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Preliminary geometric tests of an open-source metal laser powder bed fusion system

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Abstract
Commercial metal laser powder bed fusion (L-PBF) systems typically restrict the user's ability to use the machine freely. This inhibits certain research activities, slows others, and lacks transparency. The additive manufacturing group at the Technical University of Denmark offers an alternative; a fully open-source L-PBF system using a modular and open system architecture relying heavily on off-the-shelf components. Verification efforts were initially concerned with robustness, stability, and attaining dense components. Presently, a geometric benchmark component will be discussed and analyzed, evaluating the geometric precision of the system's current state. The system could manufacture nearly all the features on the benchmark piece.

Open-source, laser powder bed fusion, L-PBF, open-architecture

1. Introduction

L-PBF creates 3D objects by selectively melting fine metal powder layer-wise with a laser [1]. Commercial systems often limit material and process parameter choices. As an alternative to the state of the industry, an open-source L-PBF system is publicly disclosed for collaborative improvement and adoption, aiming to advance L-PBF research and lower entry costs. As L-PBF is often used for intricate details and complex geometries[2], the system's geometric capabilities are tested with a benchmark component to identify feature sizes, precision, and potential system calibration.

The work is part of a twin effort to analyze the same geometry on the two open PBF systems at the Technical University of Denmark. Both use the same galvo scanner, laser source, slicer, and system controller; one is polymer-based (SLS), and this work's subject is metal-based.

2. Methodology

The benchmark geometry (Figure 1) was manufactured on the open-source L-PBF system. The benchmark geometry was developed to test various features[3,4], including hollow spirals, vertical and horizontal holes, cylinders, thin walls, etc. A visual inspection and optical measurements verified the benchmark geometry.

2.1. Benchmark manufacturing

The benchmark was manufactured using 316L stainless steel powder (20-53 µm) from Höganäs (Höganäs, Sweden) using the process parameters in Table 1.

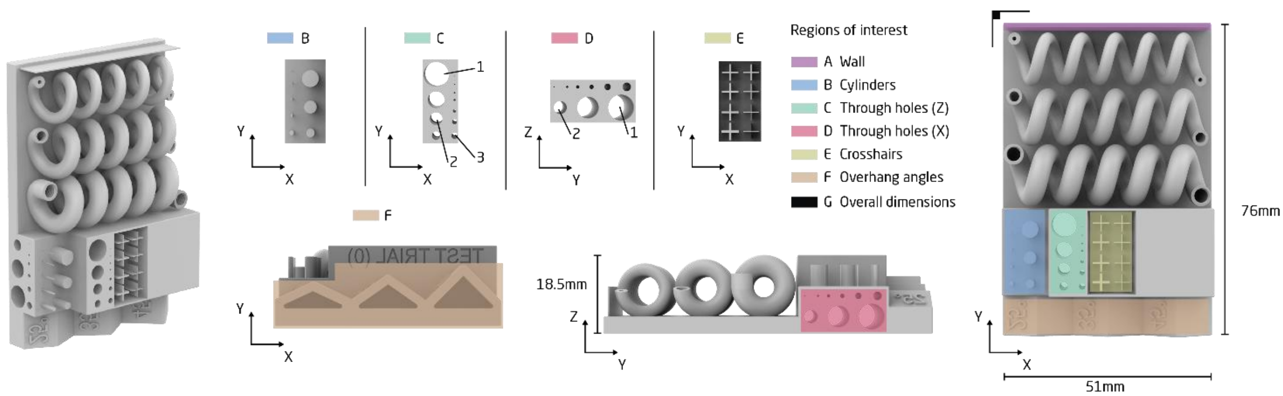
Table 1 Process parameters used to manufacture the benchmark geometry.

Feedrate	Power	Hatch	Layer	VED
750mm/s	220W	100µm	50µm	58.7 J/mm^3

The components were manufactured using nitrogen as shielding gas and a crossflow of min. 2.5m/s. The laser spot size of the system is 90µm.

The job was generated using Netfabb Premium (Autodesk, USA) with a custom script converting an XML output format to the G-code-inspired syntax used by the system controller. Netfabb allows for fast and easy integration of island-scan strategies, contour adjustments, etc. The part was manufactured without the contour scan to assess the geometric capabilities of the hatch pass in isolation. A controller bug resulted in a mirrored geometry.

Figure 1 Benchmark geometry.



	A	A1	A2	B	C	C1	C2	D	D1	D2	E	F	G1	G2
Insp.														
Feat.				1	0.5			1			0.2	35		
µ [mm]		0.41	7.04			5.92	2.90		5.91	2.76			77.31	51.81
σ [mm]		0.0072	0.0025			0.0022	0.0010		0.0007	0.0084			0.0003	0.0004
Nom. [mm]		0.3	7			6	3		6	3			76	51
Δ [mm]		0.112	0.041			-0.078	-0.101		-0.091	-0.242			1.311	0.812
Δ [%]		37.3	0.6			-1.3	-3.4		-1.5	-8.1			1.7	1.6
R [mm]		-	-			0.128	0.088		0.456	0.312			-	-
σR [mm]		-	-			0.006	0.003		0.002	0.002			-	-

Table 2 Results of the benchmark geometry with visual inspection above and DeMeet measurement below.

Figure 2 The manufactured benchmark geometry.

2.2. Benchmark evaluation

The benchmark components were evaluated along two tracks. 1: an overall inspection to determine the minimum feature of a given geometrical category (Figure 1) along with potential surface defects. 2: selected features were measured using a DeMeet 400 (Schut Geometrical, Netherlands) optical 3D CNC coordinate measuring machine to compare the nominal dimensions according to the CAD file. A measuring program was made to measure each dimension of interest five times. Where possible, the roundness was found by the DeMeet software. Each geometry category was rated red or green. Green is defined as all elements manufactured successfully, whereas red equates to a least one failed element. The evaluation of the benchmark is on the as-printed state.

3. Results

The manufactured components showed potential for improvement; however, the promising initial geometric result bodes for excellent future performance. The results are summarized in Table 2 with the visual inspection (Insp.) above and the nominal dimension of the smallest manufactured feature (feat.) within the geometry category.

3.1. Visual inspection

A thin-walled structure [A] was manufactured straight and complete. The thinnest free-standing cylinder [B] had a diameter of 1mm, where 0.5mm was bent and smaller did not manufacture. The smallest vertical hole [C] with passage all the way through was 0.5mm in diameter, whereas the horizontal holes [D] could not manufacture below 1mm in diameter with some dross formation along the top surface. Among the thin-walled crosshair structures [E], the three

smallest failed, with the smallest having a wall thickness of 0.2mm. All the overhang elements [F] were manufactured successfully; however, dross formation under the 25-degree overhang means the minimum acceptable overhang angle is 35 degrees. While outside the scope of the analysis, the three hollow spirals were manufactured successfully with a clear passage.

3.2. Measurements

The measurements showed that not all the features came out with the nominal dimensions. All the measurements produced by the DeMeet were relatively tightly grouped, with standard deviations, σ, around tens of microns or better. The means, µ, compared to the nominal dimensions, nom., formed the basis for the assessment. The thickness [A1] and the height [A2] of the thin-walled element emerged better than expected; in particular, the height (along the build direction) had the slightest deviation of all the elements. The 18.5mm deep vertical holes (6mm and 3mm) [C1, C2] were measured as 80µm and 100µm under the nominal dimensions, respectively. The roundness of the two holes was of a similar order of magnitude, with the inherent as-printed roughness being the main culprit. The 6mm and 3mm horizontal holes [D1, D2] fared slightly worse, with the smallest diameter being 0.24mm below nominal. Also, the roundness was significantly worse, primarily due to the dross effectively flattening the top portion of the hole. The major dimensions of the geometry baseplate were 1.3mm [G1] and 0.8mm [G2] above the nominal dimensions. An erroneous calibration of the galvo scanner controller caused this.

4. Summary and conclusion

The L-PBF system can manufacture sub-millimeter details within 0.2-1mm, depending on the feature type, at the current state. The main dimensions showed a need for further calibration of the galvo scanner movements relative to the building envelope. This misalignment is not a fundamental system flaw but merely fine adjustments to a single parameter in the controller firmware. The slight error mainly significantly impacts larger-scale dimensions. This miscalibration was unnoticed for months as the deviation is insignificant in, e.g., 10mm specimens for materials testing. This is catastrophic for bigger and more functional components. The dimensions in the build direction were generally closer to nominal dimensions, further suggesting the error is to be found in the galvo scanner control settings. The measured features experienced material growth, as the holes were smaller, and the wall was bigger than nominal. To mitigate will likely require slicer-settings alterations. The contour-scan when implemented fully, will alter dimensions and surfaces further and must be compensated for.

References

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