Passenger Door System for Series E235 Train of East Japan Railway Company (Yamanote Line) Designed to Improve Transportation Quality

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ABSTRACT

Electric door systems for rail cars are motor-powered devices for opening and closing passenger doors in accordance with the door operations of crew members. Fuji Electric has delivered rack-and-pinion type door systems to East Japan Railway Company for the Series E235 train (Yamanote Line), which started operation. The door system uses less permanent magnets than conventional products, thus reducing overall weight by 14%. Furthermore, by reducing the number of parts and adjustment points, the system reduces maintenance costs and failure rates. Moreover, by changing the type of locking device, the system achieves better obstruction pulling and anti-forced opening characteristics. Additionally, by improved control sequencing, the system is increased in sensitivity of obstruction detection and dragging detection.

1. Introduction

Electric door systems for rail cars are motor-powered devices for opening and closing passenger doors in accordance with the door operations of crew members. Fuji Electric has delivered a rack-and-pinion type door system to East Japan Railway Company (JR East) for the Series E235 train (Yamanote Line) shown in Fig. 1 that started operation on May 22, 2017.

Based on the existing products that had achieved lighter weight and lower power consumption, Fuji Electric developed this door system by improving functions and performance through the meetings of the "Improved Door Closing Device Development Study Group" set up in January 2009. The study group consisted of rail car manufacturers and door system manufacturers as well as the headquarters, development departments, car inspection and repair departments of JR East. The study group discussed the doors intended for the next-generation rail cars based on the requirements for safety, reliability and maintainability, and organized the development concepts. Some of the requirements and evaluation items discussed by the group are as follows:

(a) Sensitivity of obstruction detection

The system can detect obstructions with higher sensitivity than the existing equipment.

(b) Obstruction pulling characteristic

Obstructions can be pulled out while the train is stopped.

(c) Dragging detection performance

The system can detect the condition where a trapped obstruction is dragged when the train starts.

(d) Resistance to forced opening

The doors cannot be opened manually while the train is running.

(e) Maintainability

Maintenance is required less frequently and can be done more easily.

This paper describes the solutions and adopted technologies used in this door system to address these requirements.

Fig.1 External appearance of Series E235 train

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2. Device Overview

Figure 2 shows the configuration of the door system. This door system consists of a motor that is the power source for opening and closing door panels, the main unit containing a rack-and-pinion mechanism that conveys the motor power to the door panels, a locking device that ensures doors are locked when they are closed, a controller for controlling the motor and locking device, and the sliding door rails and door hangers for holding door panels.

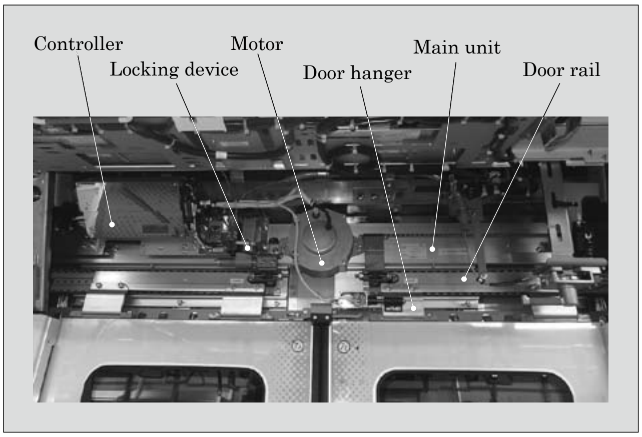

Fig.2 Configuration of door system

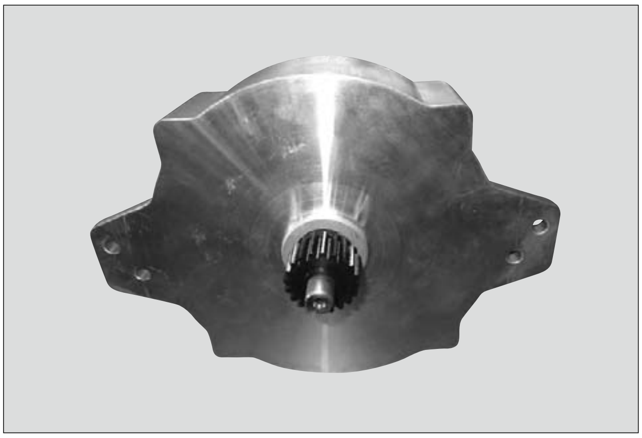

Fig.3 External appearance of motor

2.1 Motor

Fuji Electric has developed a dedicated low-profile permanent magnets motor for this door system (see Fig. 3). This motor uses permanent magnets less than one-tenth as much as that of conventional linear motors. This reduction has reduced the entire door system in weight by 14%. We have also achieved a position resolution of 0.01 mm, thrust response from 0% to 100% of 750 µs and pressing thrust force of 500 N when stopped. Furthermore, the system has an enclosed, high-precision optical encoder to improve the environmental endurance and sensitivity of obstruction detection.

2.2 Rack-and-pinion type door system

A rack and pinion mechanism has been adopted for Series E231 and E233 trains.

As shown in Fig. 4, in a rack-and-pinion type door system, the pinion is attached to the motor shaft and directly drives the upper and lower racks. Such a simple mechanism without gear shifting has made it possible to have fewer parts, improved reliability as a result of less equipment failures, and lower maintenance costs. Moreover, the maximized motor control performance and the adoption of the high-precision encoder

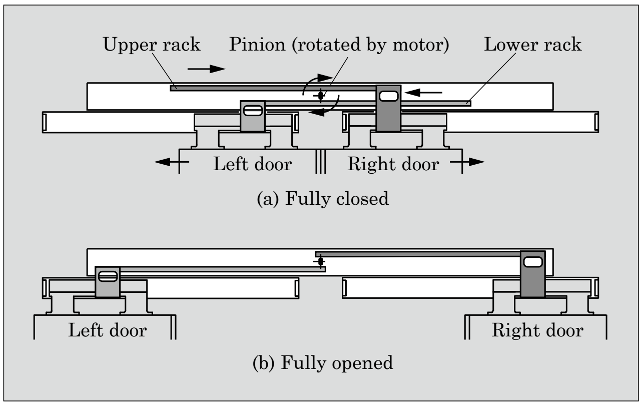

Fig.4 Principle of rack-and-pinion type door system

have improved detectability of obstructions. The main unit that contains the rack-and-pinion mechanism inherited the structure of the existing door systems for rail cars designed in consideration of dust and vibration environments.

2.3 Locking device

Figure 5 shows the configuration of the locking device. When the door panels are in the closed position, the lock pin is lowered and it engages with the lock hole to keep the door panels closed. When the doors are to be opened, the controller commands the solenoid to raise the lock pin, and the doors are unlocked. For maintenance or in an emergency, the unlock handles provided inside and outside the train raise the lock pin via unlock wires to set the lock pin in the unlocked position. Such a simple locking device will make the operation sequence of locking and unlocking more flexible. Furthermore, combining this with the software built in the controller enables various operations, and this improves detectability.

2.4 Controller

The controller adopts standby redundant architecture so that the opening and closing operation can be continued without degrading functions or performance even when a problem occurs (see Fig. 6). The commu-

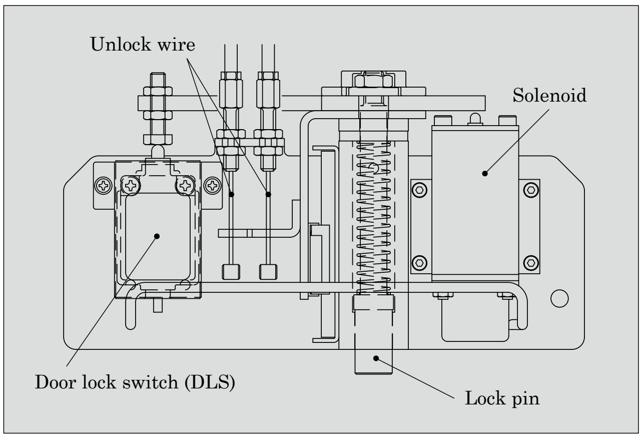

Fig.5 Configuration of locking device

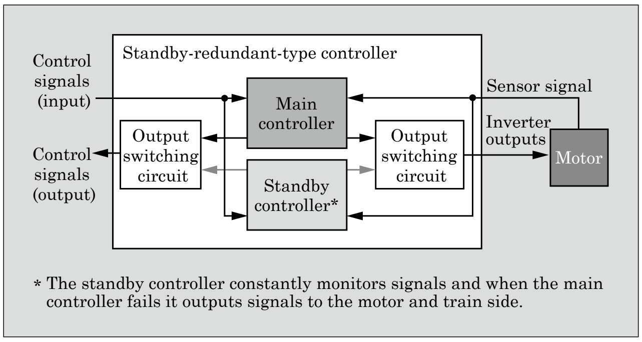

Fig.6 Basic configuration of controller

nication with upper level systems has been improved to provide higher functionality and larger capacity.

By applying state-of-the-art electronic devices to the controller, we reduced its volume to a half or less of the existing controller despite the addition of various functions. Such size reduction has allowed the controller to be mounted onto or integrated into the door closing device's main unit, resulting in saving on the labor for mounting devices onto cars and reducing wires.

3. Equipment Features

3.1 Achieving both obstruction pulling and resistance to forced opening

Table 1 shows a comparison of the required functions between the obstruction pulling and resistance to forced opening. Door systems are required to have conflicting functions: an obstruction-pulling characteristic while the train is stopped at a station and a resistance to forced opening while the train is running.

To meet the second requirement, the existing electric door systems use a locking device to turn off the motor power while the doors are closed to reduce power consumption.

This locking device also keeps the door closed when no power is supplied or when an external force exceeding the motor rating is applied. Such conventional electric door systems have poor performance in obstruction-pulling and dragging-detection. Once the door is locked, the doors could not be opened by hand. To improve the obstruction-pulling, the locking devices were adjusted to widen the locking position. However, when the doors were fully closed, a wider gap degraded the

Table 1 Comparison of required functions

Required function	Operating condition	Required performance
Improved obstruction-pulling characteristic	When the train is stopped at a station or when the train departs from a station	The doors can be easily opened to the extent that the trapped obstruction can be pulled out.
Improved resistance to forced-opening characteristic	While the train is running	The doors are fully and strongly closed regardless of disturbances such as train vibration or vandalism.

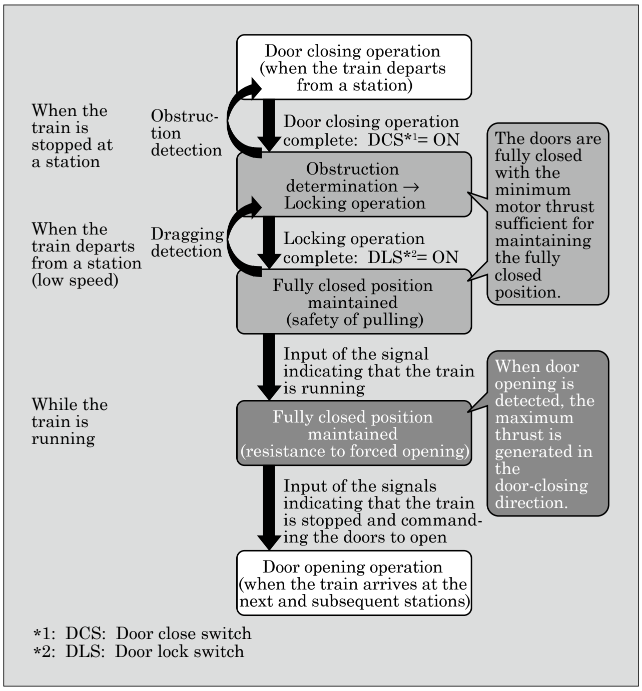

Fig.7 Operation sequence of door closing and locking

resistance to forced opening.

To solve the problem, we closely examined the functions of door systems and widened the locking position of the locking devices to ensure a sufficient obstruction-pulling characteristic. We simplified the locking device by limiting its function to locking and maintained the fully closed position by the continuous pressing function using motor thrust. Figure 7 shows the operation sequence of door closing and locking. When the train is stopped at a station before departure, the motor thrust is adjusted to maintain the fully closed position in consideration of the obstruction-pulling and dragging-detection. While the train is running, the motor thrust is adjusted to maintain the fully closed position in consideration of the resistance to forced opening.

In order to achieve the resistance to forced opening, push-back control has been adopted. This control instantaneously recognizes an external force attempting to open the door and pushes back the force strongly to prevent the door from being opened.

3.2 Problems with trapping and dragging of obstruction

Detections of trapping and dragging obstruction (train moving with an obstruction being trapped) are important functions to ensure passenger safety. These functions require high reliability because a detection failure or a malfunction will directly lead to an operation delay.

Typical electrically driven door systems use a door lock switch (DLS) and a door close switch (DCS) provided inside the train to detect the condition where the doors are fully closed and locked without a problem such as a trapped obstruction. These switches are con-

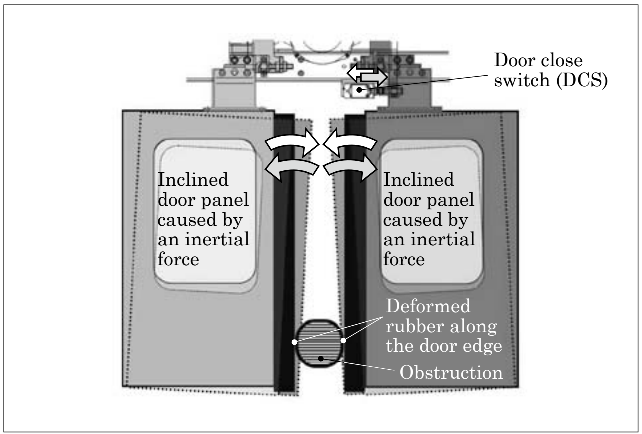

Fig.8 Causes of instantaneous lighting of door closure indicator

nected in series to interlock the devices related to train running. This circuit is also used for the train side lamps to indicate when the doors are open, and for the door closure indicator in the cab.

Detailed investigation of the detectability requirements showed that when a thin obstruction was trapped, the door closure indicator lit up instantaneously while the train side lamps went off instantaneously with the existing door systems. When the tops of the doors reach the fully closed position due to deformation of the rubber along the edge of the door or an inclination of the door panels caused by an inertial force or other reasons, the doors are locked immediately (both DCS and DLS turn on). When the inertial force vanishes, only DCS turns off due to the reaction force from the rubber. We confirmed that such a reaction was more conspicuous and the instantaneous lighting of the door closure indicator occurred more frequently when the trapping position was lower and the motor thrust became greater (see Fig. 8). Such instantaneous reactions could trigger false recognition or misjudgment of the crew, we thus took measures including the improvement of the detection performance.

3.3 Improvement of obstruction-detection sequence

Fuji Electric has studied a detection operation sequence robust to the disturbances in consideration of the following items:

(a) An unlocked condition is kept until the inertial force vanishes.
(b) The motor thrust is minimized to the extent that the door can be kept closed when the presence of an obstruction is determined.
(c) The sufficient motor thrust is applied to ensure that the doors are kept locked.

Figure 9 shows the conventional obstruction-detection sequence, and Fig. 10 shows the new one. In the conventional sequence, after the DCS turns on, the doors are mechanically locked, which makes the DLS turn on, and then the fully closed and locked signals are sent to the train side. The mechanical locking is operated independently of the obstruction-detection status recognized by the controller. Consequently, though the controller can detect a thin obstruction that allows the doors to be locked, the information is not sent from the controller to the train side.

On the other hand, the new detection sequence provides a certain waiting time between when the DCS turns on and when the doors are to be locked. This allows the system to activate the locking device after it confirms that there is no slight opening of the doors that remains after an obstruction has been pulled out by a passenger. The system can also eliminate the influence of a disturbance such as the inertial force of the door panels. Consequently, only when the DCS continues to be ON, the system will recognize that there is no obstruction and activate the locking device. The interlock circuit connected to the devices related to train running receives the signals from the DCS and DLS directly to detect that the doors are fully closed and locked. When the controller has detected a

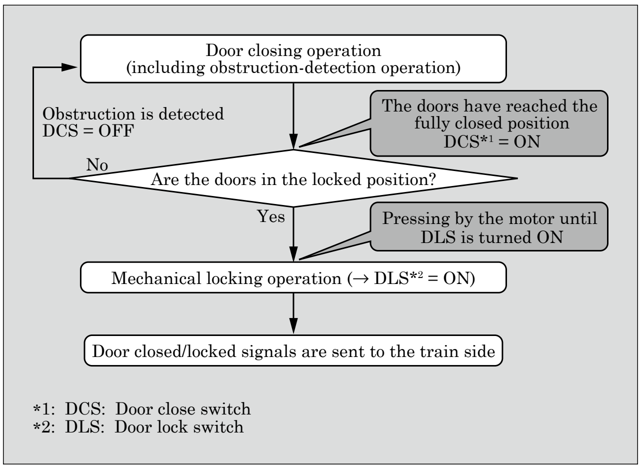

Fig.9 Conventional obstruction-detection sequence

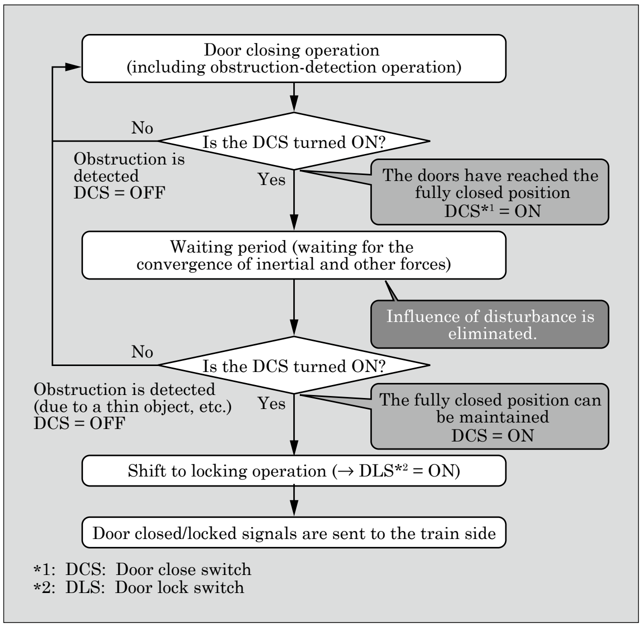

Fig.10 New obstruction-detection sequence

trapped obstruction, it checks that the doors are not fully closed and reattempts the door closing operation again. This makes the interlock circuit recognize that an obstruction is being detected.

4. Evaluation Test Result

The newly developed door system was tested on a mock-up train and an actual train of JR East.

We conducted an evaluation test on a mock-up train by manually opening the door panels with the signal condition simulating train running. This test showed that the door closed position was firmly maintained and the DCS did not turn off. The control signals of the position, speed and thrust during operation also showed proper responses in the rising of the motor thrust when forced opening is detected.

We conducted an evaluation test on a prototype equipped with the new obstruction detection sequence and the new locking device. Table 2 shows a comparison of the evaluation test results. From the evaluation results, we confirmed that this system could suppress the instantaneous lighting when a thin obstruction was trapped. Moreover, both the sensitivity of obstruction-detection and dragging-detection are improved to achieve higher safety compared with the existing equipment of Fuji Electric.

Table 2 Comparison of evaluation test results

	Sensitivity of obstruction detection in vicinity of fully closed position	Dragging-detection performance (Pull-out force when detected)
Performance of existing products	Detection: 15 mm, locking: 10 mm Instantaneous lighting occurred.	Detection impossible with DCS
Measurement result of new system	Detection: 8 mm, locking: 7 mm No instantaneous lighting occurred.	Detection possible with DCS (Pull-out force: 100 N)

5. Postscript

Eight and half years have passed since Fuji Electric started the development of this door system. By accumulating a number of specification reviews and prototype verifications and re-examining functions and performance fundamentally, we have succeeded in delivering an improved door system. Series E235 mass-produced trains for the Yamanote Line, equipped with this system, started operation on May 22, 2017. By around spring 2020, a total of 49 consists (539 cars with 4,312 door openings in total) are scheduled to be phased into operation.

After turning this technology into a platform, we will offer the series products that will meet the demands of individual regions and operators, and we will continue to improve door systems by aiming for higher safety and reliability.

Fuji Electric is committed to supplying products that support safe and stable transportation and comfortable operation of environmentally friendly railroad systems in order to contribute to greater social productivity.

We would like to conclude by expressing our sincere appreciation for the generous guidance and cooperation from East Japan Railway Company and involved parties for the specification reviews, development and testing of this door system.

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