Study on the Design of Comprehensive Test Environment for the Performance of Cable Tunnel Patrol Robot

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Abstract. The cable tunnel patrol robot has gradually attracted the attention of cable operation and maintenance units due to its high inspection efficiency and strong work safety[1]. In order to test the functions of cable tunnel patrol robot such as autonomous inspection, defect identification and fire fighting, a targeted functional test environment for cable tunnel patrol robot was designed, including autonomous inspection environment and defect detection environment. The test environment can not only be used to test the performance of cable tunnel patrol robot, but also provide an important reference for the construction of autonomous inspection environment for cable tunnel robot.

1. Introduction
Cable tunnel is a tunnel or tunnel-type structure used to accommodate a large number of cables laid on cable supports. Cable tunnel can not only protect cables, but also facilitate cable operators to patrol and inspect cables. At present, the inspection of cable tunnel mainly relies on manual inspection, which has some problems, such as high working intensity, dangerous working environment and unsatisfactory inspection effect[1]. With the popularity of electric robot, the application of the tunnel patrol robot has caught the attention of cable patrol and inspect unit. Among them, the track-type tunnel patrol robot adopts the suspension track operation mode, which has the problems of long track construction period, high cost and failure to realize the dead-angle detection of cable defects. So the ground-type cable tunnel patrol robot becomes the focus of the present study[2].

At present, there are mainly the following three situations for the test of various patrol robots in the development process or functional test before operation. 1) There is no need to set up a test environment, such as substation patrol robot. Since the work scope belongs to the no-risk area (manual inspection area), field inspection tests can be conducted to test the inspection functions such as autonomous navigation, image recognition, sound recording and video recording, and temperature measurement by photographing[3]; 2) Building a comprehensive testing environment for robot performance, such as ruins search and rescue robot. The United States, Japan and other countries have set up a complete dedicated testing environment for such robots[4]; 3) Combination of field test and construction of verification environment, such as track-type patrol fire robot. The routine inspection function of this kind of robot can be tested in the application environment, but the fire fighting test needs to set up the verification environment in the safety area.

Large number of cables are usually laid in the high voltage cable tunnel, which is a high-risk enclosed environment. Artificial cable defects and fire points are not allowed to be used to verify the
performance of high cable defect recognition rate and automatic fire fighting, so it is necessary to build a special environment that can carry out multifunctional test for the cable tunnel patrol robot. However, there is no comprehensive test environment for patrol robot at home and abroad before, so this paper designs and studies a comprehensive test environment for the performance of cable tunnel patrol robot according to the relevant rules of power cable line and channel operation.

2. Common defects in cable tunnels

2.1. Abnormal appearance of cables and cable appendages and cable channels
The cable may be damaged by external forces during laying construction and normal operation. The damaged parts show surface defects such as external damage, cracking and bending deformation of the cable and its accessories in the early stage, and then deteriorate into insulation damage gradually, which may cause the risk of cable discharge explosion[5]. Ancillary facilities of cables, such as cable support, are prone to corrosion and damage under wet operating environment; The Cable hoops or clamps may be corroded or missing. The Cable accessory equipment such as grounding box may be damaged. The wall cracking(collapse), foundation settlement and water accumulation in the working well are caused by immersion and geological activities in the passage.

The above situation is a hidden danger that affects the stable operation of the cable. By establishing the cable and channel defect sample base, image recognition technology can be used to identify defects and realize defect warning.

2.2. Partial discharge of cable
Defects in the insulation layer of power cables, such as air gap, impurities and burr, as well as manufacturing process problems of cable accessories, which will result in uneven distribution of electric field inside the cable and "non-penetrating" discharge in the internal insulation area, as shown in Figure 1.

As the discharge continues, the cable insulation will be further damaged until "penetrating" breakdown occurs. In this breakdown process, the electrons and ions generated by ionization can impact the cable's insulating polymer material(XLPE) chemical bond, cracking. The temperature rise in the serious part of discharge and the humid environment often aggravate the breakdown process: the temperature rise, such as to reach the critical point of thermal cracking of insulation material will lead to further decrease of insulation performance; When the cable is affected by moisture, the aging of the cable will be accelerated under the joint action of partial discharge and water, and then water branches will be generated, which will gradually accumulate and develop into electric branches, and the discharge channel will be gradually extended until the breakdown[6-7].

Figure 1 Electric field distribution at cable insulation break
2.3. Abnormal Cable temperature
Cable manufacturing process problems, cable accessories manufacturing process is not standard, long-term over-load, instantaneous over-voltage and other reasons, often leave irreversible insulation damage in the cable insulation layer, leading to accelerated aging and deterioration of the cable insulation layer, leading to the cable insulation breakdown gradually within the normal life cycle. Insulation damage is usually manifested as abnormal increase of cable operating temperature or abnormal rise of partial phase temperature.

2.4. Abnormal grounding current of the cable
Due to the damage of outer sheath of high voltage cable and wrong connection of coaxial cable, grounding current will rise abnormally. According to technical Specifications for State Detection of High-voltage Cables, if the ratio of maximum and minimum single-phase grounding current exceeds 5, or the ratio of grounding current to load exceeds 50%, the fault shall be deemed as cable. Excessively high grounding current will cause heating of the cable body and reduce the cable load flow. Long-term overground operation will accelerate the aging of cable insulation and affect the service life[8].

2.5. Other Defects

2.5.1. Cable fire.
Due to cable insulation breakdown, a large amount of heat is generated at the moment of short circuit, which can ignite cable protection layer and other appendages, or even ignite other cables in the tunnel, causing secondary accidents.

2.5.2. Harmful gas exceeding.
Due to the entry of external pollution, flammable and explosive gases such as methane and ammonia produced by the breeding microorganisms and bacteria are easy to exceed the standard. The epoxy resin structure of cable outer sheath is easy to produce hydrogen sulfide, even carbon monoxide and other toxic gases in sewage soaking for a long time. These will lead to the rise of harmful gas content, oxygen content decline, endanger the lives of people[9].

3. Overall design of cable tunnel patrol robot test environment
Each special functional test module is designed according to the performance index of the robot. The overall scheme of test environment design is shown in Figure 2.

3.1. Independent inspection environment design
The cable tunnel is usually about 2.5 meters in width and height. Multi-layer cable supports are installed on both sides (or one side) of the tunnel, cables and optical fibers are densely arranged. The middle inspection channel is so narrow that only one person can pass; there is a normally closed fire-proof door every 200 meters or so; each phase of high voltage cable has a middle connect or Every 500 meters, in addition, there are direct grounding box, cross connection box and other equipment in the tunnel.
Considering the factors such as land occupation, transportation and practicability, the shape of the simulated tunnel was designed as a cable tunnel canopy with 11m length × 2.5m width × 2.5m height, overall structure design is shown in Figure 3. According to *Technical Specifications for State Detection of High-voltage Cables*, the tunnel cable adopts the two-side three-layer arrangement, laying a total of 18 analog cables, and installing the supporting direct grounding box, cross interconnection box, cable bracket, cable hoop and other cable ancillary facilities and equipment.

In order to meet the requirements of independent patrol, RFID electronic tags and special reflectors are set at key inspection positions or fixed points in the tunnel, patrol robot can achieve coarse and accurate positioning of cable defect detection operating points in the autonomous inspection through remote RFID reader and high-precision laser scanner. Two wireless charging devices are installed at both ends of the tunnel shed to test whether the robot can choose nearby wireless charging. Wireless AP is interval installed in the roof to establish the communication system in the tunnel, for realize the wireless communication between the robot and various sensors and controllers. An electrical fire-proof door system is set in the passage, which can detect whether the robot can interact with the fire-proof door control system according to the inspection requirements, and realize the function of autonomous crossing the fire-proof door.

### 3.2. Defect detection environment design

Design defect detection environment for the detection functions of tunnel patrol robot, such as appearance detection, Partial discharge detection, temperature rise detection, ground current detection, harmful gas and smoke detection.

#### 3.2.1. Environment for damage identification of cables and accessories and tunnel appearance

Man-made damage defect used to verify high cable defect recognition rate. Abnormal appearance defects include external breakage, cracking and deformation of the cable, corrosion or missing of the cable bracket and clamp, damage of the ground box, crack or settlement of the tunnel wall, etc.

#### 3.2.2. Partial discharge testing environment

For the detection of partial discharge of cables, there are two linkage test methods which complement each other, a stationary sensor is used in the closed grounding box, and in an easy detection environment, it can be detected by the partial discharge sensor on the robot mechanical arm. In the simulated detection environment, a high frequency partial discharge source was used to simulate partial discharge defects, discharge sensor on the cable grounding line, sensors and partial discharge tunnel installed wireless AP constitute a partial discharge measurement unit. The patrol robot receive data from the wireless measurement unit, or use the mechanical arm carrying test sensor measurement
3.2.3. Temperature rise detection.
The application of three-phase temperature rise large current generator can increase the temperature of the cable and simulate the temperature rise defect of the cable. The high-precision infrared temperature measuring thermometer carried by the robot can accurately detect the temperature of key nodes such as cable intermediate joint, grounding box and cross interconnection box, and the accuracy can reach ±0.1℃.

3.2.4. Grounding current detection,
Design a controlled current changes environment, mainly by the dc regulated power supply, high precision of slide rheostat and related circuit. The cable string to be measured is connected to the precision sliding line rheostat, and the dc stabilized power supply is loaded to both ends to simulate the change of ground current, which provides the physical simulation foundation for the patrol robot to measure the change of grounding current in the tunnel online. The measurement of grounding current is made by using an online monitoring device and a clamp ammeter carried by the robot. First, the high precision clamp ammeter carried by the robot can accurately measure the grounding current. Secondly, the temperature sensor and the wireless network communication node installed in the tunnel constitute a wireless temperature measurement unit, patrol robot receives the data collected by the wireless measurement unit during the inspection.

3.2.5. Fire and harmful gas detection
The liquid gas ignition cable is used to simulate the fire point, the ultra-fine dry powder extinguishing agent is used by the robot to adapt to the fire extinguishing of the high-pressure cable environment, and the environment-friendly aerosol extinguishing agent is used for automatic fire extinguishing debugging and testing. The patrol robot can detect and locate the fire point through the infrared temperature measuring camera and smoke sensing alarm, and fire the miniature fire extinguisher to automatically extinguish the fire.

Smoke, harmful gas (H₂S, CO), and air oxygen content detection. Take the smoke generated by combustion as an example, gas content sensors can be used for early warning of fire, poison gas and smoke.

4. Conclusion
Cable tunnel patrol robot performance comprehensive test environment can be used for the ground-type cable patrol robot to carry out full performance tests, on one side, the electric fire-proof door system, wireless charging device and wireless communication network are set up in the tunnel shed, so it can be used to test the patrol robot autonomous through the fire-proof door, the nearest wireless charging source, and the real-time wireless communication, so as to detect the robot's obstacle breaking, charging and communication ability; on the other side, the design of defects test environment can test the patrol robot partial discharge test, temperature rise test, grounding current test, smoke test and other operational capabilities. The design of the test environment can not only provide a test scheme for the comprehensive performance of the patrol robot in the simulated environment, but also provide an important reference for the construction of the autonomous inspection environment for the cable tunnel robot.

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