Research on the Influence of 3D Printing Speed of External Special-Shaped Parts

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Abstract—In view of the current situation that traditional processing methods are difficult to manufacture external special-shaped parts, and combined with the advantages of 3D printing technology, the thesis conducts a research on the 3D printing speed of external special-shaped parts. According to the elements of the two-dimensional cross-sectional profile, a four-jaw part model with certain structural characteristics is designed. In the experiment, the effect of changing the printing speed on the printing accuracy is discussed. Using the two-dimensional measurement method, the size and error rate of the size error at different printing speeds are calculated. The research is carried out on the basis of experiments, and a certain theoretical analysis is carried out on the experimental results, which can provide a certain reference for the 3D printing research of special-shaped parts.

1. INTRODUCTION
External special-shaped parts refer to parts with weird external shapes, which exist in large numbers in engineering due to the needs of structure or assembly. Such parts are usually difficult to form using traditional processing methods, and need to design special fixtures, improve cutting tools and processing techniques. This will lead to high processing costs and is not conducive to mass production.

3D printing technology uses the principle of layer slicing, which converts a complex three-dimensional model into a two-dimensional plane contour through a slicing method, and then builds it layer by layer [1]. 3D printing technology can form any part without being affected by the complexity of the part. Based on this, the thesis carries out the research on the influence of 3D printing speed of external special-shaped parts, in order to grasp the law of the influence of printing speed on special-shaped parts and to guide the structural design of special-shaped parts.

There are many factors affecting the accuracy of 3D printing, including machine status, leveling status, process parameters, post-processing methods, etc. [3]. At present, the research of 3D printing is more concentrated in the aspects of printing error analysis, printing quality monitoring, etc., and most of the researches are based on conventional parts. Zeng [1] and others used insight software to carry out theoretical and experimental research on contour approximation error, height error, and model inclination. He [2] et al. used the echo network method to monitor the status of the nozzle with an attitude sensor, and compared the accuracy of various algorithms. At present, there are relatively few researches specifically aimed at the printing process of special-shaped parts. Therefore, the research on the process of 3D printing of special-shaped parts has certain practical significance.
2. EXPERIMENTAL PROGRAM DESIGN

The experiment is planned to be carried out with a parallel-arm 3D printer, as shown in Figure 1. The printer uses cura software for model slicing. The printing process parameters that can be adjusted mainly include printing speed, filling density, printing temperature, platform temperature, layer thickness, etc. [4]

In order to study the influence of process parameters on printing accuracy, a four-jaw part was designed. The specific shape and size are shown in Figure 2. The model has a 90° vertical profile, with a claw designed every 30°. The model consists of two contour elements: straight line and constant radius curve. The three-dimensional model is obtained by extending the model 6mm, as shown in Figure 3. The thesis mainly studies the influence of printing speed on length, radius and angle. The variables S1, S2, R, C1, C2 and C3 to be measured are shown in Figure 3.

![Figure 1. Delta 3D printer](image)

![Figure 2. 2D diagram of the printed model](image)
In order to study the influence of printing speed, the parameters such as the layer thickness and filling density remain unchanged. The printing parameters used in the experiment are shown in Table 1.

| Serial number | Parameter | Layer thickness $h$ | Filling density $\rho$ | Printing speed $v$ |
|---------------|-----------|---------------------|------------------------|-------------------|
| #1            |           | $h=0.1$mm           | $\rho=20\%$            | $v_1=30$mm/s      |
| #2            |           |                     |                        | $v_2=40$mm/s      |
| #3            |           |                     |                        | $v_3=50$mm/s      |
| #4            |           |                     |                        | $v_4=60$mm/s      |

3. MEASUREMENT METHOD

There are three types of dimensions in the model, namely straight line, radius and angle. Both the straight line and the radius are measured with a caliper. Measure different positions three times and take the average value to get the experimental data. The angle is measured with an image measuring instrument (as shown in Figure 4), and the experimental data is obtained by measuring three times and taking the average value. Image measuring instruments are used to measure the dimensions of two-dimensional planes and are widely used in various precision industries. It is mainly used for the dimensions and angles of components that are difficult to measure or impossible to measure with calipers and angle rulers, but play an important role in assembly \(^{(5)}\). When measuring the angle in the experiment, the author chooses the horizontal edge as the reference, measures the angle between the two edges of each claw and the reference line in turn, and then takes the average value.
Figure 4. Software interface of image measuring instrument

4. ANALYSIS OF EXPERIMENTAL RESULTS

According to the designed experimental plan, the samples corresponding to the four printing speeds (v1=30mm/s, v2=40mm/s, v3=50mm/s, v4=60mm/s) are sequentially numbered 1, 2, 3, 4. The printed object is shown in Figure 5. The measurement results are shown in Table 2 and Table 3.

Figure 5. Printed object
Table 2. The Effect of Printing Speed on Size

| Serial number | Printing speed v (mm/s) | Edge S1 (mm) | Edge S2 (mm) | Radius R (mm) |
|---------------|-------------------------|--------------|--------------|---------------|
| #1            | 30                      | 19.61        | 20.01        | 9.70          |
| #2            | 40                      | 19.77        | 20.00        | 9.75          |
| #3            | 50                      | 19.78        | 20.05        | 9.77          |
| #4            | 60                      | 19.83        | 20.04        | 9.79          |

It can be seen from Table 2:
1) The printing speed has a significant effect on the dimension. As the printing speed increases, the length and radius dimensions are both increasing. The faster the printing speed, the shorter the cooling and solidification time of the extruded material, and the smaller the error caused by the shrinkage of the material. So, the size tends to increase.
2) S1 and S2 are both straight lines, but the dimension deviation direction is not consistent. S1 is a negative error and S2 is a positive error. The node composition of the two straight lines is the same, and the scanning trajectory of the print head is similar. The deviation direction is different due to the different printing sequence. Straight line (S1) is printed first, the cooling time is long and the size deviation is negative.
3) The radius R presents a negative deviation, indicating that the material shrinks inward continuously due to cooling during printing. The faster the printing speed, the smaller the shrinkage.

Table 3. The Effect of Printing Speed on Angle

| Serial number | Printing speed v (mm/s) | Angle C1(°) | Angle C2(°) | Angle C3(°) |
|---------------|-------------------------|--------------|--------------|--------------|
| #1            | 30                      | 29.25        | 59.41        | 89.51        |
| #2            | 40                      | 29.57        | 59.33        | 89.30        |
| #3            | 50                      | 29.67        | 59.54        | 89.37        |
| #4            | 60                      | 29.60        | 59.24        | 89.34        |

It can be seen from Table 3:
1) As the printing speed increases, the angular size does not increase linearly. There is an inflexion point. From the perspective of the influence, there is an optimal value for the printing speed. Comparing 4 sets of parameters, it is found that when the printing speed v3=50mm/s, the angle error values of C1 and C2 are the smallest. When the printing speed v1=30mm/s, the angle error value of C3 is the smallest. It shows that different angular distributions represent different positions of the claws, and there is a certain relationship between position and the printing speed.
2) The angle errors are all negative deviations, indicating that each claw has contraction in the horizontal direction.

The error value reflects the deviation value between the actual size and the design size [6]. It cannot reflect the specific degree of influence. In order to accurately analyze the printing error and its influence, the calculated error rate is shown in Table 4. The error rate is the ratio of the difference between the actual value S and the design value S0 to the design value, reflecting the degree of deviation between the actual value and the design value.
Table 4. Error Rate Statistics Table

| Serial number | Error rate of S1 | Error rate of S2 | Error rate of R | Error rate of C1 | Error rate of C2 | Error rate of C3 |
|---------------|-----------------|-----------------|----------------|-----------------|-----------------|-----------------|
| #1            | -1.55%          | 0.05%           | -3%            | -2.5%           | -1.96%          | -1.63%          |
| #2            | -1.15%          | 0               | -2.5%          | -1.43%          | -2.23%          | -2.36%          |
| #3            | -1.1%           | 0.25%           | -2.3%          | -1.1%           | -1.53%          | -2.1%           |
| #4            | -0.85%          | 0.2%            | -2.1%          | -1.3%           | -2.53%          | -2.2%           |

It can be seen from Table 4:

1) The error rate of the straight line is smaller than that of the equal radius curve. Use the insight software to take out the node information of the contour as shown in Figure 6. There are only 2 nodes (white dots) in the straight line, and the print head moves linearly without pause or commutation. The equal radius curve has 12 nodes (white dots) when approaching the contour. Each small arc has 4 nodes (white dots), which means that the print head has been reversed three times. It affects the printing accuracy to a certain extent.

2) When printing speed v4 is 60mm/s, the error rate of straight line and constant radius curve is the smallest.

3) When printing speed v3 is 50mm/s, the error rate of C1 and C2 is the smallest. When printing speed v1 is 50mm/s, the error rate of C3 is the smallest.

4) The maximum linear error rate is 1.55%, and the minimum is 0. The maximum radius error rate is 3%, and the minimum is 2.3%. The maximum angular error rate is 2.5%, and the minimum is 1.1%. Under different printing speeds, the error rate fluctuates greatly. Different contour compositions and different part angles have different optimal printing speeds. Therefore, when designing a model, attention should be paid to the constituent elements of the profile and the angle of the model.

Figure 6. Node diagram of four-claw shaped parts

5. CONCLUSION

As the printing speed increases, the length and radius dimensions are increasing, and the accuracy is gradually improved. The error deviation direction of the straight line is closely related to the printing path and printing sequence. The error deviation direction of convex radius profile is negative due to the shrinkage. The faster the printing speed, the smaller the error value. The effect of the printing speed on the angle is not linear. The position of the different angle distribution on the part, the angle error is different, and the best printing speed is also different.
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