ELSEVIER
CrossMark
Available online at www.sciencedirect.com
ScienceDirect
Physics Procedia 70 (2015) 484 – 487
Physics Procedia

2015 International Congress on Ultrasonics, 2015 ICU Metz

Dry Storage Casks Monitoring by Means of Ultrasonic Tomography

Y. Salchak[a]*, A. Bulavinov[b] , R. Pinchuk[b] , A. Lider[a] , I. Bolotina[a] and D. Sednev[a]

[a]Tomsk Polytechnic University, 30, Lenin Ave., 634030 Tomsk, Russian Federation
[b]I-Deal Technologies GmbH, Science Park 2, 66123 Saarbrucken, Germany yasalchak@gmail.com

Abstract

Spent nuclear fuel (SNF) is one of the most hazardous types of nuclear power plant waste. This fact emphasizes the importance of careful handling and storage of SNF. There are two current state-of-the art technologies of SNF storage facility: wet and dry. It is important to mention that IAEA does not determine which kind of handling strategy should be chosen, however it is noted that dry storage of SNF could be used for one hundred years. Mining and Chemical Enterprise (MCE) is one of the leading Russian companies that deals exclusively with the dry storage of SNF. This company has implemented a long-term storage scheme. At the same time MCE faced the challenge of nondestructive monitoring of the degradation process of structural material of cask and its sealing with weld seam. Currently, X-ray testing is used for this purpose but in order to provide an effective nonradioactive method of monitoring MCE has initiated a collaborative R&D project with TPU supported by the Russian Government. Ultrasonic industrial tomography technique was proposed as the solution. The method is based on application of phased and sparse arrays transducer with real-time visualization algorithm. Received acoustic data is processed and realized by means of Sampling Phased Array technology which is a collaborative development of TPU and I-Deal Technology, GmbH. The multichannel ultrasonic set-up of immersion control was assembled for performing testing of seven experimental specimens with representative defects (side drill-holes, notches, natural welding flaws). X-ray tomography of high-resolution was chosen as the reference method. All indications were successfully reconstructed in B and C-scans and 3D image. The next step is to automate the monitoring procedure completely and to introduce an evaluation tool for current flaw state and prediction of its further behavior.

Keywords: Ultrasonic Tomography; Dry Storage Cask; Weld; Real-time Reconstruction

* Corresponding author. Tel.: +7-913-116-8572.
E-mail address: yasalchak@gmail.com

doi:10.1016/j.phpro.2015.08.291

1. Introduction

Every stage of the nuclear fuel cycle produces radioactive waste and its safe management is the major challenge. Dry spent nuclear fuel (SNF) storage is current state-of-art technology. Such type of SNF management reduces risks of radioactive contamination caused by storage SNF in cooling pools. In contrast to spent fuel pools, dry casks are not vulnerable to loss of coolant due to their passive cooling.

Mining and Chemical Enterprise (MCE) is one of the leading Russian companies that deals exclusively with the dry storage of SNF. This company has implemented a long-term storage scheme which requires an effective technique of quality control of casks. At present X-ray testing is used for this purpose. However, X-ray is a time consuming and radiation risk bearing procedure. In order to provide an effective nonradioactive method of monitoring MCE faced the challenge of nondestructive monitoring of the degradation process of structural material of cask and its weld seam.

2. Ultrasonic Inspection of SNF Casks

In 2013 MCE presented the development of a SNF storage cask. This cask was designed and manufactured by MCE (Patent RU 2500045) [1]. The cask`s body consists of three main parts: cover ring, bottom ring and middle ring. The components are fully welded to each other and represent a body of a hermetically sealed system, the cask itself. There are two types of welds: girth welds and longitudinal welds. The length of the cask`s body is 1000 mm; the diameter is 635 mm and the thickness of a wall is 4 mm, the cask`s body is made of steel (austenitic steel, X10CrNiTi18-10).

At present, there is a necessity in the development of weld inspection method of SNF casks. Owing to the advantages of nondestructive testing and advanced techniques of acoustic measurements, the ultrasonic industrial tomography technique was proposed as a solution.

2.1. Sampling Phased Array Technology

Nowadays there are many nondestructive testing methods based on the principles of synthetic aperture focusing algorithm (SAFT) [2]. The main advantage of SAFT is high spatial resolution of inspections. This algorithm is based on coherent summation of ultrasonic signals received by a transducer in different locations. State-of-art research challenge is development of an effective method of image reconstruction based on SAFT algorithm.

One of reconstruction methods by means of NDT was proposed as a collaborative development of TPU and I-Deal Technology, GmbH. This tomography method is designed for industrial application. It is based on application of phased and sparse arrays transducer with real-time visualization algorithm SAFT. Received acoustic data is processed and realized by means of sampling phased array (SPA) technology.

The Phased Array technology implies collecting data from individual elements which transmit and receive ultrasonic waves. Only one element transmits a signal during the inspection, while all the others receive reflection from any defects. Each tact of measurement coherently corresponds to each element in array and then received signals form are formed into a data matrix. Further the signals are summed up and that provides desired focusing. The main idea of applying SPA technology is the ability to form physical superposition of ultrasonic waves artificially [3].

2.2. 3-D reconstruction

3-D reconstruction can be realized by a matrix transducer or by a linear phased array 2-D scanning. The latter variant involves sector-scans of different transducer positions. Therefore, the focal area can be improved for components with bigger thickness [4].

Acoustic fields generated by the phased array have particular divergence, in that way each scan-sector of neighboring transducers can be analyzed using the SAFT algorithm in case the space between the elements is rather small. For such type of reconstruction the aperture of transducer element should be perpendicular to its length and should be bigger than the wavelength. Such arrangements determine that only restricted synthetic aperture can be achieved in prescribed direction.

Two-dimensional scanning of an object formed by linear array transducers depending on a transducer pathway enables quasi-three-dimensional tomographic reconstruction with real-time accurate visualization of inner defects.

It is possible to obtain analyzed measurement results and relevant projections (B, C, D-scans) via hardware and software. There is an example of tomographic reconstruction of a ferrite component by SPA method (See Fig. 1) [5,6].

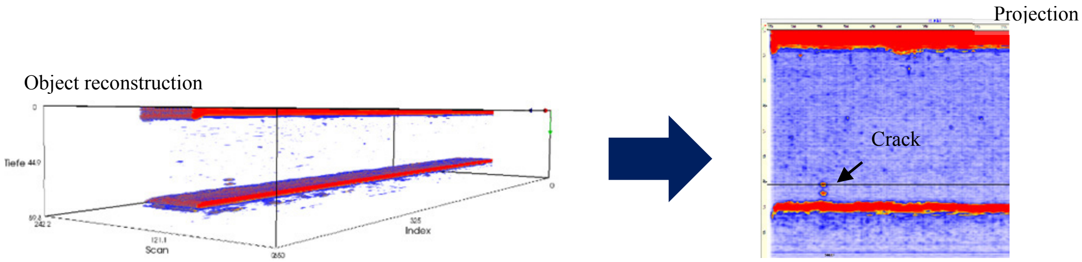

Fig. 1. Reconstruction of a Crack

3. Experimental Procedure

Hardware of the setup consists of the data processing station, including scanner controlling unit, position determination unit, PC and acoustic unit.

Ultrasonic inspections are executed with ring scanner. A two-axis ring scanner for ultrasonic testing of an object with girth welds was used. It enables scanning of curved surfaces in a given direction (meander, line or in a circle) with determination of transducers position. Measured signals are saved according to the transducer position, which is defined via position determination unit. The experimental setup enables ultrasonic inspections based on either pulse echo method or SPA technology.

3.1. Investigation of the Test Specimens

A number of test specimens were investigated during the experiment. Due to confidentiality requirements, the results of inspection of only one test specimen are presented in this paper. The experimental sample is in the shape of SNF cask`s body. It represents a cylindrical tube sample with definite dimensions and a girth weld. The length of the specimen is 460 mm, the outer diameter is 635 mm and the inner diameter is 627 mm.

Furthermore the specimen has artificial defects (flat bottom holes) placed close to the surface.

3.2. Transducer Selection

Ultrasonic inspections were conducted with the standard phased array transducers. Angle beam transducers were also used to introduce a refracted shear wave or longitudinal wave into a test specimen with 45 and 60 degrees angles of incident. Transducer nominal frequency is 5 MHz. The distance between the elements is half of the wavelength (approximately 1.7λ for longitudinal wave and about 3λ for shear wave in steel) what leads to increase of the image resolution.

3.3. Experimental Results

Due to the massive amount of information, it is impossible to obtain and save all of it at the same moment. Ultrasonic inspection was conducted in two stages (Y_1=0°÷180°; Y_2= 180°÷360°) (See Fig.2).

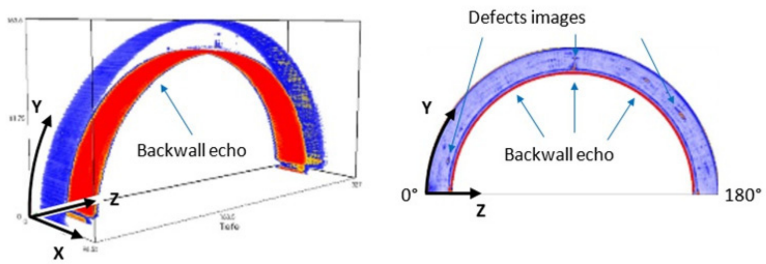

Fig.2. 2-D and 3-D imaging of Test Specimen

The results of measurements are showed in Table 1.

Table 1. Experiment Results

№	X, mm	Y, mm	Y, °	ΔY*, mm	Z, mm
1	**45**	106	**37**	18	**13**
2	**53**	140	**49**	-	**22**
3	**48**	165	**58**	10	**12**
4	**47**	188	**66**	-	**11**
5	**45**	255	**89**	10	**12.5**
6	**47**	430	**151**	12	**19**
7	**47**	465	**163**	30	**20**
8	**54**	620	**217**	6	**21**
9	**54**	702	**246**	18	**23**
10	**55**	753	**264**	-	**26.5**
11	**64.5**	873	**306**	20	**19.5**
12	**50**	873	**306**	10	**11.5**
13	**65**	960	**336**	20	**21.5**

4. Conclusion

A series of experiments have been carried out in the laboratory conditions on the ultrasonic testing of test specimens with standard defects in girth welds of SNF cask`s body designed by MCE. Successful results of visualization and 3-D reconstruction of defects were obtained during the experiment. The proposed method of nondestructive testing and reconstruction of ultrasonic waves by SPA technology enables high resolution and information capacity. It is the method of high reliability and productivity tomography defect reconstruction in real-time mode. To continue research in this project it is planned to implement the proposed method for monitoring welds of components in a hot cell.

Acknowledgements

Research has been conducted with financial support of Federal Target Programme, project unique identifier is RFMEFI57514X0048.

References

[1] Gavrilov P., Kravchenko V., Gamza U., Barakov B., 2012. Tight case for storage of ampoules with bundles of spent fuel elements, RU 2500 045 C1, 04.06.12, URL: http://www.freepatent.ru/images/patents/497/2500045/patent-2500045.pdf

[2] Stepinski T., 2008. Synthetic Aperture Focusing Technique in Ultrasonic Inspection of Coarse Grained Materials, Detailed reports from laboratories, SKI Report 2008:06, ISSN 1104-1374, ISRN SKI-R-08/06-SE, SKI, Stockholm, 26 p.

[3] Bulavinov A, Pinchuk R, Pudovikov S, Reddy K M, Walte F,2010. Industrial application of real-time 3d imaging by sampling phased array European Conference for Non-destructive Testing Moscow Russia URL: http://www.ndt.net/article/ecndt2010/reports/1_03_22.pdf.

[4] Bulavinov A., Hanke R., Hegemann J., Kroning M., Oster R., 2008. Application of Sampling Phased Array Technique for Ultrasonic Inspection of CFRP Components, International Symposium on NDT in Aerospace, Fürth, Germany, pp 21-38

[5] Lee J-R, Jeong H, Ciang C, Yoon D-J, Lee S-S, 2010. Application of ultrasonic wave propagation imaging method to automatic damage visualization of nuclear power plant pipeline Nuclear Engineering and Design vol 240 pp 3513-3520.