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ANALYSIS AND TESTING OF THE DIMENSIONAL ACCURACY OF PARTS MADE WITH THE FDM TECHNOLOGY

Abstract: In this paper the methodology applied during the analysis and testing processes of the dimensional accuracy of parts made with FDM technology is shown. The manufactured parts were made on the basis of the technical documentation delivered by the ordering company. The main purpose of the conducted research was to check the differences between chosen dimensions of original parts made with injection moulding and those made with FDM technology. The short characteristic of the applied manufacturing technology and the research methodology were also presented in the paper.

1. Introduction

The fused deposition methodology – FDM is one of the rapid prototyping manufacturing technologies in which a part model is made from thermoplastic material by subsequent printing of particular layers. The FDM technology is widely used in manufacturing process of conceptual models, prototypes and also in the small and batch production of spare parts. During the printing process in the FDM the two kinds of materials are used it is the base and support materials. The printing process accuracy is strictly connected with the printing tip nozzle internal dimension. In the table 1 the relation between the type of the printing tip and a layer thickness are tabulated [1,2,4,5].

Tab.1.Type of the printing tip vs. a layer thickness [1]

The tip symbol	Layer thickness
T10	0,127mm
T12	0,178mm
T16	0,254mm
T20	0,330mm

In the FDM technology several materials can be used which differ in mechanical and thermal properties. The base group of materials used in the printing process includes: Acrylonitrile-Butadiene-Styrene (ABS), Polycarbonates (PC), Polycarbonate-Acrylonitrile-

Butadiene-Styrene (PC-ABS), Polyphenylsulphone (PPSU/PPSF). In the conducted research in the printing process the ABS M30 was used. This type of the ABS is characterized by better mechanical properties in comparison to the standard ABS material.

2. Research preparation

In the printing process the following types of printing tips were used: for the base model material T10 and T16 respectively and T12 for the support material. Before starting the manufacturing process it was necessary to make the producibility analysis. The main goal of the analysis was to select the best printed model orientation. It is commonly known that a model can be oriented, in the machine working chamber, in any orientation but it is necessary take into consideration fact that a model quality strictly depends on this orientation – the step effect. Additional quality imperfections – dimensional inaccuracy which result from fact that during the discretization process a part model is divided into particular layers in the Z axis direction – perpendicular to building platform so according to the tip type (layer thickness) some layers might not be printed. This happens when the model layer has its volume lower than the printed one.

3. Test models dimensional accuracy analysis

The dimensional accuracy analysis for parts A and B (see: the figure 1) manufactured in FDM technology was made for the selected dimensions groups A1–A4 and B1–B4 respectively. The part A was manufactured with printing tip T16 (the layer thickness 0,254mm) whilst part B was made in the two copies with T16 and T10 tips (the layer thickness 0,127mm) respectively.

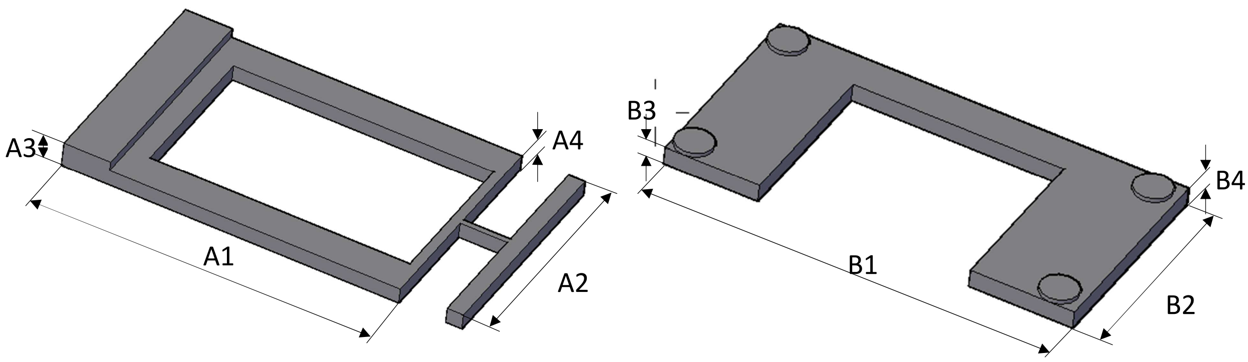

Fig.1. Manufactured parts A and B with selected dimensions

4. Measurements and testing methodology

In the first step the appropriate measurement devices were selected. For the selected dimensions group the following devices were chosen:

- for external dimensions A1, B1 and B2 – a caliper with measuring range 0 to 300mm and an electronic digital display Wilson Wolpert 160–30D. The permissible limiting error MLE was set to ±0,03 mm,
- for external dimensions A3, A4, B3 and B4 – an outside micrometer caliper with range 0 to 25mm and an electronic digital display Wilson Wolpert 200–01DDL. The permissible limiting error MLE was set to ±0,003 mm,
- the external dimension A2 – a workshop measuring microscope with measuring resolution 0,01mm. In case of the linear dimensions A2 it was not possible to apply direct measuring methods because of too big flexibility of this piece of part. The permissible limiting error MLE was calculated according to the following formula [6,7]:

$$MLE = \pm A + 0{,}7 * K + B * L + C * H * L\ [\mu m],$$

where:

A, K, B and C – constants;
L – length [mm];
H – part height [mm].

Measurements were made for series of the 15 direct measurements for A1, A3, A4, B1, B4 dimensions respectively whilst for the dimension A2 one direct measurements with the workshop measuring microscope was made. Results of measurements taken for critical dimensions were tabulated in tables 2 to 4.

Tab.2. Measurements results taken for the part A made with printing tip T16

No.	A1[mm]	A2[mm]	A3[mm]	A4 [mm]
1	110,08	63,520	4,196	6,322
2	110,04		4,190	6,301
3	110,05		4,196	6,308
4	110,04		4,202	6,294
5	110,04		4,194	6,305
6	110,01		4,192	6,322
7	110,05		4,178	6,319
8	110,08		4,164	6,309
9	110,09		4,199	6,295
10	110,09		4,184	6,335
11	110,06		4,176	6,298
12	110,03		4,195	6,305
13	110,00		4,188	6,311
14	110,07		4,180	6,304
15	110,02		4,178	6,315

Tab.3. Measurements results taken for the part B made with printing tip T16

No.	B1[mm]	B2[mm]	B3[mm]	B4[mm]
1	110,08	58,79	6,452	3,877
2	110,10	58,77	6,486	3,858
3	110,08	58,78	6,447	3,870

Tab.4. Measurements results taken for the part B made with printing tip T10

No.	B1[mm]	B2[mm]	B3[mm]	B4[mm]
1	110,01	58,78	6,499	3,871
2	109,99	58,78	6,503	3,863
3	110,02	58,78	6,489	3,870

4	110,09	58,79	6,490	3,852
5	110,07	58,81	6,455	3,886
6	110,07	58,83	6,451	3,879
7	110,09	58,79	6,446	3,885
8	110,08	58,80	6,466	3,882
9	110,10	58,83	6,458	3,878
10	110,08	58,86	6,465	3,866
11	110,07	58,83	6,461	3,855
12	110,07	58,82	6,448	3,880
13	110,08	58,78	6,453	3,870
14	110,09	58,83	6,455	3,885
15	110,08	58,83	6,486	3,855

4	110,01	58,75	6,487	3,869
5	110,00	58,74	6,486	3,853
6	110,01	58,67	6,493	3,873
7	110,02	58,72	6,500	3,873
8	109,99	58,70	6,486	3,861
9	110,02	58,78	6,486	3,869
10	110,01	58,72	6,494	3,855
11	109,99	58,75	6,484	3,874
12	110,01	58,74	6,493	3,855
13	110,00	58,72	6,493	3,867
14	110,01	58,76	6,492	3,865
15	110,02	58,74	6,486	3,870

5. Measurements uncertainty analysis

For the obtained measurements results, according to ISO standard, standard uncertainties and broaden uncertainties *U* were calculated. For the standard uncertainty the method A was applied. In this method the uncertainty is calculated by statistical analysis of series of the particular measurements (the result dispersion) in case when the calibration uncertainty is equal or greater than the calibration uncertainty calculated from the following formula (for measurement series n>10).

$$u = \sqrt{\left(\frac{s}{\sqrt{n}}\right)^2 + \frac{(\Delta x)^2}{3}},$$

where:

s – standard deviation,
n – measurement series size,
Δx – calibration uncertainty (permissible limiting error MLE was set).

The standard uncertainty explicitly describes the result value but in order to conclude about its compliance with other results and for standardization and commercial purposes the broaden uncertainty *U* was introduced:

$$U = k * u,$$

where:

k – broadening coefficient.

For *k = 2* the *U* value cover at approximately the uncertainty range with probability equal to 0.95, for *k* = 3 with probability equal to 0.99. In industry the coefficient *k* is usually set to 2. The calculated uncertainty values were tabularized in tables 5 to 7. For the A2 dimension as an uncertainty measurement the MLE value was set. The MLE was calculated according to the following coefficients values: *A* = 5, *B* = 1/20, *C* = 1/1500, *H* = 4mm, *K* = 3.

Tab. 5. Calculation results for the part element A made with printing tip T16

	A1[mm]	A2[mm]	A3[mm]	A4[mm]
Mean	110,050	63,520	4,1875	6,3095

s	0,028	0,0105	0,0105	0,0114
n	1		15	15
u	0,019	0,0105	0,0032	0,0034
U	0,038	0,0210	0,0064	0,0068

Tab. 6. Calculation results for the part element B made with printing tip T16

	B1[mm]	B2[mm]	B3[mm]	B4[mm]
Mean	110,082	58,809	6,4613	3,8719
s	0,010	0,026	0,0148	0,0120
n	15,000	16,000	17,0000	18,0000
u	0,018	0,018	0,0040	0,0033
U	0,035	0,037	0,0080	0,0066

Tab. 7. Calculation results for the part element B made with printing tip T10

	B1[mm]	B2[mm]	B3[mm]	B4[mm]
Mean	110,007	58,742	6,4914	3,8659
s	0,011	0,032	0,0058	0,0070
n	15,000	16,000	17,0000	18,0000
u	0,018	0,019	0,0022	0,0024
U	0,035	0,038	0,0045	0,0048

Below the measurements results with broaden uncertainty are presented:

The part element A made with printing tip T16:

A1 = (110,050±0,038) mm (normal size 110mm),
A2 = (63,520±0,021) mm, (normal size 63,64mm),
A3 = (4,1875±0,0064) mm, (normal size 4,3mm),
A4 = (6,3095±0,0068) mm, (normal size 6,1mm).

The part element B made with printing tip T16:

B1 = (110,082±0,035) mm, (normal size 110mm),
B2 = (58,809±0,037) mm, (normal size 58,778mm),
B3 = (6,4613±0,0080) mm, (normal size 6,4mm),
B4 = (3,8719±0,0066) mm, (normal size 4mm).

The part element B made with printing tip T10:

B1 = (110,007±0,035) mm, (normal size 110mm),
B2 = (58,742±0,038) mm, (normal size 58,778mm),
B3 = (6,4914±0,0045) mm, (normal size 6,4mm),
B4 = (3,8659±0,0048) mm, (normal size 4mm).

6. Conclusion and result analysis

The main goal of the conducted analysis was to determine dimensional accuracy for elements manufactured with FDM technology. This analysis had to answer the question if it is possible to use printed prototypes in industrial applications.

For the part element A printed with printing tip T16:
- dimensions A1, A2 and A3 (measurements results with considering measurement uncertainty) are within the tolerance range,

- the A4 dimension (measurement result with considering measurement uncertainty) exceeds the tolerance range. This comes from fact that the layer thickness in case of application of T16 printing tip is to large in order to manufacture the part model correctly in the perpendicular direction to the machine building platform (the Z direction). It is also connected with the way of the input printing data file preparation by the FDM machine software. In case when the model layer thickness is lower than the printed one, the layer is always omitted.

For the part element B printed with printing tips T16 and T10:

- dimensions B1 B2, B3 and B4 (measurements results with considering measurement uncertainty) are within the tolerance range.

As a result of the dimensional accuracy analysis it is was found that the printed tested parts fulfil the all requirements according to dimensional accuracy. In case of models for which it would be found problems similar to problem with A4 nominal size dimension it is necessary to apply printing tips with smaller internal nozzle diameter in order to get greater printing resolution. In some case it is not possible to apply smaller printing tip, because of the limited range of available tips, so in this situation it is necessary to change the printing orientation but having in mind the step effect.

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