Evaluation and Analysis of RT Suspected Defects on Reactor Pressure Boundary Weld

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Abstract. The control rod driving mechanism (CRDM) is one of the important equipments in the nuclear reactor, and its sealing shell is part of the pressure boundary of the nuclear reactor. The sealing shell is a pressure vessel made of two different material (austenitic stainless steel and nickel base alloy) cylinders welded by dissimilar metal welds. Product production process, in this dissimilar metal weld ray detection found suspected defects show. In this paper, the mechanism and process of the suspected defects are expounded through experimental verification, and it is proved that the suspected defects do not affect the quality of the weld.

1. Introduction
The control rod drive mechanism is one of the key equipment of the nuclear reactor. It can drive or maintain the control rod assembly to realize the functions of reactor power regulation, normal shutdown and accident shutdown. It is a component of the pressure boundary of the primary circuit of the sealed casing reactor in the control rod drive mechanism, and therefore the quality of the pressure-bearing weld on the sealed casing assembly is particularly important. The sealed shell is welded by a cylindrical cylinder of two different metal materials (austenitic stainless steel and nickel-based alloy). Abnormal and suspected defects were found during the weld ray inspection process, which affected the technician's evaluation of the weld quality.

2. Welding and Inspection

2.1. Welding
The base materials of the dissimilar metal welds of the sealed shell are austenitic stainless steel 00Cr18Ni10N and nickel-based alloy Inconel-690, and the welding filling material is ERNiCrFe-7A. When welding, first use manual welding to make the bottom made by manual welding, then fill the cover with automatic welding. After the final machining of the parts, the welds are composed of manual welds and automatic welds. The thickness of the manual welds is about 5mm, and the rest are automatic welds. The welding diagram is shown in Fig 1.
2.2.  Radiation detection and results

2.2.1.  Radiation detection. After the welding is completed, the surface of the part parts is machined. Then, the radiation detection is performed, and the schematic diagram of the detection is shown in Fig. 2.

![Schematic diagram of RT detection](image)

Fig. 2 Schematic diagram of RT detection

The RT inspection is performed by X-ray, and the test is performed according to the RCC-M MC3000. The test results must meet the requirements Class 1 of RCC-M 7714.3.

The X-ray generator model is Y. SMART 450. The film system is used with a metal intensifying screen. The radiographic film is made of AGFA C4 industrial film, and the background fog of the film is not more than 0.3. The intensifying screen adopts a lead foil metal intensifying screen with a front and rear screen thickness of 0.1 mm and a middle screen thickness of 0.05 mm. The film is processed by hand rinsing. The development temperature is $20^\circ C \pm 2^\circ C$, and the development time is 5 min to 8 min. The fixing temperature is $20^\circ C \pm 5^\circ C$, and the fixing time is greater than 10 min. The running water is rinsed for not less than 30 minutes. The image quality meter uses a line-type image quality meter, the material of the image quality meter is ENFe, and the image quality meter is placed on the side of the radiation source.

The transillumination detection is arranged to adopt a single-wall external transmission mode, and the relative positions of the radiographic film and the radiation source are as shown in FIG. The exposure is not less than 30 mA.min. The inspection area includes welds and their base materials within a range of at least 5 mm. The radiographic geometric undefined $U_g$ is no more than 0.3 mm.

2.2.2.  Results. No defects or other abnormalities were found in the welds of the parts after PT liquid penetration test and UT ultrasonic test, but some suspected defects were found on the RT-ray film. There is a more obvious linear display ("black line") near the hand-welding and automatic welding
transfer position on the side of the austenitic stainless-steel fusion zone. This "black line" is about 2.8 mm from the back of the weld and has a width of about 0.2 mm. This display is uniform, straight, and continuous distribution throughout the weld, that is, the display on the full weld. A schematic representation of this linear display showing the shape and position is as Fig. 3.

Fig. 3 shows the position of the linear display

3. Analysis
According to the analysis of the position of the linear display observed on the radiographic film, it is preliminarily determined that the image is due to the dilution of the weld metal and the grain size of the dissimilar steel using different welding methods (automatic welding and manual welding). The specific reasons are as follows:

The 00Cr18Ni10N side fusion zone has a distinct linear display ("black line") on the film and is continuously distributed throughout the weld. The welding process of the butt-welded parts of the sealed shell is manual welding and bottoming, and the cover surface is automatically welded, the welding groove is U-shaped, and the groove angle is 40°. After the final machining of the parts, the manual weld is about 5mm, the automatic welding is about 12.5mm, and the U-shaped bottom of the U-shaped groove is completely removed, leaving only the upper V-shaped position, the theoretical angle is 40°, and the manual weld is at The theoretical vertical distance of the inner surface of the stainless steel side distance part is about 6.5mm, and the lateral distance is about 2.5mm.

The reasons for analyzing the "black line" according to the welding process of the part and the welding process are as follows:

According to the welding process requirements, the process parameters of manual welding are different from those of automatic welding. Therefore, the grain size and dilution rate of the weld are different. The manual welding current parameters are small, the penetration depth is small, and the dilution rate is small; the automatic welding current is large, the penetration depth is large, and the dilution ratio is large. According to the welding characteristics of the nickel-based alloy, the as-cast microstructure of the weld in the fusion zone will grow upwards in the vertical fusion line, showing a long strip-like distribution. The grain size of the weld is directly related to the size of the weld pool, the weld pool Larger, the grain size is larger, and the molten pool is smaller, the grain size is smaller. In summary, the manual weld zone has a smaller penetration depth and a smaller dilution rate. The dilution of Ni in the weld metal near the weld line is small; the automatic weld zone has a large penetration depth, a large dilution ratio, and a weld near the weld line. The dilution of Ni in the metal is large, the content of Ni is low, and the content of Fe is correspondingly increased. Therefore, the weld metal of the hand weld and the weld seam in the vicinity of the weld line are inconsistent with the absorption and reflection of X-rays, resulting in the position shows a linear display on the film after radiographic inspection.
4. Verification

4.1. Test verification scheme

In order to verify that the linear display image is not defective and does not affect the performance of the part, we performed corresponding non-destructive testing and mechanical property testing on the test piece.

4.1.1. Non-destructive testing. After the test piece is welded, the corresponding non-destructive test is carried out according to the process flow of the part. The non-destructive test includes PT, UT and RT. In order to more completely test the internal quality of the test piece weld, the correctness and integrity of the test non-destructive test result are ensured. Non-destructive testing is carried out in two phases:

The first step: the test is carried out until the part size is φ105×17.5. The detection includes: PT liquid penetration test, UT ultrasonic test and RT ray test. The RT ray test uses different angles for detection, vertical and obliquely translucent along the direction of the welding groove.

The second step: the artificial test is carried out on the test piece, and the RT-ray test is performed after the groove is cut. At this stage, the RT-ray detection needs to determine the specific position of the "black line" according to the image displayed on the film of the first stage, and then manually groove the inner hole and the outer circle of the test piece according to the position, and the position of the groove is determined by the size of the image quality model that can be effectively observed on the film. The groove depth of the inner hole is 0.18 mm, and the groove depth of the outer circle is 0.2 mm (13# image quality identification wire size is 0.2mm). After the groove is completed, the test piece is again subjected to RT detection, and the image of the "black line" and the artificial groove on the film is observed to determine whether the "black line" affects the determination of the artificial groove defect, thereby determining whether the display affects the real For the determination of defects, the schematic position of the test piece is shown in Fig. 4.

![Fig. 4 Schematic diagram of the position of the test piece](image)

4.1.2. Destructive test. Since the test is directed to the fusion zone of the 00Cr18Ni10N side base metal and weld of the butt-welded test piece of the sealed shell, the destructive test is mainly carried out for this area. The destructive test of the test piece includes a bending test and a metallographic test.

4.2. Non-destructive testing results

According to the test plan, the test standards for the two stages of the non-destructive testing of the test piece are the same as the parts test requirements. The test conditions at each stage are shown in the following table.

| Table 1 Non-destructive testing results of test pieces |
### Table 1 Testing results

| Step | test | results                      |
|------|------|------------------------------|
| Step 1 | PT   | no defects                   |
|       | RT   | vertical: visible linear display  |
|       |      | Oblique: no linear display    |
|       | UT   | no defect waveform           |
| Step 2 | RT   | the artificial grooved line, which can effectively determine the grooved image. |

In the first step of RT-ray inspection, it was found that there was also a linear display of "black line" in the test piece, and the area indicated by "black line" was about 2.5 mm from the edge of the weld root. This distance was related to the depth of the hand-welded weld. Matching the width position, there is no linear display when oblique transillumination, which means that the linear display appears in the same position as the previous analysis, which occurs in the position where the manual weld is combined with the automatic weld. The negative film of the RT-ray inspection is shown in Fig. 5, and the position of the image appearing can be seen from the figure.

![Radiographic display image](attachment:image)

In the second step, it was found by RT-ray inspection that the position of the artificial groove can be clearly observed on the film, and the images of the groove on the inner hole and the outer circle are not covered or blocked by the image of the "black line", which can effectively judge the moment. Slot image. Because the film has a large black-and-white contrast under the viewing light, the camera photo is distorted, but from the above photos, it can be seen that the image displayed by the groove is obviously blacker, and the color is thicker than the un-grooved display. The difference between the image displayed on the groove and the groove is not clearly distinguished.

#### 4.3. Destructive test results

**4.3.1. Bending test.** According to the standard requirements, the bending test of this test piece is lateral bending, bending 4 pieces, the test is based on RCC-M SI200. Since the linear display appears on the 00Cr18Ni10N side fusion zone, the bending test is based on the linearity of the 00Cr18Ni10N side fusion zone. The display position is the bending center, and the diameter of the core is 40 mm. Since this linear display exists for one continuous turn, if the linear display is a defect, the stretched surface will amplify the defect during the bending test, and the opening or other defects can be observed after the test. However, after the test, no defects were found on the stretched surface of the sample, indicating that there were no defects in the weld, the 00Cr18Ni10N side heat affected zone and its intermediate position.
4.3.2. **Metallographic examination.** In view of the difference in grain size, the absorption and refraction of X-rays are different. In the metallographic examination, the grain size of the welds of different welding methods is specifically compared, and the grains of the hand welds are found through inspection. The degree of grain size of the automatic weld is about 1300-1300 μm. The grain size of the automatic weld is found to be significantly larger than that of the manual weld. The schematic is as follows.

Through the above comparison, it is verified that the grain size of the manual weld is smaller than that of the automatic weld. In the area where the manual weld and the automatic weld are combined, two different grain welds are overlapped together, when the X-ray penetrates the automatic weld. At the time of manual welds, the path of the X-rays was affected, and a certain change occurred at this position, resulting in a strange appearance at this position.

5. **Conclusions**

Through various non-destructive testing and destructive testing of 00Cr18Ni10N and Inconel-690 dissimilar steel welds, it is verified that the linear image displayed by the test specimens welded by manual argon arc welding and automatic argon arc welding is not Defects are displayed, but the pseudo-defects are displayed due to the different welding dilution rates and grain sizes of different welding methods, and this display does not affect the mechanical properties of the parts, nor does it affect the detection of true defects, which can be used by peers.

**References**

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