
<td>Turn on</td>
<td>10</td>
</tr>
<tr>
<td>900</td>
<td>Turn on</td>
<td>10</td>
</tr>
<tr>
<td>1200</td>
<td>Turn on</td>
<td>10</td>
</tr>
<tr>
<td>1500</td>
<td>Turn on</td>
<td>10</td>
</tr>
<tr>
<td>2000</td>
<td>Turn on</td>
<td>10</td>
</tr>
<tr>
<td>2500</td>
<td>Turn on</td>
<td>10</td>
</tr>
<tr>
<td>3000</td>
<td>Turn on</td>
<td>10</td>
</tr>
<tr>
<td>3500</td>
<td>Turn on</td>
<td>10</td>
</tr>
<tr>
<td>4000</td>
<td>Turn on</td>
<td>10</td>
</tr>
<tr>
<td>4500</td>
<td>Turn on</td>
<td>10</td>
</tr>
<tr>
<td>5000</td>
<td>Turn on</td>
<td>10</td>
</tr>
<tr>
<td>5500</td>
<td>Turn on</td>
<td>10</td>
</tr>
<tr>
<td>6000</td>
<td>Turn on</td>
<td>10</td>
</tr>
<tr>
<td>6500</td>
<td>Turn on</td>
<td>10</td>
</tr>
<tr>
<td>7000</td>
<td>Turn on</td>
<td>10</td>
</tr>
<tr>
<td>7500</td>
<td>Turn on</td>
<td>10</td>
</tr>
<tr>
<td>8000</td>
<td>Turn on</td>
<td>10</td>
</tr>
<tr>
<td>8500</td>
<td>Turn on</td>
<td>10</td>
</tr>
<tr>
<td>9000</td>
<td>Turn on</td>
<td>10</td>
</tr>
<tr>
<td>9500</td>
<td>Turn on</td>
<td>10</td>
</tr>
<tr>
<td>10000</td>
<td>Turn on</td>
<td>10</td>
</tr>
</tbody>
</table>

Table 1 shows an example of the detection sensitivity evaluation
results of prototypes of improved door stop rubber sensors. It indicates
the ratio of stable detections in the test where we repeatedly inserted a
plate of 90 mm width and 2.5 mm thickness. The results proved that
both improvement proposals 1 and 2 could detect the object, while
the previous door stop rubber sensor could seldom detect that. The set
detection sensitivity in the table is the comparison of the results with
different thresholds of the pressure to detect objects. Smaller values (the
smallest was 29 [Pa] in this evaluation) mean higher detection sensitivity.

Here, Fig. 9 illustrates the relation between the set sensitivity and
the detection threshold. In the figure, time proceeds from left to right.
1) After stopping at a station, the sensors measure the change of the inner
pressure of the detection tubes of each door caused by door opening
detection tubes slightly expand and the inner pressure decreases when the
right and left door stop rubbers in contact separate). 2) When doors
are closed, the sensors add the changed pressure measured in 1) to the
initial pressure (standard pressure) of the detection tubes at the start of
door closing. The sensors determine that an object is between the doors
when those detect a higher pressure than the detection threshold (the
total of the initial pressure), the changed pressure and the pressure for the
set detection sensitivity input in advance.

In this mechanism, we eliminated the effect of the difference of the
individual door gaps. We also determined the best sensitivity by the
evaluation tests using a mock-up car (to be explained later), with an aim
of achieving high accuracy detection.

5.2 Development of a Block Structure Door Stop Rubber Sensor

The improved door stop rubber sensor previously explained was able
to detect thinner objects. But it still required further improvement in
terms of the following points.

(1) Since we hardened the edge of the door stop rubber to make the
detection tube easy to deform, greater force is required to pull
out caught objects (actually more dangerous).

(2) We considered anew the functions of the door stop rubber. We
determined that the original functions are those such as
“absorbing impact if doors contact a foreign object while closing”
and “maintaining contact of the doors”.

From the perspective of preventing objects from being caught
in the doors and passenger dragging accidents, the following three
conditions will need to be met.

1) Objects caught between the doors can be easily removed →
Appropriate softness is required to allow a certain level of deformation.
2) Objects can be detected with the door close switch →
Appropriate hardness is required to prevent excessive deformation.
3) The detection tube is deformed by foreign objects without failure.

Since those three conflict with each other, we considered composing
the door stop rubber of several parts divided by function to strike a
good balance between those conditions (Fig. 10). So, as shown in Fig. 10, we decided to allocate functions to each part. Specifically, the edges of the door stop rubbers would be hollow with an appropriate gap to allow easy removal of the foreign object; the bases would be able to be deformed to a certain degree to allow easy removal of foreign objects, and then maintain thickness to ensure detection of foreign objects with the door close switch; and the detector with the detection tube at the edge would detect the foreign object with certainty, and also the base of the detector would be able to be deformed to allow removal of thicker objects. Fig. 11–13 illustrate how the contrived door stop rubber sensor works.

Fig. 10  Balance of Functions with the Block Structure Door Stop Rubber Sensor

Relatively thin objects can be easily pulled out thanks to the gap and deformation of the edges.

The detection tube is sufficiently pressed to make detection of the object with certainty.

Thicker objects fully deform the door stop rubber, so they can be detected with the door close switch even if the detector fails.

Since the deformation of the detection tube is small, objects may not be detectable.

Fig. 11  Action with Thin Objects

Fig. 12  Action with Thicker Objects

Fig. 13  Action with Objects Like Cloth or String

Based on the above design, we made a prototype door stop rubber sensor in the shape shown in Fig. 10. The evaluation confirmed that the prototype has the following functions to meet requirements for preventing passenger dragging accidents.

1. Detection of a plate of 90 mm width and 2.5 mm thickness and the prototype has the following functions to meet requirements for sensor in the shape shown in Fig. 10. The evaluation confirmed that of thicker objects. Fig. 11–13 illustrate how the contrived door stop rubber sensor works.

6 Repeated Evaluation Using a Mockup Car

In order to check the detection ability, reliability and durability of the developed door stop rubber sensor in repeated tests, we produced a mockup of the door system of an actual car along with sample-handling equipment. In the tests, a computer controlled opening/closing of the doors and inserting of the sample to simulate the sequence of a train stopping at the station → opening the doors → inserting the sample foreign object → closing the doors → determining detection of the sample → pulling out the sample → determining removal of the sample → train starting to move. By sequentially invoking at random the test conditions (type of test sample, insertion height, detection sensitivity setting, etc.) that were input to the database in advance, the computer made continuous unmanned measurements under different conditions and accumulated successful/unsuccessful detection results in the database (Fig. 14). Major evaluation criteria were as follows.

1) Detection of the object (success/failure of detection)
2) Response time (seconds required to detect the object after the door close switch is turned on)
3) Detection stability (chattering level of detection success/failure)
4) Detection error (no mis-detection)

In future, we will make further improvement in areas such as detection reliability and durability of the detection system for introduction to actual cars. Checking will continue even in that.

7 Conclusion

In order to prevent accidents where a passenger is dragged by the train, we have developed a highly sensitive detector of foreign objects caught in the doors. In the future, we plan to evaluate practicality and make further improvements while preparing for field tests using a train in commercial service.