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A Beam Diagnostics System of Electron Beam Melting For Additive Manufacturing

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Introduction

In this poster, a beam diagnostics system will be proposed for electron beam melting (EBM) process which diagnoses beam current, beam spot size for enlarged and focused beams, scanning velocity of the deflected beam, and profile of the beam. While proposed system makes use of SEM grid sensors to measure beam spot size and deflected beam scanning velocity, a novel method is put forward to measure the profile of the electron beam. The EBM test system under investigation in this poster consists of three main parts, namely electron source, electromagnetic lenses, and test chamber. The source is where the electron beam is generated by Lanthanum Hexaboride cathode at 60-100 kV. To manipulate the beam, several electromagnetic lenses are used such as focusing, correction and deflection lenses, which are essential for additive manufacturing process. Finally, the high-power electron beam hits to the target plate on the test chamber, on which selective metal powders can be used to conduct EBM experiments. The test setup system structure is as shown in Fig. 1.

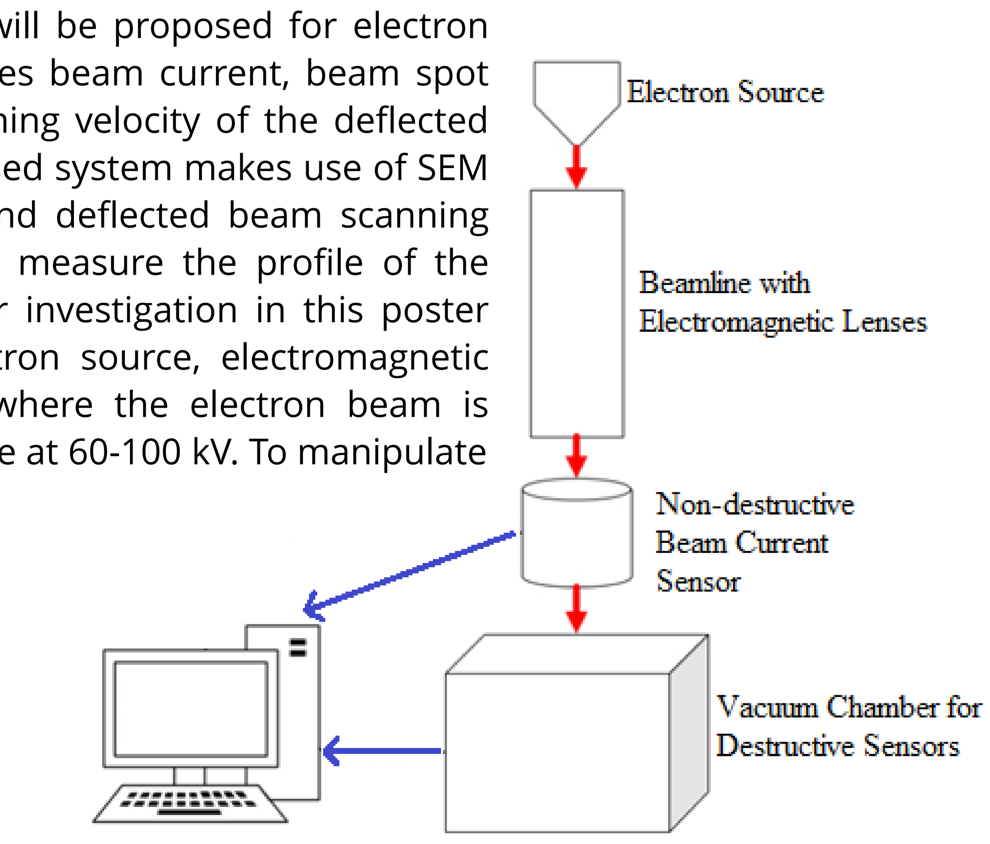

Figure 1: Overview of the EBM test setup and the proposed beam diagnostics system

Methodology

The proposed beam diagnostic system, shown in Fig. 1, is intended to measure the following beam properties, which are important specifically to electron beam melting for additive manufacturing:

i. Beam Current
ii. Beam Spot Size for enlarged and focused beams
iii. Scanning velocity of the deflected beam
iv. Beam Profile

The destructive sensors are located in the vacuum chamber and non-destructive ones are on the beamline as shown in Fig. 1. In this part, measurements of intended beam properties are described in detail.

A) Beam Current Measurement

As the electron beam under investigation is a high energy one because of the requirements of additive manufacturing, the current should be measured via non-destructive means. The existing destructive current measurement techniques are either not standard products, hence expensive, or in a very high volume due to dissipated power.

The type of the current, on the other hand, should in a DC form because of the contour tracing, heating and melting modes of operation of additive manufacturing. In these modes of operation, beam current is required to be constant. Mentioned requirements mandates the proposed beam diagnostic system to use non-destructive DC Current sensors with a microsecond grade fast response type. Authors propose using of DC Transformer type non-destructive current sensors [1], [2] for this purpose.

B) Beam Spot Size and Scanning Velocity Measurements

Beam spot size is one of most important properties of the electron beam which will precisely melt the metal powders on the target plate for additive manufacturing purposes. Different spot sizes show different melting behaviours with different times that the beam should be directed on to the unit length of metal powder. Besides, the spot size is intended to be kept as small as possible to ensure the precision on the additive manufacturing application.

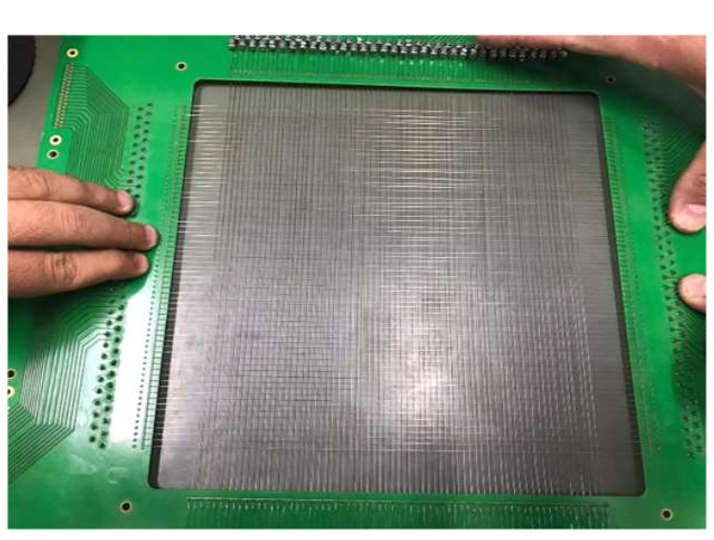

Figure 2: Manufactured SEM Grid Sensor

The proposed beam diagnostic system is intended to measure the spot size of both focused and enlarged beams. When the beam is enlarged, the overall energy of the beam is distributed on a large area, which makes easier to detect the spot size. This enlarged beam spot size measurement can be used to calibrate the electromagnetic lenses along the beamline and to ensure the precise positioning of the beam on the target plate. This diagnostic system proposes the use of SEM Grid Sensors [1], [2], the manufactured grid sensor is as shown in Fig. 2.

On the other hand, the focused beam spot size should also be measured because of the earlier mentioned reasons dictated by additive manufacturing. As the energy density is extremely high, when the high energy electron beam is further focused, either the electron beam should not be directed on a measurement system for a long time, or the measurement system should be extremely large to handle high energy densities. To overcome the high energy density problem, a novel method is used to detect the focused beam spot size. The proposed method uses the SEM Grid readings by deflecting the electron beam as shown in Fig. 3.

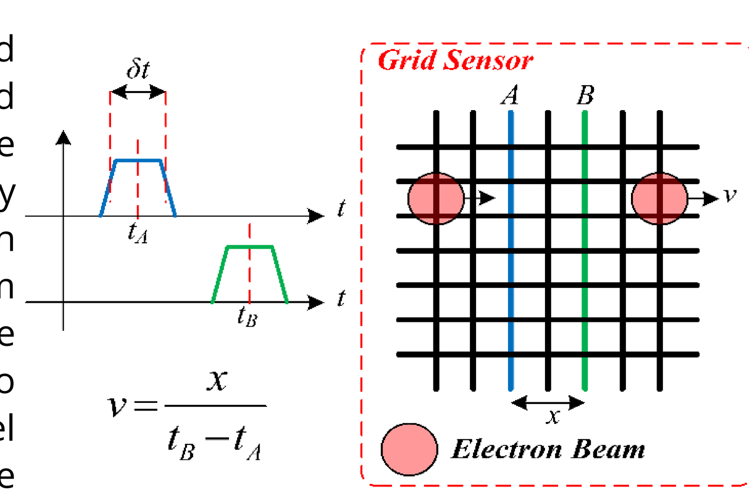

Figure 3: Proposed spot size and beam velocity estimation method using grid sensor

As shown in Fig. 3, the deflected electron beam passes through wires A and B, and blue and green waveforms are expected in the oscilloscope corresponding to wires A and B, respectively. The scanning velocity of the deflected beam can be measured by using the instants t_A and t_B that beam crosses wires A and B and the distance between them. Using this scanning velocity, one can also measure the spot size of the focused beam by using the time passes while the beam is crossing wire A, namely δt.

C) Proposed Beam Profiler

The beam profiler is an important tool to assess the disturbance of electromagnetic lenses along the beamline. For this reason, a novel destructive beam profiler is proposed in this poster. As the energy is high, measurement of the beam profile with destructive methods is not very easy. Therefore, beam is used in a pulsed mode, and it is not focused. The proposed beam profiler is composed of stacked copper plates having openings with various radii on their center as illustrated in Fig. 4. These openings are stacked in a way that the largest opening is on top of all, and the others are put in a descending order in terms of their radii as shown in the top view illustration of the proposed beam profiler in Fig. 5.

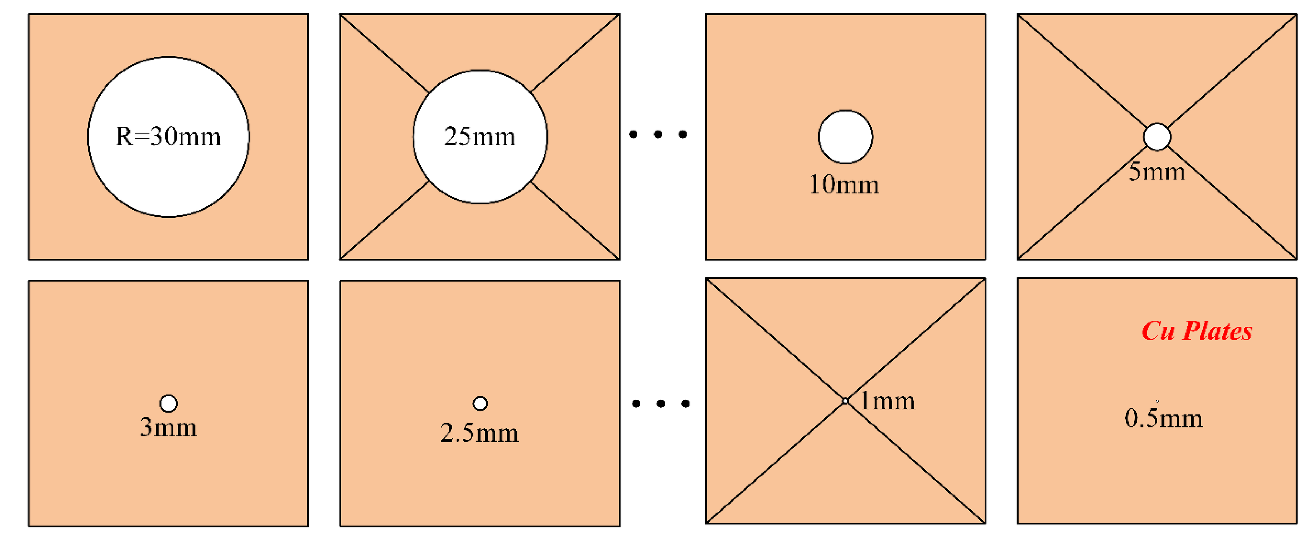

Figure 4: Copper plates of the proposed beam profile detector

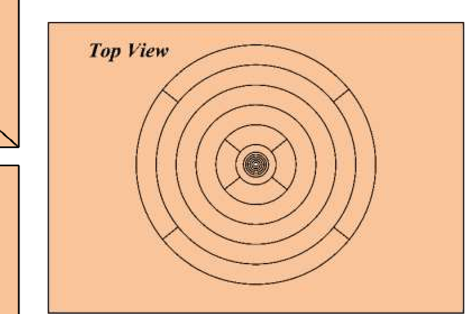

Figure 5: Top view of the proposed beam profile detector

The proposed beam profiler should be precisely located to the beamline, and this is ensured by using the segmented plates in some layers. This is achieved by measuring the segment currents and making them equal, assuming the beam profile is symmetrical.

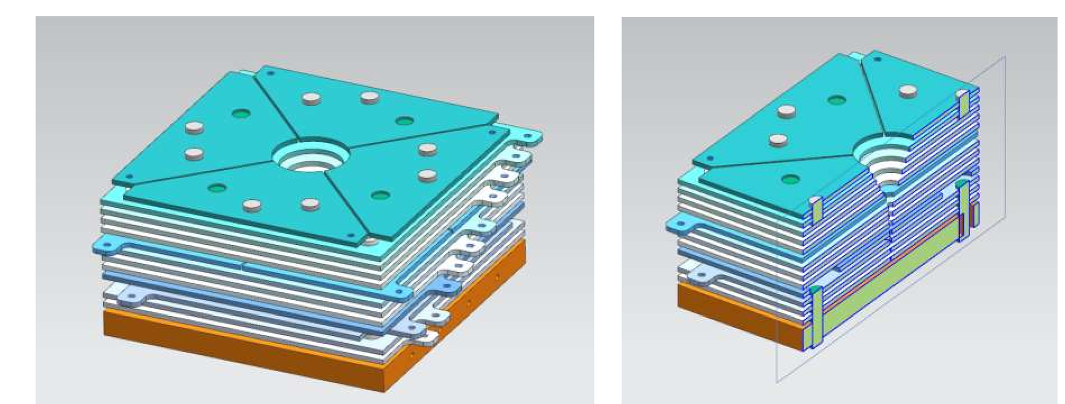

Figure 6: Mechanical design of the proposed novel beam profiler

The operation of the beam profile is such that as the beam hits towards the profiler, its portions smaller than the opening of a plate continue its way, while the others hit to the corresponding plate. The portion of the beam which hits to a plate is measured for each of the plates until the beam is finally hit to a dump plate at the bottom. The current densities are calculated by using the measured current and the corresponding effective area of each copper plate. The proposed novel beam profiler is put forward first time in the literature and it is mechanically designed as shown in Fig. 6. The designed beam profiler is under manufacturing, only the analytical calculation results of expected beam profiler output is given in the results part of the poster.

D) Data Collection and Merging

The data which is produced by forementioned beam diagnostic sensors will be collected at a Central Control Unit. Along with the data coming from the High Voltage Power Supply (HVPS), those data will be evaluated, compared and merged. The non-destructive current sensor will always be attached on top of vacuum chamber and will be sending data online. The data coming from non-destructive current sensor and HVPS will be used as a feedback to control the beam current even with changing wehnelt/grid conditions. The comparison of those two will also be used for the safety of the system. Offline comparisons and merging algorithms will be used to obtain more precise results where the limits of the sensors coincide. Beam spot size and beam profile for enlarged beams, or beam scan velocity for small angles are examples of those cases. The change at the beam quantities due to a change at system parameters can also be measured with different sensors, recorded, postprocessed offline and merged.

Results

Some parts of the proposed beam diagnostics system are already integrated to the electron beam additive manufacturing test setup, while some others are still in manufacturing or testing phase. For this reason, initial tests are performed only with current measurements, while beam profiler outputs are given as analytical calculations for a synthetic electron beam. As the novel beam profiler proposed in this work is still under manufacturing, only its theoretical results considering the analytical calculations is illustrated. As the currents that hit to the effective area of each copper plate is measured, its corresponding current density should be calculated by dividing the current value by the area of the effective ring surface that faces the electron beam. Then each of the current densities for corresponding ring areas should be drawn in a 3D graph as illustrated in Fig. 7.

The results shown in Fig. 7 is deduced using a synthetic gaussian shaped electron beam. The form of the result graph of the beam profiler is in a close correlation with the synthetic electron beam profile. The expected calculations give a hint that the proposed beam profiler is very effective for diagnosing the beam profile of symmetrical electron beams.

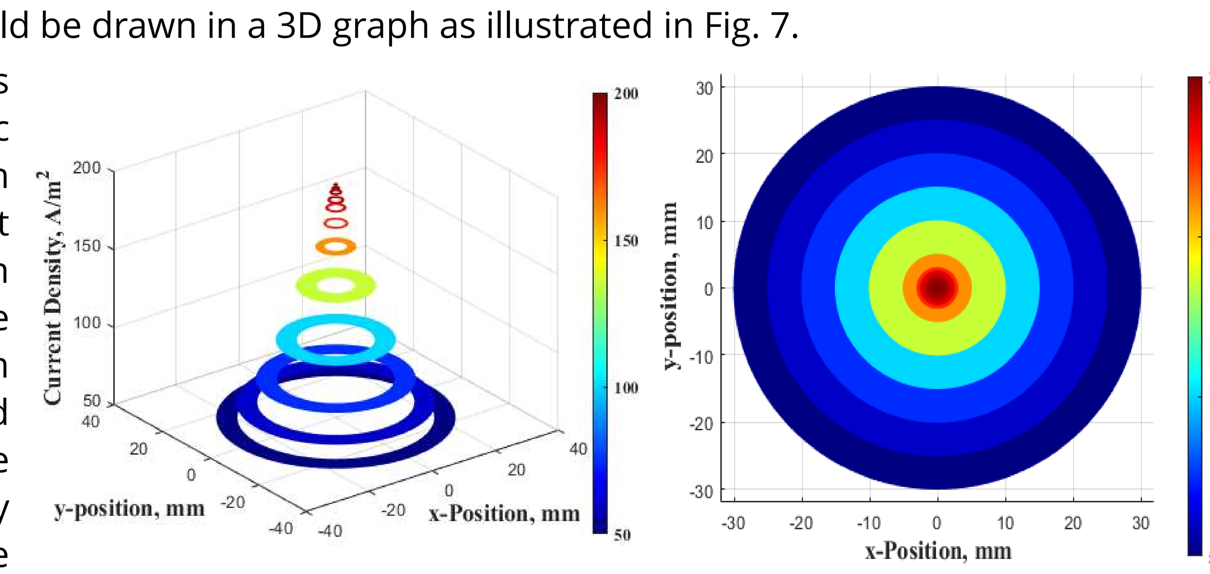

Figure 7: Analytical results of the expected performance for the proposed beam profiler: 3D view (on the left) and top view (on the right)

Conclusion

As EBM is getting more popular for AM purposes, the electron beam diagnostic tools and systems needs to be integrated to ensure precision and handle calibration needs. In this work, a beam diagnostics system is proposed for EBM process which diagnoses beam current, beam spot size for enlarged and focused beams, scanning velocity of the deflected beam, and profile of the beam. While proposed system makes use of SEM grid sensors to measure beam spot size and deflected beam scanning velocity, a novel method is put forward to measure the profile of the electron beam. As the functional tests of the proposed beam diagnostics system are still in progress, only the initial dummy victim plate tests and analytical results are included. Nevertheless, the findings of the analytical results show that the novel beam profiler device along with the other components of the beam diagnostics system is a complete tool collect, merge and evaluate the required data in order to ensure precision in AM processes and provide emergency protection and calibration of electromagnetic lens system along the beamline.

References

[1] P. Strehl, *Beam Instrumentation and Diagnostics*. Springer, 2006.
[2] P. Forck, *Lectures Notes on Beam Instrumentation and Diagnostics*. (GSI, Darmstadt, Germany) Joint University Accelerator School, January-March 2017.

Acknowledgements

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