Research on New Sprinkler Heat Insulation System Based on 3D Printing Technology

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Abstract. Firstly, the mechanical structure of the sprinkler is designed by Solidworks in this paper. The wire of the sprinkler is made of waste PET. Then the theoretical feasibility is proved by further simulation analysis with ANSYS software, and the thermodynamic theory of heating and heat dissipation is analyzed and utilized. Finally, the practical operation feasibility of the new 3D printer print nozzle insulation system is verified by physical printing test.

1. Introduction

At present, most of the common plastic bottles are "No. 1" PET plastic bottles. Recycling methods of PET plastic bottles abroad mostly adopt plastics simple regeneration method, and some of them adopt pyrolysis monomer technology. The recycling rate of domestic PET plastic bottles is only 42%. A large part of waste PET plastic bottles are treated by traditional methods such as incineration and landfill. At present, there are many problems in the recycling of PET plastics, such as waste of resources, pollution of the environment, unstable performance of recycled products and so on[1-2].

PET, as the main raw material of waste plastic bottles, has good plasticity and regeneration. It has a wide range of sources[3]. Its unique properties have been proved to be effective in 3D printing. However, FDM forming technology lacking cheap and high-quality raw materials is in need of such high-quality materials. At present, there are few studies on the combination of PET plastics and FDM moulding technology in China, mainly on the regeneration of PET and the research of new FDM materials. Waste PET plastic bottles have been studied for 3D printing, but because of its unique nozzle structure and high printing temperature, the heat dissipation of nozzle heating block through aluminium profile is excessive and a lot of heat is wasted in the experiment process, which not only increases the difficulty of temperature control, but also makes the extrusion process of nozzle unstable; it also improves the working temperature of motor and shortens the service life of motor.

Therefore, in this paper, we mainly design how to make the thermal insulation system of this new printer. Firstly, the mechanical structure of the new printer nozzle is introduced. Then, the theoretical calculation and simulation analysis of the thermal insulation system are carried out. Finally, the physical test is carried out.

2. Introduction of mechanical structure of thermal insulation system for printing nozzle of new 3D printer

2.1 Mechanical Structure of Printing Sprinkler
Because the PET material used is flat, it needs to be modified\cite{4}. We can't print with the existing printing sprinkler, so we design a new type of sprinkler insulation system. The structure of printing sprinkler mainly includes screw feeding nucleating agent adding control mechanism, screw extruding mechanism, heating and insulation system.

Figure 1 shows the structure of the printing nozzle. Among them, nucleating agent feeding motor, fixing bracket, nucleating agent feeding screw and nucleating agent barrel constitute nucleating agent adding mechanism; nozzle, feeding screw and driving motor constitute positive and negative screw extruding mechanism; heating block and nozzle constitute heating system; belt wheel, side plate with hole and heat insulation plate constitute heat insulation system.

![Figure 1. Print nozzle structure.](image)

Flake PET material enters the mixing barrel through the feeding port through the remote wire feeding device\cite{5}. The mixing barrel is heated by the heating rod. After the device reaches a certain temperature, the PET material melts. The rotation of the decelerating motor drives the rotation of the adding screw of the nucleating agent. By controlling the speed of the motor, the nucleating agent is quantitatively and steadily delivered to the mixing container below.

The extrusion screw is designed with positive and negative threads. The whole screw is divided into three sections. The upper and lower ends are positive threads. It plays the role of extrusion feeding. The middle part is reverse threads. There is an upward thrust on molten PET during the screw rotation process, which can achieve the goal of homogeneous mixing of nucleating agent and molten PET. The material is extruded from the nozzle by the downward extrusion of the screw. The driving motor provides power for the screw through synchronous toothed belt drive. Compared with the direct connection between the motor and the screw, the influence of the screw heat on the motor work is reduced.

The sprinkler heating system controls the temperature precisely by controlling the on-off of the heating circuit. A temperature sensor is installed near the heating rod. When the temperature is lower than the preset temperature, the heating circuit is connected, the heating rod works, and the temperature of the heating block rises. When the temperature is higher than the preset temperature, the heating circuit is disconnected and the heating rod stops working, so that the heating block is kept through the feedback adjustment process. At a constant temperature, the nozzle can work continuously and normally.

The insulation system adopts layer by layer insulation of heating block, feeding screw and driving motor. Thermal insulation board is installed on the heating block to reduce the heat transfer from the heating block to the outside frame of the printer nozzle. The synchronous toothed belt drive is adopted between the PET feeding screw and the motor. On the one hand, it ensures the uniformity and stability of the motion transfer during the extrusion process, on the other hand, it makes the motor work at a lower temperature and prolongs its service life.
2.2 Mechanical structure of thermal insulation system
The insulation system designed in this paper is a layer-by-layer insulation system of heating block, side plate with hole, feeding screw and driving motor. Its characteristics are: prolonging the life of the motor and improving the performance of the sprinkler. Figure 2 is the mechanical diagram of the insulation system.

The thermal insulation system uses the insulation board as the first stage, the side plate with holes as the second stage, and the synchronous belt as the third stage. Heating block is not directly contacted with mixing container when heating, and heat insulation plate is installed in the middle to reduce the heat transfer from heating block to the outside frame of printing nozzle to realize the first stage heat insulation; side plate with holes accelerates the heat transfer from heating block to the body to realize the second stage heat insulation; feed screw and drive motor are driven by synchronous belt wheel to reduce the heat absorbed by driving motor and realize the third stage heat insulation.

3. Theoretical calculation and simulation analysis
3.1 Thermodynamic Theoretical ANALYSIS of Heating and Heat Dissipation
The sprinkler heating system controls the temperature precisely by controlling the on-off of the heating circuit to ensure the sprinkler working continuously and normally. Installation of heat insulation board on the heating block can reduce the heat transfer from the heating block to the outer frame of the printing sprinkler, and make the motor work at a lower temperature to prolong its service life.

Surface Heat Dissipation Coefficient of Sprinkler Heat Dissipation Module $h_c$ (W/ (W/m²*K))
The computational expression is:

$$h_c = 11.6 + 7 \times w^{0.5}$$

The symbolic meanings in the formula: $h_c$: convective heat transfer coefficient; $w$: air velocity (m/s)
Owing to the different air velocities at different parts of the nozzle, $W_1=6.9m/s$, $W_2=3.7m/s$ and $W_3=1.44m/s$, the heat dissipation coefficients calculated are $h_c1=30$, $h_c2=25$ and $h_c3=20$.

3.2 ANSYS simulation analysis
ANSYS Workbench was used for thermal analysis of the nozzle heating and cooling module. The material of the nozzle and heating block was brass with a thermal conductivity of 108.9W/(m²*K), aluminum alloy with a thermal conductivity of 155W/(m²*K), rubber polyurethane with a thermal conductivity of 25W/(m²*K) and stainless steel with a thermal conductivity of 16.2W/(m²*K) for the synchronous belt. It is known that the melting temperature of PET is between 240 255 C. The optimum heating temperature of heating rod is obtained by thermal analysis. Through the analysis of different heating temperatures, it is concluded that when the heating rod temperature is set to 270 C,
the temperature in the mixing barrel reaches 250°C, which is in the melting temperature range of PET. The temperature distribution nephogram is shown in Figure 3.

Figure 3. Thermal Analysis Cloud Map.

4. Physical testing

4.1 Physical Printing Test
According to the model and the following analysis, we have processed the physical prototype according to the virtual model, and printed some physical objects with the 3D printer, the effect is good. Figure 4 is a printer working diagram, and Figure 5 is a printer physical diagram.

Figure 4. Printer working drawings.
Figure 5. Print physical drawings.
5. Conclusion

3D printing sprinkler is easily disturbed by various factors, which affects the continuity of spinning. Especially in the case of unreasonable temperature control, the application quality and effect of 3D printing sprinkler will be greatly reduced. Therefore, by analyzing the temperature of 3D printing nozzle, the three-stage insulation system mentioned above can prolong the life of the motor and improve the performance of the nozzle, which can provide some design references for the research in related fields.

Reference

[1] Li Yan. Chemical Recovery and Downstream Product Development of Nonferrous Waste PET Materials [D]. Dalian University of Technology, 2009.

[2] Yang Guilan, Hu Biao, Kang Zailong, etc. Recycling and utilization of waste plastics[J]. Recycling resources and circular economy, 2013, 6(1): 31-35.

[3] Progress in research and application of Wang Yang, Ye Chunsheng, Huangshu Huai and melt deposition moulding materials [J]. Plastics Industry, 2005, 33(11): 4-6.

[4] Zhu Ailan. Application of Nucleating Agent in PET Crystallization [J]. Polyester Industry, 2011, 24 (05): 1-5.

[5] Shi Shitao, Zhang Guangcheng, Xiang Shixin, et al. Effects of nucleating agents on the crystallization behavior of PET [J]. Journal of Materials Science and Engineering, 2005, 23 (3): 397-400.