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## IDENTIFICATION OF SIGNIFICANT FDM PROCESS PARAMETERS INFLUENCING DIMENSIONAL ACCURACY OF ADDITIVELY MANUFACTURED COMPONENTS

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**Abstract:** Additive manufacturing has increasingly found application in both industrial practice and scientific research in recent years. Due to its accessibility, flexibility, and rapid prototyping capabilities, Fused Deposition Modelling additive technology has become an integral part of development processes. Consequently, additively manufactured components frequently require subsequent modification, optimization, or re-documentation. In this context, the role of reverse geometric modelling gains importance. While this process is relatively stable for conventional components, the dimensional accuracy of CAD models derived from FDM parts is significantly affected by manufacturing deviations induced by printing parameters. This study presents a preliminary experiment aimed at identifying the FDM parameters influencing the dimensional accuracy of cylindrical components. The objective is to exclude insignificant factors from subsequent experiments focused on enhancing the precision of reverse geometric modelling. Four factors were investigated: layer height, infill density, wall thickness, and cut position. Based on ANOVA and Pareto analysis, layer height and cut position were identified as statistically significant, whereas infill density and wall thickness showed no statistically significant impact. The results facilitate a more efficient design of future experiments and contribute to improving the dimensional accuracy of 3D CAD models obtained via reverse geometric modelling.

**Key words:** additive manufacturing, Fused Deposition Modelling, reverse geometric modelling, dimensional accuracy, process parameter optimization, reverse engineering

### 1. INTRODUCTION

Additive manufacturing technologies have significantly advanced in recent years and have found applications across various industrial domains. The dimensional accuracy of components produced by Fused Deposition Modelling (FDM) is critical for their functionality and reliability, particularly in the context of reverse geometric modelling, where dimensional inaccuracies can degrade the quality of digital models and propagate deviations in subsequent processes. Understanding the influence of manufacturing parameters on dimensional accuracy is thus essential for FDM process optimization.

This topic is widely studied in the scientific literature, although individual studies differ in

the devices used, methodologies applied, and the outputs analysed. Research has focused on various characteristics of the printed parts, such as mechanical strength, surface roughness, or dimensional accuracy. Singh et al. [1] experimentally investigated the influence of print orientation, layer height, and infill density on the dimensional accuracy of ABS parts using a Taguchi L9 orthogonal matrix. Their results showed that the dominant parameter changes depending on part geometry.

Another study [2] reviewed 31 publications addressing the influence of process parameters on FDM dimensional accuracy and identified the most frequently examined factors as layer height, nozzle temperature, and part orientation. A subsequent study [3] focused on optimizing print speed, infill density, and nozzle

temperature to improve accuracy and surface quality. The results confirmed a positive effect of higher temperature and infill on dimensional precision but also highlighted that outcomes vary with part geometry.

An interesting approach was presented by Hind et al. [4], who combined a fuzzy inference system with the Taguchi method and a multi-performance index (MPI) to optimize parameters for ABS parts. Part orientation had the strongest effect, followed by infill density and the number of perimeter walls. Another study [5] applied a factorial experiment and a quadratic regression model to predict dimensional accuracy of micro-turbine impellers. Layer height was identified as the most influential parameter (also confirmed via CMM measurements), and optimization was carried out using Response Surface Methodology (RSM).

Muhammad et al. [6] analysed multiple parameters including layer height, number of perimeter walls, infill density and angle, print speed, and temperatures using a combination of the Taguchi method, desirability function, and WASPAS. The resulting dimensional deviations ranged from 0.05 to 0.43%. Yaqin et al. [7] extended the scope by including material type, infill pattern, and raster angle. Their optimization confirmed that a combination of PLA+, 80% infill, grid pattern, and 0° raster angle resulted in a deviation of just 1.39%.

These studies collectively indicate that FDM dimensional accuracy depends on a complex interplay of process parameters, geometry, and material. Despite frequent analyses of individual factors, interactions among them — especially in relation to reverse modelling — remain less explored.

Therefore, the objective of this study is to identify the key FDM process parameters affecting the dimensional accuracy of cylindrical components. This is a preliminary experiment intended to eliminate insignificant factors and simplify the design of subsequent experiments. The main research is focused on analysing the precision of reverse geometric modelling, including the influence of polygonization and modelling techniques on the quality of reconstructed CAD models. To objectively assess the results, it is necessary to

work with parts of varying dimensional accuracy, which must first be intentionally influenced through controlled changes in FDM parameters. The outcome of this study is a more efficient experimental design and higher-quality input data for further reverse engineering analysis.

## 2. METHODOLOGY

The experiment was carried out at the Center of Excellence for 5-Axis Machining, located at the Faculty of Materials Science and Technology, Slovak University of Technology in Bratislava. The aim was to verify the influence of selected FDM manufacturing parameters on the dimensional accuracy of cylindrical components, which will serve as input for further research focused on reverse geometric modelling.

A professional 3D printer, the Stratasys F370, was used for production. This printer is recognized for its high repeatability and printing stability. The material employed for fabricating the test specimens was ABS-M30, a widely used thermoplastic in FDM processes, valued for its mechanical strength and dimensional stability. The selection of adjustable manufacturing parameters was limited to those available in GrabCAD Print, the native software for this printer. Based on prior knowledge and relevant literature, three parameters were chosen for the experiment. These parameters are user-configurable in the software and are known to significantly influence the quality of printed components:

- Layer height (mm)
- Infill density (%)
- Wall thickness (mm)

Each of these factors was tested at three levels (low, medium, high), as shown in Table 1.

Table 1

Selected factor levels for the experiment

Factor	Low Level (-)	Medium Level (0)	High Level (+)
Layer height (A)	0.18 mm	0.25 mm	0.33 mm
Infill density (B)	25%	50%	75%
Wall thickness (C)	1.9812 mm	2.2352 mm	2.4892 mm

To examine the influence of these selected FDM parameters on dimensional accuracy, a Multilevel Full Factorial Design was created. The experiment was designed and analysed using Minitab software, with three factors each tested at three levels. This resulted in an experimental matrix with 27 combinations of input parameters, with one sample produced for each combination.

A cylinder with a diameter of 40 mm and a height of 60 mm was selected as the test specimen. This geometry was chosen due to its symmetry and uniformity, which eliminate complex surfaces and enable consistent diameter measurements at various heights.

In total, 27 physical prints were produced. Each cylinder was measured at five different positions (Fig. 1) along its height, generating a total of 135 diameter measurements, which were subsequently used in the statistical evaluation of the experiment. Measurements were distributed evenly without blocking, with each print treated as an individual experimental unit.

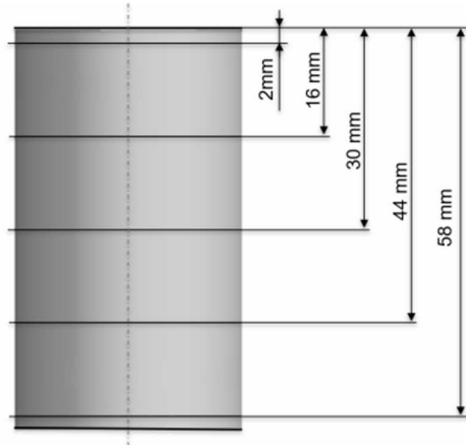


Fig. 1 Measurement locations for cylinder diameters [8]

To evaluate dimensional deviations, computed tomography (CT) was used — a technique frequently applied to components made using additive manufacturing. The scanning was performed using a Zeiss Metrotom 1500 CT system. The scanning process was performed with the following parameters:

- Current: 200  $\mu$ A
- Voltage: 180 kV
- Integration time: 500 ms
- Detector resolution: 2048  $\times$  2048 px
- Gain: 8.0 $\times$

- Measurement distance: 305 mm
- Voxel size: 40.67  $\mu$ m

Diameter measurements at specific cross-sections of the cylinder were carried out in VG Studio Max 3.0 software. The scanned sample was compared to the nominal 3D CAD model. The alignment was done using the Best-Fit method to achieve the most accurate positioning and minimize deviations from the nominal geometry.

All output data were subjected to Analysis of Variance (ANOVA) to identify statistically significant factors and interactions affecting dimensional accuracy. The ANOVA evaluation and data processing were performed using Minitab software.

### 3. RESULTS

Based on the measurements performed using computed tomography, dimensional deviations in the diameter of the cylinders were observed, depending on the set manufacturing parameters. The measured values of average diameter deviations are grouped by the values of factor A, which represents the layer height. Within each group, there are 9 samples with various combinations of factors B (infill density) and C (wall thickness). The values represent the average deviation from five diameter measurements (Fig. 1) on a single sample. The designation of each deviation follows the order of factors A, B, and C, with each factor marked by its respective level: the lower level is denoted as “-”, the middle as “0”, and the upper as “+”. These values of average deviations are listed in Tables 2, 3, and 4.

Table 2

Average dimensional deviation values for factor A-	
Parameter combination	Average dimensional deviation [mm]
- - -	-0.0140
- - 0	-0.0726
- - +	-0.0296
- 0 -	-0.0008
- 0 0	-0.0296
- 0 +	-0.0372
- + -	-0.0792
- + 0	-0.0340
- + +	-0.0816

Table 3

Average dimensional deviation values for factor A0

Parameter combination	Average dimensional deviation [mm]
0 - -	-0.0592
0 - 0	0.0040
0 - +	-0.0100
0 0 -	-0.0348
0 0 0	-0.0594
0 0 +	-0.0304
0 + -	-0.0228
0 + 0	-0.0332
0 + +	-0.0300

Table 4

Average dimensional deviation values for factor A+

Parameter combination	Average dimensional deviation [mm]
+ - -	-0.1098
+ - 0	-0.0820
+ - +	-0.0510
+ 0 -	-0.0798
+ 0 0	-0.0648
+ 0 +	-0.0364
+ + -	-0.1026
+ + 0	-0.0096
+ + +	-0.0458

To evaluate the statistical significance of the individual factors and their interactions, Analysis of Variance (ANOVA) was used. The three factors under study — A, B, and C — were each tested at three levels: “-”, “0”, and “+”. The ANOVA results are shown in Figure 2.

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Model	18	0.105398	0.005855	4.33	0.000
Linear	6	0.034569	0.005761	4.26	0.001
A	2	0.026170	0.013085	9.68	0.000
B	2	0.004142	0.002071	1.53	0.220
C	2	0.004256	0.002128	1.57	0.211
2-Way Interactions	12	0.070830	0.005902	4.37	0.000
A*B	4	0.022264	0.005566	4.12	0.004
A*C	4	0.035727	0.008932	6.61	0.000
B*C	4	0.012839	0.003210	2.38	0.056
Error	116	0.156763	0.001351		
Lack-of-Fit	8	0.026817	0.003352	2.79	0.008
Pure Error	108	0.129946	0.001203		
Total	134	0.262161			

Fig. 2 ANOVA results

Regarding main effects, factor A was found to be statistically significant, while factors B ( $p = 0.220$ ) and C ( $p = 0.211$ ) did not demonstrate statistical significance at a confidence level of  $\alpha = 0.05$ . Among the interactions, A\*B and A\*C

were statistically significant, whereas the B\*C interaction was at the threshold of significance.

From the perspective of model quality, the total explained variance (R-sq) reached 40.2%, with adjusted R-sq at 30.92% and predicted R-sq at only 19.01%. These values indicate that the model explains only a portion of the output variable's variability, suggesting that other significant factors may exist outside the scope of the current experimental design.

To supplement these results, a Pareto analysis of standardized effects was conducted (Figure 3), visualizing the relative importance of each factor and interaction based on their contribution to output variability.

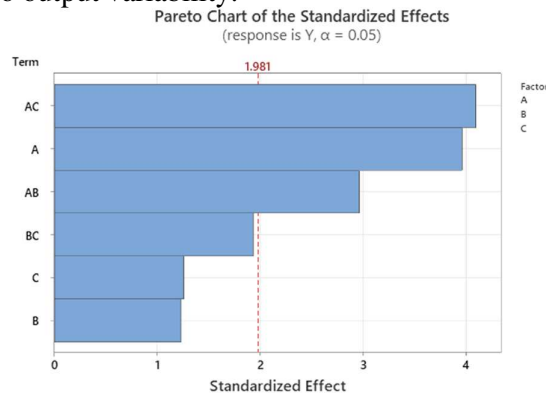


Fig. 3 Pareto analysis of effects

From the Pareto chart, it is clear that factor A (layer height) and the interaction AC (layer height and wall thickness) had the strongest impact on diameter deviation. Their standardized effects exceed the statistical significance threshold ( $t = 1.981$  for  $\alpha = 0.05$ ). The AB interaction also reached statistical significance, albeit with a slightly lower effect. In contrast, the main effects of factors B (infill density) and C (wall thickness), as well as their interaction B\*C, did not show significant influence and remained below the threshold.

#### 4. DISCUSSION

The results of the preliminary experiment indicate that among all the evaluated FDM process parameters, the most significant influence on the dimensional accuracy of cylindrical prints was exhibited by factor A, layer height.

This result is likely because with increasing layer height reduces deposition precision,

creating more pronounced inter-layer steps that can drive uneven vertical growth and cumulative Z-axis deviations. Conversely, smaller layers enable finer deposition and tighter dimensional control.

The analysis showed that infill density (B) and wall thickness (C) had no significant impact on diameter deviation. Infill density primarily affects mechanical properties, not dimensional accuracy, especially in rigid geometries like closed cylinders. For wall thickness, the tested range may have been too narrow to affect accuracy.

The explained variance of 40.2% suggests that the model captures only part of the variability. It is reasonable to assume that other parameters — such as print orientation, printing speed, extrusion and bed temperatures, or cooling method — also influence dimensional accuracy. However, their inclusion was not possible in this experiment due to the closed nature of the GrabCAD Print software, which offers limited control over certain process variables on the Stratasys F370 system.

Incorporating print orientation is planned in future experiments. The current setup provides a stable and repeatable printing environment, but it also limits the scope of experimental variability compared to more flexible systems.

From the perspective of experimental design, the obtained results offer important insights for the next phase of research. The importance of layer height as a primary factor has been confirmed, and the identified interaction effects (particularly AC and AB) may significantly impact the dimensional accuracy of more complex geometries. Conversely, infill density and wall thickness can be fixed at selected levels in future experiments, thereby reducing the number of parameter combinations and increasing the efficiency of the experimental design.

## 5. CONCLUSION

The experiment confirmed that layer height has the strongest impact on the dimensional accuracy of cylindrical parts, with noticeable interactions also observed between layer height and wall thickness, and between layer height and

infill density. On their own, however, wall thickness and infill density had only a minor effect in the case of simple geometries.

Most measured diameters were slightly below the nominal value, which can be explained by typical effects of the FDM process such as material shrinkage, thermal stresses, and the layer-by-layer deposition principle. Even so, all deviations remained within  $\pm 0.15$  mm, which is fully in line with the tolerance limits defined by ISO 2768.

The statistical model accounted for about 40% of the data variance, suggesting that other factors, such as extrusion speed or nozzle temperature, also play a role but could not be adjusted in this study due to the limitations of the GrabCAD Print software.

Despite these restrictions, the experiment proved to be an effective first step in identifying the most relevant parameters. Leaving out less significant factors will make the design of future experiments more efficient and provides a solid starting point for assessing the accuracy of reverse geometric modelling. In the next phase of research, these results will be directly applied to parts with intentionally varied dimensional accuracy to study how polygonization, point reduction and different modelling techniques influence the quality and accuracy of reconstructed CAD models.

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### Identificarea parametrilor semnificativi ai procesului FDM care influențează precizia dimensională a componentelor fabricate aditiv

În ultimii ani, fabricarea aditivă a găsit din ce în ce mai multe aplicații atât în practica industrială, cât și în cercetarea științifică. Datorită accesibilității, flexibilității și capacităților sale de prototipare rapidă, tehnologia aditivă Fused Deposition Modelling (FDM) a devenit parte integrantă a proceselor de dezvoltare. În consecință, componentele fabricate aditiv necesită frecvent modificări ulterioare, optimizare sau re-documentare. În acest context, rolul modelării geometrice inverse capătă importanță. În timp ce acest proces este relativ stabil pentru componentele convenționale, precizia dimensională a modelelor CAD derivate din piese FDM este afectată în mod semnificativ de abaterile de fabricație induse de parametrii de imprimare. Acest studiu prezintă un experiment preliminar menit să identifice parametrii FDM care influențează precizia dimensională a componentelor cilindrice. Obiectivul este de a exclude factorii nesemnificativi din experimentele ulterioare axate pe îmbunătățirea preciziei modelării geometrice inverse. Au fost investigați patru factori: înălțimea stratului, densitatea umpluturii, grosimea peretelui și poziția de tăiere. Pe baza ANOVA și a analizei Pareto, înălțimea stratului și poziția de tăiere au fost identificate ca fiind semnificative din punct de vedere statistic, în timp ce densitatea de umplere și grosimea peretelui nu au prezentat niciun impact semnificativ din punct de vedere statistic. Rezultatele facilitează o proiectare mai eficientă a experimentelor viitoare și contribuie la îmbunătățirea preciziei dimensionale a modelelor CAD 3D obținute prin modelare geometrică inversă.

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