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DESIGNING A FILAMENT RECYCLING EXTRUDER

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Abstract: In this paper we can read about designing and building a filament recycling machine especially designed for 3D printers. 3D printing is quite popular nowadays, but unfortunately the base material of this technique is polymer, which is not an environmentally friendly material, but it can be recycled in most of the cases. The filament pieces are shredded beforehand with a shredding machine to get the appropriate size. After being chopped up and heated up to the given temperature, according to the materials specific parameters the filament can be melted down and extruded again. The study deals with designing a recycling machine as mentioned.

Keywords: *3D printing, recycling, filament, extruder, PID, Solid Edge*

1. INTRODUCTION

The structure of the machine is shown in *Figure 1.* The extruder consists of many elements as a result it needs coordinated designing.

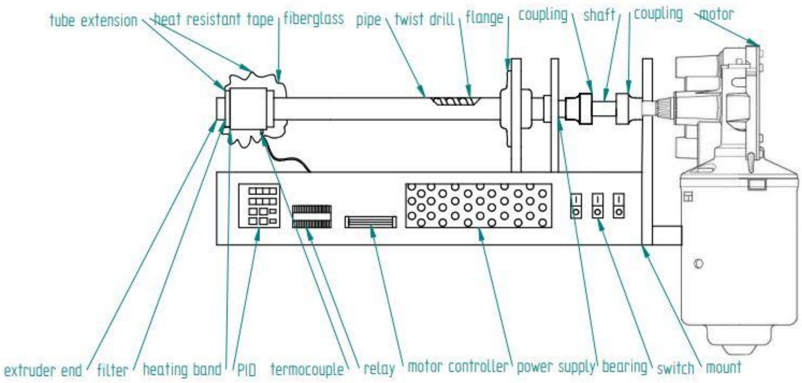

Figure 1. *Sketch of extruder machine*

The extruder unit contains two main parts. One is the user interface and the other one is the machine's workspace. The user interface displays the control buttons of different units. By pressing the buttons, the motor can be started, the ventilator can be activated, the heating can start and with the potentiometer the motor's speed can be adjusted. The setup of the extruder is far more complicated. The rotation movement is granted by a simple windshield motor, which is forwarded by a shaft coupling. The compressive force is wiped out by an axial roller bearing and the next element in the shaft line is a twist drill. The twist drill is responsible for forwarding the filament pieces. The end of the twist drill can be heated to the desired temperature by a brass band. The twist drill is covered by a tube from the outside. The heating band must be insulated well to keep the warm better, the applied fiberglass and the different types of heat resistant tapes serve this purpose. The heated and melted material leaves the end of the extruder and is winded into a coil.

2. EXTRUDER MOVING UNIT

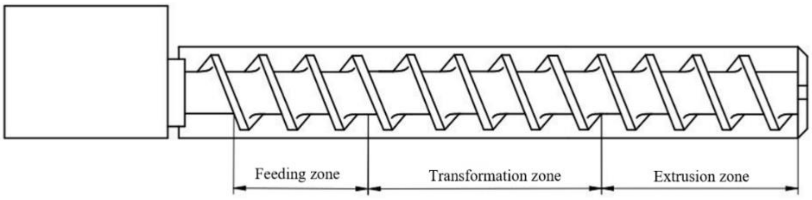

Figure 2. *Extruder zones*

During the designing process of the extruder, first the size of the extruder was determined first, and the other parts were designed accordingly. The efficiency of the motor and the sustainment were also calculated according to the mentioned units. The studied researches show that the size of the twist drill must be determined first. It is chosen according to the type and size of the material we have to use for the extrusion. [1], [2] The size of the twist drill is 16 mm (M16). This is resulted as the filament pieces are a maximum of 5 mm. According to the references the diameter of the twist drill and the length of the extruder tube should be according to the following rate [3].

2.1. The length of the extruder and extruder tube

The extruder's size must be considered, and the length must be chosen according to the found literature. These rates are the following:

- Extruder's length: $D = 16\ mm$
- Extruder tube length: $L = 200\ mm$

The rate of the extruder and the extruder tube:

$$d \div L \tag{1.1}$$

Examples for standard extruder-tube rate length:

$1:10;\quad 1:12;\quad 1:12.5;\quad 1:14;\quad 1:15;\quad 1:16;\quad 1:18;\quad 1:20;\quad 1:22.5;\quad 1:25$

Calculated extruder-extruder tube rate:

$$d \div L \rightarrow 16:200 \rightarrow 1:12.5 \tag{1.2}$$

The chosen standard rate is 12.5.

The exact final length is determined during the designing process of the structure.

The extruder can fit in the 18 mm outer diameter tube precisely, the wall of the tube is not too close nor too far from the twist drill. This is a key part of consistent extruding. The extruder tube is designed to be 200 mm long. The 200 mm long element was chosen consciously as the structure required this size for the element. From the extruder and the extruder tube it is given that with the help of the twist drill geometry, the solid flow rate can be calculated and estimated. The next chapter describes the calculation process which refers to the flow rate of the extruder feeding zone.

2.2. Solid state flow rate

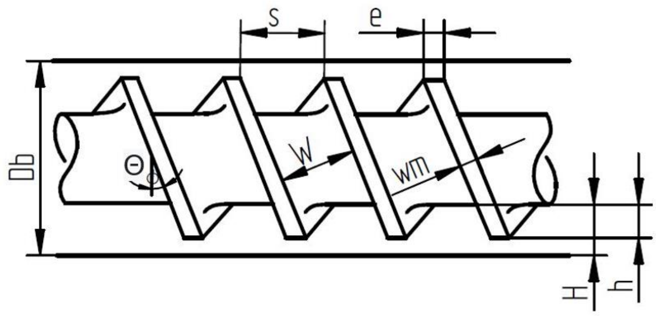

Figure 3. *Extruder geometry*

The given geometry helps in the calculating process as the following elements measures are known and can be used for calculations. [4]:

- Tube diameter: $D_b = 17\ mm = 0.017\ m$
- Screw thread: $s = 12\ mm = 0.012\ m$
- Thread number: $\nu = 1$
- Thread width: $w_m = 10\ mm = 0.01\ m$
- Channel between the threads: $W = 15\ mm = 0.015\ m$
- Depth of feeding zone in the tube: $H = 6.5\ mm = 0.0065\ m$
- PLA transport efficiency: $h_{F,PLA} = 0.395$
  ABS transport efficiency: $h_{F,ABS} = 0.235$
- Speed of twist drill: $N = 50\ rpm = 50\ 1/\min = 3000\ 1/h$

- Bulk density of polymer: $\rho_{0,PLA} = 1.24\ g/cm^3$

$$\rho_{0,PLA} = 1{,}240\ kg/m^3$$

$$\rho_{0,ABS} = 1.06\ \ g/cm^3$$

$$\rho_{0,ABS} = 1{,}060\ kg/m^3$$

- Solid state rate flow calculation and solution:

$$\dot{m} = 60 \cdot \rho_{0,PLA,\ \ ABS} \cdot N \cdot h_F \cdot \pi^2 \cdot H \cdot D_b \cdot (D_b - H) \cdot \frac{W}{W+w_m} \cdot sin\theta \cdot cos\theta \qquad (2.1)$$

- Calculation of Θ helix angle:

$$\theta = 30\ ° = 30° \cdot \frac{\pi}{180} = 0.5235987756\ rad \qquad (2.2)$$

- Solid state flow rate calculation for the two materials:

$$\dot{m} = 60 \cdot \rho_{0,PLA} \cdot N \cdot h_F \cdot \pi^2 \cdot H \cdot D_b \cdot (D_b - H) \cdot \frac{W}{W+w_m} \cdot sin\theta \cdot cos\theta \qquad (2.3)$$

$$\dot{m} = 60 \cdot 1{,}240 \frac{kg}{m^3} \cdot 32 \frac{1}{min} \cdot 0.395 \cdot \pi^2 \cdot 0.0065\ m \cdot 0.017\ m \cdot (0.017 - 0.0065\ m) \cdot \frac{0.015\ m}{0.015\ m \cdot 0{,}01\ m} \cdot \sin(30°) \cdot \cos(30°) = 463.06\ \frac{kg}{h} \qquad (2.4)$$

$$\dot{m} = 60 \cdot \rho_{0,ABS} \cdot N \cdot h_F \cdot \pi^2 \cdot H \cdot D_b \cdot (D_b - H) \cdot \frac{W}{W+w_m} \cdot sin\theta \cdot cos\theta \qquad (2.5)$$

$$\dot{m} = 60 \cdot 1{,}060 \frac{kg}{m^3} \cdot 32 \frac{1}{min} \cdot 0.395 \cdot \pi^2 \cdot 0.0065\ m \cdot 0.017\ m \cdot (0.017 - 0.0065\ m) \cdot \frac{0.015\ m}{0.015\ m \cdot 0.01\ m} \cdot \sin(30°) \cdot \cos(30°) = 395.8439\ \frac{kg}{h} \qquad (2.6)$$

The calculated values consider the full cross section of the tube (226.98 mm^2) in relation to possible amount of solid flow rate. The actual considered trans section is much smaller than the one used in the calculations; this means that the solid flow rate would also be smaller. The examined new cross section is approximately 0.01767 mm^2.With the use of this new section we got the following calculations. The solid flow rate of PLA would be approximately 18.5732 kg/h and the solid flow rate of acrylonitrile butadiene styrene would be approximately 15.8457 kg/h according to the pre-planning phase of the designing. The two materials distribute similar characteristics, (like density) that is why the two materials' calculations are close to each other. These calculations can help to estimate the amount of filament the recycling machine will be able to extrude in an hour [5]. In practice the flow rate will reduce to a lot less to the fragment of the calculated numbers because of the heating, melting and the cooling process.

The considered area is the useful area according to the shredded material because the materials arrival happens through this cross section. This area should be connected to the shredders bottom. The connection is created by a dispenser element. The dispenser was designed in Solid Edge and it was 3D printed from PLA because it does not have to withstand great temperatures.

The twist drill is longer than the tube and it continuous to the engine in a square shaft part. The end of the extruder and the motor is connected by a coupling element. One end of the coupling fits the extruder, also the other end fits the engine shaft. In the current situation a single square iron part was the coupling element. While choosing the right motor for the machine, some references and similar literatures were considered. As these papers also suggested a simple windshield motor was chosen to be the heart of the recycling machine. (medium.com) (www.filastruder.com).

The structure needs a solid base to stand on with all its elements to keep the machine steady and solid. This base was chosen to be a Hilti mounting rail which was an obvious because of its modular function. The structure also has a holding element, which fixes the extruder tube and the motor shaft. The end of the tube has an axial roller bearing on it. This bearing helps in cancelling out the compressive force coming from the kickback. The kickback protection is important for the motor because it is not designed to endure this kind of load, but to rotate. Because of this condition it is appropriate to examine the bearing force and the bearing lifetime estimation.

3. HEATING PANEL

The design and assembly of the heating panel is the most complicated part of the structure, because it contains not only mechanical components but electronic parts also which need special attention and calculation. Electric parts need to be synchronized which can be quite hard if someone does not have the electrical skills to execute it. It is easier to understand the methodology of the heating panel if we look at the elements after one another. The tube with the 18 mm outer diameter is lengthened by a brass element which has better heat conductivity than stainless steel. This section will be heated for the desired temperature, as a result a brass heating band is placed on the 50 mm lengthened brass part. (edge.rit.edu) (www.printfromsd3d.com) The heating band is responsible for getting the temperature displayed on the PID, with the help of the K thermocouple sensor. The thermocouple is the actual part sensing the temperature and the PID is adjusting according to its measures. The thermocouple is placed in the brass tube lengthening in a 3 mm hole causing it to show the exact temperature the machine has in the extruder zone. After the brass tube only one element is left from the machine, this one is the extruder end which closes the system and the melted filament is heading out from its hole to cool down.

4. ELECTRONIC PANEL

This chapter is about synchronizing and connecting the different electric elements. Every electrical part is somehow connected to the power supply this is why the right power supply should be chosen considerately. Considering all the elements the power supply must be a little bit more powerful than expected not to cause any short circuits. The chosen power supply is operating at 12 V, with 240 W output and 20 A current.

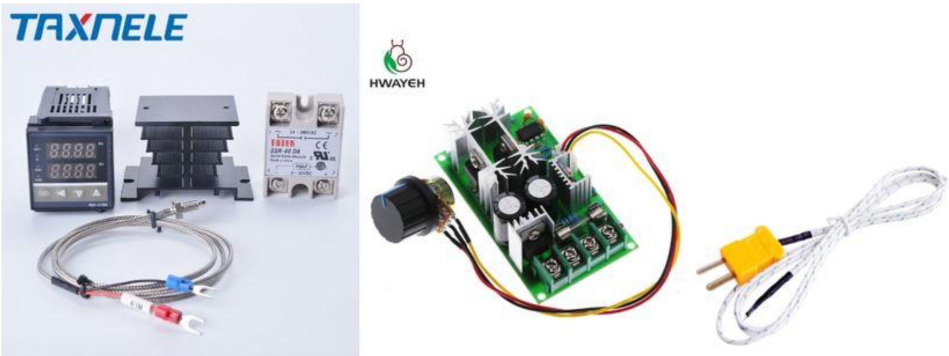

Figure 4. *PID, motor controller, K thermocouple*

The three buttons will start the whole machine's operation, one of these gives power to the machine, the other one starts the motor, the third one starts the ventilator. The user interface also has a potentio meter attached to it; this serves the ability to control the motor's speed. The motor gets power through the controller. The ventilator connected to the machine is responsible for cooling the filament which comes out of the extruder end. The PID also receives power from the power supply and is connected to the mentioned K thermocouple and the heating band. The heating band has 220 V stress, but the PID operates only at 12 V, therefore the electric panel needs a solid-state relay to connect the two elements. The ground port and the 220 V of the power supply are connected to the other two pots of the solid-state relay. When the relay closes, the heating band is heated according to the PID' signal and when the relay is open the signal will not reach the heating band and it will not heat up. The electric control works as it is described in this chapter.

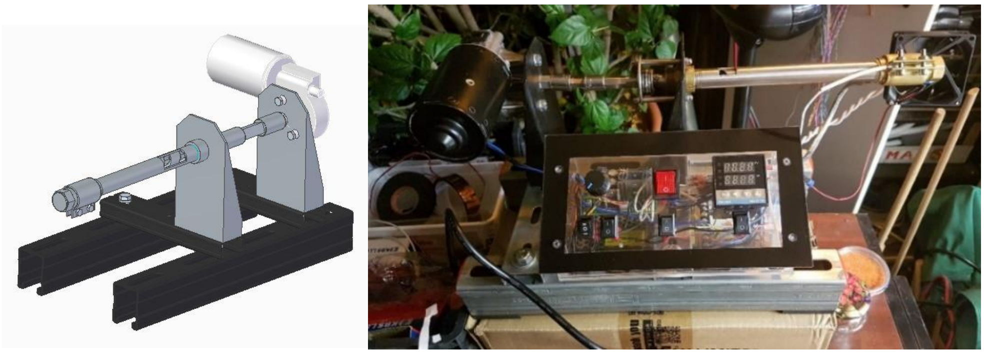

Figure 5. *Extruder model and machine*

5. SUMMARY

The research reflected on designing the element and the structure of a machine. The required calculations were executed and considered as the measurements were established. The length rate and the solid flow rate was calculated. The heating panel and the electronics were described in details and the model and the building of the structure was introduced in the article. The result of the study is a working extruder machine with a user-friendly interface ready for testing.

ACKNOWLEDGEMENT

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REFERENCES

[1] Michaeli, W.: *Extrusion Dies for Plastics and Rubber*. Hanser Publisher, Germany, 1992, ISBN 3446161902.

[2] Lafleur, P. – Vergnes, B.: *Polymer Extrusion*. ISTE Ltd. and John Wiley & Sons, Inc., USA, Great Britain, 2014, ISBN 9781848216501.

[3] Wagner, J. – Mount, E. – Giles, H.: *Extrusion: The Definitive Processing Guide and Handbook*. Elsevier, Inc., USA, 2014, ISBN 9781437734812.

[4] Birley, A. – Haworth B. – Batchelor, J.: *Physics of Plastics Processing, Properties and Materials Engineering*. Chapter 4., Hanser Publisher, Munich, Cincinatti, 1992.

[5] Rao, N. – Schott, N.: *Understanding Plastics Engineering Calculations*. pp. 67–70, Hanser Publisher, Munich, Cincinatti, 2012, ISBN 9781569905098.