https://doi.org/10.26552/com.C.2015.3.98-102

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IDENTIFICATION OF LACK OF FUSION AND PENETRATION IN CIRCUMFERENTIAL FILLET WELD BY PHASED ARRAY ULTRASONIC METHOD IN GAS INDUSTRY

The article deals with non-destructive ultrasonic identification of lack of fusion and penetration in circumferential fillet welds in gas industry by using Phased Array method. These types of welds are used mainly for repairs of gas pipelines during operation. The main aim of this paper is to compare results of measurements of the weld with and without defect. Phased Array testing procedures for circumferential fillet welds methods are also described in this article.

Keywords: *Phases Array, lack of fusion, incomplete penetration, ultrasonic testing.*

1. Introduction

Until recently, pipeline weld inspection has been traditionally solely the domain of radiography. With the advent of modern ultrasonic technique Phased Array (PA), ultrasonic testing has proven to be an effective option to detect weld defects in gas pipeline welds oriented unfavourably for radiography. Ultrasound testing can be used for gas pipelines according to current standards. Standard STN EN 12732 affords to replace X-ray by ultrasound technique in the control steel pipelines.

One of these serious weld defects is also lack of fusion and incomplete penetration in weld. It produces the notch effect, which can cause pipeline destruction during operation. This defect can be reliably identified by modern ultrasonic technique PA.

2. Ultrasonic technique Phased Array

PA ultrasonic is an advanced method of ultrasonic non-destructive testing. Ultrasonic waves at a frequency of 20 kHz are used for testing. The two main types are longitudinal (L-waves) and transversal waves (S-waves). L-waves have the particle motion and propagation in the same direction, while transversal waves have particle and propagation at right angles to each other [1].

The formulas for longitudinal and transverse waves are:

$$c_L = \sqrt{\frac{E \cdot (1-\mu)}{\rho \cdot (1+\mu) \cdot (1-2\mu)}} \tag{1}$$

$$c_T = \sqrt{\frac{E}{2 \cdot \rho (1+\mu)}} \tag{2}$$

where:

E - modulus of elasticity (Young`s modulus) $\left[N \cdot m^{-2}\right]$,

μ - Poisson`s ratio $\left[\mu = (2GE) \cdot (2G)^{-1}\right]$,

ρ - mass density $\left[kg \cdot m^{-3}\right]$ [2].

Conventional ultrasonic transducers for NDT commonly consist of either a single active element that both generates and receives high-frequency sound waves, or two paired elements, one for transmitting and one for receiving. PA probes, on the other hand, typically consist of a transducers assembly with 16 to as many as 256 small individual elements that can each be pulsed separately. These can be arranged in a strip (linear array), 2D matrix, a ring (annular array), a circular matrix (circular array), or more complex shape. As is the case with conventional transducers, phased array probes can be designed for direct contact use, as part of angle beam assembly with a wedge, or for immersion use with sound coupling through a water path [3].

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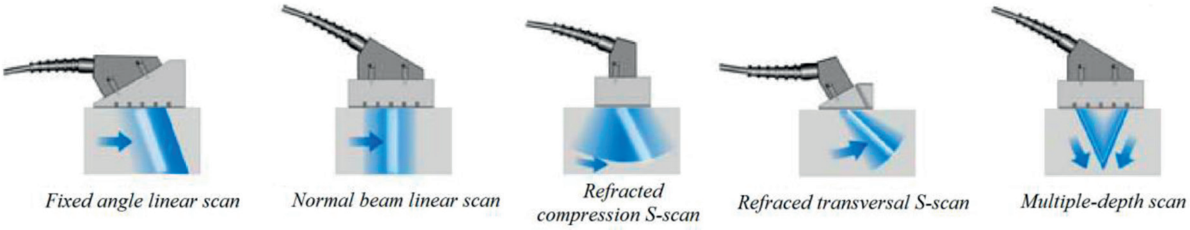

Fig. 1 Phased Array probes principle [3]

Transducer frequencies are most common in the 2 MHz to 10 MHz range. A PA system also includes a sophisticated computer based instrument that is capable of driving the multielement probe, receiving and digitizing the returning echoes, and plotting that echo information in various standard formats. Unlike conventional flaw detectors, phased array systems can sweep a sound beam through a range of refracted angles or along a linear path, or dynamically focus at a number of different depths (Fig. 1), thus increasing both flexibility and capability in inspection setups [2].

3. Lack of fusion and penetration

Lack of fusion and penetration, also called cold lapping or cold shuts, occurs when there is no fusion between the weld metal and the surfaces of the base material. This defect can be seen in Fig. 2.

The most common cause of lack of fusion is a poor welding technique. Either the weld puddle is too large (travel speed too slow) and/or the weld metal has been permitted to roll in front of the arc. Again, the arc must be kept on the leading edge of the puddle. When this is done, the weld puddle will not get too large and cannot cushion the arc [5 - 6].

Another cause is the use of a very wide weld joint. If the arc is directed down the centre of the joint, the molten weld metal will only flow and cast against the side walls of the base plate without melting them. The heat of the arc must be used to melt the base material. This is accomplished by making the joint narrower or by directing the arc towards the side wall of the base plate. When multipass welding thick material, a split bead technique should be used whenever possible after the root passes. Large weld beads bridging the entire gap must be avoided [4 and 7].

Lack of fusion is a common gas pipelines weld defect. This defect occurs mainly at repair of gas pipelines. Cause of the lack of fusion is rapid dissipation of heat from the weld edges during welding, which is due to the effects of the flow gas in the pipeline [8].

4. Identification of lack of fusion and penetration by Phased Array method on experimental samples

Identification of lack of fusion by ultrasonic method is very difficult. Difficult identification is caused by smooth surface defect, which does not direct reflect the ultrasonic energy back into the probe. Defects can be identified only by the reflected beam from the weld shape. The procedure of testing options is described in this chapter.

Three experimental samples with artificial lack of fusion were produced for ultrasonic testing. One of the samples was without defect (Fig. 3) and two samples were with artificial defect – lack of fusion on the pipe side. The samples were made of S355 steel plate with thickness of 8 mm to simplify the weld joint geometry. This geometry is very similar to the real geometry of the weld on the pipe with a diameter of 300 mm at repair of gas pipeline with steel sleeve and steel patch [9 and 6].

Fig. 2 Lack of fusion and penetration [4]

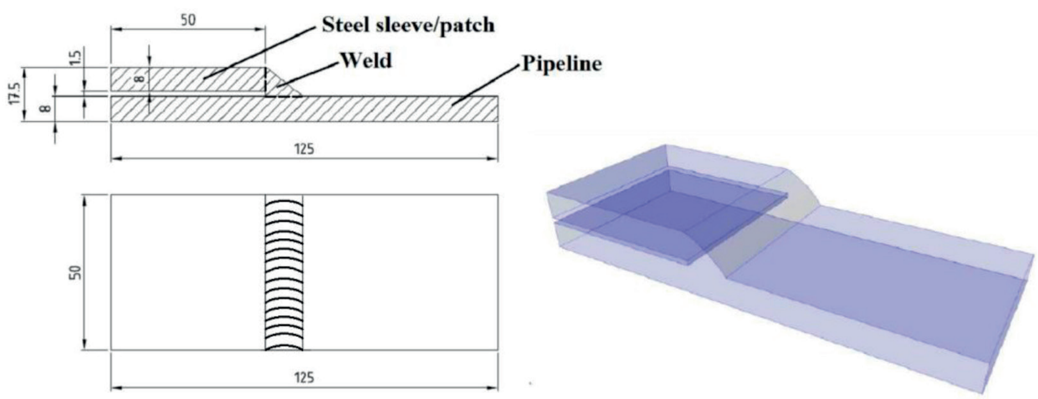

Fig. 3 Experimental sample without defect

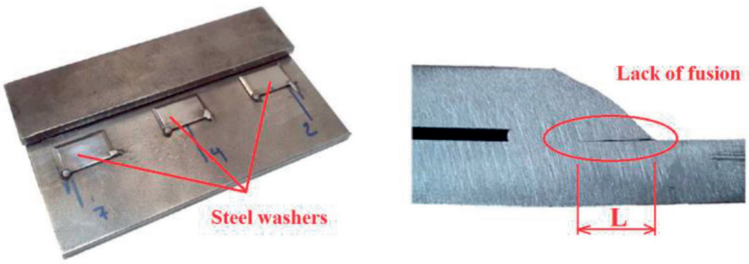

Fig. 4 Steel washers (left) and lack of fusion macrostructure (right)

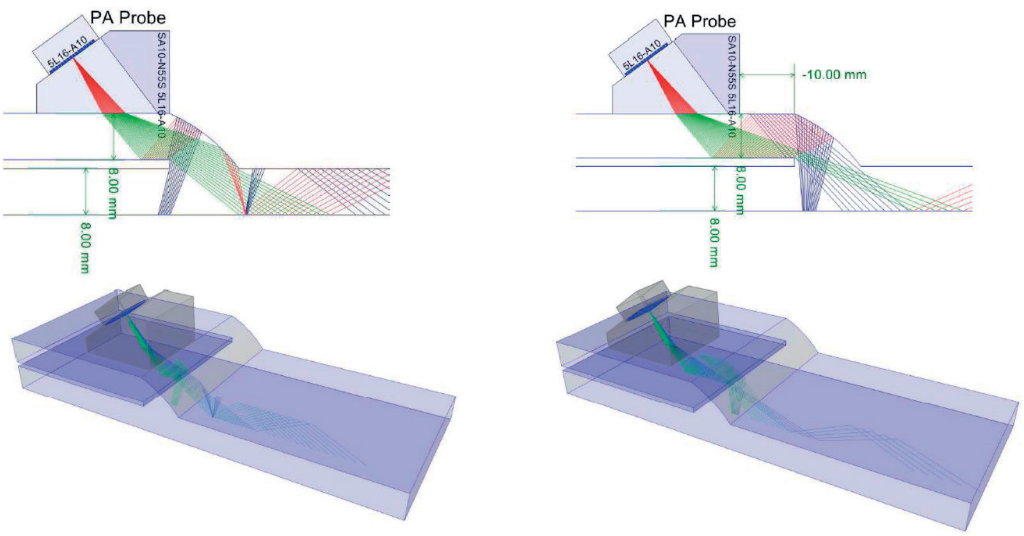

Fig. 5 Simulated testing probe position

Lack of fusion on the pipe side was manufactured with steel washers of dimension 40x35x2 mm. Defect originated during metal active gas (MAG) welding by partial melting of the surface of the steel washers. Steel washers and lack of fusion macrostructure are shown in Fig. 4. Depth of lack of fusion (L in Fig. 4) is 3.6 mm and 12.7 mm and its length is approximately 30 mm.

PA ultrasonic defectoscope OLYMPUS Omni Scan MX2, probe 5L16-A10 and wedge SA10-N55S were used for testing. The samples were tested with transversal ultrasonic waves with frequency 5 MHz (wavelength λ =0.6416, c_T = 3208 m.s^{-1}). The sensitivity of the ultrasound system was set by the DAC Ø 2 mm curve + additional gain 8 dB. Ultrasonic gel EchoMix was used to ensure acoustic contact coupling.

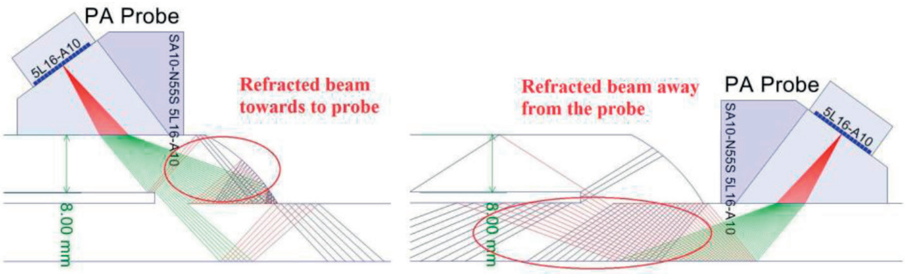

Fig. 6 Correct testing probe position from sleeve/patch: direct beam (left), reflected beam (right)

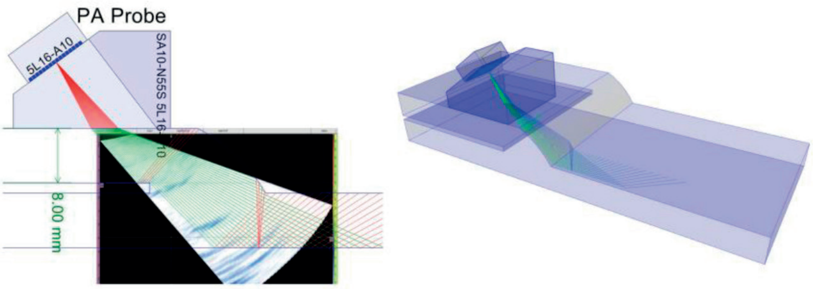

Fig. 7 PA ultrasonic record from sample without defect

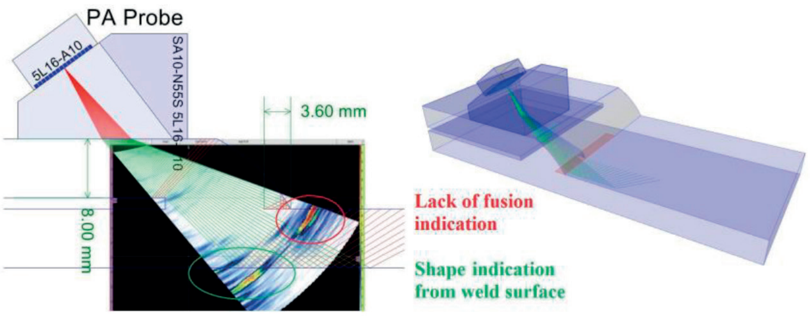

Fig. 8 PA ultrasonic record from sample with defect (defect depth L = 3.6 mm)

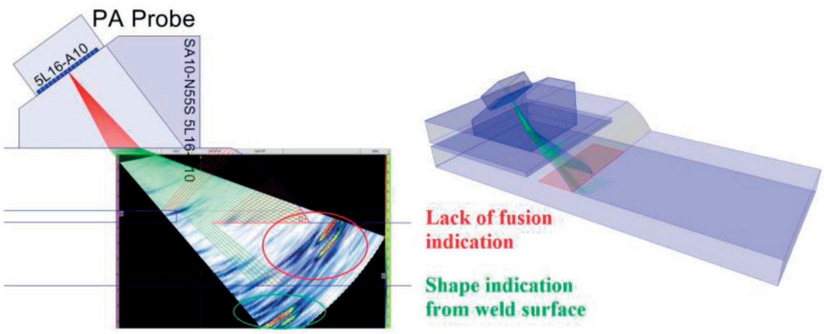

Fig. 9 PA ultrasonic record from sample with defect (defect depth L = 12.7 mm)

The correct position of the probe was designed in the program BeamTool, which allows tosimulate the propagation of ultrasonic waves in the testing material. Beam Tool ultrasonic propagation simulation in samples with defect is in Fig. 5. From the picture it is clear that the ultrasonic lack of fusion indication from sleeve (patch) side is shown through the reflected ultrasound beam from the surface of the weld. Any indications are not recorded from probe position on pipe side, because ultrasonic energy after reflection is not returned back to ultrasonic probe. Correct position for testing is therefore position by patch (sleeve) side [5].

Two probe positions on patch (sleeve) side are necessary for the correct examination of the entire weld. Ultrasonic testing with direct beam is in the first position and the reflected beam in the second probe position. Correct testing probe position from sleeve (patch) side is shown in Fig. 6.

Ultrasonic testing was performed manually. Mechanised testing in practice is inappropriate method because of the irregular geometry of the sleeve. The results of ultrasonic testing samples without defect are in Fig. 7.

Significant indications are not shown in the ultrasound recording from the sample without defect – lack of fusion, because the whole ultrasonic energy is distributed to sample and no energy is reflected back to the probe.

The results of ultrasonic testing samples with defect are in Figs. 8 and 9. A clear ultrasonic indication is seen on both ultrasound records. Two different indications are shown on records of which the first indication originates from lack of fusion obtained by reflected beam and second indication is shape indication from weld surface, which can be also seen in the weld without defect.

Differences between error indications are in angular sector view. Lack of fusion indication with depth 3.6 is angular sector of indication view about 10° (60-70° angular sector) and for the defect with a depth of 12.7 mm is the angular sector of indication view about 15° (55-70° angular sector). Based on this observation the approximate size of the defect can be assumed. The exact dimensions of the defect cannot be determined because ultrasonic indication was not received by them directly but reflected beam. Reflected beam is not obtained from real defect but from the weld surface due to the occurrence of the defect [8 and 10].

5. Conclusion

This article describes experimental ultrasonic testing of lack of fusion in repair gas pipeline weld joints. Experimental testing was carried out on simplified samples with and without the presence of lack of fusion. Performed experiments confirmed the unequivocal identification of lack of fusion in gas pipelines weld joint. The lack of fusion is displayed on the screen as angular sector indication. The problem is to determine the exact size of the defect. From the angular sector we provide only an approximate value of identification defect. According to results of measurements it is obvious that the main positive contribution of experiments is clear detection of lack of fusion, which is one of the most dangerous defects in gas pipeline welds. Ultrasonic testing procedure referred in article is accordance with the applicable gas standards and regulations.

Acknowledgment

This work has been supported by the Scientific Grant Agency of the Ministry of Education of the Slovak Republic, grant VEGA: 1/0836/13, KEGA: 034ZU-4/2015 and KEGA: 014ZU-4/2015.

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