Research of Jet Coupling Method of AUT for Weld Seam of SAWL

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ABSTRACT

The actuality analysis and systematic research of jet coupling method Automated Ultrasonic Testing(AUT) for the weld seam of Longitudinal Submerged Arc Welding (SAWL) pipe have been done. It’s certain that jet coupling method AUT for the weld seam of SAWL pipe can be fully achieved by means of Partition testing. Research mainly includes the following aspects, such as probe arrangement and distribution, detection threshold setting, reference block design, artificial defect selection, testing result display and record, etc. The research results provide a reference for the method research of AUT jet coupling method for the weld seam of SAWL pipe, and also give some basis for formulating the standard of jet coupling method AUT for the weld seam of SAWL pipe.

INTRODUCTION

Due to the AUT faster detection speed, it’s very important to choose the appropriate coupling mode. AUT coupling modes include contact and non-contact methods, non-contact method is divided into fluid immersion coupling method and electromagnetic coupling method jet coupling method is one of the fluid immersion methods, the advantage is that the probe and the work piece is non-contact, probe has long life, easy to realize automatic detection, reducing the influence of human factor.

At present, jet coupling method AUT just focus on detecting outside and inside surface imperfections of SAWL, for the internal imperfections detection of weld seam, there is neither specific claim (including API Spec 5L and DNV-OS-F101 etc) nor concrete method existing[1-4].Therefore, the detection method research of jet coupling method AUT for SAWL seam is extremely urgent, However, AUT is different from manual UT, in order to realize full coverage detection on weld seam (in the length direction, the width direction and the depth direction), manual UT could use so many scanning methods as front-back, left-right, angle turning and

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encircling, while AUT doesn’t have such advantages. Therefore, this paper have done some study on the fallow aspects, such as the probes distribution and arrangement, the threshold setting, the reference standard design, the artificial defect selection, and inspection results display and record, which is of vital importance for the achievement of full coverage detection by jet coupling method AUT on SAWL weld seam and for the operation security of pipelines.

Ultrasonic Testing of SAWL Seam

Detection of Longitudinal Imperfections. Cracks, incomplete fusion and incomplete penetration are very dangerous weld imperfections for SAW pipe. The valid width range of usual probe is from 12mm to 15mm, such as 2.5P10×12K2⁵. As a result, for SAWL pipe with weld thickness smaller than 12mm, 2 pairs of probes are needed to detect the inside and outside longitudinal imperfections. With each additional 6mm to the weld thickness, one more pair of probes is needed. Fig.1 shows the detecting the longitudinal imperfections by jet coupling method.

For SAWL pipe I-type and X-type bevels are usually furnished. The imperfections probably occurred on the bevels or root face, pulse reflection method or tandem probes usually be used. Tandem probes was mainly used for detecting the incomplete penetration imperfections in the middle of double-sided submerged arc welding seam, because the incomplete penetration imperfections generally perpendicular to the surface of weld. so the tandem probes was suitable. Fig.2 shows detecting longitudinal imperfections perpendicular to the weld surface by jet coupling method with tandem probes.

Detection of Transverse Imperfections. Transverse imperfections are generally rare for SAWL pipe during the welding process. Therefore, for detecting transverse imperfections of SAWL seam, pulse echo method arranging special probes (OB probes) on the weld should be given priority. The advantage of this method is that only 2 probes are capable of inspecting through the entire thickness
of the weld (shown in Fig.3). However, this method causes large energy loss to the probe ultrasonic beam, reducing the detection sensitivity.

Figure 3. detecting the transverse imperfections by jet coupling method with OB probe.

**Detection of Laminar Imperfections.** The quality of HAZ is the same important as that of the weld seam. Relevant specification specifies that the width of detected zones is the sum of the weld metal and the adjacent parent metal on each side of the weld metal. The width of each adjacent parent metal equals 30%\(t\). The minimum width of each adjacent parent metal is 5mm, and the maximum is 10mm\[^6\]. For light-wall thickness double-crystal probes shall be used; for heavy-wall thickness, single crystal probes shall be used in jet coupling method. (See Fig.4).

Figure 4. detecting the laminar imperfections by jet coupling method.

**Probe Arrangement and Distribution**

Manual UT is capable of achieving full coverage in the detected range (length, width and depth) through several scanning methods such as probe front-back, left-right, angle turning and encircling. However, this is not true with AUT. In order to achieve AUT 100\% detection, probe arrangements and distribution are quite crucial. The full coverage of ultrasonic beam on the weld is the main consideration of probe arrangement.

The valid ultrasonic beam width of generally used probes is 12-15mm. The most easily occurred imperfections during the welding process of SAWL pipe could be divided into longitudinal imperfections and transverse imperfections. The main imperfections are cracks, incomplete fusion, incomplete penetration, undercut, offset, etc. Considering that the probe beam used in AUT has featured width, according to the different wall thickness range of SAWL pipe, the probes are arranged and layout in specific mode to guarantee a complete coverage of weld beam by the ultrasonic. Usually the wall thickness of SAWL steel pipe is divided into six wall thickness range, respectively, \(6 \text{ mm} \leq t \leq 12 \text{ mm} \), \(12 \text{ mm} < t \leq 18 \text{ mm} \), 18
mm\(<t\leq24\text{ mm}\), 24 mm\(<t\leq30\text{ mm}\), 30 mm\(<t\leq36\text{ mm}\) and 36 mm\(<t\leq42\text{ mm}\). Taking wall thickness range 24 mm\(<t\leq30\text{ mm}\) for example, Probes’ arrangement and distribution, used for jet coupling method AUT, are studied on the SAWL steel pipe weld beam, as shown in Fig.5[7].

Detection Threshold Setting

Each set (or pair) of probes used in process of SAWL seam AUT is calibrated through their own corresponding reference indicators. The 100% detection of probes in the depth and width directions mainly depends on the position of artificial imperfections on the reference standard. The coverage in depth direction is mainly determined by the probe arrangement, and the coverage in width direction is mainly determined by the detection threshold setting. The coverage in depth direction has been resolved in the part of probe arrangement. Taking probe arrangement and distribution when the wall thickness of steel pipe is 24 mm\(<t\leq30\text{ mm}\) for sample. Here is the study of probe complete coverage detection in certain width direction.

Detection Threshold Setting for Longitudinal Imperfections. For the detection of longitudinal imperfections, the starting point of the threshold of probes L11 shall be at least 1mm ahead the reflected wave of radially drilled holes (as the dotted line showed in Fig.6), and the finishing point of the threshold shall be at least 1mm after the reflected wave of radically drilled hole in the weld[8], the threshold setting of probes L12 and L11 are similar. The threshold setting of the other probe for the detection of longitudinal imperfections are similar to probes L11-L12.

Detection Threshold Setting for Transverse Imperfections. When OB type probe T11-T12 used to detect transverse imperfection, Fig.7 shows the OB probe threshold[8], because of Ultrasound’s Z type reflection in the weld seam, it must be
defect wave which exist between interface wave and bottom wave. the starting point of the T_{11} threshold should be at least 1mm after the interface wave, the finishing point of the threshold shall be at least 1 ahead of the reflected wave of transverse groove; the threshold setting of probes T_{12}-T_{22} are similar.

**Figure 7.** threshold Settings for transverse imperfection.

**Detection Threshold Setting for Laminar Imperfections.** For the detection of laminar imperfections, the detected width is subject to specific standard or specification, and it is generally within 25mm. The threshold setting of probe D-D (double-crystal or single crystal probe) is shown in Fig. 8 (in figure, T is the initial pulse, S_1 is the first interface wave, B_1 is the first bottom wave). The starting point of the threshold is set 1mm after the interface wave, and the finishing point is set 1mm ahead the first bottom wave.

**Figure 8.** threshold Settings for laminar imperfections.

(a) schematic plot of Probe detecting defects  (b) waveform figure of probe detecting defects

**Reference Block Design and Artificial Imperfection Selection**

The reference standard of SAWL seam for jet coupling method AUT is a highly important parts. It is the foundation for the calibration of the whole system and for the assessment of welding quality. An unqualified reference standard or any artificial imperfections with a low machining precision will lead to missing detection or misjudgment of imperfection. The aim of the reference standard design is to guarantee the full coverage upon the weld of the ultrasonic beam.

Before designing the reference standard, the type of welding bevel shall be acquired from the manufacturer to accurately select the artificial imperfections. Once the type of welding bevel is determined, the various parameters of the artificial defect can also be determined. For SAWL with weld thickness \leq 12mm, “I” bevel is usually furnished; for SAWL with weld thickness \geq 12mm, “X” bevel is usually furnished. The orientation of reference indicators on outside surface, inside and on inside surface can be determined by the bevel type. The angle or orientation of inside artificial imperfections is generally perpendicular to the bevel face. For weld seam internal longitudinal imperfections defecting of different thickness steel pipe, the partition principle is: for wall thickness range is \(12 \text{ mm} < t \leq 18 \text{ mm}\), the
Wall thickness is divided into 2 equal parts, for 18 mm < t ≤ 24 mm, the wall thickness is divided into 3 equal parts, for 24 mm < t ≤ 30 mm, 4 equal parts, for 30 mm < t ≤ 36 mm, 5 equal parts, for 36 mm < t ≤ 42 mm, 6 equal parts. Taking the wall thickness 24 mm < t ≤ 30 mm for example, internal longitudinal imperfections design is studied, shown in Fig. 9[9].

Note: the wall thickness is quartered, because of the influence of the steel tube surface, parts center close to the wall thickness, so at the 30% wall thickness the flat bottom perpendicular to the groove surface is machined, at the 50% wall thickness flat bottom hole perpendicular to truncated edge, so at the 70% wall thickness the flat bottom perpendicular to the groove surface.

Figure 9. Internal longitudinal imperfections design for thickness between 24 mm and 30 mm.

Artificial imperfections on the reference block were displayed, similar to the imperfections arrangement of longitudinal imperfections, transverse imperfections and lamination imperfections. There is some space between artificial imperfections, making sure noninterference detection for each artificial imperfections detection. Considering different wall thickness, reference block for jet coupling method AUT of SAWL steel pipe weld was designed and distinguished into 6 wall thickness range, that is: 6 mm ≤ t ≤ 12 mm, 12 mm < t ≤ 18 mm, 18 mm < t ≤ 24 mm, 24 mm < t ≤ 30 mm, 30 mm < t ≤ 36 mm and 36 mm < t ≤ 42 mm. Taking the wall thickness 24 mm < t ≤ 30 mm for example, reference block design is studied, shown in Fig. 10[9].

Figure 10. Reference block design for thickness between 24 mm and 30 mm.

Note: 1. 13 are longitudinal grooves at the outside weld toe, used to simulate outside edge bite, incomplete fusion extend to the surface, the outside weld toe cracks; 2. 12 are flat bottom holes at upper bevel with 30% wall thickness depth, used to simulate groove’s incomplete fusion; 3. 11 are flat bottom holes at truncated edge with 50% wall thickness depth, used to simulate incomplete joint penetration in the middle of weld seam; 4. 10 are flat bottom holes at down bevel with 70% wall thickness depth, used to simulate groove incomplete fusion; 5. 9 are longitudinal grooves at the inside weld toe, used to simulate inside edge bite, incomplete fusion extend to the inside surface, the inside weld toe cracks; 6. 8 are radially drilled holes with certain distance to weld toe, used to confirm the start point of the threshold; 7 is radially drilled hole in the middle of weld seam, used to adjust scan sensitivity and locate the gate end point and the weld center line; 14. 15 are outside and inside transverse groove, used to adjust scan sensitivity of transverse groove detection; 16. 17 are flat bottom holes at inside steel surface, used to adjust scan sensitivity of laminar imperfections detection within 25 mm to weld toe.

Figure 10. Reference block design for thickness between 24 mm and 30 mm.
The material of reference standard remains the same as that of the pipe material (the same grade is the best). Before machining the reference standard, UT of its material shall be performed to ensure that there is no imperfection influencing the detection inside the material. If no equivalent imperfection is found (Φ2.0mm flat-bottom hole as usual), the artificial imperfections could be machined. The machined artificial imperfections can only be used after the calibration of relevant authorities.

**Detection Results Display and Record**

Through the jet coupling method AUT research of SAWL pipe weld seam, mainly ensuring the accuracy and reliability of AUT results, besides the general information like manufacture company, project name, equipment model, pipe size, steel grade, bevel type, inspection personnel, inspection time, detection results, etc., such information as the coupling monitoring of every channel, the position of imperfections, the imperfection situation of every channel, etc. should also be displayed and recorded. Only the accurate display and record of the above information can the quality of detected weld be ensured. Taking SAWL pipe with $24 \leq t \leq 29.9 \text{mm}$ for example, the wall thickness is 28.6mm in the test. The test results shown as a strip chart are given in Fig.11.

![Figure 11. AUT detection strip chart of SAWL steel pipe weld.](image)

The above strip chart mainly shows the situation of coupling monitoring at each channel (the gray zone in figure, the position of imperfections at each channel (See the upper part), and the reference indicators 1/3, 2/12, 3/11, 4/10, 5/9, 7 and 14/15 at each channel. The test results correspond to the artificial defects on the reference block, therefore, the expected test result is reached.

**CONCLUSIONS AND SUGGESTIONS**

Any imperfection at the weld and HAZ can be fully detected through probe arrangement, threshold setting, artificial imperfections selection and the technique of partition scanning.

The adding of radially drilled holes (as artificial imperfections) at a certain distance away from the weld seam to the reference block ensures 100% detection of the weld and a certain width of the HAZ.

The record of detection results displays the position and distribution of imperfections at each channel and the coupling condition of probes at each channel.

For pipe with $t > 12 \text{mm}$, flat-bottom holes perpendicular to the bevel face are added to the reference block for longitudinal imperfections.
For SAWL seam, OB probe is preferentially recommended to detect the transverse imperfections.

The permanent record of AUT results of SAW seam can replace the X-ray inspection.

REFERENCES