Influence of Cross-hole Defects of 9Ni Steel on Ultrasonic Testing

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Abstract. The cross-hole test block test, the acoustic emission characteristics of the system base metal, manual welding and automatic welding for each defect, the research shows that the attenuation of the ultrasonic wave in the base metal and the weld is different, and the attenuation in the weld is greater. Because the welding process causes the coarse crystal structure in the weld, the attenuation of the ultrasonic wave in the weld is increased, and the sensitivity of the weld detection is also increased. Ultrasonic waves pass through the manual weld seam longer than the automatic weld.

1. Introduction
9Ni steel is a low temperature steel with a nickel content of 8.5-9.5%, and the structure is martensite plus bainite. This steel has good toughness and high strength at very low temperatures. Compared with austenitic stainless steels and aluminum alloy, it has a small coefficient of thermal expansion and good economy, and its service temperature could be as low as -196 °C. It could be used safely without post-weld stress relief heat treatment and is widely used in the manufacture of large LNG storage tanks. However, due to its structural characteristics, it is extremely difficult to ultrasonic testing. In this paper, the Cross-hole test block test, the acoustic emission characteristics of the system base metal, manual welding and automatic welding for each defect are studied, and the inspection characteristics of the ultrasonic hole detection for the cross-hole defect are studied.

2. Cross-hole test process
Before the test, measure the leading edge and K value of the selected oblique probe with K=2.5, and place the selected oblique probe on the standard test block No. 1 with a hole with a radius of 10Omm and a hole of 50mm, and measure the incident point. The leading edge distance and K value of the probe could be measured, and the leading edge is 6 mm and the K value is 2.33. In the middle of the ultrasonic testing process, a suitable coupling agent is continuously added to the test block to maintain stable acoustic coupling. Then, the probe is used to ultrasonically inspect the defects of the base material with the diameters of the cross-holes of 1 mm, 1.5 mm, 2 mm, and 2.5 mm, respectively, and the corresponding gain data of the direct wave and the gain data corresponding to the first reflected wave are recorded; The cross-hole defect of the weld is tested. Because the direct wave of the T/3 cross-hole is used, the front edge of the probe used in the test is not enough. Therefore, the position of
the 2t/3 position is taken when testing the cross-hole in different welded joint. The direct wave data is recorded, and the waves are respectively recorded for the t/3 and 2t/3 positions, and the data of the one-wave reflection is recorded. The weld seam diagram of the cross-hole test block is illustrated in Figure 1, and the test block inspection diagram is shown in Figure 2.

![Cross-hole test block weld map.](image1)

(a) Cross-hole manual welding seam physical map
(b) Cross-hole manual welding seam physical map

Figure 1 Cross-hole test block weld map.

(a) Cross-hole manual welding weld direct wave detection chart
(b) One-time reflection wave detection diagram of manual welding seam of horizontal hole

(c) Cross-hole automatic welding seam direct wave detection map
(d) Cross-hole automatic welding seam reflection

Figure 2 Schematic diagram of horizontal hole test block detection.

| Defect kind | Welding process | Base metal | Defect location | Defect size mm | Weld | Defect location | Defect size mm |
|-------------|-----------------|------------|----------------|----------------|------|----------------|----------------|
| Horizontal hole | Manual welding | Distance weld at 120mm in t/3 | 1 | Weld t/3 | 1 |
| | Automatic welding | Distance weld at 120mm in t/3 | 1.5 | Weld t/3 | 1 |
| | Manual welding | Distance weld at 120mm in t/3 | 2 | Weld t/3 | 1 |
| | Automatic welding | Distance weld at 120mm in t/3 | 2.5 | Weld t/3 | 1 |

3. Results
The gain data corresponding to the flaw detection of the cross-hole base material and the gain data corresponding to the primary reflected wave are shown in Table 2. The direct wave data is applied to the 2t/3 position of the weld, and the waves are respectively applied to the t/3 and 2t/3 positions. The data of the primary wave reflection is shown in Table 3.
### Table 2 Ultrasonic flaw detection gain data of cross-holes in base metal

| Cross-hole defect size (mm) | 1.0  | 1.5  | 2.0  | 2.5  |
|-----------------------------|------|------|------|------|
| **Direct wave**             |      |      |      |      |
| Gain (t/3 horizontal hole)  | 58.0 | 56.2 | 53.8 | 52.8 |
| Gain (2t/3 horizontal hole) | 60.0 | 58.0 | 56.8 | 56.2 |
| **One reflection wave / dB**|      |      |      |      |
| Gain (t/3 horizontal hole)  | 68.4 | 66.6 | 65.4 | 63.8 |
| Gain (2t/3 horizontal hole) | 65.0 | 63.4 | 62.2 | 60.2 |

### Table 3 Cross flaw detection gain data of different welding processes

| Welding process | Automatic welding | Manual welding |
|-----------------|-------------------|---------------|
| **Direct wave** |                   |               |
| Gain (2t/3 horizontal hole) | 70.8 | 77.0 |
| **One reflection wave / dB** |       |     |
| Gain (t/3 horizontal hole) | 79.0 | 80.6 |
| Gain (2t/3 horizontal hole) | 77.8 | 80.2 |

### 4. Discussion

#### 4.1. Direct wave inspection

The gain data of the direct waves in Tables 2 and 3 are made into a defect size-gain relationship diagram. The following conclusions could be clearly drawn:

1. In the direct wave inspection of the 2t/3 cross-hole of the base metal, the cross-hole gain and the defect size of the base metal have a certain regularity, that is, the larger the defect of the cross-hole in the base metal, the higher the ultrasonic reflection wave. The smaller the gain compensation, that is, the larger the defect, the smaller the attenuation of the ultrasonic reflected wave, the easier it is to be detected, and the smaller the detection sensitivity required.

2. Comparing the same 1mm cross-hole gain compensation data of the weld seam with the gain compensation data measured by the cross-hole of the same diameter in the base material, it could be concluded that the gain compensation of the cross-hole in the weld is higher than that of the base metal. The gain compensation is much larger, that is, the welding process has a relatively large influence on the ultrasonic propagation of the weld, and the attenuation of the ultrasonic reflection wave in the weld and the base material is inconsistent. The welding process causes the coarse-grained material to be generated in the weld, which causes the scattering and attenuation of the ultrasonic reflected wave to be more, and the defect is not easily detected. The required detection sensitivity is much higher than that required for the base material of the same defect size.

3. Comparing the gain compensation of the cross-holes of the same defect size of two different welded joints, it could be seen that the gain compensation of the manual welding is larger than the gain compensation in the automatic welding. This is because the artificial factors in manual welding have increased a lot, resulting in the weld bead weld by hand welding is larger than the automatic welding, so that the cross-hole is punched at the 2t/3 position, and the weld thickness ratio of the ultrasonic wave in the manual welding is automatically. The thickness of the solder is thick (as shown in Figure 4-1), so the ultrasonic reflection wave is more attenuated in manual soldering, and the gain compensation is also increased. The required detection sensitivity is higher than that required for the automatic soldering.

#### 4.2. One reflection wave inspection

The gain data of the primary reflected wave in Table 2 and 3 is made into a defect size-gain relationship diagram.
relationship diagram. The following conclusions could be drawn:

(1) When observing the distance between the base material at the distance t/3 and 2t/3, the data has the same law inside, that is, the larger the defect of the cross-hole in the base metal, the higher the ultrasonic reflection wave, the smaller the gain compensation, That is to say, the larger the defect, the smaller the attenuation of the ultrasonic reflected wave, the easier it is to be detected, and the smaller the detection sensitivity required. However, the detection of these two positions, in contrast, could be seen that the gain compensation data measured at the t/3 position is generally larger than the gain data measured at the 2t/3 position, which is due to the required detection at the t/3 position with high sensitivity. The reason is that the ultrasonic path travels longer than the 2t/3 position when performing a reflected wave flaw detection at the t/3 position of the horizontal hole of the base material, that is, the ultrasonic attenuation is more at the t/3 position detection, and the gain is higher. As a result of this increase, the required detection sensitivity increases.

(2) Then compare the gain data at the cross-hole in the weld to the base metal. The gain in the weld is more than that of the base metal. This means that the attenuation of the ultrasonic wave in the base metal and the weld is different, and the attenuation in the weld is more. Large, because the welding process causes the coarse grain structure in the weld, which increases the attenuation of the ultrasonic wave in the weld, and the sensitivity of the weld detection increases.

(3) Observe the distribution of four points in the weld. The manual welding gain at the distance t/3 is higher than that of the manual welding. The attenuation is larger because the groove of the manual welding is wider than the groove of the automatic welding. When a reflected wave is applied at the t/3 position, the distance of the ultrasonic wave passing through the manual welding seam is longer than that of the automatic welding, so the attenuation is increased and the required detection sensitivity is increased. The manual welding of the horizontal hole 2t/3 is also higher than the gain of the automatic welding, and the attenuation is large.

5. Conclusions
In this paper, the cross-hole test block test, the acoustic emission characteristics of the system base metal, manual welding and automatic welding for each defect, the research shows that the attenuation of the ultrasonic wave in the base metal and the weld is different, and the attenuation in the weld is greater. Because the welding process causes the coarse crystal structure in the weld, the attenuation of the ultrasonic wave in the weld is increased, and the sensitivity of the weld detection is also increased. Ultrasound waves pass through the manual weld seam longer than the automatic weld.

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