Design and Simulation of a Multiple Filament Extrusion System

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Abstract

The new improvement and development of 3D printing process requires flexibility to deal with multiple filaments and reliable extrusion system to save operation cost and printing time, and increase the print quality and the printer durability. This poster presented an alternative mechanism design for handling different number of filaments with a universal extruder, the mathematical model for the extrusion system depending on the polymeric flow equations and the internal extruder's geometry, the concept of optimizing the printing parameters through the pre-movement phase for any kind of filaments, and the control model in order to get the system compatibility.

Introduction

Fused deposition modeling (FDM) is a widely used 3D printing technology. As shown in Fig. 1, a plastic filament is supplied on a reel and fed into a heated liquefier and melted into liquid state. The melt is hen extruded in a nozzle by the incoming solid filament and then selectively deposited in a layer by layer manner according to a CAD model. A wide range of materials are available for this manufacturing process, such as ABS, PC, PLA, and PCABS blend. The printed part quality depends on several printing processing parameters, such as the temperature of the melt and wire feed rate, which are often determined through tests by the manufacturer.

The FDM process relies on feedback control of the liquefier dynamics. The common control uses a thermal sensor attached to the extruder. The power of the heater is adjusted based on measuring the feedback temperature at the extruder, not the filament. This method has many disadvantages, such as temperature delay and one extruder for one filament only through the process. Fig. 2 shows a control model uses an additional feedback for the stepper motor by measuring the extrusion torque to eliminate the temperature delay and thus more accurate and faster response to the variations of processing parameters, such as change of filament speed, and start-up control.

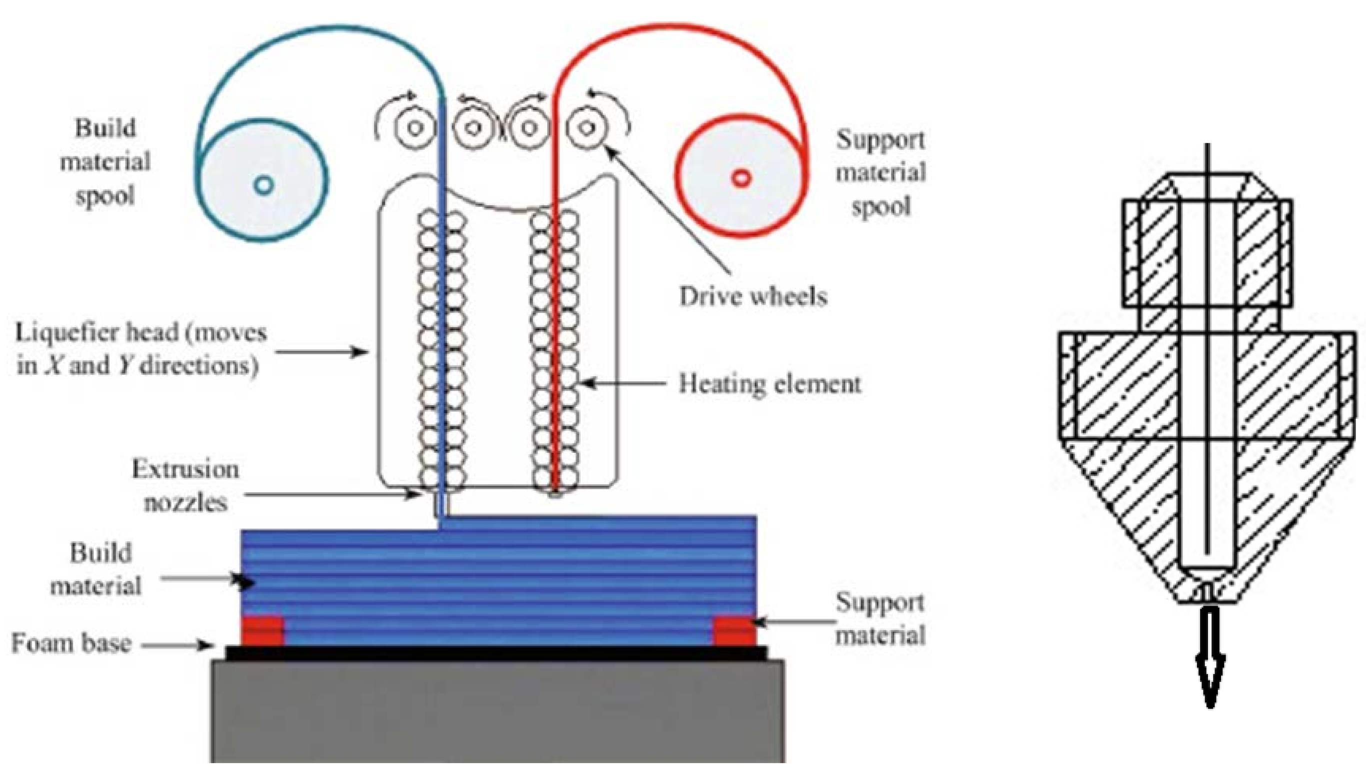


Fig. 1. Schematic of a FDM Process (left) and a nozzle (right) [1]

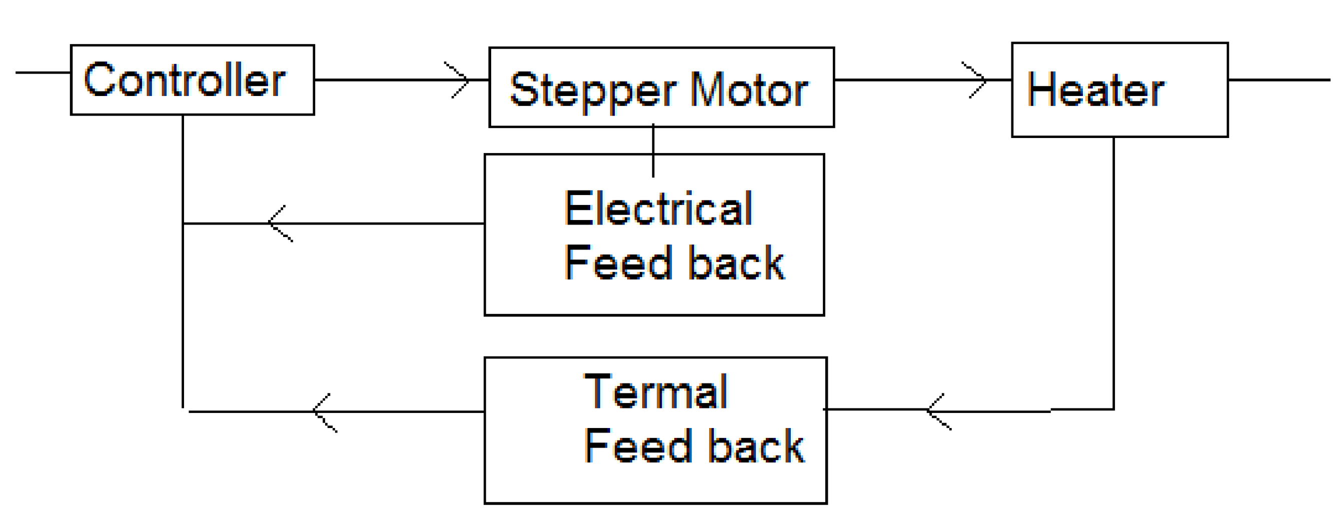
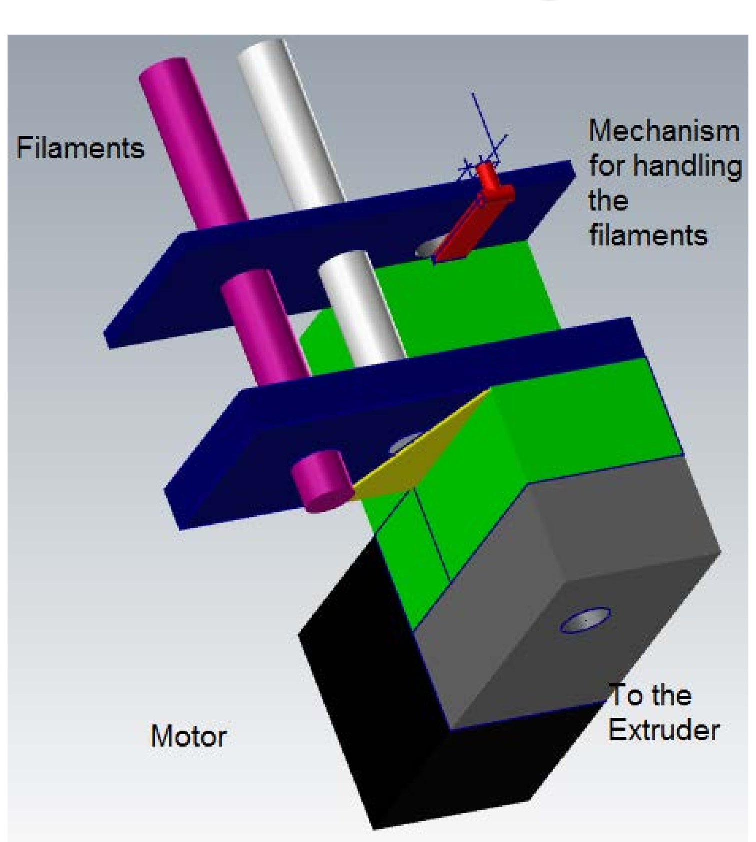
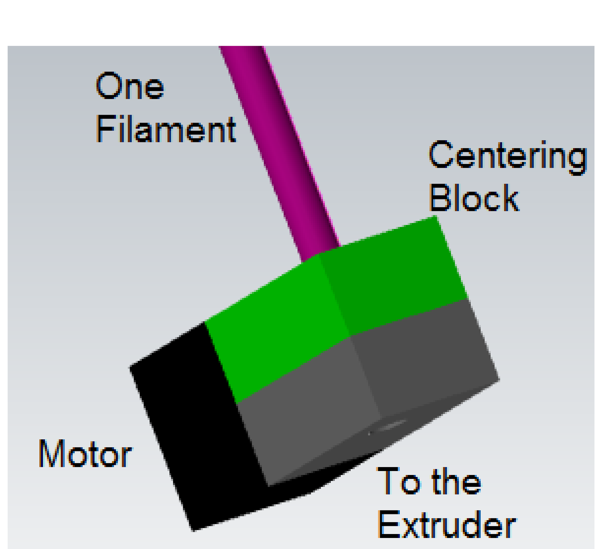


Fig. 2. Schematic of a feedback control model of the liquefier

Mechanism Design of Multiple Filament Handling



The New Design



The Classic Design

Mathematical Modeling of the Liquefier Dynamics

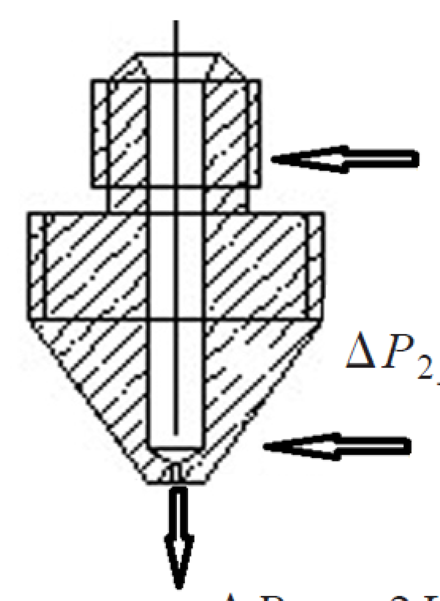
Modeling the liquefier dynamics can provide understanding of the relations between processing parameters and help choosing control parameters. Modeling the complicated melting and flow of the non-Newtonian flow in the liquefier has several difficulties [2]:

- Compressibility of the unknown fluid.
- Slippery contact conditions between the extruder walls and the melting flow.
- Possible slippage between the feed-rollers and the filament.
- Distribution of heat flux.
- Change of physical state of the melt from solid to liquid.
- Melt Filament sticking effect while it is pushed into the liquefier.
- The non-linear dependences of the material properties on the temperature and the shear rate.

Assuming axial symmetry of the flow and the Cross WLF viscosity model for viscosity, the heat transfer rate and the pressure drop along the nozzle can be calculated as:

$$q=(T-T_i)\cdot\frac{\rho\cdot v\cdot A\cdot c_p}{2\cdot\pi\cdot\left(\frac{D_1}{2}\right)\cdot L_1}$$ Heat flux

Pressure drop along the extruder



$$\Delta P_{1\_v}=2L_1\left(\frac{v}{\phi}\right)^{1/m}\left(\frac{m+3}{(D_1/2)^{m+1}}\right)^{1/m}$$

$$\Delta P_{2\_v}=\left(\frac{2\cdot m}{3\cdot\tan(\beta/2)}\right)\left(\frac{1}{D_2^{3/m}}-\frac{1}{D_1^{3/m}}\right)\left(\left(\frac{D_1}{2}\right)^2(m+3)\cdot 2^{m+3}\right)^{1/m}$$

$$\Delta P_{3\_v}=2L_2\left(\frac{v}{\phi}\right)^{1/m}\left(\frac{(m+3)(D_1/2)^2}{(D_2/2)^{m+3}}\right)^{1/m}$$

A calculation of the pressure drop and the required motor torque is calculated for a PLA filament goes through an extruder. The extruder parameters are listed in Table 1 and the processing parameters and the calculated results are listed in Table 2.

Table 1. Extruder parameters

The extruder diameter	Nozzle diameter	Heating element length	Maximum heating temperature
3mm	0.6 mm	10 mm	290°C

Table 2. Model parameters and simulation results using PLA as a filament material

Input		Output	
V_{fil}	$67\,[mm/\min]$	$\Delta P1$	$14.15\,[Pa]$
V_{ext}	$5000\,[mm/\min]$	$\Delta P2$	$20515\,[Pa]$
Q_{fil}	$450\,[mm^3/\min]$	$\Delta P3$	$21773\,[Pa]$
ρ	$1.073\,[g/cm^3]$	$TotalP$	$42302\,[Pa]$
T	$202\,[C^0]$	Force	$0.2989\,[N]$
μ	$58.68\,[Pa-s]$	Torque	$0.002989\,[N.m]$

Conclusion and Future Work

A new mechanism has been designed to handle multiple filaments for a nozzle. A control model based on the feedback of both temperature and motor torque has been presented to control the filament feed speed and filament temperature for a stable operation process. A mathematical model has been presented with an example calculation to model the dynamic liquefier process. The liquefier model will be used to simulate the dynamic liquefying process and help design a control system for the liquefier. Adding electrical feedback to the thermal one can increase the accuracy and response time of the feedback control system. The control system does not need pre test to adjust the parameters and can adjust the parameters by itself. With a new mechanism to handle multiple filament, the new extrusion system can handle and monitor the material flow for multiple filament and various materials at lower cost and shorter time.

References

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2. Anna Bellini, Selçuk Güçeri and Maurizio Bertoldi, Liquefier Dynamics in Fused Deposition, J. Manuf. Sci. Eng, 2004, 126(2), 237-246.