Error Analysis and Process Parameter Optimization of Impeller Model Manufactured by FDM Process

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Abstract. Through the process of making impeller model by Fused Deposition Modeling (FDM), the error of 3D printing forming process was analyzed, including principle error, forming error and post-processing error. The error caused by measurement is analyzed, and the causes of the error and the solving methods are expounded in detail. By analyzing the errors in the size of impeller models, the possible causes of errors can be analyzed. Combining the forming conditions and the actual situation, the optimization method of process parameters is analyzed, which can provide a certain reference for 3D printing production and testing the best process parameters.

1. Introduction
Additive manufacturing (also known as 3D printing) technology is a new manufacturing technology developed in the late 1980s. Impeller is one of the main parts of mechanical rotor, and its structure complexity makes its machining process very difficult. Depending on the 3D printing technology, the physical model can be directly produced according to the existing impeller physical / 3D model, which can not only save the tedious process of programming in the traditional processing, reduce the requirements for the impeller manufacturing environment and equipment, but also save a lot of time and manpower investment, and reduce the cost of impeller model.

As a 3D printing process, Fused Deposition Modeling (FDM) has the advantages of simple operation, low cost of raw materials and no pollution. This paper takes the manufacturing process of 3D printing sample of FDM process of impeller model as an example to analyze the accuracy and optimize the process parameters. The process parameters of fused deposition (FDM) 3D printer are analyzed. The mechanism of printing error and the effect on surface accuracy are analyzed. Through slice software to adjust layer thickness, printing speed and printing temperature to analyze, find out the primary and secondary order and the optimal combination mode of each parameter affecting the accuracy, obtain higher printing accuracy under the condition of unchanged hardware conditions, improve the working efficiency of parameter debugging personnel and the surface accuracy of parts, which is of great significance in the actual molding process.

2. 3D Printing of Impeller Model

2.1. Impeller Model Making and STL Format Conversion
Since the 3D printing software can only act on the whole part, there cannot be a single body, so it should be optimized before printing after the CAD model of impeller is made. Firstly, CAD software (UG system is used in this paper) to complete the 3D modeling of the model, and then export STL file.
2.2. Selection of 3D Printers and Printing Materials
The 3D printer used in this paper is WBSH105, and the printing material is PLA 1.75mm. Printing production is to convert the 3D part model established by UG system, and then import the model into Cura software (version 15.04.6). Through Cura system, the impeller parts are set before printing, and the print preview is carried out to determine the accuracy of its size. Then, the code that can be recognized by 3D printer is generated, and finally the code is imported into the memory of 3D printer for printing.

2.3. Print Preview and Generate Gcode
(1) Layered treatment of impeller model, When the 3D model of impeller is completed with UG system and the STL file required is generated, Cura software can be used to process the model layer by layer, and then generate Gcode (G code). First start Cura software, there are a series of parameter settings, such as layer thickness of 0.2mm, wall of 1.2mm, filling density of 20%, printing speed of 60mm / s, printing temperature of 200 ° C, support type of extension platform, diameter of 1.75mm, flow rate of 100%, nozzle diameter of 0.4. After setting, you can see the estimated printing time and consumables usage, and then preview the printing in Cura. In the Cura software interface, the print preview is shown in Figure 1. As shown in Figure 2 (a) and (b), the CAD model of the impeller and the physical model of the impeller after fabrication are respectively shown.

![Figure 1. Print preview](image1)
![Figure 2. CAD model and physical model](image2)

(2) Generating Gcode code, After confirming that the print path and parameters are correct, then save the Gcode code. Because the code is too long and the length is large, only part of the Gcode code is displayed.

```
M109 S220
;-- START GCODE --
......
;Basic settings: Layer height: 0.2 Walls: 1.2 Fill: 20
......
;M109 S220
;Uncomment to add your own bed temperature line
G1 Z65.175
G0 F7800 X146.350 Y101.287 Z70.000
;-- END GCODE --
```

3. Error Analysis of Model and Optimization of Process Parameters
3.1. Error Analysis of FDM Printing Technology
Any product in the manufacturing process must ensure a certain accuracy. The higher the accuracy, the stronger the competitiveness in the market. Only by studying the influence factors of the error, can we reduce the error in the production process better. According to the working principle and process of 3D printing technology, the error influencing factors can be divided into the following categories: ① principle error (including STL file fitting error, lamination error and molding error); ② molding error
(nozzle error, material shrinkage error and process parameter error); ③ post-processing error.

3.2. Principle Error

(1) STL file fitting error, The principle error is mainly due to the error between the STL file used in 3D printing and the actual geometry of the part. STL file is to fit the geometric shape of the part in the form of triangle. As shown in Figure 3, for a part with relatively complex geometric contour, this method can only achieve infinite approximation of the geometric contour, but can not be completely the same, which leads to the existence of errors. In Figure 3, ε represents the mirror distance between the geometric contour of the part and the connected triangle, which is called chord height. The smaller the chord height is, the closer the generated file is to the geometric contour of the part, as shown in Figure 4.

![Figure 4. Different chord heights](image)

![Figure 5. Positive and negative errors caused by slicing](image)

As can be seen from Fig. 4, the chord height has a considerable influence on the generated part geometric profile. To improve the accuracy by reducing the chord height is to increase the density and number of triangles to approximate the actual geometric contour. However, this will increase the amount of computer calculation, reduce the running speed of the software, make the STL file larger, and the processing time will also be longer. However, some software still cannot meet the user's basic accuracy requirements. The chord height of the molding machine used in this paper is 0.0328mm, and the output STL file model is shown in Figure 4. It can be seen from the model that the more complex the surface, the more density and number of triangles.

(2) Error in the process of stratification, The FDM process is sliced in layers and printed in 2D mode. However, because each layer has a certain thickness, the edge of each layer cannot be seamless with the edge of the previous layer. This leads to shape error and dimension error between the model and the actual part, which is called step error. When the gap between this layer and the upper layer is larger than the actual part contour, the error is positive, as shown in Figure 5 (a). Otherwise, it is negative error. As shown in Figure 5 (b). For parts with different requirements, different error types can be used to obtain the desired size by grinding.

3.3. Forming Error

The forming error is mainly caused by the error between the thickness of the melt filament ejected by the nozzle in the working process, the different curing speed of the melt silk material itself in the cooling and curing process, and the error caused by the process parameters such as the temperature in the molding process, the extrusion speed of the nozzle, the scanning speed of the system to the parts, and the filling method. The following analyzes the error of process parameters in the molding process.

(1) Temperature parameters, Temperature parameters include nozzle temperature and ambient temperature. When the extrusion speed is constant, the melt wire can be kept in the melting state, and there is no bias to either solid or liquid form, which is called the optimal temperature of the nozzle. The optimum ambient temperature is the temperature at which the melt wires can be cured orderly in the forming process.

(2) Extrusion speed and scanning speed, When the temperature parameter is constant, the extrusion speed which can make the thickness and texture of each spinning uniform is the best extrusion speed. It and the scanning speed affect each other, because the scanning speed directly affects the moving speed of the nozzle. If the two are not consistent, it will lead to the poor moving speed of the nozzle,
and eventually lead to uneven spinning, which makes the material accumulation in some areas too much or insufficient. In terms of printing speed, it is necessary to control the extrusion speed and the moving speed of the nozzle. In the process of printing, the starting and stopping points of each layer will appear, which is to control the speed of the nozzle and the extrusion speed to be consistent.

(3) Filling method. The filling methods are divided into fishing net filling and linear filling. No matter which filling method, there is a very important factor, which is the filling spacing. When the filling distance is too large, the mechanical properties of the parts will be reduced, but at the same time, the cost will be reduced and the processing speed will be improved. When the filling distance is too small, the mechanical properties of the parts can be improved, but at the same time, it will lead to material accumulation at the filling intersection between layers, which will affect the surface quality.

3.4. Post Processing Error
After printing, the parts are not cured completely. In the process of removing parts from the support platform, parts may be deformed due to excessive force or improper use of tools. After the parts are removed from the support platform, due to the changes of temperature, moderation and other environmental factors, the processed parts may produce secondary deformation. In addition, due to the requirements of surface accuracy or dimensional accuracy, there will be some errors in the later grinding and optimization process.

3.5. Error Analysis of Impeller Model
Due to the limitation of space, this paper only calculates the axial error $E_{a1}$ and radial error $E_{a2}$ of impeller parts made by 3D printing. In order to reduce the human error, the measurement data of each size is collected from five different places.

1) Radial error. The calculation formula of radial error: $E_{a1}=|x_i-X|$. Among them, $E_{a1}$ is the radial error, $x_i$ is the measured value each time, and $X$ is the theoretical value.

2) Axial error. Axial error calculation formula: $E_{a2}=|y_i-Y|$. Where $E_{a2}$ is the axial error, $y_i$ is the measured value each time, and $Y$ is the theoretical value.

From the data in Table 1 and Table 2, it can be seen that there are certain errors in both radial and axial directions. In addition, the radial error is relatively large. The precision of traditional manufacturing industry is as high as 0.1~0.01μm, which shows that there is still a gap between 3D printing technology and traditional manufacturing technology.

3.6. Process Parameter Optimization
In the manufacture of impeller model, the molding machine equipment and hardware, molding system, molding materials and other factors are fixed, and the only control is the process parameters of the printer for the molding process. Through the control of printing speed, nozzle temperature, layer thickness and other process parameters, the precision of parts is controlled. For the control and optimization of these process parameters, it is necessary to test the best process parameters through continuous experiments. Only in this way can the error in the forming process be minimized.

| xi(mm) | X(mm) | E_a1(mm) | E_a1(mm) |
|--------|-------|----------|----------|
| 105.10 | 105   | 0.10     | 0.256    |
| 104.62 | 105   | 0.38     | 0.256    |
| 104.70 | 105   | 0.30     | 0.256    |
| 104.72 | 105   | 0.28     | 0.256    |
| 104.78 | 105   | 0.22     | 0.256    |

| yi(mm) | Y(mm) | E_a2(mm) | E_a2(mm) |
|--------|-------|----------|----------|
| 65.04  | 65    | 0.04     | 0.152    |
| 64.68  | 65    | 0.32     | 0.152    |
| 64.84  | 65    | 0.16     | 0.152    |
| 65.12  | 65    | 0.12     | 0.152    |
| 64.88  | 65    | 0.12     | 0.152    |
Modeling optimization, In UG modeling, no matter the existence of curve or arc surface, as long as it has been zoomed in, we can see the existence of step effect. Therefore, in order to facilitate the post-processing of the printed modeling entity, the existence of error should be reduced as much as possible in the modeling process. The optimization of CAD software modeling is convenient for the later part analysis work, and also can reduce part of the accuracy error, which is more conducive to the determination and comparison of part size, and fundamentally reduces the 3D printing error, which is more conducive to the part analysis work of slicing function of 3D printer software, and further reduces the printing error.

(2) Optimization of printing parameters, The melted material is extruded and selectively coated on the worktable. After rapid cooling, a layer of cross-section is formed and coagulates with the surrounding materials. After one layer is formed, the next layer is formed until the whole part is completed. Based on this principle, there will be small step surfaces on the surface of the parts, and these step surfaces will form the plane or arc surface of the part. This is the step effect. This will greatly increase the surface roughness of the parts, and this effect will be more obvious if the layer thickness is too large. Secondly, there are some differences between the modeling of parts and the actual size of parts due to the existence of step effect stratification. When there are small features on the surface of the part, the influence of step effect will be maximized.

To sum up, in order to improve the quality of 3D printing, the following aspects can be improved:

- By using Reverse Engineering software to repair STL files, the patch quality is improved and the precision loss in the process of CAD model discretization is reduced.
- Appropriate process parameters were selected, including layer thickness, compensation, extrusion speed, filling speed, opening / closing delay, nozzle temperature, molding chamber temperature and wire material.
- Change the orientation of forming parts and reduce the length of prototype section. Surfaces with high accuracy requirements are usually formed in a vertical direction. Less important surfaces are usually formed in a horizontal direction, such as the top or bottom surface.
- Increasing the thickness of the substrate and increasing the filling interval can reduce the internal stress and the degree of bending deformation.
- Keep the platform clean and calibrate the initial height of Z-axis printing.

4. Conclusion
After describing the 3D printing process of impeller model, the error in the molding process is analyzed. It can be seen from the results that in addition to the influence of measurement factors, the accuracy of 3D printing is still very high. In terms of parameter optimization, this paper analyzes the two aspects of modeling and printer itself, and puts forward the improvement method. Generally speaking, FDM process has a lot of room for improvement in parameter optimization.

The advantages and disadvantages of 3D printing technology can be seen clearly in the actual production process. If the advantages of traditional manufacturing industry are combined with 3D printing technology, the best process parameters are tested, and the optimization method of process parameters is analyzed combined with molding conditions and actual situation, which can provide reference for 3D printing production and testing the best process parameters.

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