

Ultrasonic fingerprinting by phased array transducer

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Abstract. Increasing quantity of spent nuclear fuel that must be under national and international control requires a novel approach to safeguard techniques and equipment. One of the proposed approaches is utilize intrinsic features of casks with spent fuel. In this article an application of a phased array ultrasonic method is considered. This study describes an experimental results on ultrasonic fingerprinting of austenitic steel seam weld.

1. Introduction

Modern ultrasonic testing (UT) procedure more often starts to use phased array transducers for both manual and automated inspections. However, reconstruction of inspection results possible only with automated testing, because it is necessary to provide a precise data on position of a transducer. Ultrasonic fingerprinting procedure is requiring a precise position data also. Moreover, the maximum efficiency will be achieved when reconstructed ultrasonic images is using as fingerprint. Manual fingerprinting technique approved a feasibility of proposed concept [1]. Automatization of the procedure should increase a matching rate. However, a coupling issue still stays vital for performing a UT, especially for investigation weak reflectors like grains, that is in use for fingerprinting. The best option for coupling is immersion contact. It could be realized by local contact or immersion tank. Unfortunately, there is no commercially available equipment for local immersion contact for complex shape parts, because usually it is customer-tailored product.

This paper describes a series of experiments on immersion ultrasonic fingerprinting procedure.

2. Experimental samples and installation

Experiments were conduct on 4 samples made from austenitic steel (Russian nomenclature is 12X18H10T). Special characteristics of this steel allow to use it in different industrial applications, e.g. nuclear industry. Russian-type casks for spent nuclear fuel (SNF) made from this material [2]. In order to model SNF cask samples were made from two plates jointed by butt weld.

Edge preparing mechanically before welding. Edge and the adjacent surface are stripped from the scale, paint, oil and other contaminants on the surface width of 20 mm outer and 10 mm inner side. The surface is degreased with pure alcohol. The welded joint is performed by an automatic TIG welding consumable electrode. The centering device is applied during welding. The deviation from linearity does not exceed 0.8 mm per 100 mm. The following materials are used during welding: welding wire St 04H19N11M3 (\varnothing 1,2 mm), tungsten electrode EVL (\varnothing 2,4 mm), argon as a protective gas. Additional heat treatment is not carried out [2].

Weld metal characterized by cellular-shaped dendritic crystallization. This form is an intrinsic feature of the material, providing a set of scattering centers, that allows to generate the fingerprint.



The experiments were conducted on laboratory multichannel ultrasound system. The block diagram is shown in Figure 1.

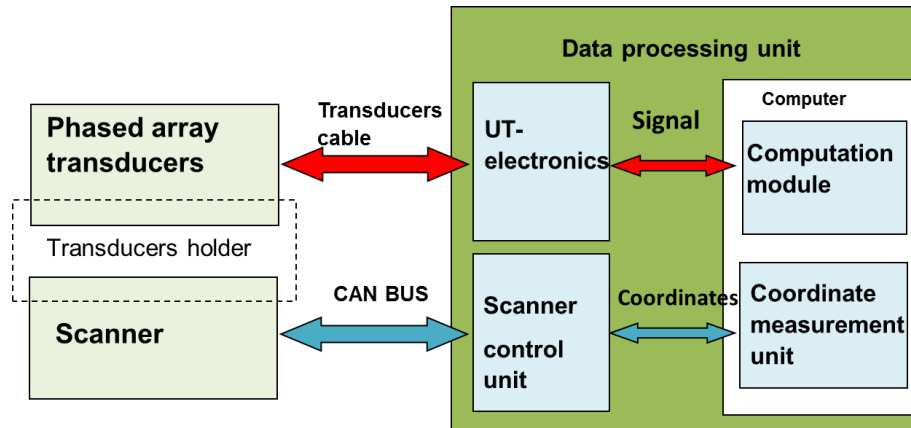


Figure 1. Ultrasound multichannel system block diagram.

The basis for the system is a unit of ultrasonic OPTUS electronics, manufactured by I-Deal Technologies GmbH. The unit has a transmitter/receiver 128 channels module that could be used for both single- and multichannel measurements. Thus, this unit can be used for a wide range of automated ultrasonic inspection tasks, e.g. the ultrasonic fingerprinting.

As a phased array were used linear probe 5L16-1.0-16-D89-P1 produced by Doppler Electronic Technologies Co. Ltd. The array contains 16 elements with 1 mm pitch. Frequency is 5 MHz. The transducer were placed on plastic wedge with 50° angle.

The samples were scanned by the three-axis manipulator that is shown on figure 2. Acoustic data is written in pair with position data of transducer, the coordinates of probe are monitored by a measurement unit.

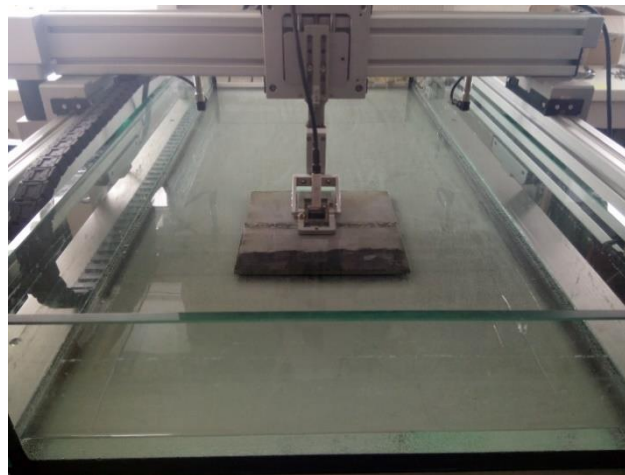


Figure 2. Immersion tank with linear array on manipulator.

2.1. Control procedure

In order to set the optimum amount of data for the volume reconstruction a meander scan path were selected. Path is characterized by two main parameters. S_s - the distance between the measuring positions, S_p - the distance between the measuring lines (fig. 3).

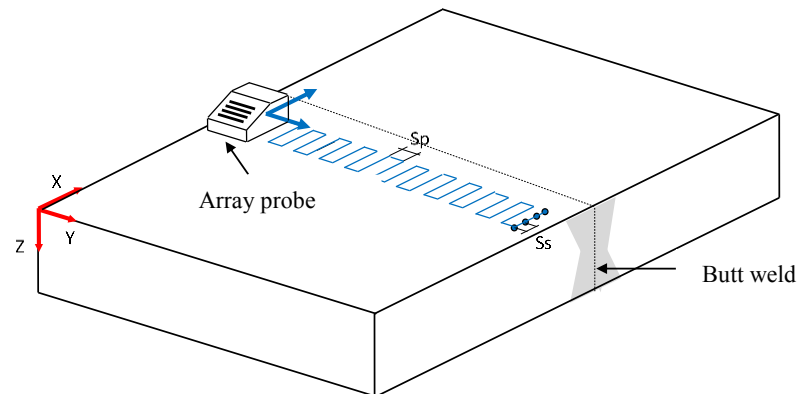


Figure 3. Testing measurement scheme.

The S_s value is 1 mm and the measuring the distance is 2 mm. The linear phased array is installed across the joint. The parameters are due to the requirements of the method of Digital Focus Array (DFA) reconstruction [3, 4], which is implemented in the software that controls OPTUS unit. When it is not possible to cut the reinforcing bead from testing welds, it is necessary to select the scanning area so that the scan path length is at least twice the wall thickness of the sample and the path ends just before the reinforcing bead edge.

Measured data is used for two-dimensional reconstruction of the sector scans in real time. Reconstructed sector scan incrementally fills a three-dimensional matrix, thus creating a three-dimensional model of the weld structure.

Testing procedure of each sample is carried out 3 times for each side of the weld. The reference fingerprint is formed as a result of this procedure. Additional measurements were made in order to determine the procedure positioning errors: offset on axes X, Y, Z and rotation.

3. Results and discussion

The measurement procedure carried out 38 times. As a result were formed 14 fingerprints for further mathcing. Example of the fingerprint is shown in Figure 4.

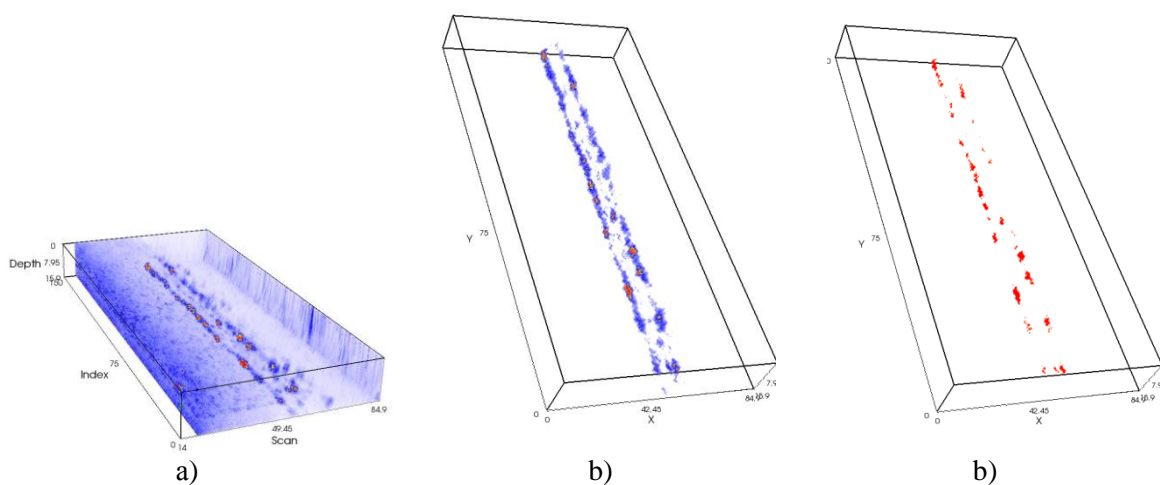


Figure 4. The process of fingerprint formation with three-dimensional visualization: a) a three-dimensional ultrasound image made with DFA method; b) the results of a segmentation process; c) the reconstructed three-dimensional fingerprint after binarization.

The fingerprint matching rate analysis were carried out. Arithmetic mean and standard deviation were calculated. Results are presented in Tables 1-5. A letter in the first row of each table is used below as a reference. Here and below, "1" - correlation, "2" - intersection, "3" - hi-square, "4" - Hellinger distance.

Table 1. The matching rate for the same position on the one sample.

a, %						
sample/method	1	2	3	4	mean	deviation
1	94.2	96.7	93.2	95.1	94.8	1.5
2	93.5	97.0	94.1	96.2	95.2	1.7
3	94.4	96.1	95.0	97.1	95.7	1.2
4	94.1	95.4	97.3	95.4	95.6	1.3

Table 2. The matching rate for the different position on the one sample.

b, %						
sample/method	1	2	3	4	mean	deviation
1	71.1	73.1	77.3	70.2	72.9	3.2
2	68.2	78.3	73.1	70.7	72.6	4.3
3	72.4	77.2	80.1	79.1	77.2	3.4
4	74.2	79.3	76.1	72.1	75.4	3.1

Table 3. The matching rate on the different samples.

c, %						
sample/method	1	2	3	4	mean	deviation
1	20.3	22.6	12.4	22.4	19.4	4.8
2	21.3	25.9	10.5	22.1	20.0	6.6
3	25.1	22.8	10.4	21.3	19.9	6.5
4	21.8	23.9	8.1	26.6	20.1	8.2

Table 4. The matching rate for the same position on the one sample with transducer rotation.

d, %						
sample/method	1	2	3	4	mean	deviation
1	49.3	57.5	47.1	51.4	51.3	4.5
2	46.3	44.4	52.7	53.4	49.2	4.5
3	48.4	46.1	56.3	47.3	49.5	4.6
4	52.9	45.8	45.4	47.9	48.0	3.4

Table 5. The matching rate for the same position on the one sample with transducer offset.

sample/method	e, %				mean	deviation
	1	2	3	4		
1	80.1	81.9	76.3	74.9	78.3	3.3
2	80.8	78.8	75.8	76.3	77.9	2.3
3	81.3	74.9	77.9	80.8	78.7	3.0
4	82.3	78.0	80.4	81.0	80.4	1.8

The results of experiment "a" show the matching rate of $95.4 \pm 1.3\%$, which is 17% different from the correlation level obtained for one-element transducer [1]. More important from a practical point of view is the result of the experiment "b" where the matching rate is $75.3 \pm 3.3\%$. This means that one weld inspected from different sides of the joint, is authenticated as the same weld. Thus the difference between different welds is still evident. The result of the matching rate for the experiment "c" shown the lowest value with high error rate – $19.3 \pm 7.5\%$.

A special attention should be paid to the experiment "e" results, where the values exceeds a selected threshold of 15% [5], which confirms the possibility of compensation the transducer offset within 3 mm by using a linear phased array . The array rotation influence (experiment "e") is still significant. These values are on average $49.8 \pm 4.1\%$.

The analysis of each of the four correlation methods were carried out. The results are shown in Table 6, the average value was 95.4 %. The best results obtained by using the intersection method, where the matching rate was $96.2 \pm 0.6\%$.

Table 6. Results of matching rate for different correlation methods

Method	1	2	3	4
Mean	94.9	96.2	94.7	95.8
Average	95.4			
Standard deviation	0.34	0.60	0.52	0.26

4. Conclusion

Comparing the results obtained by a single-element transducer and linear phased array, should be noted a significant increase in quality of the results (17.1%). Along with this application of linear array allows authenticate the same weld with different positions and to avoid errors connected with the transducer offset on X or Y axis. Industrial applications of this technology is limited to the need to implement an immersion contact between the controlled object and the transducer, and measurement sensitivity to the array rotation. The latter factor is due to the difference in the longitudinal and transverse resolution of an array, since the resolution in the lateral direction depends on the frequency of the selected transducer, and longitudinally from the distance between adjacent array elements.

Acknowledgements

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