Research on functional safety inspection method for functional safety of escalators in service

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Abstract—As a new technology, functional safety technology has been widely used in escalators. Functional safety inspection is the basis of escalator maintenance operations. This paper introduces the distribution and application of escalator functional safety, proposes a functional safety inspection method for escalator functional safety based on functional safety theory, and constructs a technical framework for escalator functional safety maintenance operation guidance, including data integrity, working environment, and daily inspection, Sensors, cabinets and control panels, wires and connectors, etc. and inspection methods. On this basis, taking the overspeed inspection of the escalator as an example, the escalator function safety maintenance operation guidance technology is explained.

1. Introduction
To improve the safety management and safety management level of escalator management, it is necessary to study the safety integrity verification method of escalators [1][2][3]. After the promulgation of the first general standard electrical and electronic programmable electronic safety-related system standard IEC 61508-2000 for functional safety, China promulgated the national standards GB/T 20438 and GB/T 21109 in 2006 and 2007, followed by the supervision of various industries in China. The department absorbs the essence of the framework and methods of the above standards, and combines the actual situation of the industry to develop standard documents for functional safety in the industry[4][5].

As an emerging technology, functional safety technology has been widely used in escalators [6]. Whether it is from a safety point of view or from a cost perspective, in the foreseeable future, more and more safety parts and components using functional safety technology will be used on escalators. How to improve the reliability of functional safety components? How to verify that it has played an effective role in the inspection process? Even further consideration, does this part conform to the original intention of design and manufacture? Or is the use of the safety component compliant? It takes a long time for escalators to introduce functional safety systems [7][8]. However, according to research, the existing brands have not developed relatively complete maintenance technology for public safety systems. Existing maintenance operation instructions often draw on traditional escalator maintenance. Work instruction materials cannot effectively cover the software, hardware, failure rate, reliability and other aspects of the functional safety system. The sensors, control systems, actuators and other subsystems that are an important part of the escalator functional safety have no special inspection and maintenance [9]. It is necessary to develop a functional safety inspection method for the functional safety of escalators in the use link, and on this basis, develop an escalator maintenance operation guidance technology based on functional safety.
2. ESCALATOR MAINTENANCE OPERATIONS AND MAINTENANCE GUIDANCE TECHNOLOGY

In order to ensure the safe, reliable and economical operation of the escalator functional safety system equipment, and to institutionalize, standardize and standardize equipment maintenance, it is necessary to formulate an escalator maintenance operation guide based on functional safety[8][11]. Detect the running status of the escalator and perform maintenance on the escalator to ensure that the escalator is in a good running state. Maintenance personnel should master the operation, maintenance, testing, and repair skills of escalators, conduct regular maintenance business training, have the ability to make accurate judgments, quickly troubleshoot faults, and have corresponding qualifications in accordance with national and industry maintenance operations related requirements Certificate, hold a certificate to work.

The maintenance operations of the escalator adopt a combination of planned maintenance, state maintenance and fault repair. Planned maintenance has a fixed maintenance cycle and content. It is a preventive maintenance mode that regularly implements maintenance operations on escalators in accordance with the maintenance plan. It is suitable for escalator maintenance items and content that have a direct impact on safety. Condition maintenance is the way of condition inspection, testing and technical diagnosis of escalators. Condition maintenance does not set a fixed maintenance cycle and content, and adopts the predictive maintenance mode of corresponding maintenance operations according to the performance index status of the escalator. It is suitable for complete detection and monitoring methods, and the monitoring performance index can directly or indirectly reflect the safety status.

2.1. ESCALATOR MAINTENANCE ITEMS AND CONTENT.

Failure maintenance is a maintenance mode in which equipment and facilities are maintained after failure of the escalator mode to restore its original functions. Failure maintenance is suitable for escalator maintenance items and contents that have a low operating failure rate and whose functions can be restored by simple handling that do not directly affect safety. For the functional safety components or functions of the escalator, the manufacturer has declared a long-term life commitment, which is also applicable to fault maintenance and maintenance, and there is no need to carry out long-term fixed-period maintenance items and contents.

2.2. THE CURRENT SITUATION IN THE FIELD OF ESCALATOR FUNCTIONAL SAFETY.

For escalators, GB 16899-2011 "Safety Code for the Manufacturing and Installation of Escalators and Moving Walks" puts forward the concept of PESSRAL. GB/T35850.2-2019 "Application of programmable electronic systems related to safety of elevators, escalators and moving walks-Part 2: PESSRAE" is suitable for the implementation of escalators and moving walks safety functions composed of programmable electronic components and programmable electronics. The specific requirements of the system composed of the system (PE system). Existing escalator safety manufacturing specifications and maintenance inspections on the functional safety of escalators generally only target the equipment components themselves, rarely involve sensing and control logic aspects, and focus more on the effects of the executive components. A given criterion can be determined qualitatively or quantitatively assembly is qualified. On this basis, qualitative judgments of safety results far outweigh quantitative considerations. Therefore, it is necessary to use functional safety methods to transform qualitative assessment and testing into quantitative methods for implementation to better evaluate the verification of the escalator safety function system. GB 16899-2011 and GB/T35850.2-2019, for escalators and moving walks, the required range for determining the target failure amount of safety-related functions is between SIL1 and SIL2. We investigated the brand and model distribution of mainstream escalator manufacturers in the public transportation sector in Beijing, and obtained the application status of escalators on the market in terms of functional safety.
Table 1. Distribution of safety functions on escalators and moving walks.

| Item Number | SIL | A | B | C | D | E | F | G |
|-------------|-----|---|---|---|---|---|---|---|
| 1           | 2   | 2 | 2 | 2 | 2 | 3 | 3 |   |
| 2           | 2   | 2 | 2 | 2 | 2 | 2 |   |   |
| 3           | 1   | 1 | 2 | 2 | 2 | 1 | 2 |   |
| 4           |     | 1 |   |   |   |   |   |   |
| 5           |     | 1 |   |   |   |   | 2 |   |
| 6           |     | 1 |   |   |   |   |   |   |
| 7           |     | 2 |   |   |   |   |   |   |
| 8           |     | 1 |   |   |   |   | 2 |   |
| 9           |     | 2 |   |   |   |   | 2 |   |
| 10          | 2   | 2 | 2 | 2 | 2 | 2 | 2 | 2 |
| 11          | 1   | 1 | 2 | 1 | 2 | 2 | 1 | 2 |
| 12          | 1   | 1 | 2 | 1 | 2 | 2 | 2 | 2 |
| 13          | 1   | 1 | 1 | 1 | 1 |   | 1 | 2 |
| 14          |     | 1 |   |   |   |   |   |   |
| 15          |     | 1 |   |   |   |   |   |   |
| 16          | 1   | 1 |   |   |   |   |   |   |
| 17          |     | 2 |   |   |   |   |   |   |
| 18          |     | 2 |   |   |   |   |   |   |
| 19          |     | 2 |   |   |   |   |   |   |
| 20          |     | 2 |   |   |   |   |   |   |
| 21          |     | 2 |   |   |   |   |   |   |

1. The seven functions of brake and additional brake not released check, step or pedal missing check, handrail speed deviation check, overhaul cover and floor plate open check, are all relatively complete by each manufacturer.

2. As the three most stringent functional safety standards, two overspeed inspections, non-manipulation reversal inspections and drive chain rupture inspections involving brakes and additional brakes at the same time are available to all major manufacturers, and even some manufacturers make them complete. The safety level was raised from SIL2 to SIL3.

3. The brake is not released check, the additional brake is not released check, the speed deviation check of the handrail, the inspection cover and the floor plate open check, because the number of personal injury accidents caused in recent years has a large impact, so many manufacturers have also made it functional. The integrity level is increased from SIL1 to SIL2.

3. **TECHNICAL FRAMEWORK FOR ESCALATOR MAINTENANCE OPERATION GUIDANCE BASED ON FUNCTIONAL SAFETY**

In the functional safety system, by calculating several factors such as software, hardware, environment, failure rate, and ultimately get the required reliability index. In the use process, it is necessary to ensure the expected reliability index of the design and manufacture of the escalator. As the units and personnel who use and maintain escalators do not have the ability to calculate functional safety expectations in terms of skills, it is even more difficult to obtain relevant failure rate data. Even under the condition of equipped with automatic monitoring devices, under the framework of existing escalator functional safety, it is difficult to calculate the functional integrity level by processing the data obtained. Therefore, it is necessary to develop a functional safety-based escalator maintenance operation guidance technical framework to check and verify the integrity of the functional safety of the escalator during use.
Escalator safety is completed by multiple protection systems. Therefore, escalators must not only consider all components in an independent system (such as sensors, control equipment and actuators), but also must consider all safety-related components that constitute a complete safety-related system. An important indicator of functional safety is to meet the performance level requirements, that is, the probability that the relevant system can completely perform an action within a specified time. The modular inspection method based on functional safety is divided into a sensor sub-module, a logic control sub-module, and a final execution component sub-module. Three-part inspection and quantified probability indicators to clarify the content and items of the three parts.

3.1. TYPE REVIEW INSPECTION BASED ON FUNCTIONAL INTEGRITY
It is a type test certificate/report and user manual. Including the hardware model and version, the type of programmable electronics, the manufacturer and model of the number of safety relays, the software model and version, the manufacturer and model of the number of switching power supplies, the number of safety function sensors, the installation location, the manufacturer and model, and the control The enclosure level of the cabinet or programmable logic device.

3.2. WORKING ENVIRONMENT
Ensure that the cabinet temperature is kept within the working range.
Check whether there is dust inside and outside the cabinet. If dust is found, it must be cleaned accordingly.
Confirm whether there is condensation inside and outside the cabinet. After condensation occurs, immediately cut off the power to remove it and dry it; and take corresponding measures to prevent condensation again.
Are there any dangerous goods around?
Whether the operating performance meets the standard specifications?
Whether there are abnormal noises, vibrations and abnormalities?
Whether there is overheating?

3.3. SENSOR SWITCH
Whether the joint is loose?
Whether the sensor shell is damaged?

3.4. CONTROL SYSTEM
Check whether the installation of the control cabinet is firm and reliable.
Whether the circuit board has discoloration and peculiar smell?
Whether the circuit board is cracked, damaged or deformed?
Whether the capacitor is free of liquid leakage, discoloration, cracks and expansion of the shell?
Whether the relay shell is cracked?
Measure whether the output voltage is normal.

3.5. ACTUATOR/BRAKE
Check the brake or additional brake according to the existing content.

3.6. WIRE AND CONNECTION
Whether the wire sheath is broken and discolored?
Whether the connection plug-in is loose, whether there is dust and foreign matter attached?
As the sensor and switch part of the functional safety integrity test, independent safety circuits are mostly used. Therefore, all safety switches and sensors can also be regarded as independent points on the same safety circuit. Since the existing safety switches and sensors basically use devices with a
uniform reliability level, they can be regarded as a series arrangement in structure, and the functional integrity level is divided into orders of magnitude. Therefore, its topological structure is functionally complete. The result of the sex rating has little effect.

4. PRACTICE OF INSPECTION SPEEDING BASED ON FUNCTIONAL SAFETY
Escalator overspeed inspection means that the escalator should automatically stop running before the speed exceeds 1.2 times the nominal speed. When the running speed of the escalator exceeds 1.2 times the standard speed, cut off the power supply of the driving host and the working brake, the working brake will work and the escalator will stop running. If the working brake fails, before the escalator travel speed reaches 1.4 times the standard speed, cut off the power supply of the additional brake to brake the escalator. The traditional inspection method for overspeed inspection is that maintenance personnel or inspectors conduct tests and confirmations according to the method provided by the manufacturer. With reference to the previous research work, the functional safety component inspection method includes the following four parts:

4.1. BASED ON FUNCTIONAL INTEGRITY CHECK
Check whether the type test report and user manual are complete and whether the content is complete. The input subsystem is checked on-site to check the effectiveness of functions and installation.
Does the manufacturer provide complete maintenance and repair instructions, as well as product life and inspection intervals?

4.2. SENSOR AND DETECTION SWITCH INSPECTION
Check the effectiveness of the motor speed sensor, non-manipulated reversal detection switch, handrail speed sensor, missing step detection sensor, working brake detection switch, and additional brake detection switch.
Whether the installation position and clearance are within the normal range?
Whether the triggered fault information is normal?

4.3. CONTROL SYSTEM INSPECTION
Check the control cabinet and switching power supply, check whether the fixing, wiring, and plug-in are loose;
Simulate the occurrence of an overspeed fault, and observe whether the fault code displayed in the control cabinet is correct.

4.4. ACTUATOR INSPECTION
4.4.1. ANALOG SWITCH VERIFICATION.
Check whether the working brake detection switch and the additional brake detection switch are normal.
After simulating the detection switch, check whether the brake mechanism can work.

4.4.2. ON-SITE FUNCTIONAL VERIFICATION.
When the overspeed protection action occurs, the escalator will stop.

5. RESULTS AND DISCUSSION
Based on the theory of functional safety, it can better solve the problem of the functional integrity of existing escalators and the inability to provide effective proof in the use of maintenance links. The conclusion of the text includes the following four points.

1. Due to the lack of skills and abilities of the escalator-related personnel, and it is difficult to obtain relevant failure rate data, it is almost impossible to verify the integrity of the escalator function by calculating software, hardware, environment, failure rate and other parameters. possible.
2. It is necessary to use functional safety-based escalator maintenance operation guidance technology to check and verify whether the escalator can be functionally safe in the course of use, and can ensure the functional safety and integrity in the course of use.

3. All safety switches and sensors can be regarded as independent points on the same safety loop, and its topological structure has little effect on the result of the functional integrity level. Since the existing safety switches and sensors basically use devices with a uniform reliability level, they can be regarded as a series arrangement in structure, and the functional integrity level is divided into orders of magnitude. Therefore, its topological structure has complete functions. The result of the sex rating has little effect.

4. The functional safety document method proposed in this paper is a very effective and simple method, and the specific application of this method in public transportation escalators is proposed. By providing reasonable safety certification documents, risks can be effectively reduced and the overall safety and reliability of the escalator can be improved.

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