Model of Filling the Internal Structure of Workpiece with Curved Layers for 3D Printing

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Abstract. This paper presents a solution to the problem of filling the internal structure of the workpiece with curve layer in 3D printing. A generalized model of filling the internal structure of workpiece with curve layer is designed. The results are presented for solving the problem on the example of curved layers of a conical shape with filling along a helical line. The research results can be in demand in the development of algorithms and software for technological equipment. They allow to ensure the formation of the internal structure of products in curved layers during 3D printing.

Introduction

The development of additive technologies is aimed at expanding the area of their application for solving various problems, including for obtaining structures with increased physical and mechanical properties. FDM printing technology is one of the ways to create such structures by filling the internal structure of products with curved layers formed by sections of various geometric shapes [1-9].

Relevance of the research topic

Research carried out by research teams [11-15] shows that the formation of the internal structure of products with curvilinear layers makes it possible to obtain structures with higher strength characteristics compared to filling with flat layers. The development of models, algorithms and software is an urgent task. It allows curve layers to form the internal structure of the product during 3D printing.

The preparation includes the following stages in printing using FDM technology in general: the separation occurs of a three-dimensional digital model, as a rule, in STL format, which is a list of coordinates of the vertices of triangular faces (facets) forming a surface into many curvilinear layers; the task is to select the trajectory of the extruder relative to the part; finding is carried out by areas of filling with material in accordance with the shape of the part [16-22]. The layer is applied one by one until the object is completely built.

An urgent task is to determine the trajectories of movement of the extruder, as well as areas of filling with material during the formation of the internal structure of products with curved layers.

Materials and methods for solving the issue

Work [10] proposes a technique for dividing a three-dimensional model into curved layers for 3D printing, for example, a conical shape (fig. 1).
Fig. 1. The section of the original part is represented by a cone: a) the position of the original part and the cutting cone; b) facets forming the intersection of the secant cone with the original part; c) a lot of sections of the original part with a cone

The task is to divide the model into curved conical layers for 3D printing by forming an array of facet numbers \(M\) that have intersection points with a secant conical surface. It is described by the equation:

\[
\mathbf{r}_0(u, v) = \begin{bmatrix} \sin u \cdot \sin(2\varphi)v; \\ -\cos u \cdot \sin(2\varphi)v; \\ \cos(2\varphi)v + v + Z_0 \end{bmatrix}, \tag{1}
\]

where \(u, v\) – cone parameters; \(\varphi\) – half the cone angle; \(Z_0\) – cone vertex coordinate.

In order to prepare for the printing of FDM technology, the following tasks are required. It consists in setting the trajectories of the extrude. Such trajectories can be described by different spatial curves, and their points are located on the cutting surface of the cone.

In particular, when dividing the model into conical layers, the trajectory can be set by the movement of the extruder by a conical helical line. It is described by the equation:

\[
\mathbf{r}(v) = \begin{bmatrix} \cos \left(\frac{k \cdot (v - Z_0) \cdot 2\pi}{P} + U_n\right) \cdot (v - Z_0) \cdot \tan \varphi \\ \sin \left(\frac{k \cdot (v - Z_0) \cdot 2\pi}{P} + U_n\right) \cdot (v - Z_0) \cdot \tan \varphi \\ v \\ 1 \end{bmatrix}, \tag{2}
\]

where \(v\) – screw parameter; \(Z_0\) – cone vertex coordinate; \(\varphi\) – half the cone angle; \(P\) – screw pitch; \(U_n\) – Initial twist angle of helix; \(k\) – screw line torsion direction: \(k=-1\) – clockwise, \(k=1\) – counterclockwise.

It is necessary to create an array of points to determine the areas of filling of the spatial curve (an array of parameters), which determines the trajectories of the extruder, which are the intersection points of the specified spatial curve with the plane of facets, the numbers of which belong to the array \(M\).
Fig. 2. Defines an intersection that represents a space curve and a face plane

Determination of the necessary intersection points of a given spatial curve with the facet planes is necessary for each facet included in the array $M$ (fig. 2) by solving the equation:

$$A_j \cdot r(t) \cdot k_j = 0$$  \hspace{1cm} (3)

regarding parameter $t$, where $A_j$ – matrix of transition to the coordinate system, built on the points of the $j$-th facet, whose coordinate center is located at the point $P_{j1}$, and the $Z_j$ axis is perpendicular to the facet plane. Fig. 3 shows a scheme for determining the point of intersection of a spatial curve with a facet plane.

Fig. 3. The diagram shows the definition of the intersection point of the spatial curve with the facet plane

The set $T$ of values of the parameter $t_k$ can be found by solving the equation. There is a need to select from the set $T$ subset of parameters for which the curve $r(t)$ as intersection points located inside the facet. Known methods [23] can be used to solve this problem.

We define the areas of filling with material by grouping the parameters of the curve $r(t)$, corresponding to the points of intersection of the curve with all facets. To do this, it is necessary
to construct a variational series of parameters \( t_k \), with properties \( t_1 \leq t_2 \leq ... \leq t_k \leq ... \leq t_{k-1} \leq t_k \) and form an array of pairs of parameters \([t_1, t_2], [t_3, t_4], ..., [t_{k-1}, t_k]\). The obtained pairs of parameters \( t_k \) will correspond to the sections of the extruder movement trajectories, on which filling with the material takes place.

For example, a diagram is presented for determining the points of intersection of a helical line with a certain body in fig. 4.

![Diagram](image)

**Fig. 4. The diagram shows the intersection of a helix with a certain body**

18 points are determined as a result of intersection of a helix with a certain body. The variation series will take the following form: \( t_{17}, t_1, t_4, t_8, t_9, t_2, t_{10}, t_5, t_7, t_3, t_{11}, t_6, t_{12}, t_{13}, t_{15}, t_7, t_5, [t_3, t_11], [t_6, t_{12}], [t_{16}, t_{14}], [t_{12}, t_{18}] \).

Therefore, the filler is completed by the material on the spiral section corresponding to the obtained pair.

**Conclusion**

The model was developed to fill the internal structure of products with curved layers for 3D printing as a result of the research. The results can be applied to research in the development of algorithms and software for technological equipment, which ensures the formation of the internal structure of products by curved layers during 3D printing.

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