Design of Machines and Structures, Vol. 14, No. 1 (2024), pp. 43–51.
https://doi.org/10.32972/dms.2024.004

INVESTIGATION OF REMESHING PARAMETERS FOR DEVIATION ANALYSIS IN REVERSE ENGINEERING

PÉTER FICZERE

Budapest University of Technology and Economics,
Department of Railway Vehicles and Vehicle System Analysis,
1111, Budapest, Műegyetem rkp. 3
ficzere.peter@kjk.bme.hu
https://orcid.org/0000-0003-3207-5501

Abstract: The use of additive manufacturing technologies in industry is increasingly common, particularly with the emergence of Industry 4.0. These technologies can produce parts quickly and efficiently, but they also place higher demands on the quality of the manufactured products. The layer-by-layer processes create an anisotropic material model, which complicates component sizing. While the topic has been extensively researched, surface anisotropy has received less attention. The surface quality of a product may be affected by various factors, including the file conversion process or the staircase effect generated by the technology. Manufacturing parameters, such as layer thickness and orientation, can also have an impact. This paper focuses on the impact of reverse engineering step adjustment on surface quality.

Keywords: *reverse engineering, remesh, stl, deviation analysis, surface roughness*

1. INTRODUCTION

Today, additive manufacturing technologies are being used in more places and on an increasing scale. Additive manufacturing technologies are increasingly used in various applications due to their ability to meet the requirements of Industry 4.0 (Albert & Takács, 2023). However, the requirements for the components manufactured using this technology are also increasing. The layer-by-layer approach creates an anisotropic material model, making component sizing a more complex task (Kovács & Kovács, 2008). This topic has been researched extensively, but surface anisotropy has received less attention (Ahn, Kweon, Kwon, Song, & Lee, 2009), (Jin, Li, He, & Fu, 2015), (Pérez, 2002). This may be due to various reasons, such as the file conversion required for manufacturing preparation, as well as the staircase effect resulting from the technology used (2.5D machining) (Kónya & Ficzere, 2023), (Pandey, Venkata Reddy, & Dhande, 2003). Additionally, the surface quality of the final part is influenced by the manufacturing parameters such as layer thickness and orientation. There are various ways to enhance the surface quality (Kónya & Ficzere, 2024), (Hanon, Alshammas, & Zsidai, 2020), (Ficzere & László, 2023). However, discussions often revolve around the accuracy of manufacturing equipment, machines, and printers when inspecting, checking, and measuring a completed, manufactured part (Dömötör, 2023). It is important to note that these control measurements also have their own level of accuracy, which may result in errors in the system. It is possible that the measurement is inaccurate rather than the part itself (Makkai & Sarka, 2023). This paper illustrates the effect of adjusting a reverse engineering step used in a back-measurement.

2. METHODOLOGY

In 3D printing, layer-by-layer construction results in a staircase effect. The magnitude of this staircase effect depends on the position of the surface, so even if the printer is accurate, an error is made in the design of the toolpaths. A test part is shown in Figure 1, which illustrates the staircase effects caused by different shape features. The same shape accuracy results in different surface quality depending on the orientation.

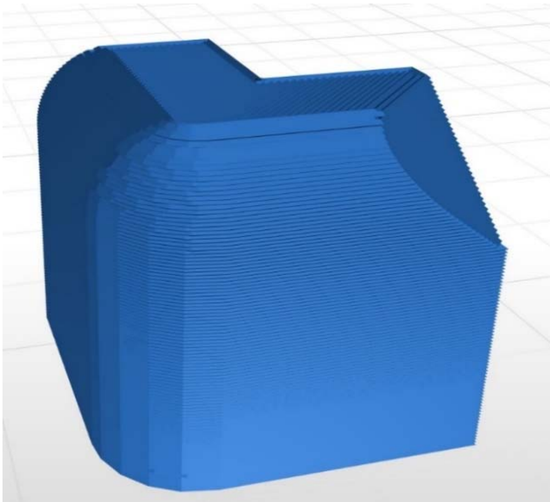

Figure 1. *Toolpath in slicer software*

Another unavoidable error is that we introduce varying degrees of error into the system when we select the layer height, a step that also affects printing speed. But even before these steps, errors are introduced during the conversion from CAD geometry to a standard triangular language (stl) file for the machine. Of course, with careful planning and thoughtful tolerances, the amount of error can be reduced to almost nothing during file conversion. The results of file conversion with different tolerances are shown in Figure 2. It is clear from the figure that when the file conversion tolerances are reduced, only the curved surfaces change in the resulting stl file. The finer the tolerance, the better it follows the original CAD geometry.

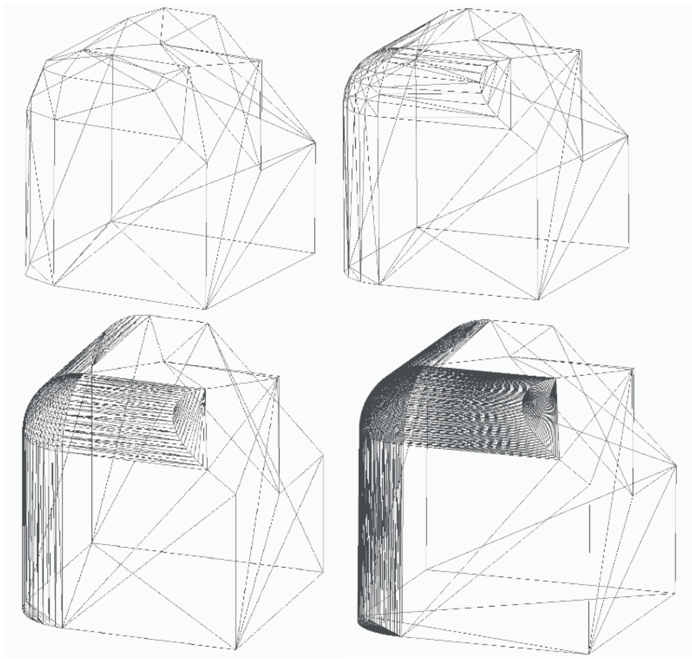

Figure 2. *CAD-stl file conversations with different tolerances*

In this study, the deviations of the part resulting from the coarsest stl conversion (top left in Figure 2) are investigated using reverse engineering methods. Today, most CAD software has a reverse engineering module. Here we have the possibility to perform deviation analysis. However, it should be noted that in the case of very coarse stl (as in the case under study), it is not possible to compare CAD and stl geometry in one step due to the large mesh sizes. We will also see later that even if it were possible, it is not practical because the coarse mesh distorts the results significantly. It is therefore advisable to remesh the stl geometry. In this case, the geometry under consideration is covered with smaller, uniformly distributed triangular elements. Such a remeshed geometry is shown in Figure 3.

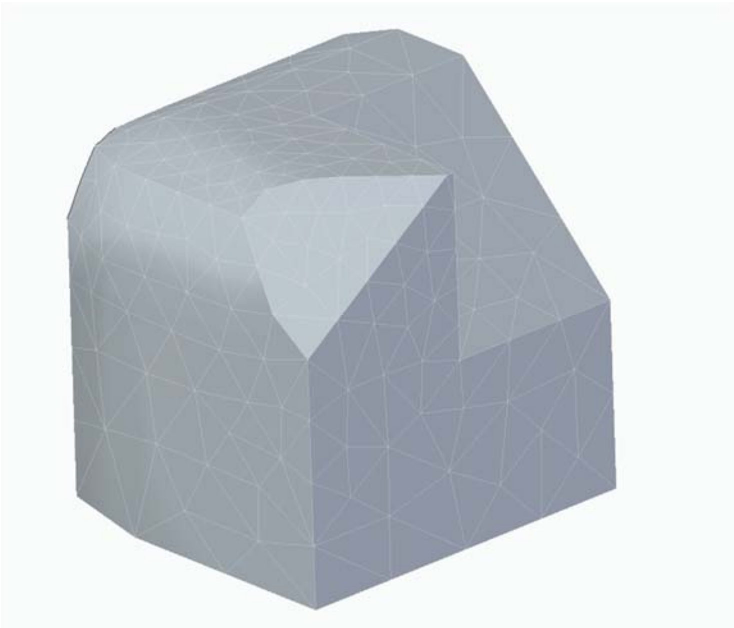

Figure 3. *Remeshed stl model*

The remeshed geometry shown in Figure 3 has been covered with triangular facets with an average element size of 6.75 mm. A comparison can now be made with the original CAD geometry. However, it is worth comparing the mesh shown in Figure 3 with the mesh shown in Figure 2, top left, where the difference is significant. We will now investigate how modifying the average element size used as a parameter for remeshing affects the accuracy of determining the deviation from the original CAD geometry.

3. RESULTS

The coarse stl mesh was remeshed with five different average element sizes (6.75 mm, 1 mm, 0.5 mm, 0.3 mm, 0.1 mm) to investigate the deviations from the original CAD geometry. Figure 4 shows the result of the deviation analysis after remeshing with the largest element size of 6.75 mm.

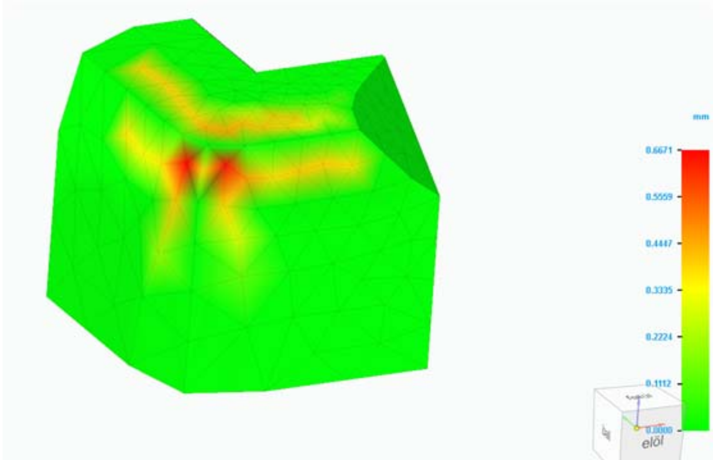

Figure 4. *Deviation analysis on remeshed (6.35 mm) coarse stl model*

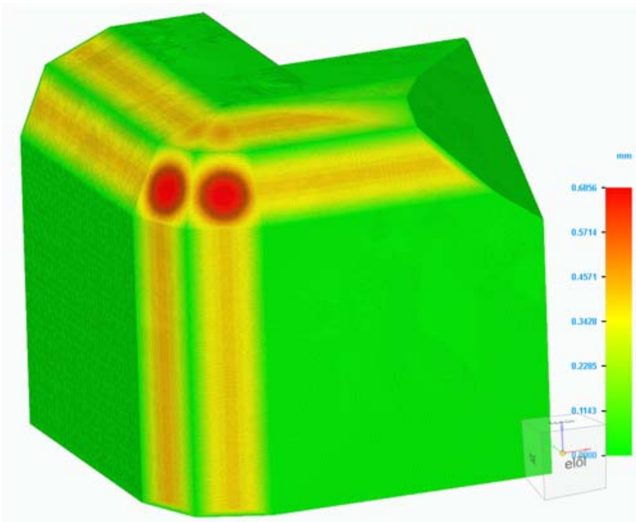

Figure 5. *Deviation analysis on remeshed (0.1 mm) coarse stl model*

It worth noting that this mesh density is not sufficient in critical areas with large deviations. Compared to the results of the analysis with an average element size of 0.1 mm shown in Figure 5, the difference is impressive and significant. The results obtained are shown in Table 1 as a function of the number of elements and the average element size.

Table 1

Deviations depending on element sizes

Element size (mm)	Number of elements	Deviation (mm)
6.75	236	0.667064
1	2594	0.678177
0.5	10449	0.679614
0.3	31482	0.685532
0.1	289128	0.685623

4. ANALYSIS

In Figure 6 we can visually observe the results of the deviation analysis for the different mesh densities.

A more detailed examination of the figure shows that even at low mesh densities the deviations from the CAD geometry are of a different nature. For example, in the upper left part of Figure 6 the deviations are only patchy, whereas in the lower right part of the figure (element size 0.3 mm) the bands along the roundings are clearly visible.

Irrespective of the numerical values, it can be seen, as expected, that there are no deviations from the CAD geometry on the flat surfaces, while there are deviations on the curved surfaces (roundings). It is also clear that the deviation varies along the curvature, which was also expected. These findings confirm that the deviation analysis within the reverse engineering module is fit for purpose, the results are in accordance with the theoretical background.

However, it is also interesting to note that the deviations are even more significant for double roundings (corner rounding, spherical surface).

It is useful to examine the numerical results in the shape of a diagram. In this way, the nature and shape of the curve can be used to determine whether an appropriate mesh density has been used. The results of the present study are presented in a diagram in Figure 7.

It can be seen that for small numbers of elements, although the shape of the curve changes significantly, the accuracy deviation is still less than 0.15 mm. Naturally, this depends on many things, so it is advisable to plot such a convergence curve for each individual part.

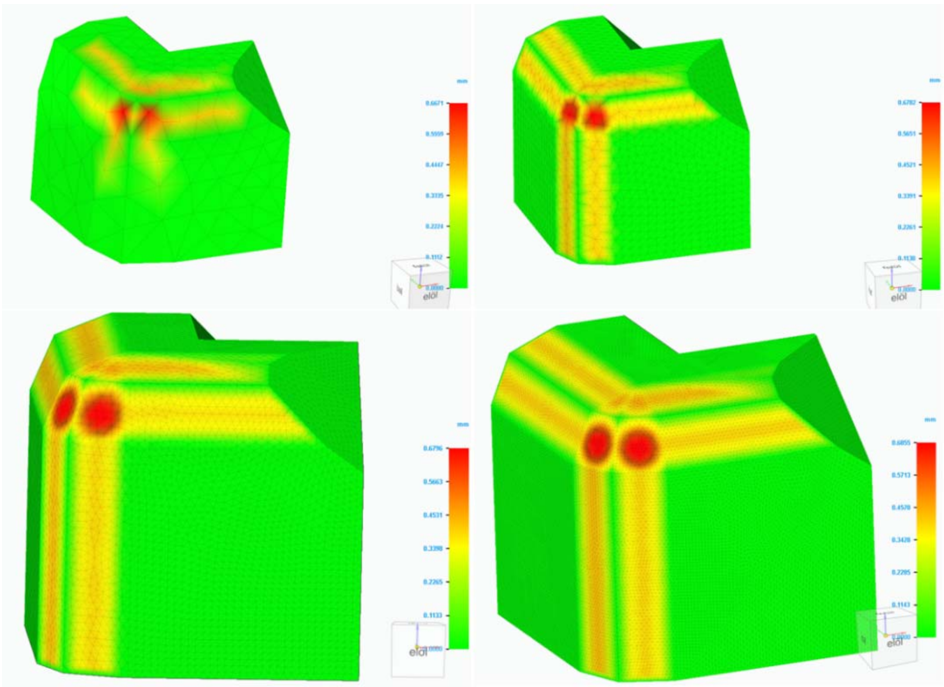

Figure 6. *Deviation analysis with different element sizes in remeshing*

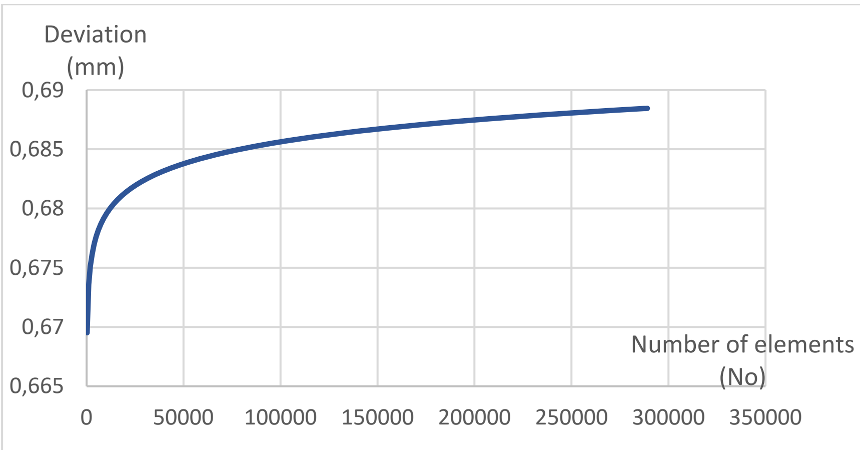

Figure 7. *Deviations as function of the number of surface elements*

5. SUMMARY

In summary, although our software is now capable of very high accuracy, without the right theoretical background we can make significant errors in file conversions, measurements and revalidation. It is therefore worth being cautious when judging the accuracy of production equipment.

REFERENCES

Ahn, D., Kweon, J.-H., Kwon, S., Song, J., & Lee, S. (2009, 8). Representation of surface roughness in fused deposition modeling. *Journal of Materials Processing Technology, 209*(15-16), 5593-5600. doi:https://doi.org/10.1016/j.jmatprotec.2009.05.016

Albert, J., & Takács, Á. (2023). Additív gyártás biomimetikai megközelítéssel. *GÉP, 74*(4), 9-12.

Dömötör, C. (2023). Reconstruction of Simple Parts Using FDM Technology. *Design of Machines and Structures, 13*(2), 13-21. doi:https://doi.org/10.32972/dms.2023.013

Ficzere, P., & László, N. (2023). Surface Modification Methods of Plastic Components Produced by Additive Manufacturing: A Review. *Design of Machines and Structures, 13*(2), 53-68. doi:https://doi.org/10.32972/dms.2023.017

Hanon, M., Alshammas, Y., & Zsidai, L. (2020, 5). Effect of print orientation and bronze existence on tribological and mechanical properties of 3D-printed bronze/PLA composite. *The International Journal of Advanced Manufacturing Technology, 108*(1-2), 553-570. doi:https://doi.org/10.1007/s00170-020-05391-x

Jin, Y.-a., Li, H., He, Y., & Fu, J.-z. (2015, 10). Quantitative analysis of surface profile in fused deposition modelling. *Additive Manufacturing, 8*, 142-148. doi:https://doi.org/10.1016/j.addma.2015.10.001

Kónya, G., & Ficzere, P. (2023). The Effect of Layer Thickness and Orientation of the Workpiece on the Micro- and Macrogeometric Properties and the Machining Time of the Part during 3D Printing. *Periodica Polytechnica Mechanical Engineering, 67*(2), 143-150. doi:https://doi.org/10.3311/PPme.21473

Kónya, G., & Ficzere, P. (2024). The Effect of Layer Thickness and Orientation of 3D Printed Workpieces, on The Micro- and Macrogeometric properties of Turned Parts. *Acta Polytechnica Hungarica, 21*(2), 231-250. doi:https://doi.org/10.12700/APH.21.2.2024.2.13

Kovács, N., & Kovács, J. (2008). Developments in the Field of Rapid Prototype Production. *Materials Science Forum, 589*, 421-425. doi:https://doi.org/10.4028/www.scientific.net/MSF.589.421

Makkai, T., & Sarka, F. (2023). CAD Modelling of a Milling Insert. *Design of Machines and Structures, 13*(2), 81-92. doi:https://doi.org/10.32972/dms.2023.019

Pandey, P., Venkata Reddy, N., & Dhande, S. (2003). Improvement of surface finish by staircase machining in fused deposition modeling. *Journal of Materials Processing Technology, 132*(1-3), 323-331. doi:https://doi.org/10.1016/S0924-0136(02)00953-6

Pérez, C. (2002). Analysis of the surface roughness and dimensional accuracy capability of fused deposition modelling processes. *International Journal of Production Research, 40*(12), 2865-2881. doi:https://doi.org/10.1080/00207540210146099