IOP Conf. Series: Materials Science and Engineering **510** (2019) 012004 doi:10.1088/1757-899X/510/1/012004

The implementation of post-processing algorithm for ultrasonic testing of welds

I Petrov, A Vdovenko, D Dolmatov and D Sednev
National Research Tomsk Polytechnic University, 30 Lenina Street, 634040 Tomsk, Russia

E-mail: dolmatovdo@tpu.ru

Abstract. The current development of systems of pulse-echo ultrasonic testing systems is conditioned by the increasing of inspection results reliability. The application of Synthetic Aperture Focusing Technique (SAFT) is one of the solutions to this problem. The implementation of the post-processing algorithms based on SAFT strongly depends on the conditions of the ultrasonic scanning. In this paper, the issues related to SAFT implementation in the case of ultrasonic inspection of welds are considered. As a result, the post-processing algorithm, which takes into account the main features of such objects inspection, is proposed. The capabilities of the suggested algorithm were verified via the computer simulations. It was determined that the suggested algorithm is able to provide accurate and precise imageries of the flaws located in the weld.

1. Introduction
Pulse-echo ultrasonic testing is widely applied in different fields of industry. Its advances are the high quality of testing results, safety of testing procedure and simplicity of equipment application. One of the biggest problems of this method is the complexity to estimate the real size and shape of determined flaws [1].

Non-destructive testing of welds is one of the most common ways of ultrasonic testing application. Ultrasonic testing of welds is related with the numerous of the features. The ultrasonic scanning of the weld and heat-affected zone is carried out from the surfaces of parent material. Inclined transducers or wedges made from known material are used for this purpose. In addition, a large number of indicators are present in the echo-signal as a result of the reflection of ultrasound from the bottom of parent materials [2].

Thus, the main problem today is to improve the quality of ultrasonic flaw detection for the inspection of welds. One of the most promising ways to solve this task is the application of methods and devices that visualize the internal structure of the testing object. For this purpose Synthetic Aperture Focusing Technique (SAFT) was developed. For the quality performance of this technique in the case of welds inspection, all features related to ultrasonic testing of such objects should be taken into account.

2. Theory
SAFT is used for improving the quality of images and implies the joint post-processing of signals received by the transducer from all its positions on the object surface. As a result, an ultrasonic aperture of large wave dimensions is synthesized and the image of the internal structure of the test object is reconstructed via the digital focusing at each point of the visualized region.

To implement this SAFT on practice, it is necessary to consider the propagation time of the ultrasonic wave in the testing object. The calculation is made according to formula (1). In the formula c_1 - the speed of sound; in the numerator, the path traveled by the signal to the defect (*tx*) and back (*rx*).

$$T = \frac{\sqrt{(x_{tx} - x)^2 + z^2} + \sqrt{(x_{rx} - x) + z^2}}{c_1} \quad (1)$$

During the ultrasonic testing of welds, wedges are placed between the transducer and the test object. In this regard, in SAFT implementation it is necessary to take into account the refraction of ultrasonic waves at the interfaces between two media (wedge-object) and the change of the propagation path of the wave. In the figure 1 the center of ultrasonic transducer is located in (0;0) coordinate, the coordinates of flaw is (x; y), the point of entry of the ultrasonic wave into the test object is (x1; y1), the reflection of the ultrasonic wave from the bottom occurs at the point (x2; y2).

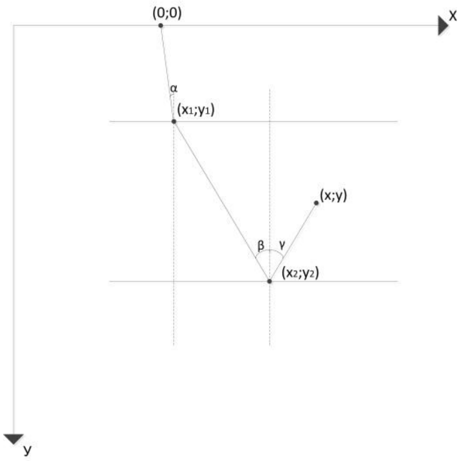


Figure 1. Trajectory of ultrasonic wave propagation and its reflection in testing object.

The process of propagation and refraction of waves through the interface of two media is described by the Snell's Law. The known wave velocities in the media are used for the one-way travel time calculation using equation (2), where c_1 is the ultrasound velocity in the contact substance; c_2 is the ultrasound velocity in the test object at entry to it and upon reflection from the bottom; l_1 is the height of the transducer position; l_2 is the thickness of the test object; l_3 - height of the defect from the bottom; α is the angle of incidence of ultrasound on the surface of the test object; β is the angle of refraction of ultrasound in the test object; γ is the angle of reflection of ultrasound from the bottom of the test object:

$$T = \frac{\sqrt{(x_1 - x_0)^2 + l_1^2}}{c_1} + \frac{\sqrt{(x_1 - x_2)^2 + l_2^2}}{c_2} + \frac{\sqrt{(x_3 - x_2)^2 + l_3^2}}{c_2} \quad (2)$$

3. Experiment

An algorithm of spatial-temporal processing based on the SAFT principles for visualization of the internal structure of welds was implemented in the Matlab R2016b. The algorithm took into account the features of welds ultrasonic testing associated with the propagation of ultrasound through materials through the media with different acoustic properties, their multiple reflections from the boundaries of the testing object, and the necessity to scan from the parent materials of the weld and small thicknesses of the objects being inspected.

The effectiveness of the proposed algorithm was considered with respect to improving the quality of the results obtained in comparison with the space-time processing algorithm, which takes into account only the direct reflection of ultrasonic waves from discontinuities inside the test object (space-time

IOP Conf. Series: Materials Science and Engineering **510** (2019) 012004 doi:10.1088/1757-899X/510/1/012004

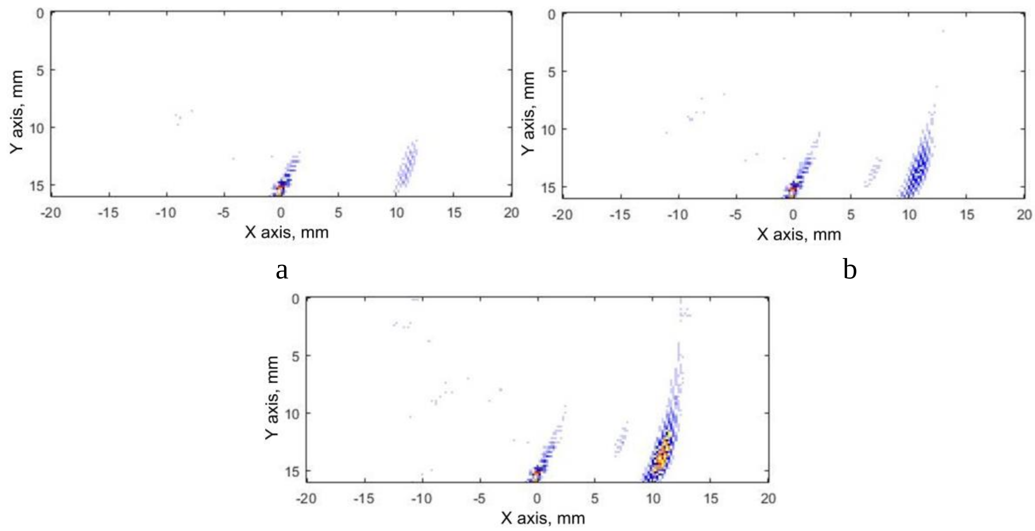
processing using "direct" ultrasonic waves). To perform this task, such algorithm was also developed using the Matlab software.

To solve this problem, the results of computer simulations implemented in the CIVA 2016 software package were used as the initial data. The simulations considered a 16 mm thick steel sample with a welded joint in which an artificial rectangular surface-breaking flaw defect was located. In total, three series of simulations were carried out, in which the height of this defect was varied (4, 6, and 8 mm).

A phased array transducer with sixteen elements was used as an ultrasonic transducer; the distance between the centers of the neighboring elements was 0.6 mm. The central frequency of ultrasonic signals which were generated by each element of phased array was 5 MHz. Ultrasound data were sampled in Full Matrix Capture mode which implies the application of full set of all possible transmitter/receiver combinations [3]. In the framework of the simulations, the ultrasonic converter was located on a plexiglass wedge, the angle of refraction of which was 45 degrees.

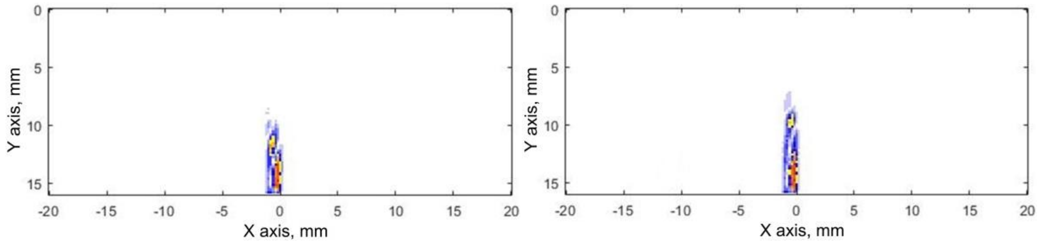
4. Results and discussions

The simulations made it possible to obtain data for post-processing using the developed algorithm. The results of post-processing using "direct" ultrasonic waves are presented in figure 2, similar results for visualization using reflected waves are presented in figure 3.

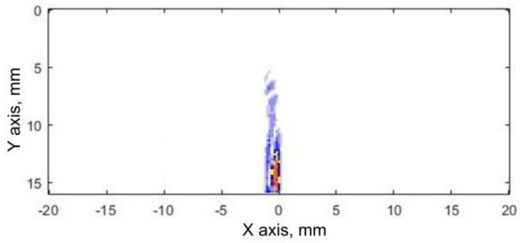


c

Figure 2. Defect image obtained using the post-processing algorithm using "direct" ultrasonic waves: a - defect height is 4 mm, b - defect height is 6 mm, c - defect height is 8 mm.



a b



c

Figure 3. Defect image obtained using the post-processing algorithm using multiple reflected ultrasonic waves: a - defect height is 4 mm, b - defect height is 6 mm, c - defect height is 8 mm.

In the images of defects obtained using the post-processing algorithm using “direct” ultrasonic waves, the defect in the coordinate (0; 0) (the real position of the defect) has an undefined shape, and in the coordinate (10; 0) a false image of the defect appears. As you can see, with increasing size of the flaw, the false image becomes more intense and drowns out the real defect. The defect images obtained using the post- processing algorithm using repeatedly reflected ultrasonic waves have a clearly defined rectangular shape and equally clearly define both small (4 mm) and large (8 mm) defects.

5. Conclusion

The complexity of the ultrasonic testing of welds is connected with the difficulties in determining the actual size of the flaws. In this manuscript, the feasibility and effectiveness of the reconstruction were investigated, taking into account the rays reflected from the bottom of the testing object. Such an approach can be more beneficial in comparison with common SAFT algorithm implementation, which implies the post-processing of the ultrasonic waves directly retracted from the controlled object. It is related to a large number of reflections of ultrasonic waves from the boundaries of the test object, which can cause the appearing on the synthesized image false indications that do not correspond to real flaws in the testing object. The considered algorithm showed high information content and accuracy of the obtained image.

Acknowledgements

The study was financially supported by the Ministry of Education and Science of the Russian Federation within the Scholarship of the President of the Russian Federation for young scientists and graduate students who carry out advanced research and development in priority areas of modernization of the Russian economy (№ SP-1836.2018.5 and № SP-1827.2018.2).

References

[1] Krautkrämer J and Krautkrämer H 2013 *Ultrasonic testing of materials.* (Springer Science & Business Media) p 677
[2] Barkhatov V A 2003 *RUSS J NONDESTRUCT+* **39(1)** 23-47
[3] Doctor S R, Hall T E and Reid L D 1986 *NDT INT* **3** 163-167
[4] Holmes C, Drinkwater B W and Wilcox P D 2005 *NDT&E INT* **38(8)** 701-711