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EXPERIMENTAL VALIDATION OF A PHASED ARRAY MODEL APPLIED IN ULTRASONIC INSPECTION OF AM PARTS

Xiangyu Lei[1], Håkan Wirdelius
Chalmers University of Technology
Gothenburg, Sweden

Anders Rosell
GKN Aerospace Engine Systems, Sweden

ABSTRACT

In aerospace industries, new and advanced manufacturing technologies such as Additive Manufacturing (AM) has been developed. New technologies create innovative designing and manufacturing possibilities, while the safety is crucial and should not be compromised. This requires that the inspection methods should have high accuracy and reliability. Non-destructive evaluation (NDE) methods are hereby utilized to ensure the integrity of the manufactured components. One potential method is phased array ultrasonic testing (PAUT) but the new application implies qualification of the technique and evaluation of the procedures. The inspection must be optimized for AM specific defect characteristics. The traditional approach of qualification work is associated with experiments, which are extensive and expensive. With the development of mathematical modelling of NDE methods in last decades, the experimental work can be assisted or partly replaced by the model-based data, provided that models are validated. The validation of the mathematical model can be done by comparing with other models, but it should finally be compared with physical experiments. In this paper an experimental validation of an ultrasonic PA model is presented. The experimental setup consists of a mechanized gantry system and an ultrasonic testing equipment with PA configuration incorporated. The simulation software – simSUNDT, developed by Chalmers University of Technology will be validated using this experimental setup.

Keywords: experimental validation, phased array, ultrasonic testing

1. INTRODUCTION

New technologies such as Additive Manufacturing (AM) has emerged in aerospace industries to facilitate designing and manufacturing of complex shaped components. AM stands for a collection of manufacturing technologies such as direct energy deposition (DED), laser processes and powder bed fusion (PBF) using electron beam melting (EBM) or selective laser melting (SLM). The application of these new technologies should not compromise the safety aspects, a critical aspect in most industries but very essential in aerospace applications. This leads to higher demands on the detection methods to ensure the components integrity. Non-destructive evaluation (NDE) as a collection of methods enabling inspection without influencing the integrity and functionality of the manufactured components are widely used among industries. Ultrasonic testing (UT) as one of the NDE methods, plays an important role in the inspection process, especially with the use of phased array (PA) techniques, which enable enhanced signal processing and specific optimizations, previously not possible to achieve with conventional single element UT.

However, new tools and corresponding evaluation procedures should be comprehensively qualified before practical applications. The traditional qualification methods involve extensive and expensive experiments on test pieces, which means that many variables need to be limited to situations relevant for the specific experiments. Despite the complexity of reconstructing the test pieces geometries and the cost of corresponding materials, the manufactured defects inside the test pieces should also be treated with care regarding their prescribed sizes, shapes and characteristics of signal response. These experiments can however, be assisted or even partly replaced by mathematical simulation models developed in recent decades. The use of models can thus simulate the process of UT inspection and generate results corresponding to relevant experiments.

Before applying these simulation tools, they need to be thoroughly validated. This can be done by comparing the simulation results with other validated models and with physical experiments. The simulation model implemented in the software, simSUNDT, developed by Chalmers University of Technology, has been experimentally validated [1-4] by comparing the simulation results with the ultrasonic benchmark study, initiated

[1] Contact author: xlei@chalmers.se

by the World Federation of NDE Centers and practically conducted by Commissariat a l'énergie atomique (CEA, France). In order to facilitate more comprehensive experiments and make full use of the data, a mechanized system is built at Department of Industrial and Material Science (IMS) of Chalmers University of Technology. The experimental setup consists of a mechanized gantry system and an ultrasonic testing equipment with PA configuration. The PA probe model implemented in the software [5] are to be further validated using this experimental setup in this paper.

2. MATERIALS AND METHODS

2.1 Test block

Test objects built with additive manufacturing using laser metal deposition with wire feed in Titanium 6Al4V will be used. Well-known, artificial defects such as side-drilled holes (SDH) and flat-bottomed holes (FBH) are manufactured in the test objects and will be used for validation as a complement to comparisons with previously published benchmark results. This allows a thorough analysis and validation of the phased array technique with limited influence from specific defect characteristics but with representative AM bulk material.

2.2 simSUNDT software

The simSUNDT software consists of a Windows-based pre- and postprocessor, as well as a mathematical kernel UTDefect [1-3, 6-7] that conducts the actual mathematical modelling. UTDefect was developed at Chalmers University of Technology and had been validated by experiments [1-4]. A series of integral transforms and integral equations are incorporated to model the probes and the scatterings by defects. This software can simulate the entire NDE inspection, i.e. technique and procedure. To accomplish that, a calibration option is available towards a reference reflector including for example, the SDH (represented by the cylindrical cavity) and the FBH (approximated by an open circular crack).

The model is three-dimensional while the component used in the software is two-dimensional as infinite plate with finite or infinite thickness and is bounded by the scanning surface, on which the scanning sequence are defined by rectangular mesh.

Volumetric and crack-like defects are available types of defect to be simulated. Specifically, volumetric defects include a spherical/spheroid cavity (pore), a spherical inclusion (isotropic material differing from the surrounding material, i.e. slag) and a cylindrical cavity (SDH). Crack-like defects include rectangular/circular crack (lack of fusion) and strip-like crack (fatigue crack). There is option to model the surface roughness for the rectangular and strip-like crack, and the degree of closure can be modeled for the circular crack. Tilting planar back surface could also be modeled for the strip-like crack, but otherwise it is assumed parallel to the scanning surface. The surface-breaking strip-like crack and rectangular crack close to the back surface can be used to model the corresponding defects in the test piece.

The conventional contact probe is represented by the boundary conditions in a half-space elastodynamic wave propagation problem, within an effective area of the probe. This enables the possibilities of simulating any types of the probe available on the market, by specifying related parameters such as wave types, crystal size and shape, angles, frequency ranges, contact conditions, etc. In addition, it is also possible to suppress the unexpected wave component in the simulation to eventually facilitate the analysis of the received signal. By modelling the receiver, a reciprocity argument [8] is applied. The arrangement of the probe can be chosen among pulse-echo, separate with fixed transmitter and tandem configuration (TOFD). These principles are the same for the phased array probe model, that element is represented by the boundary conditions, from which the plane wave is generated in the far field with a certain angle. The individual boundary conditions are translated into the main coordinate system and a phased array wave front with certain nominal angle is formulated by constructive phase interference. Phased array model enables a focusing effect by manipulating the delay law of individual element. The formulated nominal angle can also be altered by specific delay law, but it should be noted that this is only possible for small angles if no wedge is specified.

3. RESULTS AND DISCUSSION

The benchmark study conducted in 2009 [9] is compared with simSUNDT to verify the PAUT model. Comparisons for SDH with different diameters and a FBH with 45-degree tilt angle are presented in Table 1.

TABLE 1: RESULTS COMPARISON BETWEEN EXPERIMENTS AND SIMULATIONS WITH 3 SDH IN DIFFERENT DIAMETERS AND A FBH

	SDH diameter (mm)			FBH
	1	1.5	2	
Exp. (L direct echo)	-2.6	-1.3	0	2.8
Sim. (L direct echo)	-2.7	-1.2	0	5.5
Exp. (T direct echo)	-16.5	-16.3	-14.8	-
Sim. (T direct echo)	-18.9	-16.7	-15.2	-

The results show that the experimental condition could be represented with high accuracy and that trends with increasing signal strength with diameter of the SDH could be identified. The ideal conditions for the model of the FBH, drilled with an angle towards the top surface, is showing an overprediction of the received signal compared to experimental data. The result in that case is highly sensitive to the representation of the reflective surface and angle relative to the sound path. Figure 1 shows the result of a parameter study in simSUNDT with small variations in the angle and diameter of the FBH. It is clear that the overprediction of the model-based result is highly influenced by the uncertainty of how the exact representation of diameter and angle should be set.

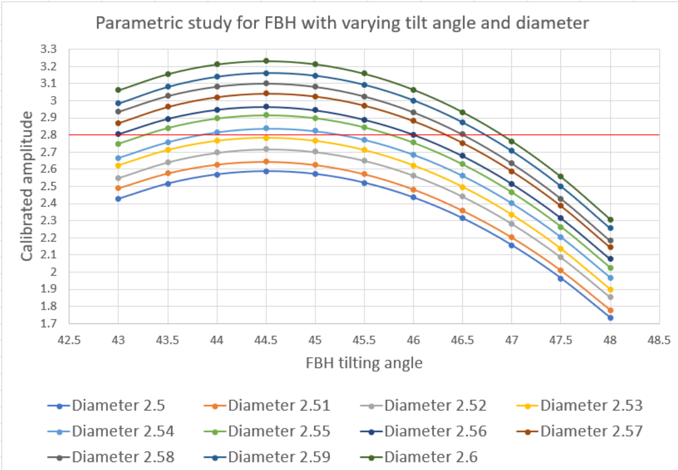

FIGURE 1: PARAMETRIC STUDY FOR FBH WITH VARYING TILT ANGLE AND DIAMETER

Reducing the reflective surface by 10-15%, depending on angle, gives a result that corresponds much more precise with the experimental data which is clear from Figure 1. This could be due to specific characteristics of the realistic FBH, such as a small curvature close to the supposed flat surface perimeter that not represented in the ideal mathematical description in the model. The results show that the model can predict phased array signal amplitude and more detailed response characteristics, as shown in Figure 2 for 3mm diameter FBH as an example.

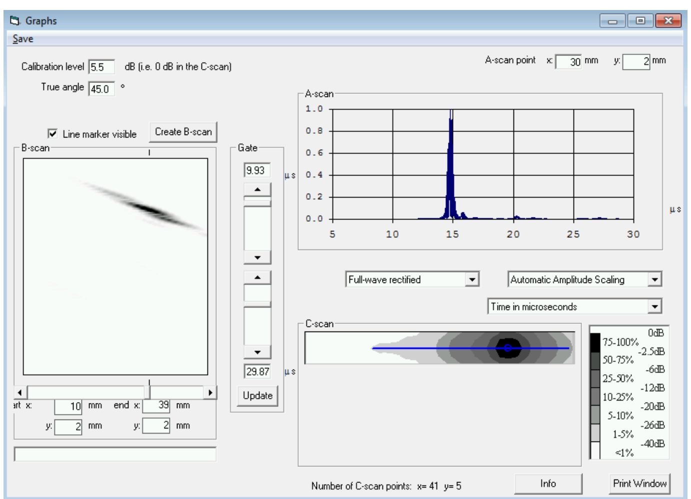

FIGURE 2: simSUNDT RESULTS PRESENTATION WITH FBH WITH DIAMETER OF 3mm

Currently the experimental system is being setup for PAUT experimental validation of artificial defect in AM Titanium 6AL4V alloy. Test objects with SDH and FBH are prepared. Wall type geometries with artificial defects provided by GKN Aerospace will also be studied. A 64-channel phased array probe will be used in the experimental validation.

4. CONCLUSION

In current work an initial validation compared with published benchmark studies is carried out for the PAUT model in simSUNDT, using SDH and FBH. The comparison shows good results. Experimental setup and comparison with artificial defects in Titanium 6AL4V samples produced by AM will be studied.

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REFERENCES

[1] Boström A, Jansson P.-Å. SKI Report 97:28.Stockholm; 1997.

[2] Eriksson AS, Boström A, Wirdelius H. SKI Report 97:1. Stockholm; 1997.

[3] Bövik P, Boström A. A model of ultrasonic non-destructive testing for internal and subsurface cracks. J Acoust Soc Am 1997;102:2723–33.

[4] Wirdelius H. Experimental validation of the UTDefect simulation software. In: Proc. 6th Int. Conf. on NDE in Relation to Structural Integrity for Nuclear and Pressurized Components, Budapest; 2007.

[5] Wirdelius H. The implementation and validation of a phased array probe model into the simSUNDT software. InProceedings of 11th European Conference on NDT 2014.

[6] Boström A, Wirdelius H. Ultrasonic probe modeling and non-destructive crack detection. J Acoust Soc Am 1995;97:2836–48.

[7] Boström A. SKI Report 95:53. Stockholm; 1995.

[8] Auld B.A., "General electromechanical reciprocity relations applied to the calculation of elastic wave scattering coefficients", Wave Motion 1, pp. 3-10 (1979).

[9] Schmerr, L., "2009 Ultrasonic benchmarks Part II – problems", http://www.WFNDEC.org