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ACCURACY OF PARTS MANUFACTURED BY RAPID PROTOTYPING TECHNOLOGY

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Abstract: *Paper presents research results of the parts accuracy after manufacturing with used Rapid Prototyping technology in context of the possible use of multi-directional layers disposition. Errors of the model by production were analyzed in two categories: external and internal model errors. External errors of models production include: conversion error, staircase error and error of slicing into layers. Internal errors of model production are related to the method of filling the interior of disposed layer. After analysis, the paper presents the solution of possible decrease of these errors.*
Key words: *Rapid Prototyping, Accuracy, Volume Error, FDM technology*

1. INTRODUCTION

Shortening time interval between the beginning of product development and starting up production is one of the most important factors in competitiveness of any company. The cycle of technical preparation of production has significant share in that time, as well as in the costs of the project. Since it is common that more and more perfect computer hardware and software is used, it makes it possible to create Digital Mock Up of a product model. Multi-functional configurations integrated with DMU enable performing static and dynamic analyses of designed product, as well as simulations related to its operation. In a great deal of cases it is recommended that a physical model of the product, its part or a functional prototype is created as an element of technical cycle of production preparing. Construction of a prototype using Rapid Prototyping technology on the basis of virtual CAD-3D models is usually sufficiently representative. Time and costs of such construction remain at much favourable level than when making a model with use of conventional manufacturing technologies.

Figure 1 shows the place of model creation in the chain leading from production preparation to delivering final product to customer. According to the diagram, currently there are many various technologies of Rapid Prototyping (RP), and parts fabricated with use of these technologies have different values of a given feature. It is important to ensure that the values of features which are required by a customer are as similar as possible to the values of features of prepared model.

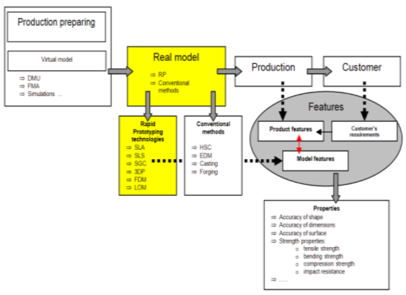

Fig. 1. Features and methods of producing physical models

The features concern mainly the dimensional and geometrical accuracy along with visual, mechanical and material properties.

In this paper, results of testing accuracy of real models, created using FDM (Fused Deposition Modelling) technology in the conditions of anisotropic material layer deposition are described.

2. RESEARCH COURSE

Testing was performed on the samples prepared with use of the FDM method. The device was Dimension BST 1200 and ABS was used as a model material. The scope of testing covered the measuring accuracy of manufactured part, with the assumption of anisotropic material layer disposition (fig. 2).

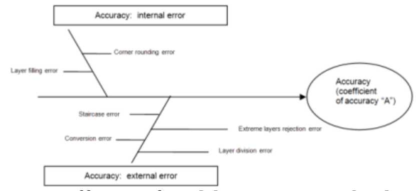

Fig. 2. Accuracy coefficient of model preparation technology

The synthetic coefficient of accuracy (A) prepared for a given technology will be equal to the sum of the following coefficients: internal error (A_{IE}) and external error (A_{EE}) multiplied by the weights of coefficient from a given group (w_{AIE}, w_{AEE}).

$$A = A_{IE} \times w_{AIE} + A_{EE} \times w_{AEE} \qquad (1)$$

Each value of coefficient of accuracy A must be between 0 (low accuracy) and 1 (high accuracy). The value of that coefficient may facilitate selection of model orientation in the FDM machine workspace (or application of multi-directional layer disposition technology), which is the most favourable from the point of view of criteria determined by weights. The choice of optimal orientation should be enabled by obtaining the most favourable accuracy model features similar to required features.

Accuracy of model manufacturing will be characterized by volume error. It is defined as a difference between the volume of material used for production of a model and the volume resulting from computer representation (3D model) of the model. Figure 2 shows that the final accuracy of model production and the accuracy coefficient prepared on that basis (marked as A) is a result of superposition of various errors in model production. They have impact on the quality of external model surfaces (especially on roughness), dimensional accuracy and weight of the product. Model production errors were grouped in two categories: external model errors and internal model errors. Causes of the above errors are various, some of them does not have any significance for a customer, while others determine the possibility of using the model for the given task. Therefore, by defining the final coefficient of accuracy of model production (A), it will be also necessary to introduce weights which define importance of specific group of errors occurring in the model for the customer.

2.1 External errors of model production

External errors of model production include: conversion error, staircase error, error of slicing into layers and extreme layers rejection error.

Error of conversion to STL format (Δ_{STL}) is connected with recording geometry of surface usually with use of a network of triangles (triangulation). Conversion error mainly relates to mapping a circle, or part of it (chordal error - fig. 3a) and consequently entire part (fig. 3b).

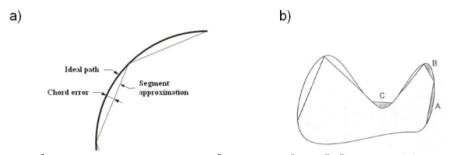

Fig. 3. Error of conversion to STL format; chordal error (a), model error (b)

Error of conversion Δ_{STL} depends on the coefficient of segmentation (tessellation value). By using lower coefficient of segmentation (seg), smaller chordal error may be obtained, thus smaller conversion error will occur. Exemplary CAD 3D model was mapped with random accuracy (results are shown on fig.4). Decreasing the coefficient of segmentation is connected with exponential increase of conversion process time.

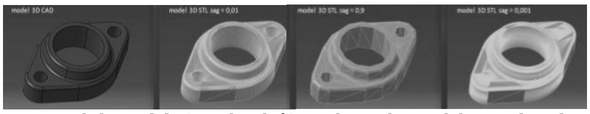

Fig. 4. Solid model (on the left) and mesh models produced with various segmentation coefficient (seg)

Staircase error (Δ_S) of a model is a distinctive error for processes where model is created layer-by-layer (fig. 5a). It occurs less frequently in models that have external surfaces parallel to direction of placing layers (this is mostly the purpose of multi-directional disposition of model layers – to reduce the frequency of staircase error).

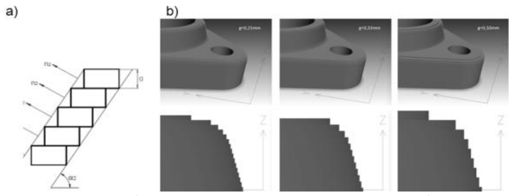

Fig. 5. The essence of staircase error (a) and impact of disposed layer thickness on the error value (b)

Staircase error (Δ_S) may be diminished by reducing the thickness of built layer (fig. 5b), however, this results in extension of model production time.

Fig. 6. Error of slicing into layers

Error of slicing into layers (Δ_W) is another external model volume error. Its essence is shown in fig.6.

Error of division into layers is connected with construction of RP devices. Fig. 6 shows an example of a model producing of the part with defined dimension "h". Assuming that it will be produced with layer slicing thickness g=0.25 mm, in case when the dimension is h=2.0 mm, the number of disposed layers equals 8. Error of layer division is approximate to zero. In case when h=2.8 mm, the number of disposed layers of thickness g=0.25 mm should equal 11.2. This is of course impossible because number of layers has to be an integer, so device control system rounds the number up and disposes 12 layers. In such case error of the slicing process is higher (fig. 7).

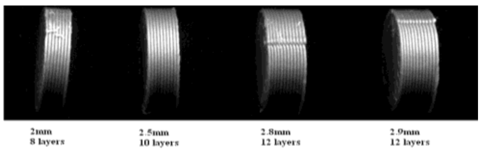

Fig. 7. Number of disposed layers

Considering the error of slicing, another one should be also mentioned - the **error of rejecting extreme layers** (Δ_R) which shape and surface do not allow to produce a closed outline and fill it (for example radius form). In such situation, software rejects extreme layers and this way a volume error is generated.

2.2 Internal errors of model production

Internal errors of model production are connected with the method of filling the interior of produced layer (fig. 8). The figure shows magnified structure of a single layer of real model built using FDM technology. FDM device control software first places a "thread" of material of width "h" to create an external outline of the model and then fills that outline with "threads" of material according to standard path programmed in the device control software.

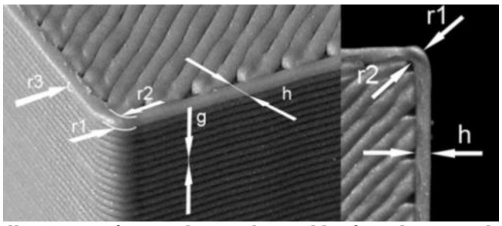

Fig. 8. Illustration of internal error; h - width of single material thread, r1 and r2 - external and internal radius of real model corner, g - layer thickness, r3 - radius of material thread rounding.

3. SUMMARY

The concept of multi-directional layer disposition in model production with application of Rapid Prototyping technology requires adequate orientation of model in relation to the head spreading material, thus determining direction for disposing subsequent layers (α). Choice of the direction (α) determines accuracy of model production, but in case of external errors of model production:

- error of conversion to STL format (Δ_{STL}) and coefficient of error conversion (A_{STL}) depends on coefficient of segmentation (seg). It does not depend on the direction of disposing subsequent layers (α). Coefficient A_{STL} equals 1,0 when chordal error equals 0,
- staircase error (Δ_S) and coefficient of error conversion (A_S) depends on the direction of disposing subsequent layers (α),
- error of division into layers (Δ_W), error of rejecting extreme layers (Δ_R) and coefficients (A_W) and (A_R) do not depend on direction of disposing subsequent layers (α).

Concerning internal errors of model production, coefficient A_{IE} does not depend on direction of disposing subsequent layers (α). According to (1) equation of accuracy coefficient is:

$$A(\alpha) = [A_{IE} \text{ x } w_{AIE}] + [A_{EE}(\alpha) \text{ x } w_{AEE}] = [(A_{IE} \text{ x } w_{AIE})] + [A_{STL} + A_S(\alpha) + A_W + A_R] \text{x } w_{AEE} \quad (2)$$

If $\frac{\partial A(\alpha)}{\partial \alpha} = 0$, we can calculate the most favourable orientation of a model in the device workspace. Therefore, it enables preparing individual strategy of material layer disposition for each case of required properties of a model.

4. ACKNOWLEDGEMENTS

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5. REFERENCES

Chlebus E., Techniki komputerowe CAx w inżynierii produkcji. WNT Warszawa 2000. (in polish)

Pajak P.T., De Silva A.K.M., McGeough J.A., 2005, Resarch and developments in laser beam machining. Zeszyty Naukowe Politechniki Budowa Maszyn I Zarządzanie Produkcją (Poznan University of Technology Science Journals), no.2: 63-90

Patil V.N., Patil A.A., Kumavat S.A., 2008, Reduction of staircase curvature effect on surface finish in adaptive slicing by trusurf system. Ist. International Conference on Tredds in Engineering and Technology, IEEE: 721-724

Singh P., Dutta D., 2001, Multi-direction slicing for layered manufacturing. Journal of Computing and Information Science and Enginerring, vol.1: 129-142

Sung-Hoon Ahn, Montero M., Odell D., Shad Roundy, Wright P.K., 2002, Anisotropic material properties of fused deposition modelling ABS, Rapid Prototyping vol.8, no.4 : 248-257

Weiss E., Warczyński B.: 3D-Printing – Models Accuracy, Euro-u Rapid 2005, Leipzig, May 10-12, 2005, FhG Fraunhofer Alianz Rapid Prototyping, B3/1

Weiss E., Waraczyński B.,2007, Zastosowanie technologii Vacuum Casting do wytwarzania prototypów funkcjonalnych. Zeszyty Naukowe Politechniki Poznańskiej. Budowa Maszyn I Zarządzanie Produkcją (Poznan University of Technology Science Journals), no.5: 89-96 (in polish)

Yang Y., Fuh J.Y., Loh H.T., Wong Y.S., 2003, Multi-orientational deposition to minimize support in the layered manufacturing process. Journal of Manufacturing Systems, vol.22, no 2: 116-129