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Comparative Analysis of Geometric Deviations in Contact Measuring Instruments for Control and Laser Contactless Scanning

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***Abstract*. The factors affecting the dimensional accuracy of 3D scanning using a measuring arm with an integrated scanner and a custom open source 3D printer using FDM technology are researched in this paper, with the purpose of isolating and reducing the sources of errors affecting the results. A consumer 3D printer is analyzed in terms of achieving accurate physical dimensions, consistent shapes, and predictable surface coverage.**

Keywords: Geometric accuracy, laser scanning, tactile sensor. 3D printing Error.

I. INTRODUCTION

Hardly any other technical field has developed as quickly in recent years as 3D printing. It not only finds application in the commercial, technological, industrial and scientific sectors, but also in private households. Interest in 3D printing [6][9] is growing rapidly, as is the variety of 3D printers for personal use. Factors such as easy development of customized products and reduction in production costs are driving more and more industries and companies to embrace 3D printing and incorporate it into their business. FDM (Fused Deposit Modeling) or FFF (Fused Filament Fabrication) are 3D printing processes where a filament in the form of a thermoplastic thread is heated in a print head and printed on a print platform through a nozzle. In this process, the chosen model is built up layer by layer. When talking about 3D printers, most of the time it is meant FDM printers. The so-called filament is a material that is wound on a spool and processed by the printer. There are a number of different materials (PLA, PETG, ABS, PE (nylon), etc.). They differ significantly in their properties. Filaments also available in different diameters and multiple colors.

Since layer height depends on the 3D printer used, it is one of the most important parameters of 3D printers. In general, the lower the layer height, the finer and smoother the model surface will be. On commercially available 3D printers, the average layer height is from 0.1 mm to 0.32 mm. The height of the layer depends not only on the 3D printer used, but also on the software with which a given model is cut (so-called Slicing). Today's 3D software has almost no limitations on layer height. On the other hand, however, the constantly increasing requirements for the quality of manufactured details and elements, especially in the field of mechanical engineering, lead to the need to improve both the technological equipment and the methods and means of measurement. One of the important metrological tasks in this regard is carrying out measurements with proven accuracy of the geometrical parameters of machine-building products, including both determining the deviations from the correct geometrical shape and the mutual location of the surfaces and axes, as well as all other requirements that are set in the technical drawings of engineering products. The high level of automation and intellectualization of measuring systems nowadays expands the possibilities of applying new metrological procedures based on non-contact scanning methods.

Contactless scanning systems are entering the industry more and more every day. These systems allow a significant reduction in production costs, mainly due to a significant reduction in inspection time. They allow the acquisition of a large amount of data, which provides very good levels of quality of results. Despite the well-known advantages that these systems offer, there are also some difficulties, such as the undefined and unstandardized

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accuracy compared to traditional inspection systems based on tactile sensors with touch. This is one of the reasons for the practical absence of scanning systems in metrology applications: they have not been adequately tested for accuracy to control geometric and dimensional tolerances. In fact, these systems are mainly used as reverse engineering or multimedia applications. Two different measurement systems were analyzed: by a non-contact laser scanner and a contact tactile sensor, both mounted on a seven-degree-of-freedom Romer measuring arm. A common alignment method is defined to compare the geometry generated for the two measurement systems. Finally, an analysis was performed to compare them in terms of geometric and dimensional tolerances, being accounted for the contact measurements as a benchmark. As a result, some advice is given regarding the best scanning strategies and deviations are evaluated. Control dimensions of an aluminum part were measured by both methods (contact and non-contact). Using a 3D printer, copies of the aluminum detail were made and checked for deviations of their control dimensions and deviations from geometric accuracy (flatness and parallelism).

II. SEQUENCE MEASUREMENT

The measurement results show that the errors of non-contact and contact measurement methods are within the tolerance of the measuring arm. The sources of most deviations are due to the printing process of the details(Table 2). The main sources of these deviations are due to: material shrinkage and deformation challenged by residual stress or rapid cooling, machine positioning errors [3], first layer adhesion problem, material extrusion problem (over or under-extrusion). Before starting any print, it is important to check the bed level. If the bed is not properly leveled, the first layer may not stick to the slab. The bed temperature is checked while printing starts. Some materials require a heated substrate to ensure that the print will stick to the substrate. The temperature of the bed can be easily controlled by the slicing software. Nozzle height can also affect layer adhesion. This is mostly a one time adjustment where the height of the nozzle from the bed is adjusted to the optimum level. If the nozzle is too high from the bed, then the deposited layer will not stick or even fall in the desired place. If the height is too low, then the nozzle itself can scrape off the build-up material. The height of the nozzle can also affect the extrusion of material, if the nozzle is too close to the build plate, then the extruder may not be able to apply the required amount of material to the bed. Therefore, it is important to set the appropriate height of the nozzle.

The HEXAGON Absolute arm 8525-7 measuring arm with 7 degrees of freedom with integrated RS5 laser scanner and OPTIV M 4.4.3 multisensor and optical coordinate measuring machines (CMM) draw on the strength of Hexagon's Enhanced Productivity Series (EPS) were used for the research.

TABLE 1 MEASUREMENT ACCURACY VALUES

Model	E_{UNI} mm	P_{SIZE} mm	L_{DIA} mm	P_{FORM} mm	SSA mm
8525-7	0.031	0.012	0.048	0.025	0.048

The certification specifies four accuracy values (see Table 1) known as E_{UNI}, P_{SIZE}, P_{FORM} и L_{DIA}. Each of these values represents a different aspect of the contact measurement accuracy of a portable measuring arm. The E_{UNI} value is the maximum allowable error for unidirectional length measurements. Therefore, it most accurately reflects most measurement needs. The P_{SIZE} value is the maximum allowable error for measuring the diameter of a sphere. Therefore, it reflects the accuracy of the feature measurements.

The value of P_{FORM} is the maximum allowable error for the shape of a sphere. This is a value that determines the accuracy of the shoulder variance.

The L_{DIA} value is the maximum allowable error for the articulation location. It therefore represents the repeatability of the arm. Scanning accuracy is the SSA [mm] value.

The results of determining the geometric deviations (length, thickness, flatness and parallelism) of the control aluminum detail and the printed copies using the laser scanner (laser scan copy LSC) and the tactile sensor (tactile probe copy TPC) were established using the high-precision multi-sensor measuring machine OPTIV M 443 for which a protocol has been created.

III. ALUMINUM DETAIL RESULTS

The deviations in manufacturing of the aluminum detail are:

Length = 59,9825 mm (60mm by specification), Width = 10,5073 mm (10.5mm by specification), flatness - plane 1 = 0.009 mm and plane 2 = 0.003 mm, parallelism between plane 1 and plane 2 = 0.032mm.

All deviations are within the tolerance for the accuracy requirements of the detail.

IV. TACTILE SENSOR RESULTS

The dimensions obtained by measuring the aluminum detail using the tactile sensors (see above) were used to print this copy. Measurement errors [5] are limited mainly by the shape deviation and roughness of the sensor sphere and the overall stability of the instrument during the measurement procedure. Deviations after printing are shown below:

Length = 59,6861 mm, Width = 10,4295 mm, flatness - plane 1 = 0.093 mm and plane 2 = 0.003 mm, parallelism between plane 1 and plane 2 = 0.484mm.

V. LASER SCANED PART RESULTS

The dimensions (fig.1) obtained from the non-contact laser scan were used to print this copy of the detail. The laser-scanned part processing program PolyWorks allows high-end point cloud inspection to produce a CAD model in STL format. Dark, shiny and transparent surfaces cannot be scanned with this method. This is because from the experiments we have done in order to obtain a quality model of the scanned object there must be a diffuse reflection of the laser beam. During the scan operation [2], the system allows the selection of different exposure times, so that a complete image of the scanned surface can be obtained even in the conditions of the existence of areas with relatively important color differences.

Object positioning during scanning can also be a source of errors. Correct positioning must be done to avoid object surfaces being parallel to the incident beam. If this cannot be avoided, the scan will be performed in several reference positions. That is how views are obtained in which the surfaces are with sufficiently wide angles versus the incident beam to avoid gaps in the point cloud. Although non-contact scanning allows a faster point cloud, a larger number of points, and access to narrower channels or holes than contact scanning, there are situations where areas of the detail cannot be reached [12]. These surfaces are of the type of holes or narrow channels, the deep areas of which are shaded by their walls.

Sometimes it is possible to inspect them by choosing a convenient position on the detail, but there are cases when they cannot be reached, necessitating physically cutting the piece or giving the inspection to the relevant areas.

The results after printing the model thus obtained are shown below:

Length = 59.9825 mm, Width = 10.5073 mm, flatness - plane 1 = 0.259 mm and plane 2 = 0.324 mm, parallelism between plane 1 and plane 2 = 0.267mm.

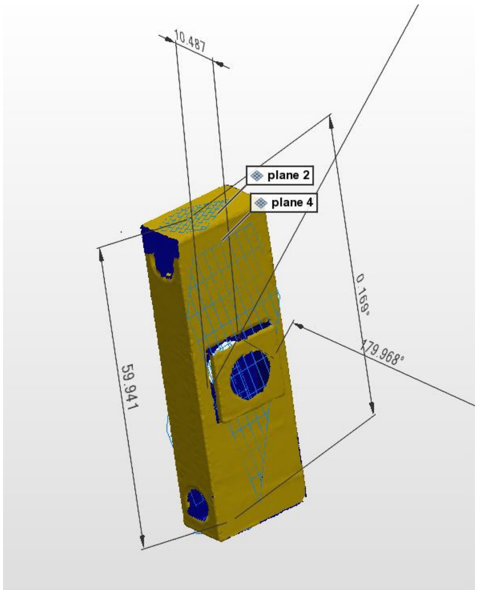

Fig.1 Laser-scanned part dimensions.

TABLE 2 MEAUSERMENT PROTOCOL

PART NAME :	latvia				февруари 02, 2023	11:12
REV NUMBER :		SER NUMBER :			STATS COUNT :	1
	MM	FLAT1 - PLN1				
AX	NOMINAL	+TOL	-TOL	MEAS	DEV	OUTTOL
M	0.000	0.010	0.000	0.009	0.009	0.000
	MM	FLAT2 - PLN2				
AX	NOMINAL	+TOL	-TOL	MEAS	DEV	OUTTOL
M	0.000	0.010	0.000	0.003	0.003	0.000
//	MM	PARL1 - PLN1 TO PLN2				
AX	NOMINAL	+TOL	-TOL	MEAS	DEV	OUTTOL
M	0.000	0.010	0.000	0.032	0.032	0.022
	DEG	ANGL1 - PLN2 TO PLN1				
AX	NOMINAL	+TOL	-TOL	MEAS	DEV	OUTTOL
A	0.037	0.010	-0.010	0.037	0.000	0.000
	MM	FLAT3 - PLN3				
AX	NOMINAL	+TOL	-TOL	MEAS	DEV	OUTTOL
M	0.000	0.010	0.000	0.093	0.093	0.083
//	MM	PARL2 - PLN2 TO PLN3				
AX	NOMINAL	+TOL	-TOL	MEAS	DEV	OUTTOL
M	0.000	0.010	0.000	0.484	0.484	0.474
	DEG	ANGL3 - PLN2 TO PLN3				
AX	NOMINAL	+TOL	-TOL	MEAS	DEV	OUTTOL
A	0.449	0.010	-0.010	0.449	0.000	0.000
	MM	FLAT4 - PLN4				
AX	NOMINAL	+TOL	-TOL	MEAS	DEV	OUTTOL
M	0.000	0.010	0.000	0.259	0.259	0.249
	MM	FLAT5 - PLN5				
AX	NOMINAL	+TOL	-TOL	MEAS	DEV	OUTTOL
M	0.000	0.010	0.000	0.324	0.324	0.314
//	MM	PARL3 - PLN4 TO PLN5				
AX	NOMINAL	+TOL	-TOL	MEAS	DEV	OUTTOL
M	0.000	0.010	0.000	0.267	0.267	0.257
	DEG	ANGL5 - PLN4 TO PLN5				
AX	NOMINAL	+TOL	-TOL	MEAS	DEV	OUTTOL
A	180.044	0.010	-0.010	180.044	0.000	0.000

VI. CONCLUSION

Despite the rapid growth of 3D printers in many fields of technique and household, the factors that affect the accuracy of 3D printed models have not been thoroughly studied. It is often necessary to create models by laser scanning, which are then to be printed on a 3D printer. According the results obtained in the paper, it can be concluded, that current scanning technologies allow the creation of 3D models with accuracy within tolerances, this is not always achieved when printing the model in practice. Inaccuracies are due to errors occurring during the 3D printing itself. Understanding and researching the factors that affect the accuracy of a 3D printed model and the metrics used to measure that accuracy is key in creating methodologies leading to the reduction of these errors and the corresponding increase in the accuracy of printed models.

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