Application of acoustic emission technology in hydraulic pressure test of nuclear power plant

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Abstract. Combined with the technical characteristics of hydraulic pressure test and acoustic emission technology in nuclear power station, this paper discusses the application status and technical features of acoustic emission technology in primary circuit hydraulic pressure test, vessel hydraulic pressure test, boundary valve leak detection of hydraulic pressure test and pipeline hydraulic pressure test in detail, and this paper also looks forward to the application prospect of acoustic emission technology in the field of hydraulic pressure test in nuclear power station.

1. Introduction

The hydraulic test of nuclear power plant is an important technical means to verify the pressure bearing capacity and tightness of the vessel, and it is an important part of in-service inspection of nuclear power plant according to the RSE-M and RCC-M [1,2]. The hydraulic pressure test of nuclear power plant is divided into pre-commercial hydraulic pressure test which mainly refers to the hydraulic pressure test conducted by the container in the manufacturing plant stage and in-service hydraulic pressure test. According to the test objects, the hydraulic pressure test in service stage is mainly divided into primary circuit hydraulic pressure test, secondary circuit hydraulic pressure test, container hydraulic pressure test, boundary valve leak detection, pipeline hydraulic pressure test, etc. The acoustic emission technology plays an important role in the implementation of most hydraulic tests.

2. Technical characteristics of acoustic emission:

Acoustic emission is a kind of physical phenomenon that the transient stress wave is generated by the rapid release of elastic energy when the object is subject to deformation or external action. The basic principle of acoustic emission detection is shown as Figure 1.
Acoustic emission technology is to receive and process the acoustic emission signal with sensitive instruments. Through the analysis and research of the characteristic parameters of acoustic emission source, the position and development trend of the defects in the material can be inferred. If the acoustic emission signal is intermittent and it can be separated in time, the signal is a burst acoustic emission signal. The crack growth and inclusion fracture in the material can produce a burst acoustic emission signal. If a large number of acoustic emission events occur at the same time and they cannot be distinguished in time, the signal is a continuous acoustic emission signal. The plastic deformation of metal materials and the leakage of gas and liquid can produce continuous acoustic emission signal. Acoustic emission is a dynamic nondestructive testing technology, which has the characteristics of real-time and online. It is a kind of overall detection technology. By setting a small number of fixed sensors according to a certain array, the acoustic emission instrument can obtain all the activity information of the sound source in the detection process and determine the location of the sound source. Acoustic emission can be used to detect equipment of various materials to achieve non-destructive testing. The acoustic emission system is mainly composed of the signal reception sensor, preamplifier, main amplifier, filter, various processing instruments and signal display devices, etc.

3. Application of acoustic emission in primary hydrostatic pressure test

During the hydrostatic test, acoustic emission monitoring shall be carried out on the penetration parts, seal welding parts of the reactor pressure vessel and pressurizer to determine whether there is leakage in these inaccessible parts. The Location of probe on reactor vessel head and pressurizer head is shown as Figure 2 and Figure 3.
Figure 2. Location of probe on reactor vessel head

Figure 3. Location of probe on reactor vessel head

The inspection shall be able to find all leakage signals of the above areas so as to further determine the nature of defects by visual inspection and take appropriate corrective measures. Due to the influence of space and radioactive environment, the acoustic emission monitoring signal should be sampled from a long distance, and the probe should be placed simply, quickly and accurately. During the preparation of the inspection, the acoustic sensor shall be placed at the designated position at the lowest radiation dose. The leakage point can be located by selecting the number of acoustic emission receiving probes and arranging the probe position reasonably. If the acoustic emission signal is continues, visual inspection shall be carried out immediately to determine whether there is leakage, the severity of the leakage and the location of the leakage. If the recorded signal is lower than the background noise reference value, the coupling condition of the acoustic emission receiving probe and the signal transmission of the channel shall be checked immediately.
4. The application of acoustic emission in hydraulic pressure test of vessel

During the implementation of hydrostatic test for vessels, the important acceptance criteria are as follows: There is no obvious deformation and abnormal noise on the vessel body. The acoustic emission technology has some advantages in detecting the abnormal sound of the container. In the process of pressurization or pressure maintaining in hydrostatic test, if there is some defect in the pressure vessel, the stress concentration near it will increase, and then the defect will release elastic mechanical wave to generate acoustic emission signal. The stress concentration degree of different types of defects is different. By observing the output figure and parameter analysis, the preliminary conclusion can be drawn. Combined with the inspection results of conventional nondestructive testing, the severity of the defect and the safety evaluation of the equipment can be analyzed.

Before starting the hydrostatic test of the vessel, it is necessary to know the material and welding characteristics of the pressure vessel. The information includes the chemical composition, mechanical properties, heat treatment state, and the pressure bearing history of base metal. In order to determine the method of continuously recording the pressure during the pressure test, the method should be able to show the relationship between the whole process of pressure and the characteristic parameters of acoustic emission. Generally, the following three parameters are selected number that is the number of acoustic emission events, the location of acoustic emission source, and the amplitude of acoustic emission signal. The recording should start at least 30 seconds before boosting. The acoustic emission parameters shall be measured and recorded continuously in the process of boosting and pressure maintaining. At the initial stage of boosting, special attention shall be paid to the occurrence of noise. If there is external noise interference, the test shall be conducted after eliminating the interference.

During the test, when the acoustic emission parameters detected are judged to be dangerous signals or the acoustic emission signals continuously appear during the pressure maintaining process, the acoustic emission tester shall report to the person who is in charge of the pressurization to determine whether to continue the test or not, and the acoustic emission tester shall also report the acoustic emission detection and defect hazard evaluation results. After the pressure relief, other nondestructive testing methods are used to verify the nature, shape and size of defects detected by acoustic emission, and key monitoring areas are selected for key monitoring when pressure rise test is conducted again. The background noise level of each channel must be measured to determine whether the background noise increases during the pressure rise to the maximum pressure for pressure maintaining. If it increases, measures must be taken to suppress the noise.

5. Application of acoustic emission in valve leak detection

During the implementation of hydrostatic test, if there is internal leakage of boundary valve, it will lead to the failure of normal pressure rise and maintenance. Therefore, how to detect the internal leakage of boundary valve is an important technical guarantee for the success of hydrostatic test of vessel.

At present, the detection methods of internal leakage of valves mainly involve ultrasonic, vibration, acoustic emission and other methods [3]. Acoustic emission detection method is suitable for the boundary valve detection of vessel hydrostatic test. Vibration detection is to detect and analyze the valve body vibration signal amplitude change under different opening. This detection can only detect the valve with vibration, and it is very difficult to detect the valve with small vibration. Ultrasonic detection is to use the phenomenon that the ultrasonic wave will occur when the fluid leaks. By using this phenomenon, it can analyze the recorded ultrasonic signal. When there is less fluid in the downstream pipeline of the valve, this method has a very narrow scope of application. Acoustic emission can monitor the whole object online, and it can reduce the unnecessary cost of valve disassembly. Thermal infrared leak detection method which belongs to the temperature detection method can detect the change of the surface temperature of industrial equipment by using infrared imaging technology and image processing technology. The heat loss caused by the leakage of the valve will lead to the obvious change of the temperature outside the valve or the pipeline downstream of the valve. This leak detection method is only applicable to the situation where the temperature
difference between the upstream and downstream of the valve is large. Downstream opening leak detection method is to look for the opening position downstream of the suspected internal leakage valve, such as funnel, pit, etc.

The leakage can be verified. After the installation of the temporary device for the hydrostatic test of the vessel, it is necessary to fill the vessel with water and use the test pump to raise the pressure to the test pressure platform. When the pressure can be maintained, it is to prove that there is no leakage at the vessel and the isolation boundary. When the test pressure cannot be maintained, the outside surface leakage of the valve at the test boundary shall be eliminated first. The outside surface leakage can be found through the on-site inspection by the staff. When the external leakage factor is eliminated, the influence of internal leakage factor of boundary valve shall be considered. It can be considered to find the corresponding acoustic emission detection point after the corresponding isolation boundary valve, and detect the acoustic emission signal. Along with the boosting process of the test pump, a controllable test pressure source is provided for the boundary valve of acoustic emission testing. The boosting tool of the hydraulic test is the hand pressure pump, and the boosting rate is controllable. In order to meet the needs of leakage detection of the boundary valve, the method of pressure rise and fall can be used for matching. However, it should be noted that the boosting pressure of the test pump should be lower than the pressure bearing capacity of the vessel. The boundary valves of hydrostatic test can be divided into gate valve, ball valve, and needle valve, etc. The internal leakage form of the valve is as follows. That is the packing leakage of valve, the Flange leakage, and the leakage of valve body and disc.

The valve sound source is mainly caused by the following reasons: mechanical vibration, turbulence or aerodynamic sound. Mechanical vibration is due to the irregular fluctuation of the pressure in the valve body and the impact of the fluid on the movable or elastic parts of the valve, so that these parts vibrate at their natural frequency. The acoustic emission generated by this vibration is similar to the metal clapping sound. When the valve element resonates at the natural frequency, this sound source can be identified with its monotonous high-frequency tone. Turbulence or aerodynamic sound is generated by the sudden acceleration or deceleration of the fluid in the process of flow. The speed of the fluid and the size of the turbulence area control the sound level of the shock wave. The factors that determine the type of sound source are: fluid speed, flow, pressure in front of the valve, valve pressure drop, pipeline layout and physical properties of the fluid. The turbulent mixing of the fluid produces the sound propagating to the pipe wall, which causes the vibration and noise of the valve components. Usually, this phenomenon occurs in the through hole or downstream of the valve, where the low viscosity fluid is mixed with the high-speed jet flow.

The signal characteristics of acoustic emission for each type of corresponding valve are as follows. The amplitude of acoustic emission increases with the increase of leakage rate. For the same leakage rate, the amplitude of ball valve is the largest, and the needle valve is the small, which is determined by the special structure of the valve. For the same leakage gap in the turbulent state, the pressure difference on both sides of the leakage gap is greater, the leakage rate is greater, and the acoustic emission intensity is greater. Through the analysis of the flow state in the process of valve leakage, it shows that the relationship between the acoustic emission amplitude and the leakage rate can be expressed by \( V = a + b \log Q \) equation. The values of coefficients \( a \) and \( b \) are related to the medium property, valve pressure drop, and valve type, etc. It is necessary to establish leakage databases of different sizes of various valves and establish a benchmark, that is, how much leakage corresponds to how much acoustic emission signal amplitude. The recommended measuring point position of valve internal leakage sensor is shown as Figure 4.
6. **Application of acoustic emission in hydraulic pressure test of pipeline**

When carrying out the hydraulic test of the pipeline, it is similar to the pressure vessel, and it is also necessary to fill the pipeline first, and then the pressure is boosted to the test pressure through the pressure boosting device. After maintaining the pressure for a certain period of time, it needs to observe whether the pipeline has obvious deformation or leakage. However, due to the pipeline length is longer, the probe spacing of ordinary pressure vessel cannot be used. The detection accuracy is affected by many factors, such as the attenuation law of pipeline materials, the type of medium in the pipe, the distance between the leakage point and the sensor, etc., as well as the environmental interference of the detection location and the pressure interference of the leakage hole. When the pressure difference of the leakage hole is large, the detection time is shorter and the detection effect is better.

7. **Conclusion**

As a non-destructive testing technology, acoustic emission technology has a wide range of application prospects in the field of nuclear power plant hydrostatic test, especially in the primary circuit hydrostatic test, pressure vessel hydrostatic test, boundary valve leak detection, pipeline hydrostatic test, and it is an effective tool for defect diagnosis and safety condition evaluation in the process of hydrostatic test.

**References**

[1] RSE-M In-service Inspection Rules for the Mechanical Components of PWR Nuclear Island, AFCEN, 1997 edition [S].

[2] RCC-M Design and Construction Rules for Mechanical Components of PWR Nuclear Islands, AFCEN, 2000 edition [S].

[3] E. Meland, V. Henriksen, E. Hennie. et al. Spectral analysis of internally leaking shut-down valves, J. Sci.Measurement. 44 (2011) 1059-1072.