Research Progress on Detection Technology of Composite Electrical Traction Steel Strip for Elevator

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Abstract. Aiming at the problems such as detection accuracy, damage identification, and performance evaluation in the inspection and testing of elevator composite traction steel strips, the related research results of nondestructive testing of elevator composite traction steel strips at home and abroad are comprehensively analyzed, and the future is summarized and proposed Research direction. First, the structural characteristics of composite traction steel strips for elevators in use today are introduced, and the advantages of composite traction steel strips for elevators on steel steel ropes are specifically analyzed. Second, the development of nondestructive testing technology is introduced, and the research and application of non-destructive testing of composite steel strips and steel steel ropes for elevators are emphasized. Among them, non-destructive testing of steel steel ropes mainly including AC electromagnetic method, permanent magnet method, magnetic flux leakage method and residual magnetism method. The detection methods of composite steel strip mainly include magnetic flux test method, life setting method and resistance test method. Finally, on the basis of comparing the current non-destructive testing methods, a differential field-weak non-destructive testing method of dual magnetic circuits is proposed, and the research trend of defect detection of elevator traction steel strips is pointed out.

Keywords: composite steel strip, elevator, non-destructive testing, differential dual magnetic circuit.

1. Introduction
With the rapid development of China's economy and society, there are more and more high-rise buildings in cities, and elevators have become an indispensable transportation tool in modern urban construction[1]. The number of elevator is growing rapidly, and according to data released by the relevant departments, by the end of 2020, the number of elevator in use in China was 7,865,500, making it the world's largest elevator manufacturing base and elevator market.

Steel steel rope, as one of the most important flexural components, is an important part of the elevator. In the process of its use, fatigue, rust, wear and tear and even sudden breakage may occur[2],...
resulting in reduced load-bearing capacity, endangering equipment and personal safety. Therefore, it is of great significance to conduct nondestructive testing on the reliability of steel rope.

For a long time, researchers are committed to the study of various nondestructive testing methods for steel steel rope. However, as a new type of load-bearing component, the complex structure and the limitation of existing testing methods make the testing of composite steel strip more difficult. In this paper, the methods of nondestructive testing for steel steel rope and composite traction steel strip used in elevators at home and abroad were comprehensively analyzed, and the research trend in the future was summarized and proposed.

2. Development status of composite traction steel strips
In order to respond to the national policy of energy saving and efficiency, elevator technology is also constantly innovating and developing. New technologies, materials and techniques are being gradually promoted and applied in the manufacture of elevators, and new elevators with traction steel strips as the traction medium have emerged in the elevator market, as shown in Figure 1. The traction steel rope of elevator is an important part of load bearing and drive of elevator[5]. Compared with the traditional steel rope, the rope strands of the traction steel strip are rearranged, which increases the traction force while maintaining the strength of the steel rope. In the new technology, the polyurethane layer is used instead of the rope core to wrap around the steel rope strand, which has the effect of anti-rust and anti-wear. Traction steel strip has the characteristics of light weight, small bending radius, low traction noise, no need for regular lubrication, environmental protection, etc., which is favored by the major elevator manufacturers. Otis first completed the theoretical demonstration of the steel strip traction system and the actual elevator manufacturing, and subsequently, Schindler, ThyssenKrupp, Hitachi and other brands also launched the elevator products with composite steel strip as the bearing parts[6].

Due to the many performance advantages of composite steel strip, more and more elevator manufacturers adopt composite traction steel strip to replace the traditional steel rope. In addition, the State Council has written the policy of installing elevators in old communities into the government work report, which has actively promoted the work of installing elevators in old communities. The machine room-less structure and composite steel strip are used as traction elements in the retrofitted elevators. With the development of the installation of elevators in various places, the number of composite traction steel strip elevators will increase sharply. However, there is no special requirement for the traction steel strip in GB7588-2003 "Safety Code for Elevator Manufacturing and Installation". In TSG T7001-2009 "Rules for Supervisory and Periodic Inspection of Elevators - Traction and
Forced Drive Elevators", there are also no detailed requirements for the inspection of the traction steel strip. Standards for non-steel rope suspension devices for elevators are still being developed. In the market, there is a lack of portable testing equipment that meets the requirements of measurement. The front-line inspectors lack operability in the inspection of traction strips, especially in the detection of internal wire defects. As the steel rope strands of the composite steel strip are wrapped in polyurethane, it is hard to find that the diameter of the internal wire becomes smaller or broken, and the damage or fracture is not easily detected, which directly affects the load-bearing capacity and performance of the traction steel strip, forming a major hidden danger to the safe operation of the elevator[7].

3. The development status of the detection technology of elevator steel rope and composite steel strip at home and abroad

In recent years, the overall level and comprehensive strength of China's non-destructive testing technology has been substantially improved, so the application of non-destructive testing technology to steel rope inspection is an effective method. The steel rope non-destructive testing technique is used to inspect the interior of the steel rope without causing damage to its internal structure and to evaluate the safety performance of the steel rope based on the test results. The failure modes of steel rope are generally divided into four categories: rope strand fracture, rope diameter reduction, elongation deformation and corrosion damage. The fracture of steel wire generally occurs on the side in contact with the pulley. The occurrence of fracture is often visible outside, can be found by visual inspection method, but the internal steel wire fracture needs to be detected by nondestructive testing. Among the methods in use today, the main ones include magnetic and non-magnetic detection techniques. Magnetic detection method is divided into AC electromagnetic method, permanent magnet method, magnetic leakage method and remanent magnetic method according to its principle. The research on the traction steel strip elevator started late, and there are few researches on the inspection technology of the traction composite steel strip at home and abroad, mainly including the magnetic flux detection method, the life setting method and the resistance test method.

3.1. Research on testing technology of elevator steel rope

In order to ensure the mechanical capability of the steel rope, electromagnetic non-destructive testing is often used to test its mechanical properties, internal structure and working condition, and to assess the condition of the steel rope according to the test results and certain guidelines. This method has been widely used because of its high sensitivity, good reliability, low cost and many advantages, and has great advantages in the field of steel rope nondestructive testing. According to the American Standard ASTM E1571-2001 "Standard specification for electromagnetic inspection of ferromagnetic steel ropes", the principle of non-destructive testing of steel ropes is divided into three categories: AC electromagnetic instruments, DC and permanent magnetic instruments, and leaky magnetic instruments. On the basis of the American standard and the specific situation in China, the national standard GB/T 21837-2008 "Electromagnetic Testing Method for Ferromagnetic Steel Ropes" has added "Remanent Magnetism Class Method", which is subject to further follow-up research and application verification.

In 1906, R. Colson and C. McCann, South African scientists, developed the world's first electromagnetic non-destructive testing device for steel rope, which was excited by the alternating current (AC) excitation method for measuring the cross-sectional area loss of steel rope. Due to skin effect and eddy current loss, this method has some disadvantages, such as low penetration depth and intense heating of steel rope during detection. In 1925, German researchers successfully developed the first practical electromagnetic steel rope testing instrument, which can be used for on-site testing. From 1925 to 1955, foreign researchers developed a large number of steel rope testing instruments based on DC method. The DC-based method is gradually being replaced by the permanent magnet method due to the difficulties associated with DC excitation and the installation of detection coils, as well as the drawbacks of a large and complex instrument structure. In 1964, H. R. Weischedel
developed a steel rope electromagnetic testing instrument using a permanent magnet as an excitation source. In 1978, B.G. Marchent invented an instrument that used permanent magnets and electromagnets to magnetize steel ropes to detect defects in steel ropes. In 1995, Canadian researchers put forward the concept of Total Change in Metallic Area (TCMA) testing, i.e. the degree of change in the metal cross-sectional area of a steel rope after a period of use relative to the metal cross-sectional area at the factory, which breaks through the defects of the Loss of Metallic Cross-sectional Area (LMA) detection that needs to find the detection benchmark. In 1999, J. M. Nussbaum of the University of Stuttgart, Germany, designed two sets of sensors consisting of a detection array consisting of 30 Hall elements. With the help of computer technology, the spatial location of broken wires was successfully achieved. In 2018, Kaur.Akshpreet invented a new type of steel rope tester based on the principle of magnetic flux leakage. The instrument has a Hall effect sensor mounted inside the yoke, which generates a defect signal whenever a defect in the steel rope passes through the sensor.

China's research on steel rope non-destructive testing technology began in the early 1960s, until the early 1970s, the first generation of TGS-type steel rope flaw detection equipment was developed. In the 80's, Professor Shuzi Yang and Yihua Kang of Huazhong University of Science and Technology started to research steel rope broken wire detection technology and produced MTC-94 type steel rope flaw detector and GDIY series steel rope broken wire quantitative detector, which realized the quantitative detection of broken wire. Harbin Institute of Technology and Fushun Coal Mine Branch successfully developed the GST steel rope flaw detector in 1994, which can simultaneously perform LF and LMA type damage detection. In 2006, metal magnetic memory technology was applied to the diagnostic detection of steel rope damage, without the need for artificial excitation devices, using highly sensitive probes to directly receive the leakage signal of steel rope defects under the action of the geomagnetic field. In the 21st century, with the rapid development of computers, the virtual instrumentation technology, which replaces traditional instruments with software, has gradually taken shape. Steel rope nondestructive testing at home and abroad is being developed from the early detection of steel rope breakage and other defects to the detection of steel rope metal cross-sectional area loss, strength assessment and steel rope life prediction direction.

3.2. Research on detection technology of traction steel strip for elevator

In contrast to traditional steel steel ropes, elevator traction strips are made up of a number of steel steel rope cores arranged in parallel and fused with a polymer polyurethane. The rope core carries the majority of the load on the strip during operation. At present, other types of suspension devices (such as traction steel strip) are allowed to be used in elevators. However, there are no clear terms for the inspection requirements of traction steel strip at present. This can only refer to the inspection requirements and methods of steel steel rope in relevant standards and specifications, and combine with the relevant provisions in the manufacturer's product manual to inspect the traction steel strip. The normal wear process of a traction steel strip goes through three stages: the polyurethane surface of the strip wears brightly, traces of wire are seen on the surface and the wire leaks out, as shown in Figure 2.

![Figure 2](image-url)
However, the composite steel strip is a new thing, in addition to normal wear and tear in the process of use also often occur strength loss problems, such as broken strands, wear and tear, which affect the normal operation of the elevator. Due to the small number of types of elevator traction steel strips currently on the market, there are relatively few corresponding non-destructive testing methods available. At present, there are mainly the following three nondestructive testing methods: magnetic flux testing method, life setting method and resistance testing method. At present, the elevator manufacturers mainly use the resistance detection method to monitor the broken stock defect of the elevator traction steel strip.

Lei Hua-Ming and Tian Gui-Yun proposed a nondestructive testing method using magnetic flux detection to detect broken wires in steel strips for elevators. The method uses a pair of sensors to detect the steel strip, forming a differential signal with high accuracy for the detection of the number of broken wires.

Through the experimental verification of the steel band resistance detection method, Hu Xiao from Jiangsu Special Equipment Safety Supervision and Inspection Research Institute obtained the relationship between the resistance change rate of the steel band rope core and the strength of the steel band, and put forward a comprehensive detection method combining the life setting method and the resistance measurement method. A nondestructive testing device and method for elevator traction steel strip is proposed by Shanxi Huida Aoxing Technology Co., Ltd., which is used to solve the problems of low testing accuracy, easy to miss detection, poor anti-interference ability and poor accuracy of the existing technology. Since the test method is in the idea conception stage and not yet commercialized, the test instrument is not directly obtained. Luoyang Weier Ruopu Inspection Technology Co., Ltd. has developed a W-GDAJ elevator traction steel strip safety monitoring device, which can identify the fracture of the steel core inside the traction steel strip. The instrument can solve the problem of monitoring the broken core of the towed steel strip, but it cannot determine the broken core position of the towed steel strip. In addition, the instrument requires fixed installation, not suitable for portability, for testing organizations, the instrument can not provide accurate quantitative test results data.

The above-mentioned electromagnetic non-destructive testing methods are not yet good enough to solve the cross-sectional changes and fracture defects of traction steel strips. With the development of nondestructive testing theory and technology, many new nondestructive testing instruments have appeared on the market, such as ultrasonic phased array, which can detect the internal defects of materials well. However, it is necessary to apply coupling agent on the surface of the steel strip to be tested. As the traction strip relies on friction to transmit power, applying coupling agent on the surface of the steel strip reduces the friction between the traction steel strip and the traction wheel, and even the phenomenon of skidding may occur. For example, digital radio-graphic inspection can detect macro-geometric defects within an object without damaging the object itself, but the complexity and high cost of the equipment makes it difficult to extend the application to the inspection of traction steel strips in elevators in service.

4. Conclusion

At present, there are three problems in the nondestructive testing of steel strip. First, the testing method is single. Electromagnetic detection is the most widely used method, but it can only detect macroscopic defects of composite steel strip. There is no suitable method to detect the microstructure change and fatigue damage of steel strip. Secondly, the excitation magnetic circuit is single. Today's excitation devices are large and bulky, and excitation is difficult for spiral structured steel ropes, and the excitation effect is not ideal. Finally, quantitative positioning detection is not accurate. The structure of composite steel strip is more complex, and the identification of defect location in multiple steel ropes side by side requires higher accuracy[30].

To solve the above existing problems, drawing on ferromagnetic steel rope defect detection methods, research can be carried out in the following areas: The magnetic flux sensor and leakage field sensor are integrated into an electromagnetic sensor, and a differential dual magnetic circuit method is proposed for the non-destructive testing of low intensity magnetic field. Further research on the weak
magnetic detection theory of steel wire defects inside the steel strip, the electromagnetic response characteristics of steel wire defects inside the steel strip and the development of differential dual magnetic circuit electromagnetic detection sensor are carried out, which provides scientific basis and technical support for the defect detection of elevator traction steel strip in service. With the rapid development of science and technology, the non-destructive testing technology of steel strip is developing towards high precision, multi-function and simplicity, and gradually replaced by instruments, and then developed a portable multi-function integrated composite steel strip testing device.

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