Implementation and Optimization Strategy of SG-CCTV Inspection of CPR1000 Nuclear Power Station

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Abstract. The video inspection for primary side water chamber of the steam generator (For short: SG-CCTV inspection) was an important item of nuclear island in-service inspection. According to the structure of primary side water chamber and SG-CCTV inspection equipment, implementation and management strategies of SG-CCTV inspection were introduced. From the perspective of equipment and item management, the problems during SG-CCTV implementation process were analysed. To solve those problems, suggestions for equipment improvement and item optimization management were put forward.

1. Introduction
According to the requirements of RSE-M1997 (2000) specification [1], it was necessary to conduct a video inspection of the surfacing layer on the surface of SG primary water chamber during the complete in-service inspection and between two complete in-service inspections. The inspection content included a comprehensive inspection of the surfacing layer on the surface of the cold and hot side water chamber, the partition plate, tube plate and the hydrophobic pipe of the water chamber. The purpose of the SG-CCTV inspection was finding irregularities, foreign bodies, deformations, surface oxidation and deposits, scratches, dents, cracks and oxidative corrosion on equipment parts.

The SG-CCTV inspection was a major equipment inspection item during the refuelling overhaul. The operation place was the steam generator rooms. Before the inspection activities, the manholes of the SG primary side were opened, and the area was controlled according to the requirements of the orange area operation. The SG-CCTV inspection usually crossed with the eddy current inspection of SG tubes [2], so it took a long time to work in the orange zone. In addition, this work required more relative departments like the mechanical department, the service departments and, the radiation protection. During the refuelling overhaul, the implementation strategy of SG-CCTV inspection was mainly guided by time oriented. At the same time, the quality and safety also required high attention. However, there were still some deficiencies during the implementation of SG-CCTV inspection, such as heavy inspection equipment, frequent failures, personnel fatigue work, untimely response from the relative department, and long time for the SG water chamber transition. In this article, the implementation process of SG-CCTV inspection was analysed and some optimization suggestions were put forward.

2. Inspection process
2.1. Inspection object
The water chamber of the SG lower head is a hemispherical head. A heat transfer tube plate is on the top of the water chamber, which separates the primary water chamber and the secondary side cylinder...
In the middle of the water chamber, a partition plate divides the water chamber into a hot end and a cold end water chamber. Each water chamber has an inlet pipe (hot end) or outlet pipe (cold end), and one manhole.

The SG-CCTV inspection objects include the surfacing welding layer on the surface of lower head water chamber, the surfacing layer on the water chamber partition plate (incon nickel), the surfacing layer of the tube sheet (surfacing incon nickel) and the nozzle of drain pipe.

2.2. Video inspection equipment

2.2.1 Technical and performance indicators.

The SG-CCTV equipment worked under the environment of high temperature, high pressure and high radiation for a long time. In order to meet the requirements of RSE-M rule and process requirements of video inspection, The SG-CCTV equipment should meet the following technical and performance indicators:

1. Material selection: The mechanical device preferentially selects materials with good rigidity and strength performance. In order to reduce the overall weight and facilitate the installation of the equipment, the overall structure is mainly made of aluminum alloy, and part of the structure is made of stainless steel.

2. Camera: The angle between the central axis of the camera's field of view and the inspected surface is not less than 30°, so that the focal length of the lens can ensure a sufficient angle of view. The scanning range of the field of vision covers 100% of the inspected objects such as tube sheets, partitions, hemispherical heads, etc. When a suspicious area is found, the optical zoom can be used for multiple observations. There is no distortion and distortion in the image. At the same time, it can also be observed for a certain period of time.

3. Scanning accuracy: the repeat coverage rate of adjacent inspection areas is greater than 10%. The scanning speed is less than 50mm/s. The repeated positioning error of the device is less than (±15mm) × (±10mm).

2.2.2 Composition of equipment system.

The SG-CCTV equipment includes a mechanical unit, a control unit, a camera and recording unit. The mechanical unit includes a top rod, an external positioning flange, a support frame, and a multi-axis mechanical rotating arm. The main function is to drive the camera to locate the part to be inspected. The control unit is the "brain" of the SG-CCTV inspection system, including a computer, control software, control box, interface box, power supply and cables. The control software installed on the computer can send commands to the controller through the control interface. In this way, the multi-axis mechanical arm is controlled to drive the camera to follow a preset trajectory. The camera and recording unit includes a camera, a monitor and a video recording device. Its main function is to display the image of the video inspection in real time, and store the image file in the recording medium.

2.3. Implementation Process

According to the requirement of the RSE-M rule, the SG primary channel head inner cladding (including tube plate, partition plate and drain tube holes) was inspected every five years by the method of CCTV inspection. The usage frequency of the SG-CCTV equipment was quite low. Before the refuelling outage, the SG-CCTV equipment was tested and maintained for a long time as two weeks. The collective dose was also very high during the maintenance and testing process. Therefore, it is necessary to strictly abide by the radiation protection management regulations. The main steps of the SG-CCTV inspection include the SG-CCTV equipment transportation, the precondition preparation, the installation and testing of SG-CCTV equipment, carrying out the SG-CCTV inspection, recording the inspection results and cleaning up after work.
Before the implementation of SG-CCTV inspection, it was necessary to test the sensitivity of the equipment system. The human eye can clearly distinguish the monitor picture and the black line with width less than 0.8 mm of the 18% neutral gray resolution card by video. The inspectors are mainly responsible for operating the computer after the equipment installation. Through the computer control, it was ensured that the mechanical device completes the automatic scanning work according the set trajectory. The resolution and articulation of video image must meet the relevant requirements of visual inspection. Figure 1 showed the result images of SG-CCTV inspection.

3. Problem Analysis and Optimization Suggestions

3.1. Problem analysis
For the CCTV inspection process of each SG cladding, the SG-CCTV equipment will be installed and demolished twice (the hot end and the cold end). Other times to enter the SG room are for removing the equipment failure. The performance of the inspection system was stable after maintenance before the refueling overhaul. Once the SG-CCTV equipment failed during the inspection process, it was necessary to remove it from the SG water chamber, and solve the equipment problems. If the equipment failure cannot be removed in time and there was no spare equipment, it would not only increase the collective dose, but also affect other work, even the critical path at the low and low water level stage.

Analysis from the perspective of equipment, there are some problems when using the SG-CCTV equipment system, such as the insufficient reliability, the inflexibility, bulky equipment and long inspection time. The common equipment failures can be summarized into three categories. They were respectively the control software problem, signal transmission problem and equipment parts failure.

(1) Control software problems: during the process of SG-CCTV inspection on the SG primary side in a certain refueling outage, the computer interface reported errors and wrong instructions, which led to the failure to connect the mechanical parts of the equipment and the electronic control part. The inspection work could not proceed. Through analysis and investigation, it was finally determined that the control card in the control box was damaged, and led to the above failure. After the control card was replaced, the computer interface became normal. The equipment returned to normal operation, and the SG-CCTV inspection process continued. For this fault, several feedback actions are put forward. The equipment should be equipped with corresponding spare parts for follow-up needs. The equipment should be handled with care during the process of SG-CCTV equipment transportation to prevent damage. By strengthening training and standardizing the inspectors operation, it could prevent the equipment and parts from burning out and touching by mistake.

(2) Signal transmission problems: there are many signal problems in SG-CCTV inspection system. Firstly, the image signal is unstable during the operation of the camera. Secondly, the set length of the cable retracting and releasing device is inconsistent with the actual length signal feedback. Thirdly, the damage of the cable at the output end of the image signal causes the image signal to be incomplete and
unstable. For above faults, during the maintenance and testing process of the equipment, it is necessary to strengthen the troubleshooting of the transmission cable and extension line joint, and select the transmission cable with appropriate length. In addition, the equipment should be strictly controlled according to the equipment operation manual, avoiding the damage and pulling of the signal transmission medium.

(3) Equipment parts failure: at present, SG-CCTV inspection equipment has multiple connections. The application of video amplifier was mainly to eliminate the influence of video signal attenuation and obtain stable video signal. If the video amplifier was damaged, it would also lead to abnormal feedback of video signal. This problem can be solved from two aspects: one is to reduce the use of the connector. In this way, serious signal attenuation was reduced and video amplifier can be avoided. The other was to strengthen the test of video amplifier during equipment maintenance if video amplifier was used.

From the perspective of item management, the main problems of SG-CCTV inspection lied in the long time and complex process of the transition process, including the transitions with the mechanical department and the transition between SG-CCTV inspection and SG-ET item.

According to the inspection conditions, the inspected area should be dry and clean without any substance affecting the inspection observation and evaluation. At the same time, the ambient temperature of the inspection should be lower than 40 ℃. Appropriate place and power supply should be provided near the water chamber. Therefore, the key points of water chamber transition with mechanical specialty are the protection of manhole sealing surface, the drying condition inside the water chamber, the treatment of residual water at the bottom of water chamber, SAS construction in SG room and power supply lighting. The transition work between different disciplines is carried out between SG-CCTV item team, mechanical specialty and eddy current item team. There are three times in total. Each time needs to confirm the integrity of sealing surface, occupy a certain low and low water level maintenance period, and increase a certain collective dose. Before the implementation of SG room item, SAS room needs to be built. Users include in-service inspection specialty and mechanical specialty, and the total service time is more than 10 days. If the SAS construction quality is poor, it is easy to cause rework and reconstruction, resulting in the delay of SG-CCTV inspection and other items, and increase the collective dose of SAS construction personnel. Lighting conditions in SG room are similar to SAS. If lighting failure occurs during inspection implementation, rework will be caused. It will affect construction period and collective dose. During the refuelling overhaul, the transition process (including equipment transfer, disassembly and installation) between SG-CCTV inspection and the mechanical specialty is one to three hours, and the transition process (including equipment transfer, disassembly and installation) between SG-CCTV inspection and the eddy current inspection of SG tubes is about 3 hours. Generally speaking, the collective dose of inspectors is positively correlated with the execution period of the item. If SG-CCTV inspection equipment can be improved, the failure rate can be reduced, and the implementation strategy of SG-CCTV inspection can be optimized, which has a positive effect on shortening the inspection period and reducing the collective dose.

3.2. Optimization suggestions

Based on the problem analysis, the following optimization suggestions are put forward from two aspects of equipment and item management.

In view of the structure and performance of SG-CCTV inspection equipment, there is a large room for improvement in equipment research and development. The research and development of the equipment involves material, mechanical, electrical, control and software development and design, and is upgraded and improved according to the application experience of inspectors. At present, SG-CCTV inspection equipment is heavy as a whole, with complex mechanical components and many parts, which not only is not convenient for the transportation, installation and disassembly of the equipment, but also brings the potential risk of foreign matters in the inspection process. The main work of equipment installation includes transporting the equipment near the manhole on the primary
sid of the evaporator, installing positioning flange, support frame and rotating arm, connecting the signal transmission line between the control unit and the recording unit, etc. In view of the narrow area of the evaporator room, the installation activities were carried out by one to two personnel, the installation time was about one hour, and the collective dose was about 600 uSV. By above analysis, it can be seen the focus of equipment research and development is the transformation of mechanical device, and the transformation direction is to improve the integration degree of SG-CCTV inspection equipment, reduce the use of parts and components, and reduce the overall quality of mechanical device. After the transformation of SG-CCTV inspection equipment, one person can complete the installation activities independently, and the installation time is reduced to less than 30 minutes, which has obvious optimization effect on manpower, construction period and collective dose. Aiming at the common fault types of SG-CCTV inspection equipment, by upgrading the system control software, optimizing the signal transmission cable (such as reducing the use of connectors), improving the quality of the camera, can also greatly improve the overall performance of the inspection equipment.

In addition, in order to reduce the radiation level during equipment maintenance and commissioning, the equipment protective cover can be considered to reduce the contamination level in the process of equipment use, which helps to reduce the collective dose during the implementation process.

For preparation of the precondition and the SG water chamber transition, the person in charge of the SG-CCTV inspection should hold a joint technical clarification meeting, including all the inspectors and the relative departments, such as the mechanical department, the service departments and the radiation protection. It mainly aimed at making the acceptance criteria of the precondition and the water chamber transition, to avoid unqualified acceptance leading to rectification and rework. For the internal cleanliness of SG water chamber, sufficient drying is required and there is no foreign blocking the inspection area. For the SG SAS room, it should be reinforced with steel wires at the top. The ground should be laid with double red plastic sheeting. And it didn’t block the room lights. For protection of the SG manhole sealing surface, camera or video shall be used to take photos and record during the transition process. For application of work permit table in orange area, when the main ticket engineer applied the working ticket, several cooperated workers can be written into the table, avoiding a repeat ticket application and the waste of time at the low and low water level stage. There are two advantages of the above measures. First, the whole inspection process and coordination work are planned, arranger and implemented together. The time connection is more closely and the allocation of human and material resources was more adequate. On the other hand, the preconditions preparation and the process of SG water chamber transition were optimized. It was estimated that the whole inspection time dropped 20% and the collective dose of the inspectors decreased 600 uSv.

4. Summaries

SG-CCTV inspection was a statutory nuclear island in-service inspection item required by the RSE-M code. For the CPR1000 unit, some problems were exposed in the process of inspection implementation, including the equipment problems and item management. The consequences of above problems were long operation time, fatigue operation and high collective dose. Based on the problem analysis, the following optimization suggestions were put forward from two aspects of equipment and item management. Firstly, it was necessary to reform the mechanical device, improve the degree of equipment integration, reduce the use of parts and components, and decrease the overall quality of mechanical device. The second was to reduce the equipment failure. The third is to hold a multi-discipline joint technical disclosure meeting to clarify the acceptance requirements of start-up conditions and simplify the work flow of SG water chamber transmission. Through the above optimization measure, it was conducive to improve the overall performance of SG-CCTV inspection equipment, shorten the overall time of inspection implementation, and reduce the collective dose of the inspectors.
References

[1] French association. Design and construction rules for mechanical components of PWR nuclear islands, In-service inspection rules for the mechanical components PWR nuclear island (1997 edition + 2000 addendum), French, 2000.

[2] Tian Li. Implementation and optimization Strategy for SG Primary Side Cross Inspections [A]. Proceedings of IEEE FENDT 2018, 2018: 32-36.

[3] Training Center of China General Nuclear Power Group. Systems and equipment in 900 MW PWRs. Beijing: Atomic Energy Press. (2004).

[4] Xiaorong Liu, Changzheng Xu. Research progress of nickel-based alloy thick plate for nuclear power steam generator divider plate [J]. 2018 2(25):47-52.