MCU System-based Intelligent High-speed Elevator Door Operator Fault Analysis and Research

Wang Qibing\textsuperscript{1,2,*}, Leng Yonggang\textsuperscript{1}, Li Dongliu\textsuperscript{2}, Zhang Xiaoqiang\textsuperscript{2}, Li Ren\textsuperscript{2}, Zhu Hongmei\textsuperscript{2} and Zhang Hao\textsuperscript{2}

\textsuperscript{1}Tianjin University Tianjin 300072
\textsuperscript{2}Sicher Elevator Co., Ltd. Zhejiang 313009

*Wang Qibing: 43410697@qq.com

Abstract: The elevator hall door lock MCU system is the important safety core component installed on the elevator. It can monitor the fault information of the elevator operation in real time. At present, MCU system can not adapt to the changes in the application of the intelligent high-speed elevator. This paper first analyzes the reasons of MCU system fault on the intelligent high-speed elevator based on the actual case analysis, and summarizes the optimization measures for the safety monitoring, and provides reference for the further research on the performance and the system intelligent technology of the intelligent high-speed elevator door operator system.

Key words: MCU system; high-speed elevator; elevator door operator; fault analysis

1. Introduction
With the rapid development of the modern cities in China, the elevators are widely applied in multi-floor, high-rise and super high-rise buildings. Featuring with convenient, fast and labor-saving performance, the elevators improve people's life quality. According to the statistics of China Elevator Association, 679 thousand and 779 thousand elevators were produced in China respectively in 2017 and 2016. The output and sales volume of elevators in China ranked No. 1 in the world. The intelligent technology of elevator keeps innovating, with higher automation degree. However, the casualties caused by elevator accidents always exist in both developing countries and developed countries. According to the statistics of elevator accidents at home and abroad, the elevator accidents caused by the door system fault and maintenance operation error accounted for more than 80% of all the elevator accidents. The high proportion shows that the elevator door system is the main cause for serious accidents. Improving the reliability of the door control system is one of the key methods to eliminate the elevator accidents [1-2].

2. Basic structure and working principle of elevator door system
The door system, as shown in Fig. 1, is mainly consisted of landing door (hall door) and car door, door operator, door lock device, driving mechanism, protection system and accessory parts. The hall door is located at the landing entrance, the car door is set on the elevator car, the door that the passenger sees after he/she enters into the elevator. When the elevator stops at the landing, the car door is the drive door, and the hall door is the driven door. The door vane is embedded on both sides of the door lock roller. When the car door opens, the door vane presses the roller to one side to unlock the hall door.
lock and the car door will open or close the hall door. When the hall door and car door are completely closed, the elevator can run normally [3-6]. From the structural function, the elevator door system is consisted of driving motor, door controller, motion actuator and related driving device.

![Elevator door structure diagram](image)

**Figure 1.** Elevator door structure diagram

3. Main fault and reason of elevator hall door lock MCU system

3.1. Shearing and collision accidents
The accident is caused by the case that the door lock switch is short circuited, the door lock switch contacts can not be reliably opened, and the door lock relay device can not be open or delayed to open. Such problems are mainly caused by the case that the elevator linkage door interlocking is invalid due to human factors or non-human factors. The elevator can operate normally when the hall door opens or is ajar. But if there is a person between the hall door and the car door, it may cause shearing or collision, even cause casualties if the case is serious.

3.2. Well dropping accident
Such accidents are caused by the case that the door lock is short circuited, in that case, the emergency unlocking device opens the hall door when the elevator car stays at other floors when the hall door and car door open; the hall door is forced open when the door lock is damaged or the door lock has small meshing length; the damaged hall door is also the reason causing the accident. The short circuit of the door lock may also cause the accidents. Meanwhile, the hall door positive closing device fails or is damaged [7-9]. Such case will cause that the elevator hall door and car door open while the elevator car does not stop in the floor due to human factors or non-human factors. It will easily cause the well dropping accidents and then cause injury or even death.

4. Fault and safety hazard analysis of elevator door MCU system
The elevators work frequently in places with high visitors flow rate, such as station, airport and office buildings, the elevator door system keeps working at high frequency. The failure rate of the electromechanical equipment is a function of time, and the elevator is also consistent with the fault bathtub curve distribution rules [10]. Continuous working at high frequency and increasing time also increase the elevator door system fault rate.

4.1 Mechanical fault summary
When the clearance between the elevator door vane and the roller is less than 5mm, when the elevator passes through the floor, the door vane will collide with the roller, which causes the roller bumped or the hall door unlocking, so the electrical interlocking contact is open and the elevator is suddenly stopped; if the clearance is too large, and the door vane and the roller will be misplaced. During elevator leveling, it will cause that the door vane can't drive the roller to move horizontally, causing the hall door cannot be open. This will cause the hazards for persons trapped in the elevator.

For example, when the lock hook position of the elevator door is offset, the meshing depth of the lock hook and the door lock block is too small, less than 7mm, the door lock contact is not completely pressed, which leads to the poor contact of the electrical safety loop, increasing the fault rate of the abrupt stopping in the normal operation. The hall door will suddenly open when the passenger pulls down the door due to too small meshing depth. It provides the probability of well dropping accident with potential hazard.

As shown in Fig. 2, the clearance between the lock hook and the door lock block is too large. If the passengers pull down the door outside the hall door, the electrical contact of the main lock or the auxiliary lock will be open and the elevator in the normal operation will stop suddenly, causing the accident.

Because (1) the safety shoe microswitch is pressed without action (2) the safety shoe is blocked (3) the safety shoe contacts the casing, the elevator door will be closed, the safety shoe is clamped, and can not automatically rebound to open, causing the potential hazard.

![Figure 2. Elevator door lock structure](image_url)
From the analysis above, we realize that the locking of the drive door and the driven door doesn’t have a necessary relationship, but associated relationship. The driving parts such as the belt and the wire rope between the drive door and the driven door may fail, no matter from the manufacturing process, or material or installation process. Taking the common steel wire rope linkage door as example, the linkage steel wire rope will easily rust, fracture or even fail because of the influence of the frequent bending and other factors in the working process [11–12]. As shown in Fig. 3, we need to design a new elevator door anti-clamp device to ensure the safe and reliable operation of the elevator door operator to solve the problems above.

4.2 Elevator door system electrical fault and potential hazard analysis
The door lock safety contact is not connected through due to pollution and poor contact caused by the human factor, the safety loop is not connected, the signal feedback is blocked, causing the elevator stopping. It will cause persons trapped in the elevator. Improper human operation: the door lock switch is short circuited; the emergency button is short circuited, and the door lock is short circuited. Non-human factor: door lock switch contacts are not open; door lock relay is delayed to open or not open; door lock is short circuited due to fault. [13–14] The elevator door lock electrical loop fails. As shown in Fig. 4, when the electrical safety contact of the door lock is open, the elevator works with the door open, and the passengers will have the risks of being sheared, crushed and dropping into the well. The safety shoe and the light curtain wiring are short circuited, the automatic closing device fails.
4.3. Other possible situations

In addition to the problems mentioned above, we analyze the steel wire rope breaking in the elevator door system. In the actual operation, the steel wire rope will be broken, as shown in Fig. 5, but the researchers still don’t focus on this possibility at present. If the steel wire rope is broken, and the elevator is not in the unlocking area, the drive door is locked effectively. Restrained by the steel wire rope, the driven door can not be opened, and it is also locked effectively.

If the elevator stops to the locking area during leveling, the car door is opened because the door operator starts, meanwhile the drive door is open being driven by the door vane, and the driven door is closed with the effect of the automatic closing device since the driven door is not driven by the door vane. The door is likely to be ajar. However, since the steel wire rope is in a relaxed state when the drive door opens, it is easy to get out of the pulley groove. It is easy to be stuck by the related hall door parts. If the steel wire rope is tore during the closing, the steel wire rope will be broken and eventually lead to the condition that the driven door can not be effectively locked [15].

5. Preventive measures for elevator accidents

5.1. Precaution in type selection

The elevator with national license shall be selected. The reliability is not guaranteed if the elevators are produced without national license. Do not select the elevators at lower price that are produced without the national license. The elevator reliability and technology shall be taken into consideration when purchasing. Especially, we must pay attention not to purchase the elevator with variable
frequency and variable voltage technology [16]. Usually, if the installation technology is guaranteed, the fault rate of the elevator is very low, so we must pay attention to the reliability and technology. We must purchase the qualified products and strictly control the installation, to avoid potential hazard during installation.

5.2. Precautions in design
In the elevator design, we shall design two safety contacts in the dual-lock hook via the single door lock and dual-lock hook structure, called as single door lock dual-hook dual-contact type. The two safety contacts verify the locking positions of the drive door and the driven door. The elevator can operate normally only when two safety contacts are connected and the two lock hooks are locked on the drive door and the driven door. This will effectively prevent the elevator from operating normally when the hall door is not locked.

5.3. Precautions in maintenance
In the elevator maintenance, the relevant staff in the maintenance unit shall improve the elevator quality effectively. In the actual situation, pay attention to check the steel wire ropes and the joints. Once the potential hazards are found, it shall be eliminated within the shortest time. The elevator with fault must not be used.

5.4. Precautions in testing
The inspectors shall inspect the elevator regularly. At the same time, the inspectors shall further enhance their sense of responsibility and improve the inspection. It is noteworthy that this problem is also involved in the Elevator Supervision Inspection and Regular Inspection Rules - Traction and Forced Driving Elevators, but it emphasizes the electrical verification of the hall door closing in place only. The inspectors shall fully understand the corresponding provisions of the rules, and learn from others in actual working, so as to effectively avoid missing and incorrect judgment.

5.5. Remote monitoring and fault warning system for elevator door system
With the development of electronic information technology and data processing theory, the maintenance of mechanical equipment is developing from traditional fault diagnosis to intelligent maintenance and early warning. The key point of elevator door system maintenance is gradually changing from fault diagnosis to the research in door operator intelligent maintenance area mainly including state monitoring, predictive maintenance and performance degradation analysis. With artificial intelligence theory, advanced information technology and network monitoring technology, the elevator door system is modeled and feature signals of the system are extracted, processed and analyzed to judge which parts of the elevator door system may have faults in the future [17-20]. The famous elevator manufacturers both at home and abroad are able to provide remote monitoring and management system matching with the elevators with improved functions. Its principle is shown in Fig. 6:
The state requires the supervision inspection and the annual regular inspection for special elevator equipment. The equipment shall only be used after passing the annual inspection. This artificial regular inspection method plays a role in ensuring the safe operation of the equipment, but it can only detect the status of the monitoring points of the elevator at that time, and can not know the daily operation state in the whole year, as well as the real-time operation status view. It has defect in fault warning and troubleshooting. The elevator door system intelligent monitoring system is designed to continuously monitor and make fault warning of the daily operation state of the elevator, and provide the basis for the elevator inspection and management department to learn the elevator operation condition.

6. Conclusion
To sum up, the elevator door MCU system has a direct impact on the safety and comfort of the elevator operation. In this case, the elevator manufacturing, design, installation, inspection, maintenance shall be improved. At the same time, there are defects in fault warning and troubleshooting. The elevator door system intelligent monitoring system is designed to continuously monitor and make fault warning of the daily operation state of the elevator, and provide the basis for the elevator inspection and management department to learn the elevator operation condition.

References
[1] Special equipment safety technical regulation TSG T5001-2009 Elevator service management and daily maintenance regulation [J]. Modern Property Management, 2009, (12).
[2] Zhou Jie, Wen Zengyu. Technical retrofit for eliminating the self-closing fault of elevator hall door [J]. China Plant Engineering, 2011, (3).
[3] Zheng Weifeng. Discussion on fault diagnosis and repair of elevator electrical control system [J]. China Homes (last third publication), 2014, (4).
[4] Wang Qibing, Li Dongliu, Zhu Liqiang etc. Research on application of ship elevator in ship engineering [J]. Ship Engineering, 2012, Ship Engineering, 2012, (supplement 2): (S2):145-147.
[5] Wang Qibing, Hu Jie, Ge Qing. Analysis of traction explosion-proof elevator design and installation [J]. Lifting and Transportation Machinery, 2014 (4): 34-35.
[6] Wang Qibing, Li Dongliu, Liang Deliang etc. Research on Design an Elevator to be Used in Clean Room and Controlled Environment [J]. Machinery, 2014(S1):11-12.
[7] Q.B.WANG,D.L.LI,L.Q.ZHU,Q.M.LI,Z.B.CHEN.B.Z,Z.H.LI : Research on Design of an Elevator in the Controlled Environment of Clean Room. International Asia Conference on Industrial Engineering and Management Innovation. (IEMI2012) Proceedings,(2013).
[8] F.J.MA,G.J.ZHAO,H.T.ZHANG:Malfunction Detection of Elevator Based on Expert System.Computer Automated Measurement & Control, (2002).
[9] Zhu Changming, Hong Zhiyu, Zhang Huiqiao. Principle, structure, installation and testing of elevator and escalator [J] Shanghai: Shanghai Jiao Tong University Press. 1995
[10] Wang Baoqiang, Yang Chunfan, Jiang Xuesong. Latest elevator principle, use and maintenance [J] Beijing: China Machine Press. 2006
[11] Jiang Chunyu, Zhang Yuanpei, Chen Jiafang. Elevator installation, use and maintenance manual [M] Beijing: China Machine Press. 2002.1
[12] Wang Qibing. Analysis on safety protection function of mine lift auxiliary elevator [A]. Zhejiang Association for Science and Technology, Shanghai Association for Science and Technology, Jiangsu Association for Science and Technology. Marine Economy and Power Development – Symposium of the 10th Yangtze Delta Motor, Power Technology Sub Forum [C].Zhejiang Association for Science and Technology, Shanghai Association for Science and Technology, Jiangsu Association for Science and Technology, 2013:3.
[13] Wang Xin. Application of fuzzy PI control in permanent magnet synchronous motor elevator door operator system [D]. Tianjin University, 2012.
[14] Weng Dan, Zhu Changming, Hu Hui, etc. Experimental study and analysis of electromechanical performance of elevator door operator system [J]. Hoisting and Conveying Machinery, 2008, 2008(8):93-96.
[15] Luo Dan, Xiao Huaming, Xie Bohuai. Discussion on common problems in inspection and use of elevator door operator system [J]. China Elevator, 2009(23):58-60.
[16] Ren Y, Xue-Juan M O. Simulation and analysis of harmonic suppression strategy in elevator door-machine servo system [J]. Journal of Mechanical & Electrical Engineering, 2012.
[17] Wan J R. Soft-drive elevator door machine without mechanical link[J]. Hoisting & Conveying Machinery, 2003.
[18] Hong Y H, Zi-Min Y U, Luo H C, et al. Remote Fault Monitoring and Early Warning System for Industrial Robots [J]. Science & Technology Vision, 2017.
[19] Tian L Y, Xiao-Zhu L I, Wang H J. Mine Air Compressors' Remote Monitoring Early Warning and Fault Diagnosis Expert System [J]. Instrument Technique & Sensor, 2012.
[20] Tao Z, Zhang B, Zhang P, et al. Fusion design between beidou satellite communication technology and sliding force remote monitoring warming system [C]// International Conference on Information Science and Engineering. IEEE, 2011:4542-4545.