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Ultrasonic Fingerprinting of Structural Materials: Spent Nuclear Fuel Containers Case-Study

D. Sednev, A. Lider, D. Demyanuk, M. Kroening and Y. Salchak

Tomsk Polytechnic University, 30, Lenin Ave., 634030 Tomsk, Russian Federation
sednev@tpu.ru

Abstract

Nowadays, NDT is mainly focused on safety purposes, but it seems possible to apply those methods to provide national and IAEA safeguards. The containment of spent fuel in storage casks could be dramatically improved in case of development of so-called "smart" spent fuel storage and transfer casks. Such casks would have tamper indicating and monitoring/tracking features integrated directly into the cask design. The microstructure of the containers material as well as of the dedicated weld seam is applied to the lid and the cask body and provides a unique fingerprint of the full container, which can be reproducibly scanned by using an appropriate technique.
The echo-sounder technique, which is the most commonly used method for material inspection, was chosen for this project. The main measuring parameter is acoustic noise, reflected from material's artefacts. The purpose is to obtain structural fingerprinting. Reference measurement and additional measurement results were compared.
Obtained results have verified the appliance of structural fingerprint and the chosen control method. The successful authentication demonstrates the levels of the feature points' compliance exceeding the given threshold, which differs considerably from the percentage of the concurrent points during authentication from other points. Since reproduction or doubling of the proposed unique identification characteristics is impossible at the current state science and technology, application of this technique is considered to identify the interference into the nuclear materials displacement with high accuracy.

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1. Introduction

Around the world, demand for dry cask storage facilities for spent nuclear fuel (SNF) is on the rise. Rosatom – Russian nuclear stakeholder is focused on further development of dry storage in order to implement the open fuel cycle strategy. Mining and Chemical Enterprise (MCE) is a pioneering facility exploiting the abovementioned technology in Russia. Dry storage technologies have a number of advantages over traditional wet storage approach, such as passive cooling system, zero radioactive wastes generation and cask mobility.[1] However, the technology has some challenges. One of those is the required monitoring of cask body condition. At present Tomsk Polytechnic University (TPU) is involved in National Project for development of ultrasonic testing system for casks' safety monitoring. Safety providing is not the only challenge in SNF management. Security and safeguards issues represent the major concern as well. The main purpose is to ensure that SNF is not misused for malicious purposes. The Office of Nuclear Safeguards and Security (USA) has proposed to develop "smart casks" that contain features for cask integrity validation. [2]

TPU has proposed the approach for gathering valuable in respect to security and safeguards information during standard ultrasonic testing for safety reasons. Analysis of cask design (Patent RU 2500045) [3] has showed that vital part to be inspected for both safety and security reasons is a cask closure weld.

2. Ultrasonic Feature Extraction

It was assumed that any structural material could be identified by measuring backscattered acoustic noise from point reflectors that have unique, unreproducible distribution in controlled volume. Feasibility study has proven this assumption. [4] Ultrasonic system allows to gather backscattered signal and through applying of reconstruction procedure to get a 3-D image of object volume. Such images could be processed to extract fingerprint features.

Data processing for ultrasonic fingerprinting mainly falls into two stages: fingerprint extraction and fingerprint identification.

2.1. Fingerprint Extraction

Fingerprint extraction or fingerprinting is a technique in which software identifies, extracts and then compresses characteristic components of an acoustic image, enabling that image to be uniquely identified by its resultant fingerprint features. Fingerprinting software is based on suitable extraction of acoustic features from the reconstructed acoustic image and takes into account a preselected level of uncertainty for comparing two fingerprints. It consists of two steps:

- Segmentation;
- Thresholding.

Ultrasonic images are usually empty beside the noise that appears rather homogeneous in case of application of appropriate measurement technique. Segmentation of images reduces further image processing to relevant, meaningful parts of the image. A simple binary threshold removes the geometric complexity without losing the sensitivity contrast when extended reflector images are processed. Two steps, the image segmentation for feature localization and the optimization of the image segments yield in fingerprint characteristics. The threshold enables adjusting the fingerprint structures for robust identification.

Image Segmentation is a process that deals with the partitioning of images into multiple labels. Further processing of the labels may include acceptance or rejection based on the shape, size or any other statistical parameters. In the fingerprint technology implementation there are provisions for rejecting labels that are below a certain size (measured by the number of pixels in the label) or those that are close to the boundary of the image since these labels are often distorted and contribute to fitting problems. Static labels like transducer dead-zone or back-wall echo are rejected as well.

Thresholding is a procedure of conversion of initial half-tone image to a binary one. The main idea of this step is data compressing and optimization of further identification procedure through elimination of inhomogeneous structures of acoustic images. During this step each pixel of initial image $f(x, y)$ should be replaced by $f'(x,y)$, so that:

$$f'(x,y) = 1, \text{ where } f(x,y) >= T$$
$$= 0, \text{ where } f(x,\mathrm{y}) < T \qquad (1)[5]$$

2.2. Fingerprint Identification

Identification is a matching of reference fingerprint with measured one. Overview of common fingerprinting technologies has discovered two major aspects: correlation procedures are the most wide spread for matching purposes; the average threshold for positive decision on matching is 65% [4]. Therefore 65% matching was taken as the reference value for process validation. Matching procedure was realized by means of Qt/QML 5.3.1 and OpenCV 2.3.1. The four major correlation approaches where implemented:

a. Correlation (CV_COMP_CORREL)
b. Chi-Square (CV_COMP_CHISQR)
c. Intersection (CV_COMP_INTERSECT)
d. Bhattacharyya distance (CV_COMP_BHATTACHARYYA)

3. Experimental Technique Validation

The series of experiments were performed on the setup based on multichannel OPTUS hardware with 16 element linear phased array transducer with wedge. Pitch – 1 mm, frequency – 5 MHz. Shear wave mode was applied during inspection procedure due to its higher sensitivity to small reflector over longitudinal waves. Sampling phased array (SPA) approach is utilized for visualization of acoustic image. [6] The main advantage of SPA is real-time visualization with full-depth focusing which is vital for robust fingerprint data acquisition. Three-axis manipulator was used as scanning unit. Measured signals were saved according to the manipulator position that enable to perform 3-D imaging. The study has been performed on austenitic steel (X10CrNiTi18-10) sample with longitudinal weld joint. Sample thickness – 8 mm. The abovementioned characteristics correspond to standard MCE dry storage canister parameters.

3.1. Performance

In order to acquire required for 3-D imaging optimal data quantity, meander was chosen as scanning path (Fig.1) The meander could be described by two main parameters: the distance between two scanning lines and the distance between two neighbor measurement on such line. The distances are 2 and 1 mm accordingly. Linear array is placed in transverse direction respectively weal seam (dotted line on Fig.1). All these parameters were chosen in compliance with SPA technique requirements. During experiment 10 measurements from each side of weld seam were conducted. The main factors with possible negative influence (i.e. displacement, disorientation, lack of coupling) were modelled and considered during the performance testing.

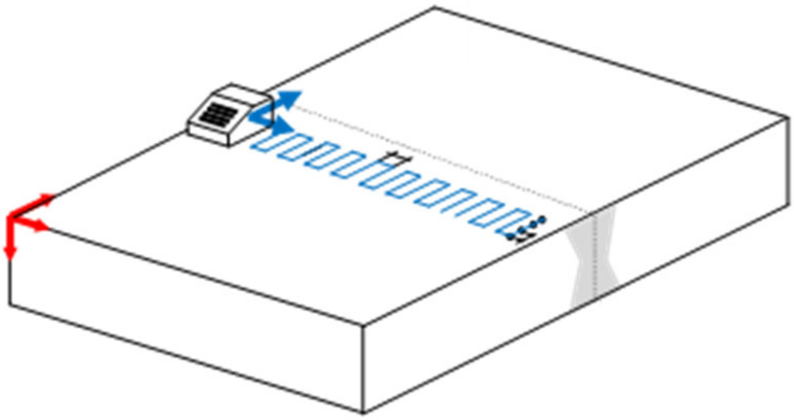
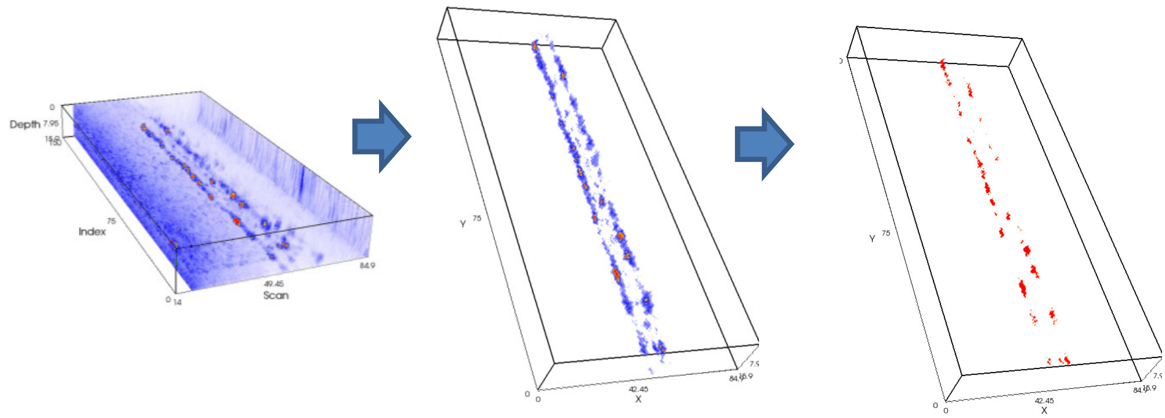


Fig.1. Scanning path on experimental sample.

3.2. Experimental Results

Figure 2 illustrated the chain of experimental application of 3-D fingerprint extraction from reconstructed ultrasonic image by means of SPA.



a) Initial image b) Segmented image c) Extracted fingerprint

Fig.2. Step-by-step fingerprint extraction from UT data.

In series of measurements 2 main reference fingerprints were gathered, 18 patterns for further matching and 12 measurements with performance inaccuracies were conducted. The matching procedure has shown the best result for Chi-square method. Median correlation value is 94,7% that considerably exceeds the given threshold in 65%. Among possible error's causes the worst influence was provided by disorientation of transducer and weld. That could be related to different sensitivity and resolution of experimental method in longitudinal and transverse direction. Mainly it could be avoided by replacement of linear array with matrix transducer with uniform sensitivity.

4. Conclusion

A number of tests have proven the applicability of weld seam microstructure for ultrasonic fingerprinting of structural material, i.e. intrinsic features of weld – natural fingerprint of material can be used as non-tamperable seal for controlling and accounting purposes. Since reproduction or doubling of the proposed unique identification characteristics is impossible at the current state of science and technology development, application of this technique is considered to identify the interference into the nuclear materials displacement with high accuracy. The main limitation of the technology is the scanning unit with high precision required due to the fact that the position accuracy strongly correlates with fingerprint matching level.

Further investigation will be focused on application of matrix transducer and its optimization for migration principle. Merging fingerprinting technology with data migration on matrix arrays would significantly increase the accuracy and allow to perform manual procedure.

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References

[1] Romanato L.S., 2011. Advantages of dry hardened cask storage over wet storage for spent nuclear fuel, International Nuclear Atlantic Conference - INAC 2011 Proceedings, URL: http://www.iaea.org/inis/collection/NCLCollectionStore/_Public/42/105/42105214.pdf
[2] Philip C.D., 2012. Safeguards-by-Design: Guidance for Independent Spent Fuel Dry Storage Installations, NIS Office of Nuclear Safeguards and Security, URL: http://nnsa.energy.gov/sites/default/files/nnsa/10-12-multiplefiles/2012-10-03%20NGSI%20SBD%20Guidance-ISFSI_final.pdf
[3] 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
[4] Dalitz C., 2014. Soft Thresholding for Visual Image Enhancement, Hochschule Niederrhein Technischer Bericht Nr. 2014-01, URL: https://www.hs-niederrhein.de/fileadmin/dateien/fb03/gruppen/technische-berichte/fb03-tb-2014-01.pdf
[5] Demyanuk D., Kroening M., Lider A., Chumak D., Sednev D., 2013, Intrinsic fingerprints inspection for identification of dry fuel storage casks, ESARDA Bullitin №50 URL: https://esarda.jrc.ec.europa.eu/images/Bulletin/Files/B_2013_50.pdf
[6] 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.