Joint Special Interest Group meeting between euspen and ASPE
Advancing Precision in Additive Manufacturing
Ecole Centrale de Nantes, France, September 2019
www.euspen.eu

Deployment of an in process surface measurement system for E-Beam AM

Liam Blunt[1]*Yue Liu[1], Zonghua Zhang[2], Chris Smith[3] David Knight[3], Feng Gao[1], Andrew Townsend[1] Xiangqian Jiang[1]

1. EPSRC Future Metrology Hub, University of Huddersfield UK.
2. School of Mechanical Engineering, Hebei University of Technology, Tianjin, China.
3. Reliance Precision, UK.
l.a.blunt@hud.ac.uk

Abstract

Additive manufacturing (AM) of metal powder fusion techniques by electron beam fusion offers significant advantages compared with traditional subtractive manufacturing techniques. AM technologies have continued to develop over recent years and have seen uptake in particular for medical implants and aerospace parts. Unfortunately despite it clear advantages AM suffers from several significant limitations which need to be addressed before wider take up of the technology is achieved.

Powder delivery is a process that occurs many thousands of times during build cycles, consequently it is important to qualify that the powder is delivered without encountering problems such as ridges and furrows resulting from rake damage or rake vibration and areas of low dosage. Like wise during the build process it is important to observe out of plane defects on parts such as thermal swelling. It is additionally useful to observe in-plane information such as the boundary of the melted powder and unmelted powder, which effectively constitutes the layer by layer part edge during the build.

This paper describes the deployment of an in process powder/part surface measurement system on a commercial E-Beam AM machine. The inspection system is based on phase measurement profilometry. A temporal synchronisation technique is employed for data capture with and acquisition time of 2 seconds for each inspection. A novel calibration method based on a surface fitting algorithm is investigated and employed to reduce the influence of phase error and random noise. Examples of the development of part thermal swelling monitoring during the build and eventual rake damage are given. Experimental results demonstrate that powder quality and part geometry defects can be efficiently inspected during the build process and future work continues to investigate fusing CAD and measurement data to enhance the data usefulness.

Key words: Additive manufacturing, fringe projection technique, In-situ measurement, surface geometry, powder bed, part swelling, calibration.

1. Introduction

Additive manufacturing (AM) techniques, also referred to as three-dimensional (3D) printing, have developed for recent years with many clear advantages [1]. Implementation of an effective in-situ detection approach for assessment of powder bed and printed parts geometry quality is essential to improve manufacturing precision and to enhance product quality. At the same time, feedback from the data has clear potential for process improvement [2]. This paper presents an E-Beam additive manufacturing machine with a fringe projection measurement system for powder bed and part analysis. During the build cycle, the areal surface of the powder bed and the edge of the solid part are measured and reconstructed by the system every layer. This paper shows the recent deployment of the in-process measurement system on a newly launched commercial E-Beam measuring machine and gives examples of part swelling during the build leading to spreader rake damage.

2. Process basics

A conceptual illustration of the in-situ measurement system applied to the E-beam AM printing machine is shown in Figure 1. The E-beam AM printing machine comprises an E-beam powder melting source, powder delivery system, a powder bed transfer stage and the fringe projection inspection system.

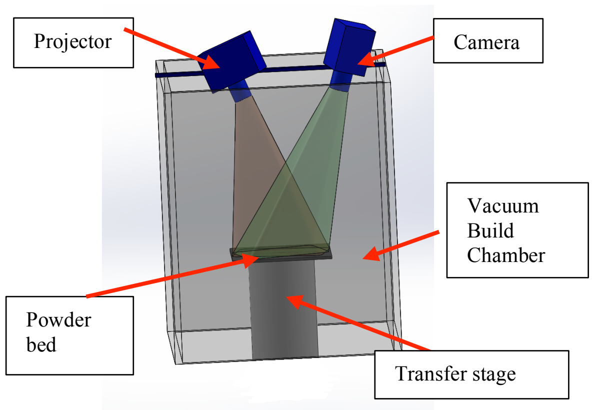

***Figure 1**. A conceptual set up of the detection system*

During the manufacturing process, a layer of powder is dispensed from a powder hopper each build layer. The detection system then capture images and analyses data from the dispensed powder surface, following this the E-beam source melts the powder along defied scanning paths, following this melt cycle the system then assesses the bed again recording the boundary of the re-solidified material pertaining to each part layer. This process is repeated until the end of the build cycle. The detection system is capable of measuring for example: rake damage, delamination, part swelling, porosity, lack of powder delivery and the boundary of the re-solidified material (part edge). An interactive interface is used to control the camera and projector settings and display the calculated measurement results during the build cycle.

3. System setup and metrology method

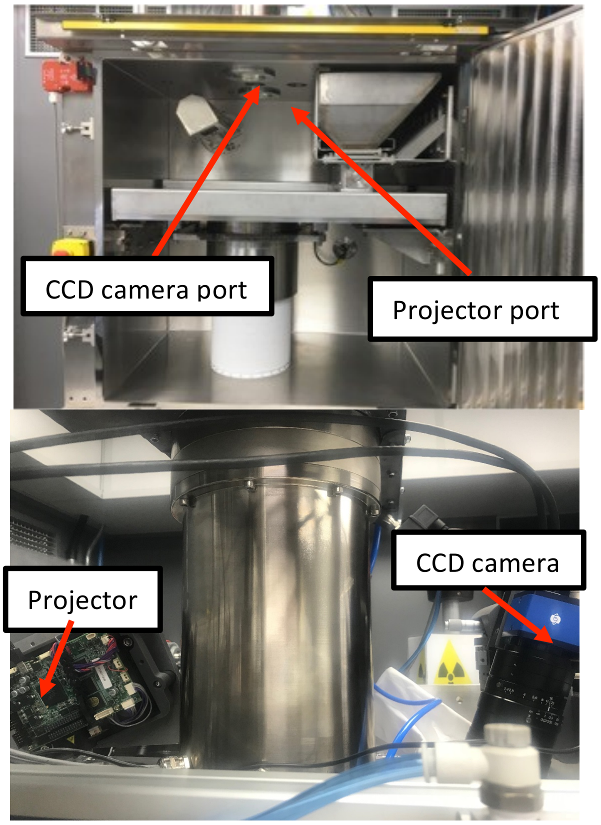

Figure 2. *E-beam system with inspection system above image shows viewing windows in build chamber. Lower Image shows camera and projector*

Figure 2 shows the deployment of the proposed in-situ system on a new E-beam system. An off the shelf relatively inexpensive Light Crafter DLP projector and the (SVS) CCD camera are positioned outside of the vacuum chamber with the viewing ports underneath the camera and projector. The pre melt powder temperature is 400 °C with the final melting/printing temperature being 1400 °C. The principle of fringe projection system is triangulation where sinusoidal fringe patterns are generated by a computer and projected onto the surfaces of the powder through the projector. The deformed fringe patterns are captured by the camera and analysed in order to quantify defects across a large area of the powder bed[3]. A novel calibration method based on a surface fitting algorithm and a set of certified ceramic plates and "chess boards" is employed to reduce the influence of phase error and random noise and to calibrate to x y and z axes.

4. Fringe projection system evaluation and quality control

4.1. System evaluation

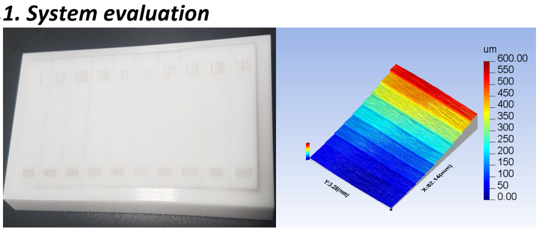

Figure 3. *Illustration of the standard ceramic step and measured 3D shape data*

A set of standard ceramic steps gauges was measured with the proposed fringe projection measurement system as illustrated in Figure 3. The measured results obtained by the inspection system were compared to the standard step gauge values. The maximum absolute error was 10.2 µm. The standard deviation is 15.8 µm and the repeatability is 6.8 µm.

4.2. Powder bed quality control

An interactive interface is used to display the calculated measurement results in the build cycle. The software consists of image capturing mode, powder delivery mode, melting mode and display mode. 3D shape measurement results of powder bed and part edge are calculated and shown in display mode. The time for one data capture cycle is 2 seconds. Based on the measurement results, the AM process can be adjusted to maintain part quality. Figure 4 shows two simple annular αTi printed parts with clear edge swelling issues and associated powder "wake" problems. Figure 4 shows the reconstructed results of two intermediate layer during the build (layer 45 and 255) where the issue of part swelling and powder wake are clear. In fact for layer 255 the part swelling was so severe that powder rake damage occurred resulting in excessive powder delivery and the appearance of a ridge across the image.

Figure 4. *Two annular printed parts showing part swelling and powder "wake" issues (parts at build termination)*

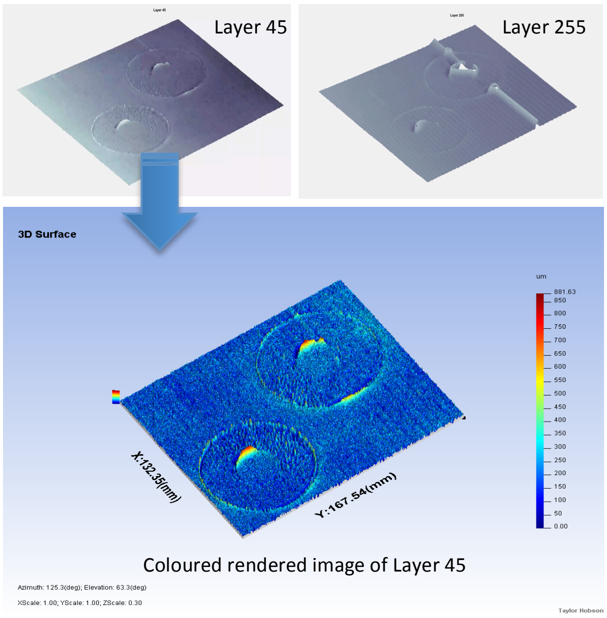

Figure 5. *In-process captured images of 3D printed parts layer 45 and layer 255*

Figure 6 shows an image of the parts shown in figure 5 having been scanned post build using a Romer Absolute Arm (laser scan mode). Though Figure 5 and 6 show different layers the scale of the swelling is similar and verifies the capability of the system for assessing build defects.

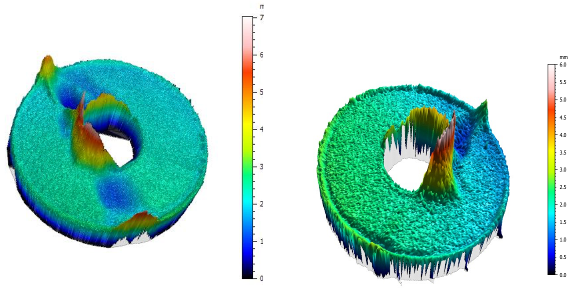

Figure 6. *Reconstructed 3D shape results of the two annular printed parts showing part swelling and powder "wake" issues measured using Romer Absolute Arm.*

5. Conclusion

This paper has shown the deployment of an E-beam additive manufacturing machine with a fringe projection system for powder bed detection. Powder bed inspection by using fringe projection technique was taken every 15 layers. The vertical resolution is 15.8 µm and capturing speed is 2 seconds. Some defects like lack of powder and excessive powder delivery issues are explained.

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