Research on condition monitoring device of HDTSE for intelligent maintenance

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Abstract. The role of HDTSE is becoming increasingly important. According to the operation characteristics of, This paper analyze the causes of escalator failure, adopts Internet of things, intelligent sensing and distributed technology, presents an escalator operation monitoring system architecture for intelligent maintenance, design the hardware and software of the monitoring device, realize the real-time monitoring of key parameters of escalator and fault warning. It has high application value.

1. Introduction
In recent years, with the rapid development of China's economy and society, the process of urbanization is accelerating. More and more cities begin to build urban rail transit, and the application of Heavy-Duty Transportation System Escalator(HDTSE) is becoming more and more common. HDTSE are very common in the condition of large passenger flow and long running time, which brings great challenges to the safety management and operation and maintenance of escalators. However, at present, the escalator maintenance is mainly based on regular maintenance and emergency maintenance. There are some shortcomings, such as excessive maintenance, high intensity and high cost, which are difficult to adapt to the actual needs of the carrier. Heavy Duty Transportation System Escalator Design Guidelines[1], formulated by American public transportation association(APTA), it is clearly stipulated that the bearing of key parts of escalator must be equipped with vibration analysis equipment(VAE) with fast Fourier transform (FFT) function, and it is explained that this requirement is "in order to reduce the difficulty of escalator maintenance in the future. Paying for the VAE will be more than compensated for by the overall reduced life-cycle costs and improve customer safety, satisfaction and convenience.

Now, in domestic urban rail transit construction projects, escalators are usually connected to the Building Automation System (BAS) and Integrated Supervision Control System (ISCS) to realize remote monitoring [2]. However, they mainly focus on the escalator operation management, and does not have the ability to warning of the status trend, nor can it provide the necessary data support for maintenance. Therefore, it is very urgent to develop an escalator condition monitoring device which can monitor the escalator status, intelligently warn and effectively support intelligent operation and maintenance. In this paper, combined with the typical incident cases of escalators, we will analyze the main causes of escalator failure, explore and propose an escalator operation monitoring framework, develop an escalator operation status monitoring device, realize the collection of main operation parameters of escalators, meet the urgent needs of real-time monitoring of escalator status and fault warning, and provide a new technical means for escalator maintenance, mean to reduce the failure time of escalator.
2. Failure analysis of escalator

In recent years, safety incidents caused by failure of HDTSE occur from time to time, some of which also cause casualties and economic losses, causing widespread concern. In addition to the use reasons, the main causes of the incident are the poor quality and maintenance. For example, on July 5, 2011, the escalator at entrance A of Zoo station of Beijing Metro Line 4 and on December 14, 2010, the escalator from platform of Guomao Station of Shenzhen Metro Line 1 leading to the station hall caused a safety incident. The technical investigation report showed that the direct cause of the incident was the displacement of the driving host and the falling off of the driving chain, which caused the escalator incident \(^3\). On March 25, 2017, an escalator in Langham Place, Hong Kong suddenly stopped and ran in the opposite direction, resulting in 18 passengers injured. The investigation showed that the direct cause of the incident was the double failure of the main drive chain and the broken chain safety device (BCD) \(^4\).

The above escalator incidents are mainly caused by the failure of fixed parts and the failure of transmission parts which are not repaired in time. In the process of operation, equipment vibration usually contains rich equipment status information, and condition monitoring and fault diagnosis technology based on vibration signal has been widely concerned \(^5\). Due to design defects, abnormal vibration and abnormal dynamic load of the structure are caused, which are also the main causes of escalator incidents \(^6\). Predictive maintenance technology based on the status development trend and residual life warning of equipment will greatly improve the safety of equipment, improve maintenance efficiency, reduce production costs and improve production efficiency \(^7\-8\). Vibration monitoring is still perhaps the most widely used method of predictive maintenance and, it can be applied to a wide range of rotating equipment. For this reason, the author explores the deployment of status acquisition equipment on escalators, collects the status parameters of main components, monitors the operation status in real time, identifies the abnormal status, and provides early warning or alarm in time, which can not only effectively discover the safety risk of escalator, but also reduce the intensity of maintenance, and improve the scientificity and effectiveness of maintenance.

3. Architecture of escalator condition monitoring system

In order to realize the real-time monitoring of the escalator operation status, identify the abnormal status, provide early warning for faults and alarms, and take emergency measures to reduce risks when necessary. It is very important to design an appropriate escalator running status monitoring architecture. The monitoring system architecture is mainly based on the collection, monitoring, analysis and modeling of a huge amounts of historical and real-time data generated during the operation of escalators. The escalator risks predicted by the model are graded, and the corresponding strategies are formulated according to the grading to maintain the escalators. The architecture of the monitoring system is mainly composed of five parts: status signal sensing, data acquisition, condition monitoring, early warning model construction and intelligent decision-making. The architecture of the monitoring system is shown in Figure 1.

![Figure 1 The architecture of the monitoring system](image)
3.1. Status signal sensing
Status signal sensing is the key of escalator condition monitoring and fault early warning. On the one hand, the status signal should effectively reflect the abnormality of the tested parts, on the other hand, the relevant status signal should be obtained at an acceptable cost. According to the typical elevator incidents and the causes of faults, and conducive to reducing the difficulty of escalator maintenance, the escalator operation status signal is selected, and the status signal is shown in Table 1.

| Fault type                        | Status signal                  |
|----------------------------------|--------------------------------|
| failure of fastening parts       | motor base vibration           |
| failure of rotating parts        | vibration and temperature      |
| control system failure           | running speed                  |
| electrical fault                 | electrical parameters and      |
| safety device abnormal           | controller operation data      |
| service life of handrail         | handrail temperature           |
| operating environment           | temperature and humidity       |

3.2. Data acquisition
Data acquisition is an important basis for real-time monitoring and is the data source of all fault warning and alarm. On the one hand, data acquisition is to use the existing controller of escalator to monitor data, on the other hand, it is to install online monitoring device to collect the status signal of escalator.

3.3. Condition monitoring
By collecting the current status signal and operation data of the escalator, the characteristic signal is extracted to identify the operation condition of the escalator and judge whether the escalator is faulty.

3.4. Model construction
Selecting the appropriate early warning model, using a large number of historical and simulation data obtained from condition monitoring, training the model, combined with expert knowledge base, to obtain the model of escalator fault early warning under different working conditions.

3.5. Intelligent strategy
The intelligent strategy is based on the real-time monitoring of escalator and the identification of abnormal status, combined with expert knowledge, according to the prediction model, analyze and calculate the operation risk and risk level of escalator, and provide corresponding repair and maintenance measures for various risk levels to realize intelligent operation and maintenance.

4. Design of escalator condition monitoring device
The condition monitoring device senses the running status signals of key components, collects the running signals of the controller, monitors the running status of the escalator real-time, identifies the abnormal situation, and carries out intelligent warning and intelligent decision-making of the running status according to the expert knowledge, so as to serve the safety management and intelligent maintenance.

4.1. Hardware design
The hardware architecture of escalator condition monitoring device is shown in Figure 2, which mainly includes sensor module, acquisition module, signal processing and storage module, communication module and power supply module. Considering that there are many kinds of sensors and the field transmission line is long, the sensing signal is digitized at the near sensing end and distributed networking is carried out through the field bus. The sensor module consists of four types of
sensors: PY-21 acceleration sensor are used to sense the vibration of the main engine base and the main rotating parts, py-3v sensor is used to collect the running speed of the escalator, PY-41 sensor is used to sense the temperature of the handrail and ME631 power quality collector is used to measure the electrical parameters. The acquisition module is connected with the sensor module through the field bus to realize the acquisition of the status signal; the signal processing and storage module is responsible for the real-time monitoring and fault warning of the status signal, and stores the relevant information, also, it interacts with the cloud server through the communication module. The main processor of signal processing is a high-performance 32-bit microcontroller based on ARM cortex M7. EC20 module is selected in the communication module, which supports a total of 7 bands, such as 2G / 3G / 4G, and can better adapt to the field network environment. The power supply module is used to provide the working power for the monitoring device and the standby power when the external power supply is interrupted.

Figure 2 The hardware architecture of escalator condition monitoring device

4.2. Software design
The escalator condition monitoring device is developed with C language. In order to adapt to the collaborative processing of multiple tasks and improve the real-time performance, FreeRTOS is proposed to be used as the operating system. It is a lightweight operating system with the characteristics of open source, portability, tailoring and flexible scheduling strategy, which can be easily embedded to the cortex M7 controller. Embedded software mainly includes five parts: system environment, data acquisition, monitoring and early warning, data transmission and system configuration. The composition of software function modules is shown in Figure 3.

Figure 3. The composition of software function modules
4.3. **Experiment**

A Hitachi escalator is selected to carry out the experiment. It is 6m lifting height, 0.5m/s running speed, and 7.5kW main engine power. The field test photo is shown in Figure 4. The escalator is in normal operation mode, and the status data monitored by the monitoring device is shown in Table 2.

![Figure 4. Field test photos](image)

| Status signal                        | Value     |
|--------------------------------------|-----------|
| Motor base vibration                 | 0.60mm/s  |
| Motor vibration                      | 0.29mm/s  |
| Gear vibration                       | 0.31mm/s  |
| Main drive shaft vibration (Right)   | 0.26mm/s  |
| Tension carriage shaft vibration (Left) | 0.27mm/s |
| Speed                                | 0.51m/s   |
| Instantaneous power                  | 1.35Kw    |
| Handrail (Left)                      | 19.7℃     |
| Handrail (Right)                     | 20.7℃     |
| Ambient temperature                  | 19.2℃     |
| Operation status                     | Normal    |

5. **Conclusions**

The HDTSE is more and more widely used. In view of the challenges brought by the escalator with high load and long daily operation time to safety management and maintenance, this paper selects typical escalator safety incidents, analyzes the main causes of escalator failure, proposes an escalator operation monitoring system architecture, develops an escalator operation status monitoring device, and realizes the escalator operation. The real-time collection of main operation parameters, condition monitoring and fault early warning provide a new technical means of operation and maintenance, greatly reduce the difficulty and labor intensity of escalator maintenance, improve the scientificity and effectiveness of maintenance, help to reduce the failure rate, improve the operation efficiency. It has high application value.

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