Process Analysis and Experimental Research of 3D Printing with Variable Parameters

Zeng Lianghua
Beijing Institute of Technology, Zhuhai Campus, Zhuhai, Guangdong, China
04038@bitzh.edu.cn
zhuhai09@sina.com

Abstract—In view of the current situation that 3D printing uses fixed parameters, the reasons for the need to carry out 3D printing with variable-parameters are proposed based on theoretical analysis. The paper conducts a theoretical analysis of the adaptive layering algorithm and calculates the error expressions of different contours. The effects of variable printing speed and variable layer thickness on printing accuracy are analyzed based on experiment, which provides a basis for dynamic control and optimization of printing parameters. Finally, the necessity of printing with variable parameters is demonstrated.

1. INTRODUCTION
There are many factors that affect the quality of 3D printing, such as layer thickness, support angle, scanning strategy, filling method, printing speed and temperature setting, etc. The current 3D printers basically set all the printing process parameters in the pre-processing process, and then start printing until the end. The entire printing is performed using fixed process parameters. But the cross-section profile, printing height, temperature gradient of the hot bed and fan blowing direction are all dynamically changed during actual printing. Fixed-parameter printing cannot respond flexibly to the dynamic changes in the printing process, which has a large impact on printing quality and accuracy. Based on the FDM process, the paper conducts analysis and experimental research on 3D printing process with variable parameters. The purpose is to explore the change law of the printing process parameters following the printing process and provide a basis for the dynamic control and optimization of parameters.

2. REASON ANALYSIS OF VARIABLE PARAMETER
3D printing is based on the principle of layered overlay, which converts a three-dimensional model into a two-dimensional cross-sectional profile by slicing, and then forms it layer by layer. The outstanding feature of 3D printing technology is that it is not affected by the complexity of the part. However, 3D printed models are usually obtained through software modeling or 3D scanning, and their shapes are ever-changing. The 2D cross-sectional profile of each layer of the 3D printed model differs greatly and the complexity is also different when slicing. In addition, the printing height gradually increases during printing, the temperature influence of the heated bed on the printed part changes dynamically, and different shapes and contours require different filling methods and paths. All of these require the printer to respond in time. Real-time adjustment of process parameters such as printing speed and filling speed is to obtain the best printing quality.
3. ADAPTIVE LAYED ANALYSIS
The components of cross-sectional profile of 3D printed model are basically two types: straight lines and curved lines. There are three types of straight lines: horizontal straight line, vertical straight line, and inclined straight line. According to the direction and change of the curvature, there are four types of curves: variable curvature, constant curvature, concave curve, and convex curve, as shown in Fig.1. In the figure, the ab section is a convex curve of variable curvature, the bc section is a vertical straight line, the cd section is a concave curve of variable curvature, and the de section is a oblique straight line. The parts are printed horizontally (the layering direction is vertical).

![Figure 1. Error analysis of equal thickness layering](image)

When the equal thickness layering method is used, there is an approximation error between the contour boundary curve and the layered outline. The size and direction of the approximation error can be expressed by the area Sx that forms a triangle between the two-level layered height and the contour boundary curve. As shown in Figure 1, set the radius of curvature of the arc is ρ, the thickness of the layer is t, and the angle between the oblique straight line and the laying direction is θ. The size of Sx can be calculated as follows:

\[
S_x = \begin{cases} 
\frac{1}{2} \rho \left( 1 - \cos \arcsin \frac{t}{\rho} \right) & \text{curve contour} \\
0 & \text{vertical straight contour} \\
\frac{t^2}{2\tan \theta} & \text{oblique straight line contour}
\end{cases}
\]

From the expression of Sx, it can be seen that the size of different cross-section contour errors is very different, which is closely related to the thickness of the layer, the radius of curvature, and the inclination. Therefore, it is not suitable to use the equal thickness layering method for the cross-sectional contours of different constituent elements and contours with varying curvature. The adaptive variable layer thickness method should be adopted according to the accuracy and surface quality requirements of the printed part, and the different contour boundary curve when printing.

4. RESEARCH ON THE INFLUENCE OF PRINTING SPEED
Printing speed is an important parameter that affects printing quality, and is related to the profile shape of the cross-section, the scanning path, and the filling form. In order to explore the impact of printing speed on printing quality and accuracy, a italic cylinder (30 * 41.6 * 10mm, inclination angle of 40°) is selected as the printing object. The layer thickness t is 0.2mm, the filling density is 10%, and the
printing material is PLA. Using a delta3D printer to carry out experiments, the printing samples obtained at speeds from 20mm / s to 60mm / s are shown in Fig. 2.

![Samples with different printing speeds at t = 0.2mm](image)

Figure 2. Samples with different printing speeds at t = 0.2mm

The two parameters of the height h and the inclination angle α of the printed part in Fig. 2 are measured to represent the printing accuracy, and the changes are shown in Table 1. Through experimental observation and analysis, the reasons for printing failure at v = 60mm / s are: 1) the speed is too fast, the inertia of the nozzle movement is large, and the pulling force of the filament on the printed layer increases; 2) the speed is too fast, spinning cooling and solidifying time is not enough, the first few print layers and the hot bed are not firmly bonded; 3) the spinners are easy to stick together to form a mass of tumor (as shown in Fig. 2). After the tumor solidifies, it forms a hard bump, which will collide with the nozzle when it moves. It will greatly affect the adhesion between the printed layer and the hot bed.

For a single oblique cylindrical profile, it can be seen from the measurement results in Table 1.

a) The printing speed has a significant impact on printing quality. The height and angle of the workpiece change dynamically with the printing speed.

b) The height and angle errors gradually decrease with the printing speed.

c) When t = 0.2mm and v = 0.3, the height and angle errors are 0, and the best accuracy can be obtained. For a certain contour shape, the optimal printing quality corresponds to a suitable set of process parameters.
Table 1. PRINTED MEASURED VALUES UNDER DIFFERENT PARAMETERS

| Printing speed v (mm/s) | Measured height h (mm) | Height error | Measured Inclination α(°) | Angle error value | Printing time (minute) |
|------------------------|------------------------|--------------|---------------------------|------------------|----------------------|
| t=0.2 mm               |                        |              |                           |                  |                      |
| 20                     | 10.36                  | +0.36        | 41.5                      | +1.5             | 47                   |
| 30                     | 10.00                  | 0            | 40                        | 0                | 35                   |
| 40                     | 10.20                  | +0.2         | 41                        | +1               | 29                   |
| 50                     | 10.10                  | +0.1         | 40.1                      | +0.1             | 25                   |
| t=0.1 mm               |                        |              |                           |                  |                      |
| 20                     | 9.82                   | -0.18        | 47.8                      | +7.8             | 106                  |
| 30                     | 9.90                   | -0.1         | 42                        | +2               | 78                   |
| 40                     | 9.80                   | -0.2         | 43                        | +3               | 63                   |
| 50                     | 9.82                   | -0.18        | 43                        | +3               | 55                   |

5. RESEARCH ON THE INFLUENCE OF LAYER THICKNESS

Generally the smaller the layer thickness is, the higher the accuracy of the printed part will be, but the longer it will take. To obtain the best accuracy, different layer thicknesses should be used for different cross-sectional profiles. In order to grasp the influence of layer thickness on printing accuracy, the above-mentioned oblique cylinder (30 * 41.6 * 10mm, inclination angle of 40 °) is used as the printing object. The same equipment and other printing parameters as the printing speed research are selected. Printing experiments at different printing speeds at t = 0.1mm and t = 0.2mm are carried out. The specific experimental results are shown in Fig.3 and Table 1.

Figure 3. Samples with different printing speeds at t = 0.1mm

For a single oblique cylindrical profile, it can be seen from the measurement results in Table 1.

a) When the thickness of the layer is reduced, the measured height h decreases at the same printing speed, and both have a negative deviation.
b) When the thickness of the layer is reduced, the measured angle α increases at the same printing speed, and all of them have a positive deviation, showing a property completely opposite to the height.
c) At t = 0.1mm and v = 20mm / s, the angle error value reaches 7.8 °. It is found in the experiment that this is due to the occurrence of tumor many times during printing, and the nozzles collides with it many times during moving, which results in serious layer-to-layer misalignment and the largest angular error.
d) Under t = 0.1 and 0.2, the best print quality is obtained at a print speed of 30mm / s.
e) For a single contour shape, there is a relatively good set of process parameters. For different contour shapes of the actual part, if the fixed layer thickness and printing parameters are used, the
errors will be different. Therefore, it is very important to adaptively adjust the relevant printing parameters during the printing process.

6. CONCLUSION

Based on the principle analysis of 3D printing with variable parameter, a 3D printing experiment is carried out. An adaptive layering method is proposed for different cross-section profiles, and the error expressions under different cross-section profiles are calculated. The effects of variable printing speed and variable layer thickness on printing accuracy are analyzed. Each section profile has a set of more suitable printing process parameters which has been proved through experiments. The necessity of developing 3D printing with variable parameter is also explained.

ACKNOWLEDGMENTS

Guangdong Ordinary Universities Youth Innovative Talents Project (3D Printing Quality Real-time Detection and Quality Prediction Key Technology Research:2018KQNCX343); Key Disciplines of Guangdong Province: Mechanical Engineering.

REFERENCES

[1] Zeng lianghua , Zou xinfeng. “Error Analysis and Experimental Research on 3D Printing”. MTMCE (2019):1~7
[2] Marco Grasso , Bianca Maria Colosimo. “ Process defects and in situ monitoring methods in metal powder bed fusion: a review. Measurement Science and Technology",2017( 28) :1~25
[3] Kun He , Zhijun Yang. “ Intelligent Fault Diagnosis of Delta 3D Printers Using Attitude Sensors Based on Support Vector Machines”. Sensors, 2018(18):19~28
[4] S. Adamczak, J. Bochnia, B. Kaczmarska. “An analysis of tensile test results to assess the innovation risk for an additive manufacturing technology”. Metrol. Meas. Syst,2015( 22) :127–138
[5] Yedige Tlegenov, Geok Soon Hong, Wen Feng Lu. “Nozzle condition monitoring in 3D printing. Robotics and Computer Integrated Manufacturing”.2018( 54):45–55
[6] Sarah K. Everton , Matthias Hirsch, Petros Stravroulakis , Richard K. Leach , Adam T. Clare. “Review of in-situ process monitoring and in-situ metrology for metal additive manufacturing”. Materials and Design, 2016(95) :431–445
[7] Y. Li, B. S. Linke, H. Voet, B. Falk, R. Schmitt, M. Lam. “ Cost, sustainability and surface roughness quality - A comprehensive analysis of products made with personal 3D printers. CIRP Journal of Manufacturing Science and Technology,2017( 16):1-11
[8] Cheng B, Shrestha S and Chou K. “Stress and deformation evaluations of scanning strategy effect in selective laser melting Add. Manuf, 2016(12):240–51