Study on real-time detection method for electron beam selective melting process

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Abstract—In order to solve the problem of lack of effective and real-time monitoring evaluation method for electron beam selective melting (EBSM) processing, a technique of acquiring real-time secondary electron (SE) imaging through layer-by-layer scanning is presented, which could monitor the defects of components. Basic design scheme, including the Electron beam scanning system, signal processing and imaging system, is introduced in this paper. Capability of generating digital image and choosing different monitoring area for the real-time monitoring system has been verified by series of experiments. Results suggest that the maximum resolution of the prototype has reached 0.3mm.

1. INTRODUCTION
Electron Beam Selective Melting (EBSM) technology has attracted wide attention, belongs to an additive manufacturing (AM) technology [1-3]. Compared with the traditional casting technology and cutting processing technology, EBSM is a "bottom-up" technique to obtain processed parts by "discrete stacking"[4-5] of materials based on 3D model data. EBSM can manufacture components that are difficult to manufacture with traditional processes, and the mechanical properties such as tensile strength of the components are superior to parts manufactured with traditional processes [6]. In addition, EBSM technology, which has the advantages of high energy utilization, extensive processing materials, and no pollution to the vacuum environment. Therefore, EBSM has become one of the most popular and commercially-available power in bed Additive Manufacturing (AM) methods since Larson applied for a patent for direct preparation of metal components using powder bed selective melting technology in 1994.

Although EBSM technology has been widely used by countries around the world for its unique advantages, this technology has many limitations which include: (1) Distortion of beam spot shape which is caused by large deflection of electron beam. (2) Uncertainty of weld pool shape and temperature. (3) The difficulty of controlling the thickness and uniformity of powder bed. All the challenges faced by EBSM could cause defects such as non-fusion, porosity, cracks, warping deformation, slag inclusion appear in the components [7-8]. This deflection will affect the quality of components. Therefore, it is necessary to monitor the components quality of each layer in the process of EBSM and it could ensure the quality of components and provide information for enhancing
manufacturing process. This monitoring method could provide significant information for improving the molding process, which is more conducive to optimizing the structure design of the electron gun.

2. THE PRINCIPLE OF IMAGE ACQUISITION

The high-energy electron beam will interact with the surface of the components and generate different electronic signals, such as secondary electrons (SE), backscattered electrons (BSE), X-ray, auger electrons, absorption electrons when the deflection coil controls electron beam to scan the surface of processed layer. The SE escape depths of about \( \lambda \approx 1 \) nm from metals and so the SE yield counts on the topography of the specimen [9]. Normally, \( \delta \) increases with increasing angle of incidence \( \theta \) measured relative to the surface normal for \( \theta < 80^\circ \) according to Equation (1) [10].

\[
\delta = \delta_0 \times \sec \theta
\]

Where:

\( \delta_0 \) is defined as the secondary electron yield of the specimen surface irradiated vertically by the electron beam.

\( \theta \) is defined as the normal angle between the electron beam and the sample surface.

Actually, the morphology of the samples is uneven, but it could be considered as composed of many extremely small planes with different tilt angles. Because the deflection angle of the electron beam is small, the direction of the incident electron beam can be regarded as fixed. So according to Equation (1), there will generate different numbers of SE when the electron beam deflected to different positions on the specimen as illustrated in Figure 1. A special sensor, shown in Figure 2, will be used to capture the feedback electrons when the electron beam is controlled to do raster-scanning. The 16-bit analogue-to-digital converter (ADC) will convert the electron signal captured by the detector into a digital signal as the electron beam move from one position to another. Then, an image will be produced from the digital signal. Figure 4 shows the relationship between the sample point and the trajectory of electron beam. Because of the interference factors such as high voltage system and uneven beam power distribution in the electron gun, the quality of image is degraded. Then, a signal processing system, consists of a differential signal amplifier and an ADC, was established. Figure 5 presents the block diagram of the differential signal amplifier and ADC.

3. ELECTRON BEAM SCANNING SYSTEM DESIGN

To acquire electron signal, the host computer sends an instruction to make the electron beam to do raster-scanning. Figure 3 gives an instance of typical machine X and Y scan signals during raster-scanning and Figure 4 shows the corresponding trajectory of electron beam raster-scanning. The scanning system actually outputs a step signal when the electron beam is deflected from one sampling point to another.
Due to the response characteristics of the deflecting coil, the electron beam will jitter near the sampling point and stabilize at the sampling point finally, see in figure 6. Without the appropriate sampling delay time, the AD sampling system will collect inaccurate sampling values. Thus, it is necessary to set a proper delay time to avoid this problem. The minimum delay time for sampling should be set to $t_{\text{min}} = t_2 - t_1$, which can be measured by oscilloscope. The minimum delay time measured by the system is 2 ms.
4. EXPERIMENT

Electron beam scanning system, electron signal acquisition system and image generation software together formed an electronic imaging prototype for the EBSM process. The experiment tested the ability to produce electronic images according captured electron signal when interfaced with the EBSM machine at the room temperature. In the experiment, the prototype was interfaced with the EBSM machine to acquire feedback electron signal from the component made by Ti-6Al-4V at room temperature. In order to verify that the prototype could generate more clearer image as the magnification of imaging increases, the electron beam was controlled to do raster-scanning on the monitoring area. Figure 7 (a) (b) (c) (d) show the image with different magnification. The prototype was interfaced with the EBSM machine and electronic imaging trials were carried out under room temperature. It can be seen from Figure 7 (a) to Figure 7 (d) that the image becomes clearer and clearer as the scanning area become smaller and the prototype achieved monitoring different area flexible. In addition, the maximum resolution of this system, measured by the industrial microscope, has reached 0.3mm.

Figure. 6 Schematic diagram of coil
Figure 7. (a) (b) (c) (d). Results of the electron beam scanning different areas of the component made by Ti-6Al-4V; (e) shows the real morphology of the component.

5. CONCLUSION
A real-time monitoring system prototype for EBSM has been designed to generate digital image by capturing feedback signal. Capability of the prototype was verified by the test. It is observed that the prototype could select different monitoring area and the digital image has higher resolution than image generated by conventional method. It is believed that the electronic imaging system prototype could be used for evaluating the quality of the processing layer in real time and improving the processing technology of components.

ACKNOWLEDGMENTS:
This paper is supported by the national key research and development plan of China (2018YFB1105202).

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