46th Annual Review of Progress in Quantitative Nondestructive Evaluation
QNDE2019
July 14-19, 2019, Portland, OR, USA

QNDE2019-XXXX

LASER INDUCED PHASED ARRAYS - TOWARDS ONLINE INSPECTION OF ADDITIVE MANUFACTURING

Don Pieris[1], Theodosia Stratoudaki[2], Adam Clare[1], Peter Lukacs[2], Richard J Smith[1], Paul Wilcox[3], Matt Clark[1]

[1] Faculty of Engineering, University of Nottingham, UK
[2] Department of Electronic and Electrical Engineering, University of Strathclyde, UK
[3] Department of Mechanical Engineering, University of Bristol, UK

1. ABSTRACT

The effective deployment of Additive Manufacturing (AM) in safety-critical applications is limited due to concerns around part integrity. Non-Destructive Evaluation (NDE) is required to provide assurance if AM is to progress into a mainstream manufacturing process in high-value industries such as aerospace. The non-contact and non-destructive nature of Laser Ultrasonics (LU) is well suited to the online inspection of AM.

This paper discusses Laser Induced Phased Arrays (LIPA) as a NDE solution capable of detecting defects and/or features up to 26 mm deep and as small as 0.5 mm in diameter. It also discusses the capability of the system to be used as a quality control tool in terms of internal feature geometrical accuracy.

2. INTRODUCTION

The popularity of Additive Manufacturing (AM) is growing within the manufacturing industry due to its capability to manufacture complex components with nested features. The American Society for Testing and Materials (ASTM) defines AM as the process of joining materials to make objects from 3D model data, usually layer upon layer [1]. Due to it still being a developing technology, post-manufacture Non-Destructive Evaluation (NDE) is required to provide assurances before any AM components could be used in safety-critical applications - such as aerospace.

The layer by layer nature of AM presents a unique opportunity for surface-based NDE techniques to be used as part of an intermediate layer inspection. Several of these can be used to build up a volumetric dataset and aid the construction of a digital twin of the part being built. Laser-based NDE is well suited to be adapted towards an online inspection of laser-based additive processes such as Powder Bed Fusion.

Currently, the only manner in which an inspection of any internal defects and features could take place would be post-manufacture, by X-ray computed tomography (XCT). This method cannot be integrated as part of an online inspection. Therefore, there is a need for an NDE technique which is both capable of being integrated into an AM build platform and which can detect defects or features embedded within components.

2.1 Laser Induced Phased Arrays

Conventional phased array ultrasonics is widely used in NDE and is well documented in the literature. Stratoudaki et al. [2] developed a laser phased array which used Full Matrix Capture (FMC) and the Total Focusing Method (TFM) to non-destructively image fabricated internal defects. The non-contact and non-destructive nature of laser-induced phased arrays (LIPA) makes them well suited to be adapted towards an online inspection of AM.

3. MATERIALS AND METHODS

The component inspected as part of this study was manufactured using a Realizer SLM50 build platform with AlSi10Mg powder. The sample was designed with six mock side drilled holes of alternating diameters of 1 mm and 0.5 mm as illustrated in the figure below.

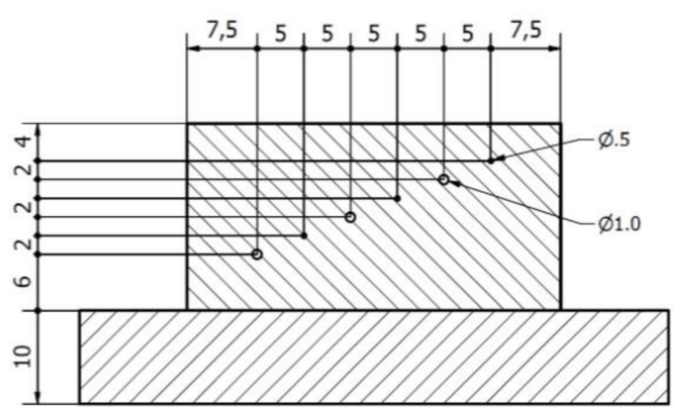

FIGURE 1: AM SAMPLE SCHEMATIC ILLUSTRATING MOCK SIDE DRILLED HOLES OF VARYING DIAMETERS AND INCREASING DEPTH, MANUFACTURED USING SELECTIVE LASER MELTING.

Where more conventional phased arrays use multiple transducers, a laser phased array could not be constructed in this manner due to the prohibitive cost of the lasers themselves. The array of N elements was synthesized by capturing the signal of all possible combinations of generation and detection, with respect to position, which compose the NxN elements of the Full Matrix. This was done by scanning the generation and the detection laser beams.

The experimental setup was designed to work on the underside of the component. Here the surface was polished to a mirror finish for maximum IR absorption and detection laser reflection. This consisted of a pulsed IR laser which was focused down to a line source and used to generate the ultrasonic shear waves. A Polytech vibrometer was used to measure the out of plane displacement. This used a 633 nm continuous wave 1 mW laser.

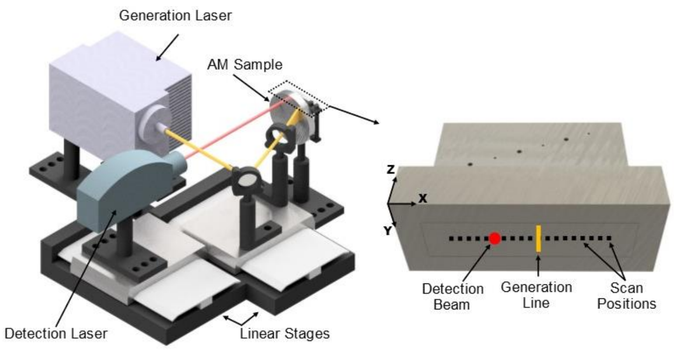

FIGURE 2: (LEFT) EXPERIMENTAL SCHEMATIC ILLUSTRATING IR GENERATION AND RED DETECTION LASERS. (RIGHT) SCHEMATIC OF THE UNDER SIDE OF THE AM SAMPLE WHERE THE IR GENERATION LINE SOURCE AND THE RED POINT SOURCE ARE FOCUSED ON TO EACH ELEMENT OF THE ARRAY.

An 18 element laser phased array with an element spacing of 194 µm was synthetized on the underside of the build plate. The obtained FMC data set was processed using the TFM imaging algorithm which synthesizes a focus at every point in the image [2]. The shear wave arrival was used for the TFM process.

4. RESULTS AND DISCUSSION

The following figure illustrates the TFM image, using the shear wave arrival while a digital filter of 3 MHz was used in post processing, showing the ultrasonic component at this frequency. The FMC in this case was captured using the Polytech vibrometer as laser detection system and the LIPA was synthesized at the back of the build plate.

Five clear indications were obtained from the gathered data. The deepest of these was 26 mm from the underside of the build plate. The results illustrated a large indication close to the bottom of the sample, but this was known to be the surface wave. As there were no known defects in this region, it was seen not to hinder the inspection taking place.

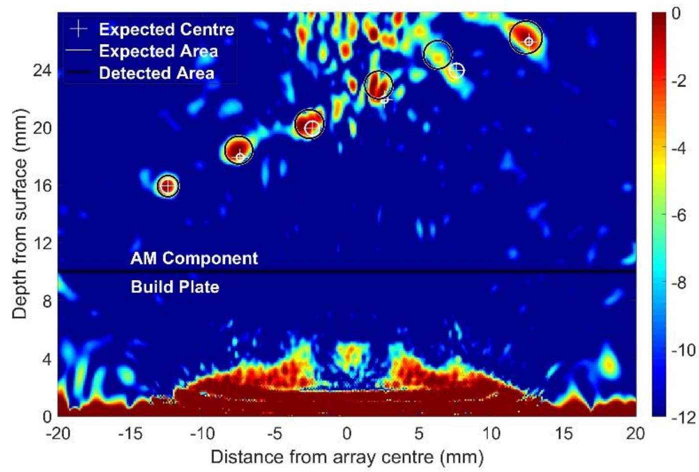

FIGURE 3: TFM IMAGE USING THE SHEAR WAVE ARRIVAL FROM A LIPA SYNTHESIZED ON THE UNDERSIDE OF THE COMPONENT. ILLUSTRATING SIX INDICATIONS OF THE NESTED FEATURES AS DEEP AS 26 MM AND AS SMALL 0.5 MM.

Following some further image processing, the location and size of the indications were extracted. This was compared to the expected size and location of the features. The gathered data was validated further using conventional phased arrays and XCT.

5. CONCLUSION

It was clear from the preliminary results presented above that a LIPA was capable of detecting nested features within AM components. The results illustrated that defects between 1-0.5 mm and as deep as 26 mm could be detected. Furthermore, it was illustrated how a LIPA system could be used as part of the online inspection of AM which could measure the geometrical accuracy of internal features of AM components.

REFERENCES

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[2] T. Stratoudaki, M. Clark, and P. D. Wilcox, "Laser induced ultrasonic phased array using full matrix capture data acquisition and total focusing method," *Opt. Express*, vol. 24, no. 19, p. 21921, 2016.