Research and Application of Neutron Detection Technology in Inspection of Void Defects in Turbine Runner Chamber

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Abstract. After a long-term operation of the turbine runner chamber, there may be voids between the steel lining and the concrete. If it is not discovered and treated in time, the safe and stable operation of the unit will be affected. In engineering practice, the hammering method is often used to detect hole defects, and the accuracy is low. The neutron detection technology is proposed to detect the void defects of the steel lining, quantitatively display the void location and size, and improve the accuracy of void defect detection.

1. Introduction

The water diversion system of a hydropower project is mostly composed of water diversion penstocks, volutes, runner chambers and draft tubes. It often uses steel lining structures. During the construction process, after the steel plate structure is installed, the method of backfilling and pouring of high-liquid concrete is used. The steel plate structure and the concrete are combined densely, and the steel lining structure is supported when the high-speed water flows.

When the concrete is backfilled and poured, due to the complex steel lining structure, construction site restrictions and poor construction quality control, the quality of concrete ramming is difficult to guarantee, and it is easy to cause void defects between the steel plate and the concrete. When the power station is put into operation, under the action of high-speed water flow, the void area lacks concrete support, and the steel lining structure is often fatigued and damaged, and even large-scale tearing of the steel lining occurs, which affects the safe operation of the power station[1].

At present, the hammer method is used to detect hole defects in the project. The method is to listen to the sound of the mallet, and judge by the individual's hearing, the reliability is poor and the accuracy is low[2]. In addition, the defects cannot be quantitatively measured, and the reliability is poor, which adds difficulty to the implementation of the later grouting repair treatment.

For a long time, people have been trying to use X-ray, gamma-ray, ultrasonic and pulse echo methods to detect holes, but they have failed to achieve the expected results. The neutron non-destructive testing method introduced in this article is to use the principle of fast neutron moderation to detect the void defects of concrete under the thick steel plate. By measuring the thermal neutron count and establishing a corresponding relationship with the void depth of the concrete, the void range and depth of the concrete under the steel plate can be accurately measured, and good results have been achieved in practical engineering applications[3].
2. Principles of neutron detection technology

Neutron detection is accomplished by the interaction of neutrons with other substances\[^4\]. Since the neutron itself is not charged, it does not interact with the electrons of the substance, and cannot cause ionization. It can only rely on the interaction of the neutron and the nucleus to produce secondary particles that can cause the ionization reaction for recording.

When fast neutrons interact with matter, they have very strong penetrating ability to heavy matter, but hydrogen matter has a good decelerating and slowing down effect. The moderating power of hydrogen is hundreds of times greater than that of oxygen, silicon, aluminum and other common elements that make up the medium. Therefore, hydrogen is the main cause of neutron moderation, and the moderation effect caused by other common elements can be ignored\[^5\]. According to this feature, the fast neutrons are shot in the direction perpendicular to the steel plate, because the fast neutrons have a strong penetrating ability to the steel plate, that is, the steel plate has a small contribution to the slowing of the fast neutrons and is relatively constant; while the concrete contains a lot of Hydrogen atoms have a strong ability to slow down fast neutrons and form thermal neutron spheres when they interact. Through the measurement of thermal neutron count, the distribution of concrete under the steel plate can be indirectly calculated. If the concrete is unevenly distributed in the depth direction, that is, there is void defect, the corresponding thermal neutron distribution will be abnormal\[^6\].

Under a collision between neutrons and hydrogen, the slowing process of fast neutrons is represented by the reduction of the average logarithmic number of neutrons

\[
\xi = \ln \frac{E_1}{E_2}
\]

In the formula: \(E_1\) is the neutron energy before colliding with the hydrogen nucleus, and \(E_2\) is the neutron energy after colliding with the hydrogen nucleus.

The value of \(\xi\) depends only on the mass of the scattering nucleus and has no correlation with the initial energy of the neutron. There is the following relationship between the \(\xi\) value and the mass number of the medium element:

\[
\xi = 1 + \frac{(A-1)^2}{2A} \ln \frac{A-1}{A+1}
\]

Where: \(A\) is the mass number of the element

The number of collisions to slow down the neutron from the initial energy to the final value is:

\[
ln \frac{E_0}{E_k} = \frac{m}{\xi}
\]

Where: \(E_0\) is the initial energy, \(E_k\) is the final value, and \(m\) is the number of collisions.

According to this principle, the concrete void quality inspection instrument uses americium-beryllium neutron source 241Am-Be in the field of water conservancy and hydropower engineering construction, which can quickly and accurately measure the defects of the concrete structure under the steel lining, as shown in Figure 1.
3. Instance verification

3.1 Project overview
A power station is equipped with 4 axial-flow paddle-type hydro-generator units with a single unit capacity of 150MW. From 2011 to 2015, the power station completed the expansion and transformation of all four units, and the single-unit capacity increased to 175MW after the expansion and transformation. The capacity expansion and transformation of the power station is to increase the flow rate and replace the water turbine and generator with the fixed flow-through components unchanged. After the power plant's No. 2 unit was expanded and reconstructed, the steel lining of the runner chamber was damaged and torn continuously. After grouting reinforcement and steel lining structure strengthening measures, damage still occurred. It is analyzed that after the expansion and transformation, the original hydraulic characteristics of the runner chamber have changed. After being coupled with the void defect under the steel lining of the runner chamber, the steel lining lacks sufficient support locally, and the stress of the steel lining is concentrated under the action of water flow, resulting in Fatigue tear. In order to avoid the occurrence of similar defects and ensure the safe operation of the unit, during the capacity increase process of Unit 3 of the power station, research was carried out on the void defects of the concrete under the steel lining, with a view to quantitatively identifying the void defects under the steel lining. For the purpose of adding safeguard measures and other purposes for the subsequent capacity expansion and transformation of the same type of units.

3.2. Layout of measuring points
The object to be detected this time is the runner room of Unit 3 of the power station, and its basic parameters are as follows:

- Height: 2.4m
- Circumferential welding seam: 4
- Perimeter: 26.0m
- Longitudinal ribs: 48
- Material: Austenitic stainless steel
- Longitudinal rib spacing: 52cm
- Thickness: 35mm
- Transverse ribs: 6
- Shape: cylindrical
- Center ring spacing: 52cm
- Diameter: 8.5m
- Lower ring spacing: 40cm
The steel plate of the runner chamber can be divided into 48 steel plates in the clockwise direction from the manhole, numbered b1～b48.

According to the structural characteristics of the ribs in the runner chamber of Unit 3 of the power station, the detection sections and measuring points are arranged. Starting from the vertical axis of the manhole, 52 longitudinal measurement sections are set in the clockwise direction of the runner chamber to compensate the section and the junction surface of the lower ring is the starting point, 8 transverse measurement sections are set to form a total of 416 measurement grids with a width of 30cm and a height of 50cm. The instrument probe is placed in the center of the above square grid for point-by-point measurement. The arrangement is based on considering the plane measurement range of the detector to ensure that there is no measurement blind zone. The structure of the runner chamber and the layout of the measurement section are shown in Figure 2.

![Figure 2 Schematic diagram of runner chamber structure and measurement section layout](image)

3.3. Test results

The total number of void detection points in the runner room of Unit 3 of the power station is 416, of which, the number of non-empty points is 343, accounting for 82.45% of the total number of points; the number of void <3mm is 70, accounting for 16.83% of the total number of measuring points; 3 measuring points with 3 to 10 mm voids, accounting for 0.72% of the total number of measuring points; no voids > 10mm and abnormal points with high water content were found. Table 1 shows the statistical table of the emptying detection results of the runner chamber of Unit 3 of the hydropower station.

| Defects of unit emptying | None | <3mm | 3～10mm | >10mm | Abnormal area | total |
|--------------------------|------|------|---------|-------|---------------|------|
| Number of measuring points | 343 | 70   | 3       | 0     | 0             | 416  |
| The proportion (%)       | 82.45| 16.83| 0.72    | 0     | 0             | 100% |
As shown in Figure 3, the overall situation of the steel-lined concrete void distribution in the measurement section of the No. 3 unit runner room #1～#52 before and after the grouting treatment is visually displayed. The measurement of thermal neutron count at the measuring point plots the plane distribution and depth range of void defects in steel-lined concrete within a range of about 60m².

(1) The neutron method test results show that the background value of the concrete moisture content under the steel lining of the runner chamber of Unit 3 is relatively balanced, and there is no obvious abnormal area with high water content or low water content, reflecting that the plane mass distribution of concrete is relatively uniform. There is no large and serious void defect of >3mm into pieces.

(2) There are dispersive small pieces of tiny void areas less than 3mm (the void area accounts for 16.83% of the total detection area) and partially isolated void points of 3mm to 10mm. These voids are mostly caused by the shrinkage of concrete or cement slurry. The peeling void indicates that the concrete pouring quality is generally good.

(3) In view of the fact that the defect in the steel lining of the runner chamber of Unit 2 of the power station is caused by the coupling of the defect of the runner chamber and the change of hydraulic conditions after the runner is replaced. The main mechanism is not yet clear. In order to fundamentally eliminate the hidden dangers of safe operation, it is recommended After the completion of the capacity expansion and transformation of Unit 3, retest should be carried out at an opportunity, combined with the test data of the turbine, to comprehensively analyze the characteristics of the transformation of a power plant.

4. Conclusion
The use of neutron method to detect void defects of concrete poured under thick steel plate is an innovation of engineering detection technology, which can be widely used in large-scale water conservancy projects and shipping project dam sand holes, hydraulic power diversion penstocks, and unit volutes. The runner chamber, the base, the draft tube and other steel-lined concrete structures have been tested for voids, which solves the technical problems of non-destructive testing of the void defects of the concrete under the steel plate. In addition, this technology has gradually become an important method for checking internal defects of concrete during the operation of hydropower stations, especially after major modifications. It has played an important role in guiding grouting construction, shortening grouting construction period, saving grouting costs, checking grouting effects, and ensuring grouting quality. The successful application of the No. 3 runner chamber of a power station fully demonstrates
that this detection method has a very broad application prospect in the non-destructive detection of concrete defects in the water diversion system of hydropower projects.

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