

Reliability Analysis of Metro Door System Based on FMECA

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ABSTRACT

The metro door system is one of the high failure rate subsystems of metro trains. The Failure Mode, Effects and Criticality Analysis (FMECA) method is applied to analyze the reliability of metro door system in this paper. Firstly, failure components of the door are statistically analyzed, and the major failure components are determined. Secondly, failures are classified according to their impacts on operation, and methods of calculating failure mode criticality and the related coefficients are illustrated. Finally, the FMECA is detailed in the selected 12 failure modes, and the failure modes are discovered that they have the most significant effect on metro door system. The obtained results can be used for optimal design and maintenance of the metro door system.

Keywords: Reliability; Sliding Plug Door; FMECA; Criticality

1. Introduction

Metro door system is one of the subsystems which has a high failure rate in metro vehicles. Frequent failures of the door bring much inconvenience to passengers and have a negative impact on metro train corporation. Currently, reliability research has become an important part in developing, using, maintaining and evaluating a modern product. So, to determine the key components and failure modes, making a reliability analysis on metro door system has an important significance, and it's very useful for maintenance and optimal design of door system.

Failure Mode Effects and Criticality Analysis (FMECA) is a common reliability analysis method for products, which has been applied to product designs and maintenance decisions in many fields. ZHANG Qiang, *et al.* [1] applied FMECA method to make a reliability analysis on truck bogie, the criticality of the failure modes on bogie was identified and the result could provide a useful reference to bogie maintenance decision-making and daily management. GENG Feng *et al.* [2] used FMECA method to analyze the criticality of failure modes in high-speed EMU brake system for classifying severity of fail-

ure modes and making appropriate suggestions for improvements. GU Wen-juan *et al.* [3] utilized the traditional FMECA and fault tree analysis (FTA) methods to conduct a comprehensive analysis on train security.

The FMECA method is applied to the door system of metro train in this paper. According to the door fault information which is found in the main line operation and maintenance of metro train corporation, the FMECA analysis is carried out on the several key components which have a high failure rate, so the failure modes which have a great effect on door system are obtained and auxiliary decision-making reference could be provided for maintenance of door system.

2. The Brief Introduction of FMECA

The FMECA method is mainly used to analyze all possible failure modes of every component belong to one system and their impacts on the system, and all failure modes are classified and assessed comprehensively according to their failure level and probability of occurrence or criticality [4]. The FMECA method could found the key components and the key failure modes, and provide the foundation for maintenance and improvement of the product.

The FMECA method includes two parts: Failure Mode Effects Analysis (FMEA) and Criticality Analysis (CA). FMECA is developed and perfected gradually on the basis of FMEA. In 1950s, FMEA was applied to operating system design analysis of fighter plane in USA, and some good results were achieved. From the late 1960s to the early 1970s, the FMECA method had been widely used in many fields, such as aviation, aerospace, weapons, cars and so on. In the early 1980s, the concept and method of FMECA began to become popular at domestic, and the GB/T 7826-1987 <System reliability analysis technique failure mode and effects analysis (FMECA)> and a series of other standards were promulgated. Currently, the FMECA method have received a great degree of popularity in aviation, aerospace, weapons, ships, electronics, automotive and other industrial fields, and played an important role in ensuring the reliability of products [5].

3. Door Structure and Statistical Analysis of Failure Location

3.1. Description of Metro Door Structure

Door system mainly consists of five subsystems: bearing orientation mechanism, basic components, electric control device, internal and external operating mechanism, driving and braking unit [6]. The chassis, the rack, long and short guide pins, rails and bearings mainly constitute bearing orientation mechanism; basic components include door leaves, adhesive tapes, indicator lights and locating pin, etc.; electric control device mainly consists of an EDCU, switches, buttons and so on; the unlocking device and a handle, etc. comprises internal and external operating mechanism; driving and braking unit is comprised of an electric motor, screw-nut pair, end unlocking and two belt wheels and so on. The basic components of five subsystems are shown in **Table 1**.

3.2. Statistical Analysis of Fault Location

The reliability analysis of door system in this paper is carried out on the basis of the 18-month fault information which is obtained from the main line operation and maintenance of a metro train corporation. And the fault information of door system contains all fault records of 28 vehicles. A statistical analysis is conducted on the collected fault information, and the results are shown in **Table 2**.

This shows that total 443 cases of failure occurred, the 297 cases of which belong to the four components including the door controller EDCU, door closing limit switch S1, nut component and portable mast mounting rank top 4, which occupy 67% of the total failures. So the four components could be considered as major fault factors and should be analyzed in detail. In addition, the

Table 1. Basic structure of door system.

Door subsystem	The basic component parts
Bearing orientation mechanism	Rack, portable mast mounting, long and short guide pins, up and down rails, pressure roller, linear bearing and so on
Basic components	Adhesive tapes, glass, buzzer, abacus, buffer head, locating pin, indicator lights, ground wire, door leaves and so on
Electric control device	EDCU, door closing limit switch, chopping limit switch, emergency unlocking limit switch, locking limit switch, door control button and so on
Internal and external operating mechanism	Internal emergency unlocking device, steel wire rope, external emergency device, internal operating handle and so on
Driving and braking unit	Electric motor, belt wheel, toothed belt, screw-nut pair, end unlocking device, shifting fork, middle unlocking component and so on

Table 2. Statistics of door failure components.

Door component	Failure numbers
EDCU	138
Limit switch S1	61
Nut component	50
Portable mast mounting	48
Pressure roller	25
Screw	22
middle unlocking component	19
Limit switch S4	18
Limit switch S3	17
Long guide pin	15
Idler wheel	11
Door indicator light	10
End unlocking mechanism	9

failure numbers of pressure roller, drive screw, door locking limit switch S4, emergency unlocking limit switch S3, middle unlocking component, long guide pin, idler roller, door indicator light and end unlocking device are a little low, but they still occupy approximately one-third of the total failures number, so the maintenance department should pay enough attention to them.

4. FMECA on Door System

4.1. Door System Failure Classification

Failure level stands for the severity of the consequences of failure mode on system. The failure level should be determined firstly, and then the criticality of every failure mode can be ultimately determined by using the criticality matrix diagram. In this paper, the failure level of every failure mode is divided into five categories according to the actual situation [7], as shown in **Table 3**.

Table 3. Failure level classification.

Failure level	Definition
I	Passenger safety is harmed due to door failure during train operation process;
II	Door failures can't be ruled out, so the train can't continue to operate and the passengers have to get off;
III	Door failures can't be resolved in short time, the door must be removed, or the train won't continue to operate;
IV	The driver could settle the failure, but the failures cause a little delay to main line operating;
V	Door failures have no impact on train operations and could be maintained after returning the train depot

4.2. Calculation Method of Failure Mode Criticality

The component failure mode criticality C_i is used to evaluate the perniciousness of a single failure mode, and it could be calculated as follows:

$$C_i = \lambda \alpha \beta t$$

where, λ is the failure rate of a component; α is the frequency ratio of the failure mode, which means the percentage ratio of a failure mode to a component's total failure modes; β stands for the effect probability of a failure mode; t is the working time of a component.

Component criticality C_c is used to evaluate the perniciousness of every component and it could be calculated as follows:

$$C_c = \sum_{i=1}^n C_i$$

where, n is the number of failure modes for every component.

The failure rate of every component could be obtained by using the average failure rate calculation method [8], which is calculated as:

$$\lambda = N/t$$

where, λ is the failure rate of a component; N is the failure numbers within the specified time for a component, t is the working time of a component.

Failure effect probability β is the identified failure effect that a failure mode leads to in the conditional probability, β is usually an estimated value. During FMECA on metro door system, β is as follows [9]: $\beta = 1.0$, which means that the system is certainly malfunction; $\beta = 0.5$, which means that the system may malfunction; $\beta = 0.1$, which means that the system rarely fails; $\beta = 0$, which means that the failure mode have no effect on the system.

4.3. Ascertain the Criticality of Door Failure Mode

During reliability analysis of door system, the FMECA

method is conducted on EDCU, door closing limit switch, nut component, and portable mast mounting four components which have been deemed to have a high failure rate, as shown in **Table 4**. Obviously, four components only cause failure level of III, IV, V, no I and II. Failure modes of EDCU belong to failure level of III and IV, and closing limit switch S1 or nut component only cause failure level of III, and failure modes of portable mast mounting have the failure level of IV and V. When the failure level is III, the maximum and minimum criticality component is EDCU and nut component, the criticality is 125.67 and 25.53 respectively; when the failure level is IV, the maximum and minimum criticality component is EDCU and portable mast mounting, the criticality is 6.21 and 2.16 respectively; when the failure level is V, only failure modes of portable mast mounting have the failure level, the criticality is 21.8.

According to failure level and failure mode criticality in **Table 4**, combining with statistical analysis of failure data, the criticality matrix diagram could be obtained, as shown in **Figure 1**.

The **Figure 1** shows the relationship between the failure levels and criticality of 12 failure modes, which is the further of failure mode distribution points along the diagonal direction from the origin, the greater of the failure mode criticality, and indicates that more attention should be paid to corresponding defective parts [10].

From the **Figure 1**, we can conclude apparently that the failure modes in descending order of criticality are that 2 (EDCU function failure), 3 (S1 breakage), 6 (Nut component breakage), 5 (S1 function failure), 9 (Nut component loose), 4 (S1 abnormal clearance), 7 (Nut component poor lubrication) and 8 (Nut component angle offset), 1 (EDCU plug loose), 12 (Portable mast mounting bolts loose), 11 (Portable mast mounting has crackson screws), and 10 (Portable mast mounting bushing for

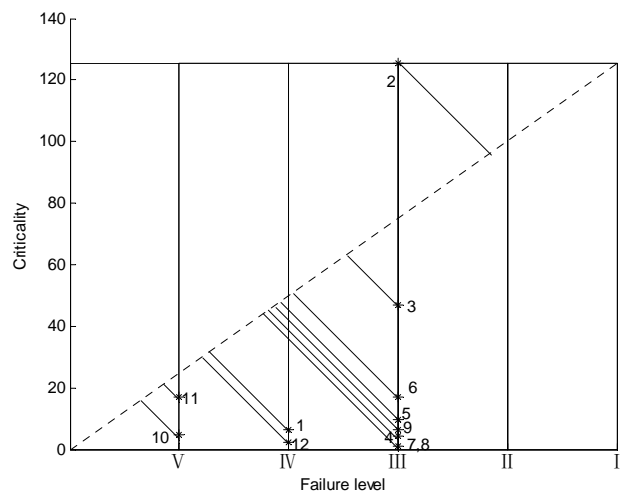


Figure 1. Criticality matrix diagram of failure modes.

Table 4. FMECA of metro door system.

No.	Component	Failure mode	Failure cause	Failure effect	Failure level	λ	α	β	C_i	C_c
1	EDCU	Plug loose	Not inserted in place; Vehicle vibrations	Door can't operate normally	IV	5.19	0.09	0.5	6.21	III: 125.67
2		Function failure	Safety relays/communication interfaces are damaged	Door can't operate normally	III		0.91	1	125.67	IV: 6.21
3		Breakage	Retainer lose; Thrust pressure ring lose; Arm spring failure	The train won't start	III		0.77	1	46.92	
4	Door closing limit switch S1	Abnormal clearance	No adjustment in place	Start the pinch function; The train won't start	III	2.29	0.07	1	4.27	III: 60.94
5		Function failure	Quality defects; End of life	Indicator light anomalies; The train won't start	III		0.16	1	9.75	
6	Nut component	Breakage	Screw bolts missing; Shifter level fracture	Door can't operate; Unable to lock and unlock the door	III	1.88	0.68	0.5	17.01	
7		Poor lubrication	Lacking of maintenance; Lubricant quality bad	Door operates slowly; Abnormal sound	III		0.04	0.5	1.01	III: 25.53
8		Angle offset	No adjustment in place	Start the pinch, the door can't operate	III		0.02	1	1.01	
9		Loose	Locking washers not into the slot	Start the pinch, the door can't operate	III		0.26	0.5	6.5	
10		Bushing for cracks	Material defects; Improper heat treatment	The door can't be closed tightly	V		0.2	0.5	4.79	
11	Portable mast mounting	Screw has cracks	Too much stress	There is the risk that the door can't operate	V	1.8	0.71	0.5	17.01	IV: 2.16 V: 21.8
12		Mounting bolts loose	No adjustment in place; Vehicle vibrations	The door can't be closed tightly	IV		0.09	0.5	2.16	

*: λ is the failure rate, α is the failure mode frequency ratio, β is the effect probability, C_i is the failure mode criticality, C_c is the component criticality.

cracks). It is thus clear that the criticality of EDCU function failure and door closing limit switch S1 breakage are greater than other failure modes criticality, and they should be regarded as the key failure modes of the door system and the focus of attention in the routine maintenance. In addition, corresponding improvement measures which are combined with the actual situation should be given to door closing limit switch S1 breakage and other failure modes.

5. Conclusion

Through statistical analysis of defective components of metro door system, the FMECA method is utilized to analyze four components which have a high failure rate. The results show that the EDCU function failure and the breakage of limit switch S1 are the weakness of door system, and should be concerned in the maintenance operation. By site investigation, the results are consistent with the actual experience of field engineers. So the effectiveness of the method is verified, and the results will

provide the technical support for the metro door design and maintenance decision-making.

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