Analysis of piping and support weld defects of VVP system in nuclear power plant and study on treatment measures

Cheng Li

Suzhou Nuclear Power Research Institute, CGN Inspection Technology Co., Ltd., Suzhou, Jiangsu, 215021, China

*Corresponding author’s e-mail: 794875396@qq.com

Abstract. The main steam system (VVP) support of nuclear power plant protects the main pipe by welding the guard plate on the main pipe. This paper takes defect treatment of the VVP main steam system (VVP) pipe and support weld in a nuclear power plant as an example. From the analysis of the effective mechanism of the weld generation to the proposal, discussion and implementation of the final scheme, the technical points are comprehensive described, defect types were determined by penetrant testing and metallographic observation, and further root reason analysis was carried out. Accordingly, the defects are eliminated by technical means to avoid the expansion of defects and ensure the safe and stable operation of the unit. The analysis and treatment scheme of the defects in this project provides a technical scheme for inspection and maintenance in the nuclear power field, and provides an important reference for the future treatment of defects.

1. Introduction

The function of the VVP system in the nuclear power plant is to transfer the main steam produced by the steam generator to the steam turbine, which drives the turbine and turns the generator to generate electricity. VVP support is used to weld the guard plate on the main pipe to increase the weld cross section and protect the main pipeline. The use of the guard plate is to avoid direct contact between the support and the pipe, which may cause impact and damage to the main pipe under some working conditions. The guard plate is the intermediate accessory of the connection between the support and pipe, which can avoid the welding of the support and the pipe support. At the same time, the stress between the support and the pipe can be reduced due to the large contact area between the guard plate and the pipe. If the guard plate fails, the VVP pipe and support weld will fail. In the case, the damper tension latching function failure (seismic conditions), which can cause an accident in severe cases. VVP main steam system (VVP) pipe and the support of weld defects show that when the liquid penetrant during an overhaul of a nuclear power plant. Adhering to the principle of safety first, quality first, based on liquid penetrant testing, magnetic particle testing and metallographic observation technology, defects are characterized in a step-by-step manner, propose and implement defect resolution plan. Through the root cause analysis of defects and eliminate defects, fundamentally defects of welding seams were removed. Figure 1 shows the location and field environment of the pipeline where the defects are located1.
Figure 1 The location and field environment of the VVP pipe and support weld

2. Inspection process
Penetrant testing is a non-destructive testing method for surface opening defects based on the principle of capillary action. After the tested surface is coated with a permeable solution containing fluorescent dyes or colour dyes, the permeable solution can penetrate into the surface opening defects after a certain period of time under the action of capillaries. Remove the residual penetrant from the tested surface, dry it, and then apply the photographic developer on the tested surface; similarly, under the capillary action, the permeate is permeated back into the photographic developer, under a certain light source, (black light or white light), the permeate trace at the defect is displayed (yellow-green fluorescence or bright red), so as to detect the morphology and distribution of the defect[2].

According to the field implementation characteristics of VVP pipeline and support welds, the solvent removal colouring penetrant detection method and solvent suspension imaging are preferred for inspection after the unit is shut down. The detection process is: pre-cleaning→ infiltration→ removal→ imaging→ evaluation→ post-treatment. The material of VVP pipeline is P280GH, which belongs to carbon steel, and its surface is covered with paint. Before inspection, the paint shall be polished clean and the surface roughness of the weld shall be less than 6.3um. The grinding range shall be extended outward from both sides of the weld at least 25mm[3].

3. Problem Analysis and Optimization Suggestions
On stage VVP pipeline in service and support the weld defects of display to conduct a comprehensive analysis, can strengthen the understanding of VVP with support of weld pipe failure mechanism, it is beneficial to improve the inspection personnel to improve the screening of relevant display and non-relevant display, at the same time, it can make inspection personnel for VVP pipeline and support welding the point of failure parts have a whole cognition. Taking the failure case of VVP pipeline and support welding bell of a unit as an example, in the process of penetrant testing (PT) of the VVP pipeline and support welds, 5 welds were found to exceed the standard, the specific situation is shown in table 1, and the defect photos are shown in Figure 2.
Table 1 PT results and acceptance criteria\textsuperscript{[4]}

| Weld dimension | PT results | Acceptance criteria. |
|----------------|------------|----------------------|
| A1             | There are multiple linear displays, the longest one is about 6mm. | The following displays are not allowed: 1. linear display; 2. The largest size of the ring display is greater than 4mm. |
| A2             | There are two linear displays, the longest one is about 7mm. | |
| A3             | There is a linear display about 3mm in length. | |
| A4             | There are a number of circular display, a maximum of 5mm. | |
| A5             | There are a number of circular display, the longest one is about 6mm. | |

Figure 2 PT defect photos

In order to confirm the existence of defects and assist in determining the characteristics of defects for further evaluation and analysis, MT (magnetic particle testing) was used to conduct supplementary inspection on the defective parts of the five welds. The inspection results are shown in table 2, and defect photos are shown in Figure 3.
Table 2 Comparison of MT result and PT results

| Weld dimension | PT results                                                                 | MT results                                                                 |
|----------------|-----------------------------------------------------------------------------|-----------------------------------------------------------------------------|
| A1             | There are multiple linear displays, the longest one is about 6mm.           | There are multiple linear displays, the longest one is about 6mm.           |
| A2             | There are two linear displays, the longest one is about 7mm.                | There are two linear displays, the longest one is about 7mm.                |
| A3             | There is a linear display about 3mm in length.                              | There is a linear display about 3mm in length.                              |
| A4             | There are a number of circular display, a maximum of 5mm.                   | There are multiple circular displays.                                        |
| A5             | There are a number of circular display, the longest one is about 6mm.       | There are multiple circular displays.                                        |

Figure 3 MT defect photos

Through PT and MT, it can be confirmed that the circular display in weld A4 and A5 is the porosity in the prefabricated welding process. The extension film metallographic test was conducted for the linear display of weld A1 by grinding and polishing about 0.3mm, and the results were shown in the following Figures. More extension film metallographic tests were conducted in A2 and A3.

Figure 4 PT results and Untreated state after corrosion
According to the results of metallographic examination, it can be seen that the structure of the defect is netlike ferrite. The width of the defect is wide, the tip is blunt and rounded, the shape of the defect is smooth, and there is no obvious low melting point eutectic such as impurities. The cracks are usually intergranular or transgranular, relatively narrow, sharp tip. Three linear defects are considered as welding defects rather than cracks, that is, lack of fusion and slag stringer. The reasons are as follows:

The backing material is P295GH. Carbon steel. Hot crack: hot crack generally appears after the welding is completed, this crack cracks along the grain boundary cracking, crack surface oxidation colour, blue or blue black, often produced in the weld centre (longitudinal or perpendicular to the weld fish scale ripple), irregular zigzag. Usually it occurs in austenitic stainless steel, carbon steel with more impurities, low alloy steel and other materials weld. The thermal crack occurs at the end of solidification of the weld metal and the sensitive temperature zone are roughly in the high temperature zone near the solid phase line. Crystallization crack is the most common thermal crack. The reason for its formation is that during the solidification of the weld metal, crystallization segregation makes the eutectic with
low melting point generated by impurities highly gather at the grain boundary, forming the so-called “liquid film”. In a specific sensitive temperature range, its strength is small, and it is subjected to tensile stress due to the solidification and contraction of the weld, and finally cracks are formed. Crystallization crack is the most common along the length of the weld center direction, longitudinal crack, sometimes also occurs between two columnar crystals inside the weld, transverse crack.

Cold crack: cold crack generally occurs when the welding is cooled to a lower temperature, generally occurs in the welding of low alloy high strength steel, carbon steel, alloy steel and other easy to fire steel, its characteristics are: ① produced at a low temperature, after a period of time; ② mainly in the heat affected zone, in some cases, such as welding ultra-high strength steel or some titanium alloy, cold cracks also appear in the weld metal; ③ intergranular cracking, transgranular cracking or a mixture of the two; the damage caused by; ④ is typical brittle fracture. There are three factors that cause cold crack: ① the welded joint forms the hardened microstructure (martensite); ② the presence or concentration of diffused hydrogen; ③ there is a large welding tensile stress. The metallographic inspection results show that there is no hardened microstructure in the weld, and the defects are generated in the weld, so cold cracks can be eliminated.

4. Treatment measures for weld defects of VVP pipe and support
According to RCC-M standard, the weld defects of VVP pipe and support must be repaired. The maintenance unit is entrusted to prepare the treatment plan for the over standard defects of VVP pipeline and support weld, five PT over standard defects are treated and PT inspection is conducted after treatment until they are qualified[4]. The defect treatment process is shown in Figure 8.

![Figure 8 The defect treatment process](image-url)
In addition, the equipment management department puts forward the following requirements according to the structure of VVP pipeline and support weld.

When grinding the weld between VVP pipe and support, visual inspection, dimension inspection (weld leg size) and penetration inspection shall be carried out on the grinding area. If the grinding depth is large, that is, the weld leg size is less than the minimum standard value, the weld shall be repaired; Repair the weld according to the welding process, and carry out visual inspection, dimension inspection and penetration inspection after polishing and grinding. In the process of treatment, attention should be paid to the following items[5].

1) Two welded junctions (A1, A5) need to be repaired due to the excessive grinding size and the weld leg does not meet the requirements. Therefore, during the grinding process, try to grind a small amount of weld for many times, and verify with Pt in time to remove all defects, and pay attention to excluding the structural linear display at the root. The grinding conditions of five welds with excessive defects are shown in Table 3.

| Table 3 Grinding sizes of the welds |
|------------------------------------|
| **welds** | **Initial weld leg size (mm)** | **Grinding depth (mm)** | **Remaining weld leg size after grinding (mm)** | **weld leg size after repair welding (mm)** |
|--------|------------------------------|------------------|---------------------------------|----------------------|
| A1     | 24.4                         | 11.92            | 12.2                           | 22.5                 |
| A2     | 22.0                         | 1.10             | 20.5                           | NA                   |
| A3     | 22.5                         | 1.00             | 20.5                           | NA                   |
| A4     | 23.4                         | 1.34             | 21.0                           | NA                   |
| A5     | 23.2                         | 16.12            | 7.0                            | 22.5                 |

2) During the grinding process, the thickness of VVP base metal should be paid attention to at all times, and ultrasonic thickness measurement can be used when necessary, which should meet the minimum dimensional tolerance requirements of VVP pipeline procurement technical specifications;

3) After grinding, according to the welding procedure qualification confirmed by the manufacturer, strictly implement the process documents and conduct heat treatment on the welded joint;

4) Arrange welders with rich personal experience and strong operation skills for welding, conduct post heat hydrogen elimination treatment immediately after welding, and conduct VT and PT again after 48 hours.

5. Conclusion

Combined with the manufacturing process, material characteristics, structural characteristics and defects, structural characteristics and defects found during in-service inspection of the welds between the pipes and supports of VVP system in nuclear power plant, this paper summarizes the implementation points, characteristics and precautions of the penetrant inspection technology for the welds between the pipes and supports of VVP system, and analyses the defects found in the penetrant inspection. This paper points out the main failure mechanism and defect treatment measures of VVP system pipeline and support weld during in-service inspection, which is of great significance to guide the implementation of penetrant inspection.

References

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