Automated Measurement System for Laser Focus Errors in Laser Powder Bed Fusion

Samuel Parsons, UNC Charlotte
Dr. Jaime Berez, Mechanical Engineering

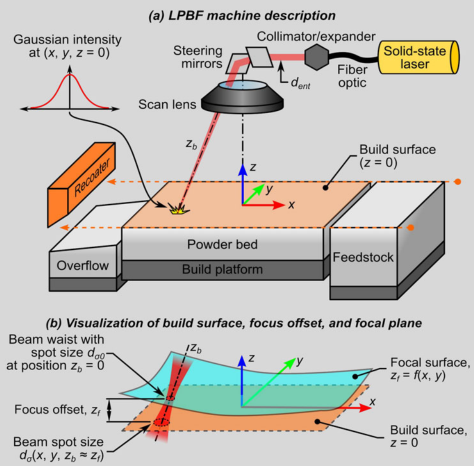
UNIVERSITY OF NORTH CAROLINA CHARLOTTE

Abstract

This work introduces an automated, high-throughput microscopy system for characterizing focal errors in Laser Powder Bed Fusion (L-PBF) additive manufacturing processes. The system comprises of a semi-inverted optical setup with a high-resolution camera and objective lens, an efficient sample handling system, and embedded software for rapid image acquisition, feature extraction, beam caustic fitting, and data analysis. The system also generates the necessary machine build files for artifact production. Preliminary results demonstrate strong agreement with manual measurements, with each sample processed in under 5 seconds, offering a significant advance toward practical, real-time focal calibration in L-PBF systems. This step is necessary to fully understand where and how errors propagate in L-PBF systems

Background

Throughout its technological history, the significant capabilities of additive manufacturing development have been haunted by limitations related to precision and repeatability. In L-PBF research, much work has been put into in-situ monitoring and printed artifact-based error characterization in efforts to increase the precision of this manufacturing system. However, the study of the machines themselves is a relatively new concept. L-PBF is prone to a wide range of process instabilities, one of which is focal offset due to the inherently non-collimated nature of the laser beam in combination with intrinsic properties of the F-Theta scan lens that is used to focus the beam onto the planar powder bed. This can result in variations in energy density and lead to critical defects such as lack of fusion and internal stress inconsistencies.

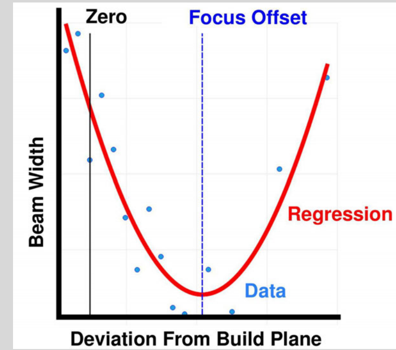


Focal Error in the L-PBF Process

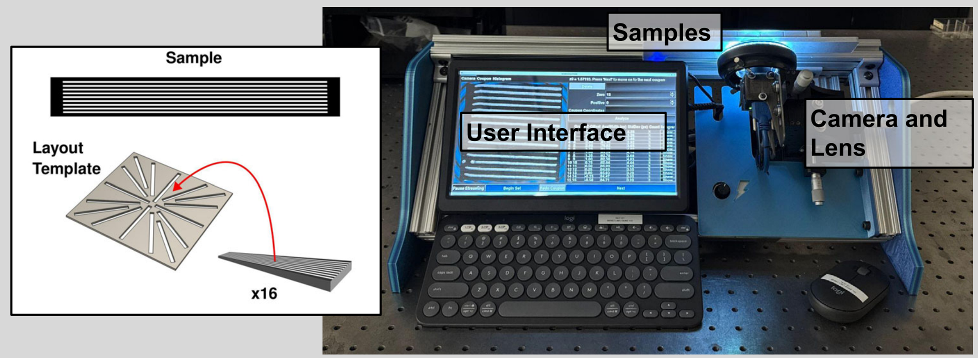
Methods

The method in which this system uses to determine focal errors in L-PBF systems relies on the correlation of defocused beam spot size to focus offset, which naturally has a hyperbolic change with respect to deviation from the focal point[1]. The measurements are accomplished by programming L-PBF machines to produce engraved lines on test samples spread across machine build chambers at a variety of heights. From here, the thicknesses of the lines will correlate to a beam spot size each offset. By applying a hyperbolic regression to this width data with respect to programmed z-height, the minimum of this regression will correspond to the focus error.

The automated system starts by acquiring a high definition of each test sample. Within each test sample, the image is binarized, then contours are detected. principle component analysis is conducted through each contour to determine the orientation vectors relative to the image. Contours are split across the primary vectors and measurements are taken along the secondary vectors. This data is filtered, and the average saved for each. With measurements complete, the hyperbolic beam caustic equation is fit to the data to yield the focal offset as the minima.



Example Data and Focal Error Calculation



Full Error Characterization System

Results & Conclusions

Results show a strong alignment of width data to the expected width from the mathematical model. Data from the automated system also heavily lines up with manually acquired data, at a small fraction of the time and effort. The embedded software allows for easy data acquisition, analysis, and visualization.

This successful proof of concept opens the door for future innovation into further optimization in the mechanical layout, sample design, data processing, and other aspects of the system.

Acknowledgements

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References

[1] Jaime Berez, Enea Dushaj, Elliott Jost, Christopher Saldana, and Katherine Fu. Measurement of focal plane error in laser powder bed fusion machines. Additive Manufacturing Letters, 9:100196, April 2024.