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An Overview of Structured Light Scanning (SLS) inspection of an Additively Manufactured small Turbojet Engine Nozzle

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ABSTRACT: *Additive Manufacturing has made it easier to manufacture complex configured parts like that of a turbojet aero engine. However, ensuring the dimensional/geometrical accuracy and surface quality remains a paramount challenge. The current paper explores the application of 3D structured light scanning (SLS) for dimensional and geometrical inspection of the additively manufactured small turbojet engine nozzle. The paper discusses the specific considerations for inspecting AM parts due to their inherent layerwise build process and the advantages offered by structured light scanning in this context. It highlights the suitability of structured light scanning for capturing intricate geometries and facilitating rapid, non-destructive inspections.*

NOMENCLATURE

AM	Additive Manufacturing
CAD	Computer Aided Drafting
CMM	Coordinate Measuring Machine
SLS	Structured Light System
STL	Standard Tessellation Language
FOV	Field of View
SLS	Selective Laser Sintering

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I. INTRODUCTION

Additive manufacturing offers vivid design freedom and ability to create intricate geometries for components like that of a small turbojet engine. However, stringent quality characteristics like dimensional, geometrical and surface quality etc. are essential for the good performance and safety of the engine. The contact type 3D inspection method like Coordinate Measuring Machine (CMM) can be time consuming and also poses a measurement challenge due to rough surface which can affect the probe and also can potentially damage the delicate AM parts if there are any. 3D structured light scanning as shown in figure 1, provides a comprehensive solution for high-resolution data capture ideal for inspecting and analysing intricate features and also identifying potential defects in addition to noncontact dimensional inspection [1].

Fig 1: Structured Light Scanner

There are numerous challenges which need to be taken in to consideration for inspection of the AM parts and include:

Surface Topography: As the manufacturing process is a layer by layer deposition, the surface is a textured one with high surface roughness value. While scanning the surface roughness can introduce noise and affect the measurement accuracy.

The support structure removal also can lead to surface irregularities that can have an effect on the projected structured light pattern and will require additional data processing.

The material structure of the AM parts also has a substantive effect on the effectiveness of the structural light scanning process. Specular surfaces will require tweaking of the scanning parameters or surface treatment for the optimal results.

In 3D-SLS a projector casts a patterned light (usually stripes or grids) onto the surface of the object being scanned. Cameras capture multiple images of the deformed pattern from different viewpoints. Specialized scanning software then analyzes the distortion of the pattern to create a highly accurate 3D representation of the object's surface with the help of the point cloud and then turning it in to a STL model [2,3].

The scanner (figure 1) used is based on the principle of triangulation in which the position of a point is determined by forming a triangle between projector, the object and the camera. This principle involves steps of projection of a light pattern (blue in this case), image capture, pattern distortion and triangulation calculation using known positions and angles of the projector and cameras (two in this case). Along with the captured images of distorted pattern, the system calculates the 3D coordinates of points on the object's surface through triangulation. The 3D coordinates (x,y,z) of point on the object's surface are given as [4]:

$$x = \frac{b1tan(\theta 1) - b2\, tan(\theta 2)}{tan\theta 1 - tan\theta 2}$$

$$z = (x - b1)tan\theta 1$$

$$y = \tan(\alpha 1)\,.\sqrt{x^2 + z^2}$$

$$= \tan(\alpha 2)\,.\sqrt{x^2 + z^2}$$

Where

- b_1 and b_2 are baseline distances for cameras C_1 and C_2
- θ_1 and θ_2 are horizontal angles for cameras C_1 and C_2
- α_1 and α_2 are vertical angles

II. OPTIMISATION OF OPTICAL SCANNING PROCESS FOR AM TURBOJET ENGINE NOZZLE

The turbojet engine nozzle under study is manufactured using Ni-based superalloy which has high strength and thermal resistance. The part is manufactured through Selective Laser Sintering (SLS) process which often produces parts with complex geometries with high precision. There are challenges in getting the dimensional accuracy of the part through this process. Dimensional deviations can occur due to thermal stresses, powder features and layer by layer build process. These deviations necessitate accurate post-manufacturing inspection to ensure compliance to the design specifications. Structured Light Scanning process is adopted for the inspection as the surface is rough and the part is flimsy in nature. It gives a full shape capture of the part and gives a high-fidelity data capture which is required for verification of the part. The process includes pre-scanning preparation, scanning process, data processing and dimensional analysis [5,6]. The steps are shown in figure 2.

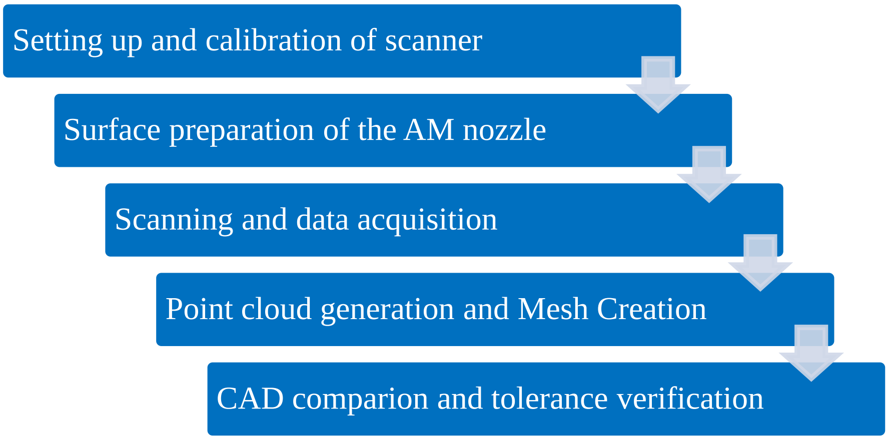

Fig 2: SLS process for the inspection of AM nozzle

Several strategies were adopted for the optimisation of the scanning process for the dimensional and geometry verification of the AM turbojet nozzle.

a) High-resolution scanning: The nozzle is scanned with an eight megapixel double camera blue light scanner to capture the finer details and mitigate the effects of the surface texture on data accuracy.
b) Data filtering and processing: Software settings are used to filter out noise introduced by the surface texture and support structure removal.
c) Surface pre-treatment: The part is cleaned thoroughly and a few micron coating of developer is applied to improve light interaction with this reflective surface.
d) Multi-view/angle scanning: The scanning is carried out at multiple views and orientations created with the help of scanner head and rotary table to overcome limitations associated with line of sight dependence for capturing full details of the nozzle.

III. SCANNING OF THE TURBOJET NOZZLE

The SLS measurement process was started with the calibration of the scanner with 300 mm FOV. The calibration accuracy was of the order of 10microns. The details are depicted in the figure 3.

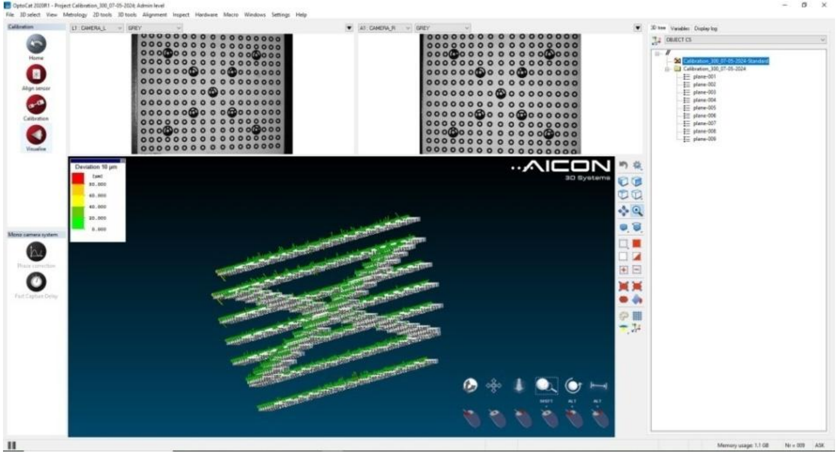

Fig 3: Calibration of SLS with 300mm FOV

The scanning here was carried out as target scanning as the part is identical. Different targets were fixed on the component surface at various places. Various other parameters used during the scanning of the AM turbojet nozzle are depicted in the following table 1:

Table1: Structured Light Scanning (SLS) parameters for AM nozzle inspection

SL No.	**Parameter**	**Value**	**Remarks**
1.	**Target: Target size**	ϕ4.00 mm	
2.	**Developer**	Magnaflux SKD-S2	
3.	**2D filter**	No filter used	
4.	**Spray compensation**	5 microns	
5.	**Image Capture**		
	a) Averaging of reduce noise	4	
	b) Number of captures per shot	1	
	c) Manual brightness	Yes	
	d) Mask overexposed pixel	Yes	
	e) Stability check	Yes	Tolerance before scan= 5% Tolerance after scan= 5% Noise ratio=3.5
6.	**Reference matching:**		
	a) Automatic matching	Yes	
	b) Distance tolerance	71 microns	
	c) Maximum matching error	36 microns	
	d) Minimum number	3 targets	
	e) Maximum number of deleted points	10 targets	
	f) Max. percentage of deleted points	5 percent	
7.	**Sensor**		
	a) Exposure time	25ms	
	b) Gain	1%	
	c) Noise reduction	4	
	d) Brightness	63	
8.	**Target Detection-Find parameters**		
	Processing mode	Automatic	
	Old data set	Overwrite	
	Type of target	Indexmark	
	Selection	White & encoded	
	Tolerance	5 Pixel	
	Point Order	Homology	
	3D threshold	0.142 mm	
	Median filter	No	

The target marked AM nozzle during the scanning process is shown in the following figure 4:

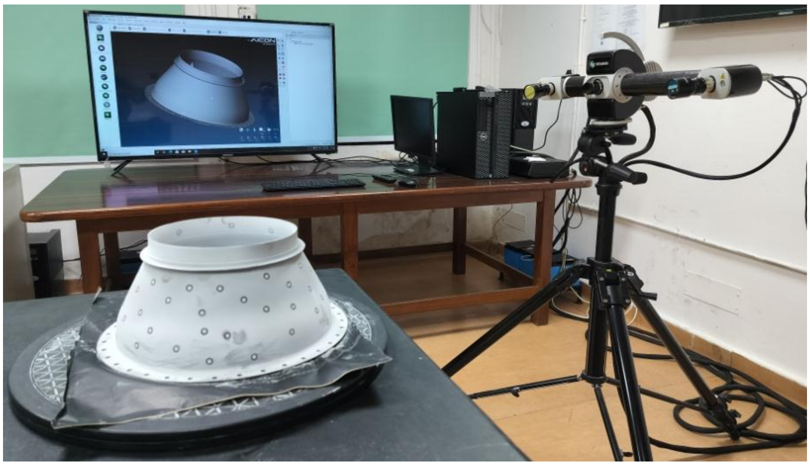

Fig 4: AM nozzle undergoing scanning process

The scanning parameters were selected as mentioned in the table above and the scanning was carried out in the automatic mode. A total of seventy five scans were taken throughout to obtain the full 360 degree view of the part. It is a water tight mesh with fill targets and spray compensation. The point cloud obtained was merged to get a STL model of the part. The CAD model and the scanned polygon model obtained are aligned through the Point Pairs alignment best fit method in the measurement software as shown in the figure 5. The best was done automatically with seven iterations with a best-fit convergence value of 0.000000395391177 against target (automatic) of 0.00000196000000.

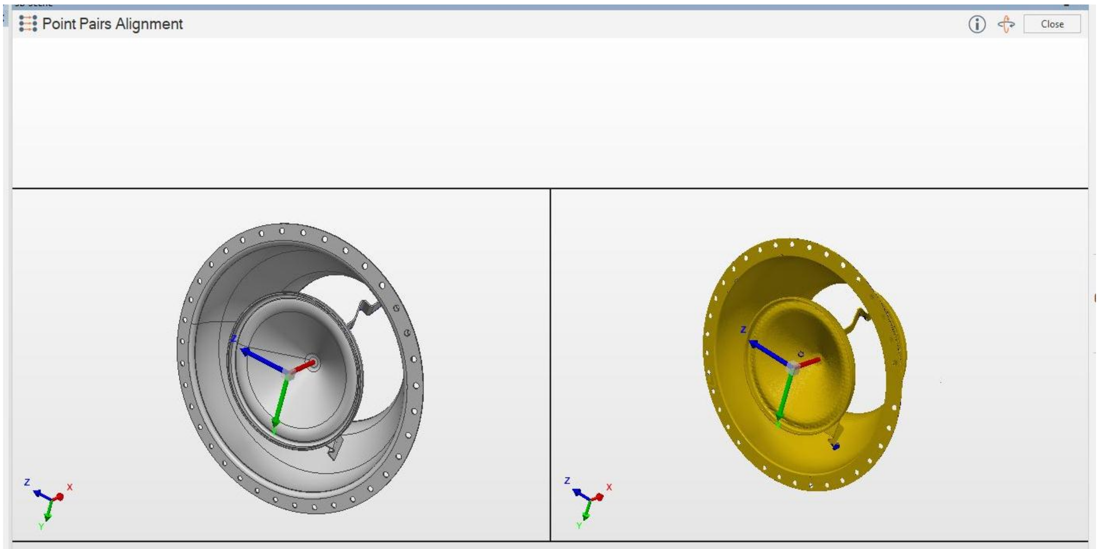

Fig 5: Alignment of part CAD model and scanned polygon model

IV. RESULTS AND DISCUSSION

All the required dimensional and geometric parameters were measured and compared directly with the design specifications form the CAD model with automatic report generation. The colour/heat map was generated after giving the minimum/maximum limits. The colour map obtained is shown in the figure 6.

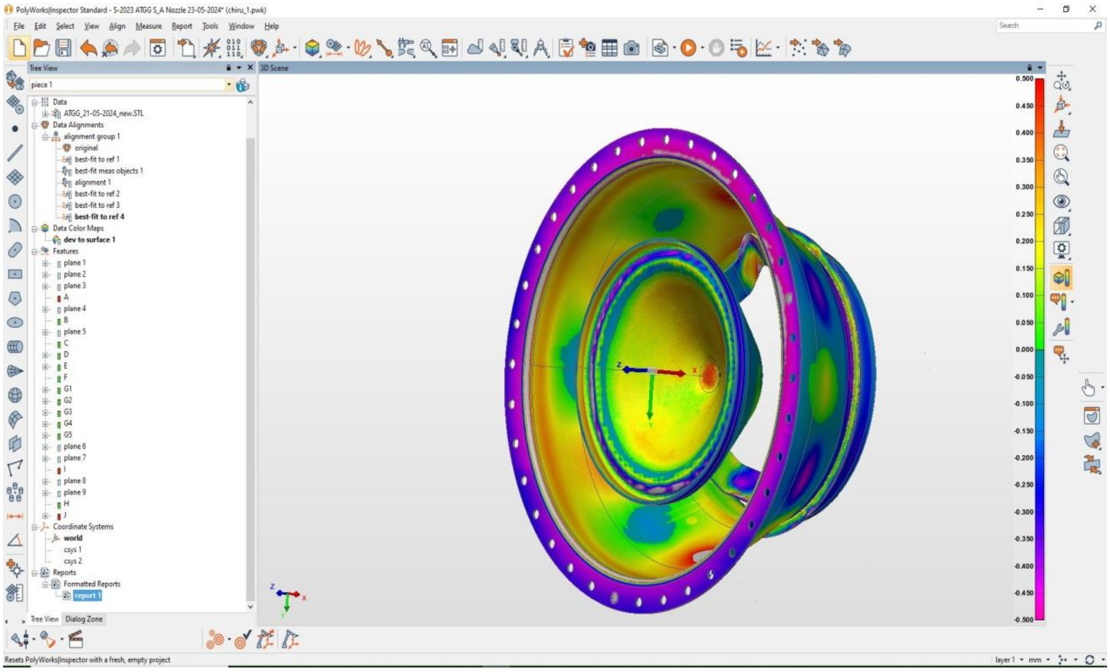

Fig 6: Colour map of the AM nozzle depicting deviations

The colour map for the sectional view was also obtained as is shown in the following figure. Going from green to red area shows positive material beyond the limit and from green to pink shade depicting negative material as compared to the limit. As the thickness is difficult to measure with conventional instruments in the flow path and other areas a cross-sectional thickness plot against the CAD model was generated to inspect the specific cross-sectional shapes and thickness variation as shown in figure 7. Similar to the above the colour mapping deviation is applied in a cross-sectional colour map to carry out the 2D cross section analysis on the specific points of the design CAD model.

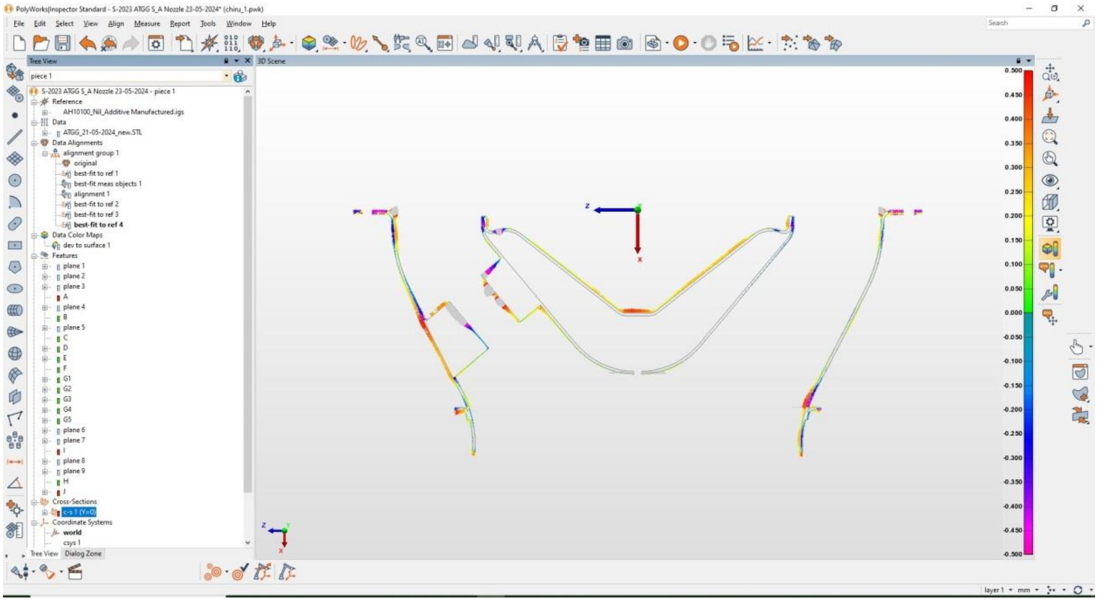

Fig 7: Colour mapping of the Cross-sectional view

The structured light scanning of the nozzle revealed minor deviations on the internal surfaces which may be primarily due to powder removal inconsistencies. All critical dimensions were within the specified tolerances, validating the AM process. The entire inspection process was completed in less than two hours, demonstrating significant time savings over conventional methods.

V. CONCLUSION

This paper aims to provide a comprehensive overview of the application of 3D structured light scanning in inspecting additively manufactured turbojet engine nozzle, highlighting the technology's efficacy and the benefits it brings to aerospace component quality assurance.

3D structured light scanning presents a valuable tool for the dimensional inspection of additively manufactured small turbojet engine nozzles. It offers a rapid, non-destructive approach to capturing detailed surface data, facilitating the detection of geometric deviations, surface defects, and potential layer-related issues. By optimizing scanning parameters, data processing techniques, structured light scanning ensures the quality and performance of additively manufactured nozzles.

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