Special edition paper

Study on Failure Sign Detection Using Monitoring Data for Door Operating Equipment of Commuter Trains

Tsuyoshi Akaogi*   Jun'ichiro Mishima*   Tsuyoshi Ichigi*   Yoshimitsu Sugiura*

Improvement of commuter train reliability and reduction of maintenance costs can be expected by changing from time-based maintenance (TBM) to condition-based maintenance (CBM). In this study, in order to achieve CBM by a monitoring system, we conducted operation examination using a door test machine that simulates the deterioration and failure of door operating equipment of commuter trains. We subsequently performed principal component analysis on the test data. Then, we proposed appropriate measurement items and a method of analysis for a monitoring system of door equipment.

●Keywords: CBM, Monitoring data, Door operating equipment

1 Introduction

In current maintenance of equipment of rolling stock, inspection and repair is done based on travel distance and operating time regardless of deterioration level (time-based maintenance, TBM). If deterioration level and signs of failure can instead be identified by monitoring of items that show the condition of equipment, timing and details of maintenance required can be determined, and accordingly inspection and repair can be done based on the condition of individual devices of rolling stock (condition-based maintenance, CBM). That will achieve improvement of rolling stock reliability and reduction of maintenance costs.

Up to now, we had carried out bench tests of air conditioners and selected effective items to be monitored with an aim of identifying deterioration level and signs of failure.[1]

In this study, we carried out bench tests for door operating equipment of rolling stock where abnormal conditions were simulated with an aim of identifying deterioration level and signs of failure from monitoring data, and we selected effective items for monitoring. We further considered a data analysis method using monitoring data that enables simple judgment of abnormal conditions.

2 Overview of Bench Test

2.1 Door Operating Equipment Tested

The door operating equipment tested was electric door operating equipment widely used for conventional lines in the greater Tokyo area. It consists of components such as motor-driven main unit, door suspension device (slide rail), door hanger, and electromagnetic locking device. The door operating equipment is driven and controlled by varying the current and voltage applied to the motor to open and close the doors at the specified time.

2.2 Testing Method

As a testing method, we performed operating tests using door operating equipment that simulates abnormal conditions such as failures and deterioration. By comparing the data obtained in those tests and data of operating tests of equipment in an appropriately maintained condition, we identified deterioration level and signs of failure. Fig. 1 shows the door operating equipment used in the bench tests. As testing conditions, we picked out abnormal conditions that can be considered to be deterioration or a sign of failure as shown in Fig. 2, and we considered and decided methods to use in reproduction tests for those individual abnormal conditions. The abnormal conditions shown in Fig. 2 are often seen to occur in actual maintenance work. Those were assumed and picked out as
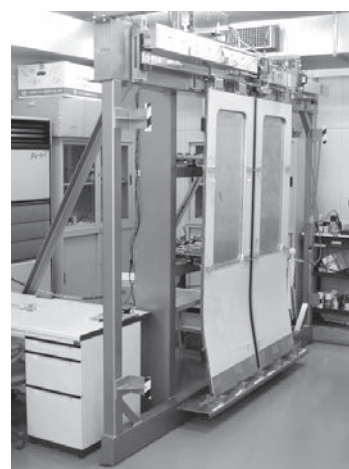

Fig. 1 Test Unit for Door Operating Equipment

Abnormality assumed	Method of reproduction test
Normal condition	Normal operation (without simulated abnormality)
Foreign object caught in door case	Plastic panel inserted
Abnormal condition of lower slide rail	Battery or pen inserted
	Lower slide rail raised
Loose attachment bolt	Loose attachment bolt of door operating equipment Loose attachment bolt of door leaf
Deteriorated grease	Grease for slide rails wiped off
Dirty slide rails	Slide rails with loam powder applied

Fig. 2 Abnormalities Assumed and Methods of Reproduction Test

*Technical Center, Research and Development Center of JR East Group

abnormal conditions that occur before the door operating equipment actually breaks down. In this study, we did not deal with cases where the door operating equipment did not work at all or did not open/close the doors within the specified time. This was done because the purpose of the study was to identify the deterioration level and signs of failure from monitoring data before actual failure occurs, and obvious failure can be handled by the existing failure detection and other systems. Fig. 3 to 5 show some examples of the operating tests. Fig. 3 shows a test where a plastic panel was attached to the door case end of the door, assuming a foreign object caught in the door case. Fig. 4 shows a test with an abnormal lower slide rail where a liner was inserted to raise the lower slide rail, making it in contact with the door leaf. Fig. 5 shows a test with a dirty slide rail where a slide rail had a powder of Kanto loam applied to it (JIS Z 8901 test powder 1 class 8). In addition to those, we carried out tests in the conditions shown in Fig. 2, such as where a battery or other foreign object was inserted, a bolt of the equipment was loose, and grease for the slide rail was wiped off.
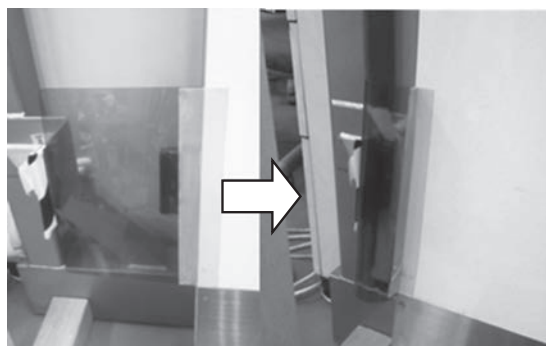

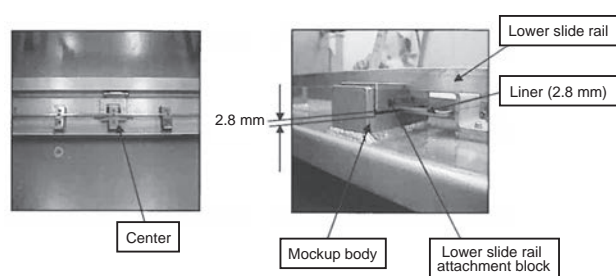Fig. 3 Foreign Object Caught in Door Case (plastic panel)

Fig. 4 Lower Slide Rail Raised

Fig. 5 Dirty Slide Rail

2.3 Items Measured

Table 1 lists the items measured to check the condition of the door operating equipment. Current and voltage of the motor at opening/closing the doors, door opening/closing time, door stroke position, and motor temperature are the items considered to be related to the load applied to the door operating equipment when opening/closing the doors. We also recorded information of the door opening/closing commands as control information.

Table 1 Measurement Items and Measurement Methods

No.	Measurement item	Measurement method
1	Motor current at door opening	
2	Motor current at door closing	
3	Motor voltage at door opening	
4	Motor voltage at door closing	LCU output signal
5	Time required for door opening	
6	Time required for door closing	
7	Door stroke position	
8	Motor temperature	Thermocouple
9	Door opening command	Door control signal
10	Door closing command	

3 Test Results and Consideration

In the case when a foreign object was caught in the door case, we observed a change in the value of the door stroke position when the door finishes opening. This change can be considered to occur because the doors did not fully open due to the foreign object, thus displacing the door stroke position. In the case when a foreign object was in the lower slide rail, we observed an increase of the average current and voltage of the motor when the doors were closing. This increase can be considered to occur because contact of the lower slide rail and the door leaf generated resistance and caused the current and voltage of the motor to be raised in order to achieve the set door opening/closing speed. In the case when a bolt was loose, we found that a loose bolt at some parts can be detected by the door stroke position. This could be because the position of the door leaf was displaced due to the loose bolt, resulting in a change in the door stroke position. In the case when grease for the slide rail was wiped off, we found no change in any measurement item. In the case when the slide rail was dirty, we observed that the average current and voltage increased as door opening/closing operations were repeated. This could be because the slide rail being dirty generated resistance against door opening/closing movement, resulting in increased current and voltage. Those results and consideration proved that measurement of motor current, motor voltage, and door stroke position are effective for monitoring.

In contrast, motor temperature showed no change over normal motor temperature in any of the tests. The time taken for door opening/closing showed no obvious change either. This can be explained in that those slight abnormalities as in the tests would not cause remarkable change of door operation time because the door operating equipment is a system where doors are controlled to open/close in a specified time. In periodic maintenance of the door operating equipment, door opening/closing time is checked as an important inspection item. When the time is not within

the specified time range in periodic inspection at rolling stock depots, the equipment is adjusted.

Those test results clarified that measurement items effective for monitoring to perceive the deterioration level and signs of failure are 1) motor current at door opening/closing, 2) motor voltage at door opening/closing, and 3) door stroke (Table 2).

Table 2 Effective Monitoring Items

No.	Measurement item	Effectiveness
1	Motor current at door opening	Very
2	Motor current at door closing	Very
3	Motor voltage at door opening	Very
4	Motor voltage at door closing	Very
5	Time required for door opening	Some
6	Time required for door closing	Some
7	Door stroke position	Very
8	Motor temperature	None
9	Door opening command	N/A
10	Door closing command	N/A

We further checked detailed monitoring data on operation to see whether more detailed analysis could be done. In studies so far, we evaluated motor current using the average or maximum current at door opening/closing. We also evaluated the door stroke position using the stroke value when the doors are fully open or closed. So, in order to understand operation in more detail, we collected data in Fig. 6 showing that operation and conducted detailed evaluation. Fig. 6 shows the data for door opening command, door closing command, motor current, and door stroke position of the door operating equipment in normal operation.

As examples, Fig. 7 shows the bench test data of a case when a foreign object (plastic panel) was caught in the door case, and Fig. 8 shows that of a case when the slide rail was dirty. Comparing the data of normal operation shown in Fig. 6 with the data for a plastic panel caught in the door case shown in Fig. 7, we can that see the current fluctuated while doors were open (part enclosed in a dotted line). It can be presumed that rebound occurred due to the foreign object while doors were open. Similarly, comparing data of normal operation shown in Fig. 6 with data with a slide rail dirty shown in Fig. 8, we can see that current with the slide rail dirty was slightly higher than that in normal operation while doors were opening (as enclosed with the dotted line). It can be presumed that the slide rail being dirty generated resistance against operation, and the current thus increased. In this way, it can be expected that checking data of the door operating equipment while opening/closing the doors would allow us to estimate abnormalities in more detail.
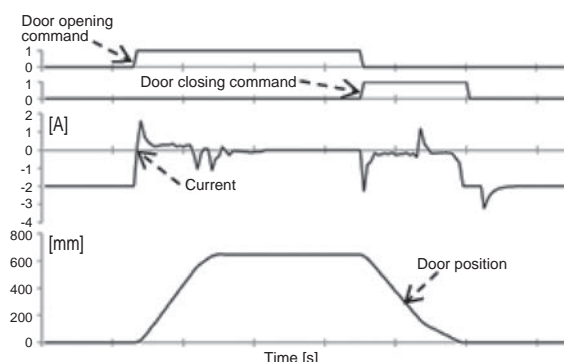
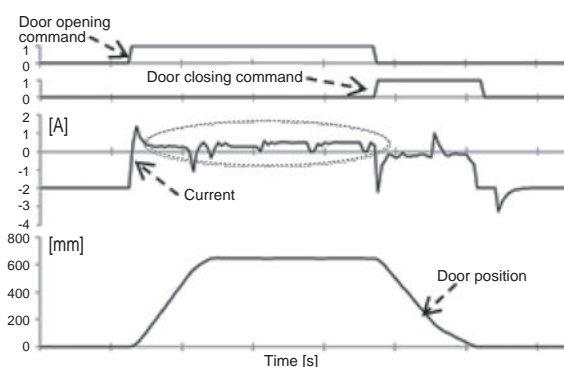Fig. 6 Normal Door Operating Equipment Operation

Fig. 7 Operation with Foreign Object Caught in Door Case (plastic panel)
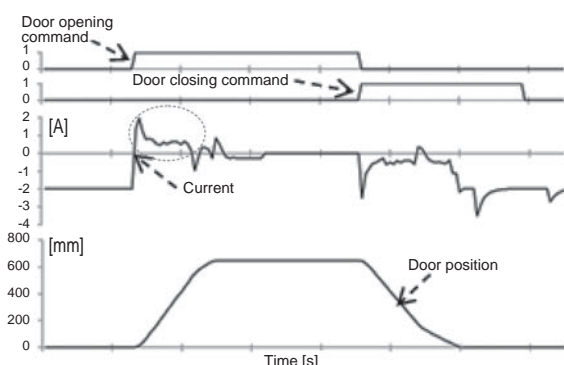
Fig. 8 Operation with Dirty Slide Rails

4 Examination of Data Analysis Method for Judging Abnormality

As previously explained, we can expect that details of abnormal operation such as what condition current or door stroke position is abnormal could be identified by checking data of the door operating equipment at door opening/closing. Such abnormalities are signs of failure or deterioration before actual failure, and it is expected that engineers who understand the operation mechanism of the door operating equipment well can identify those by checking and judging individual data at door opening/closing. However, when assuming ten-car trains cars with eight doors on each car, which are now widely operated in the greater Tokyo area, a trainset has 80 sets of door operating equipment. It is very difficult in terms of work time for engineers to periodically check the data at door opening/closing of all those units, thus it is difficult to estimate their condition in detail.

In light of that, we examined various types of mathematic

data analysis methods for a new evaluation method. Of those, we used the principal component analysis method, a multivariate analysis method that can be applied to data of the door operating equipment, to make simplified analysis this time. The principal component analysis method is a method where principal
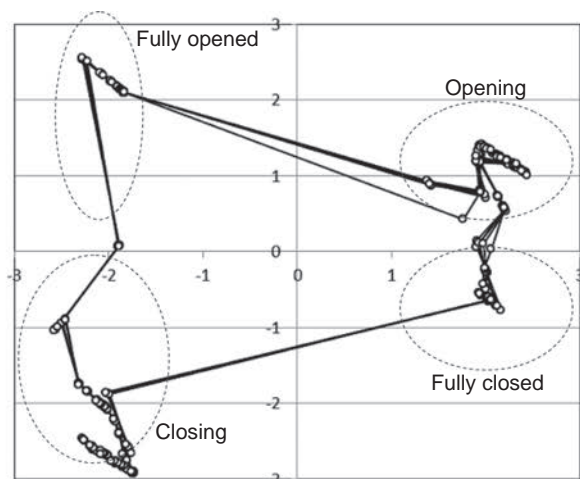

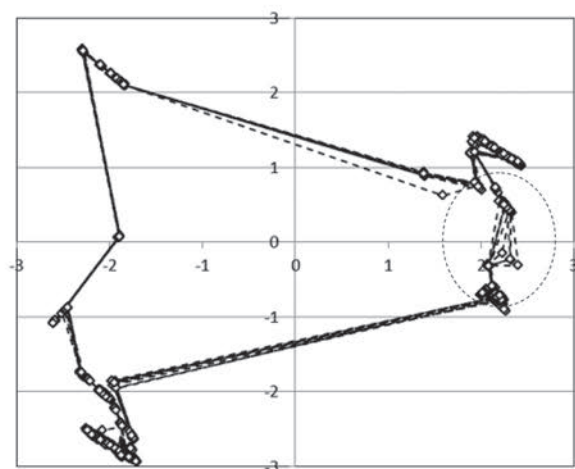Fig. 9 Two-dimensional Mapping of Principal Component Analysis of Normal Condition Data

Fig. 10 Principal Component Analysis of Data for with Foreign Object Caught in the Door Case
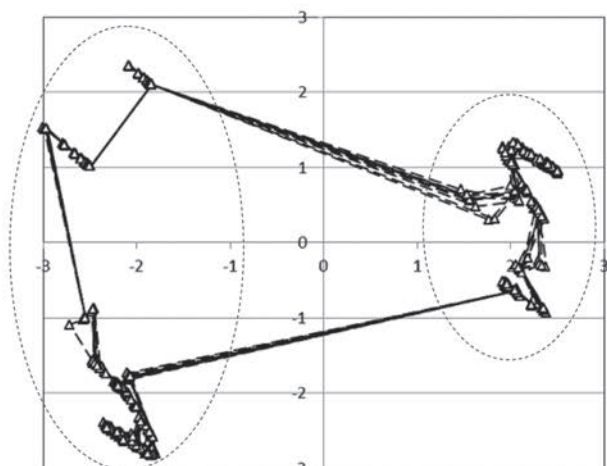

Fig. 11 Principal Component Analysis of the Data for with Dirty Slide Rails

components are derived from data having multiple parameters as the whole of all data. By deriving with principal component analysis the first principal component and the second principal component showing the characteristics of the data and plotting those components two-dimensionally, data with multiple parameters can be visualized as a two-dimensional map. Fig. 9 to 11 show the two-dimensional maps of the principal component analysis results derived from the data at door opening/closing of Fig. 6 to 8. As two-dimensional mapping is a conversion of time series data, the zones shown in Fig. 9 correspond to "fully closed", "opening", "fully open", and "closing". Comparing data with a foreign object caught in the door case (Fig. 10) and data of the normal condition (Fig. 9), we can find the difference in the "fully open" zone. And, by comparing data with a dirty slide rail (Fig. 11) and data of the normal condition (Fig. 9), we can find the difference in the "opening" and "closing" zones.

Furthermore, by calculating the area of the figures shown in the two-dimensional maps and numerically evaluating the change of the area, signs of failure and the progress of deterioration can be predicted. To achieve that, we need to check data obtained in actual train operation in detail and determine whether the data can be quantitatively evaluated or not. We will thus continue R&D for those. Moreover, we will continue seeking applicable analysis methods other than the principal component analysis method used this time as the data analysis method.

5 Conclusion

Aiming to identify deterioration and signs of failure of door operating equipment from monitoring data, we carried out bench tests using door operating equipment to which simulated abnormalities were applied to select effective measurement items. The test results proved motor current and door stroke position to be effective items.

Using the monitoring data, we further considered a data analysis method that enables simple judgment of abnormality. Applying the principal component analysis to the data at door opening/closing, the first and second principal components were derived and compared to normal condition and abnormal condition data in the two-dimensional maps. The results suggested the possibility of distinguishing normal condition data from abnormal condition data. Based on the findings of the bench tests, we hope to obtain data using trains in actual operation to verify the effectiveness of this study and put the results into practical use.

Reference:
1) Naoki Ushirozako, Kazuki Hamaada, Otaki Kosuke, Akira Yokokura, Yoshimitsu Sugihara, "Research on Monitoring of Air Conditioners for Rolling Stock", *JR EAST Technical Review*, No. 22 (Spring 2012): 15 - 18
2) Tsuyoshi Akaogi, Jun'ichiro Mishima, Akira Yokokura, Yoshimitsu Sugihara, "A Study of the Monitoring System for the Door Operating Equipment of the Commuter Train [in Japanese]", *Proceedings of the 19th Jointed Railway Technology Symposium (J-Rail 2012)* (December 2012): 165 - 166