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DESIGN OF PLASTIC FILAMENT EXTRUDER FOR RAPID PROTOTYPING

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ABSTRACT

Plastic filament extruder produces plastic filaments of specified diameter by using corresponding dies. Input materials (thermoplastics) used is in the form of granules and pellets and it can be of waste plastic materials. Ceramic band heater is used to melt the input material. Barrel screw is used to feed the input raw materials longitudinally along the screw. Screw consist of three zones namely feed, melt, and transition zone. Input raw material is melted by using ceramic band heater for . Two barrel heaters and one die heater is used to acquire maximum efficiency. Analog temperature controller is used to control the temperature of the three heaters. Die used extrudes the filament at the diameter of 3mm. Diameter of the filament can be further reduced by using DC-motor to draw the filament coming out of the die. Production can be further increased by increasing the barrel diameter above 65mm and screw diameter above 60mm. Mechanical and thermal properties can be increased by adding fillers to the input raw material.

KEYWORDS: Extruder screw, Extruder barrel, Die head, Reduction gearbox.

INTRODUCTION

Rapid prototyping is a method used to produce components in 3D using CAD. This method is usually done using 3D printing technology. FDM is one of the techniques used for 3D printing. FDM works on the principle of additive manufacturing. Additive manufacturing is the process used for making 3D models by joining materials. FDM uses plastic filaments to produce a part. Generally plastic filaments used in FDM are Acrylonitrile Butadiene Styrene (ABS), Polylactic acid (PLA), Poly carbonate (PC), poly amide (PA), polystyrene (PS), polyethylene (PE) etc. Available material for 3D printing costs high and the plastic filament used is manufactured and it is mostly imported. In order to reduce the manufacturing cost and plastic filament's cost, this extruder machine is developed. Extruder produces plastic filament at the diameter of our required size. The main theme of our project is to produce the extruder machine at low cost. We can use the recyclable plastics in this process. We can use this extruder as eco-friendly. Strength of the extruded plastics can be increased by adding the fillers while reinforcing the input raw materials.

LITERATURE REVIEW

Kensaku Nakamura in the publication "US4840492 A" said that the present invention relates to the mixing of various resins such as carbon, glass fiber along with plastics and the mixing takes place efficiently by keeping the extruder screw threads at desired design requirement.

G Pettit in the publication of journal " US3733059 A" said about the various temperature control system used for controlling temperature of the heaters.

Geo Raju , Mohan Lal Sharma , Makkhan Lal Meena (2014), said about the Recent Methods for Optimization of Plastic Extrusion Process.
George Holmes, Frank Keyser in the publication "US4564350 A" discussed about the plastic extruder assembly, extruder barrel assembly ,and an extruder die at the end of the extruder barrel assembly.

Wu-Chung Su ; Dept. of Electr. Eng., Nat. Chung-Hsing Univ., Taichung, Taiwan ; Ching-Chih Tsai (2014) said about the Discrete-time VSS temperature control for a plastic extrusion process with water cooling systems in the paper published by IEEE Transactions on Control Systems Technology.

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COMPONENTS USED

Table 3.1 Components used

S.No	List of Components
1 2	Ceramic band heater. Barrel screw
3	Extruder barrel
4	Gear box
5	Motor
6	Hopper
7	Die
8	Pulleys
9	Belt
10	Shaft

1. Ceramic band heaters

Ceramic band heater which is shown in Figure 3.1 is a type of heater, used to produce heat by positive temperature coefficient. It produces high temperature by consuming low power of 0.9 units for 45 minutes in Barrel heaters and 1.12 units for 45 minutes in die heater. we have used three ceramic band heaters. Two barrel heaters and one die heater is used. Used heater can produce the temperature from the range of 100^0c to 1300^0c.

Figure 3.1 Ceramic band heaters

2. Barrel screw design

The screw which is shown in the figure 3.2 is fitted inside the screw barrel. It is driven by AC motor through the reduction gear box. The screw is divided into three zones: the feed zone, the compression zone, and the metering zone. The feed zone delivers plastic resin pellets from hopper into the barrel to start the longitudinal movement of the plastic. By using axial rotation, the screw threads move the plastic down the barrel. Within the barrel, heaters help the plastic to develop a contact to increase its friction against the barrel wall. Without friction the plastic could not be conveyed forward and would merely rotate inside the screw. In the compression zone, the root diameter of the screw increases while the height of the flight decreases. The plastic granules is melted here because of compression, shearing and heating produced in the barrel. Next the melted plastic moves through the metering zone. In this zone the screw diameter remains constant and the melted plastic which is under high pressure is pumped into the extruder die. we have designed the screw 3d-model in solidworks and it is shown in the figure 3.3.

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Figure 3.2 Extruder screw

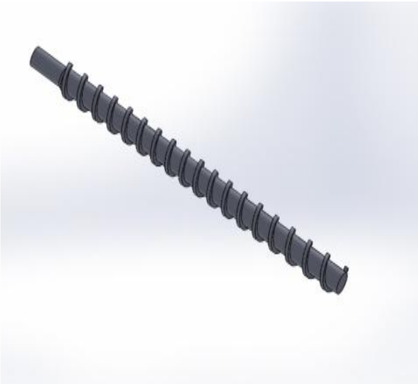

Figure 3.3 CAD model of Screw

3. Extruder barrel

Barrel is the outer cover for the screw and it has an opening at the rear for the feed from the hopper and at front it has projection for die head. Barrel is made up of hardened steel. Rear of the barrel is coupled with the gear box with help flange coupling. Figure 3.4 shows the fabricated component and the 3d-model is designed in solidworks, it is shown in the figure 3.5

Figure 3.4 Extruder barrel

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Figure 3.5 CAD model of Barrel

4. Gear box

Gear box used in the extruder is a reduction gear of speed ratio 1:3.power to the gear box is given by the motor. Reduction gear box is used as the speed of the motor is 1440 rpm and the speed of the screw show be around 20 rpm so that the material mixing and melting will be proper.

OVERALL ASSEMBLY

Extruder screw is kept inside the barrel. Barrel is mounted on the frame. Barrel is connected to the gearbox and gearbox gets the power from electric motor through the pulley and belt. Extruder die is kept at the front of the barrel. Heaters are placed around the barrel and the die heater is placed around the die. Three phase AC supply is given for the heaters and single phase AC supply is given for the electric motor. Input plastic is given in the hopper which is attached to the barrel. Analog temperature controller is given to control the temperature of the three heaters used. overall assembly of the machine is shown in the figure 4.1.

Figure 4.1 Overall assembly

DESIGN CALCULATIONS

A. Calculation for heaters.

1. Barrel Heater 1,2

Specifications
Voltage, v=230 V
Current, I=15 A
Power, P=1200 W
Power factor $=\frac{P}{V \times I} = 0.35$
Unit consumed for 45minutes= P × t = 0.9 units
Volume of heater ,$V = \frac{\pi}{4}\left({d_0}^2 - {d_i}^2\right)$
$= 490.87\ mm^3$

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2. *Die heater*

Specifications
Voltage, v=230 V
Current, I =15 A
Power, P=1500 W
Power factor = $\frac{P}{V \times I}$ =0.43
Unit consumed for 45minutes= P × t =1.12 units

B. Calculation for screw

1. Feed zone

$G_0 = 60.\rho_\circ.\mathrm{N}.\eta_\mathrm{F}.\pi^2.\mathrm{H}.\mathrm{D_b}.(\mathrm{D_b} - \mathrm{H}).$

$\mathrm{G} = G_0.\frac{\mathrm{W}}{\mathrm{W}+\mathrm{W_{Flt}}}.\sin\emptyset.\cos\emptyset$

Table 5.1 Screw parameters

S.No	Particulars	Dimensions
1	Barrel diameter Db	65 mm
2	Flight width $\mathbf{W_{Flt}}$	2 mm
3	Channel width W	40 mm
4	Depth of the feed zone H	5 mm
5	Conveying efficiency η_F	0.35
6	Screw speed N	20 rpm
7	Bulk density of the polymer $\rho_\circ$	970kg/ m^3
8	Helix Angle ∅	30degree

Geometry of feed zone G by using the given parameters as shown in table 5.1 and applying it in the formula, we get

G = 32 kg/hr.

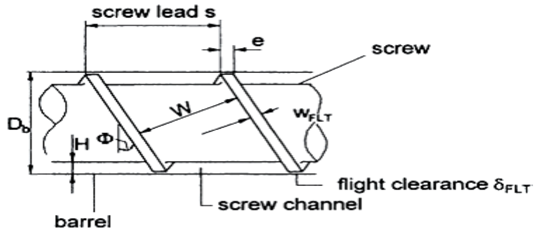

Fig 5.1 Screw design

2. ***Meteringzone***

$$\mathrm{Q_m} = \mathrm{Q_{md}} - \mathrm{Q_{mp}}$$

$$Q_m = \frac{p\rho V_{bz} WHF_d}{2} - \frac{P\rho WH^3 F_p}{12\eta}\left[\frac{\partial P}{\partial Z}\right]$$

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Table 5.2 Metering zone parameters

S.NO	Symbols	Parameters
1	Q_m	Total Mass Flow Rate
2	Q_{md}	Mass rotational flow
3	Q_{mp}	Mass pressure flow
4	F_d	Shape factor for rotational flow
5	θ_b	Helix angle of the barrel
6	V_{bz}	Barrel velocity
7	η	Shear viscosity = 846.5 pa.sec
9	P_{dis}	Discharge pressure
10	l_m	Axial length of the metering section
11	P	Flight starts
12	$\tan\theta_b$	$\frac{L}{\pi . D_b}$
13	L	Lead length
14	$\frac{\partial p}{\partial z}$	$\frac{P_{dis} . \sin\theta_b}{l_m}$

By using the given parameters as shown in the table 5.2 and using the formula, following values are calculated.

$$\tan\emptyset = \frac{L}{\pi . D_b}$$
$$\tan 30^\circ = \frac{L}{\pi * 65}$$
$$L = 117.8\text{mm}$$
$$Q_{md} = 1058 \text{ kg/hr}$$
$$Q_{mp} = 59.6 \text{ kg/hr}$$
$$Q = Q_{md} - Q_{mp}$$
$$Q = 998.4 \text{ kg/hr} .$$

C. Calculation for power transmission by belt.

Table 5.3 pulley parameters

S.No	Particulars	Dimensions
1	Diameter of smaller pulley(d)	80mm
2	Diameter of larger pulley(D)	300mm
3	Motor speed(N1)	1440rpm
4	Centre distance(C)	300mm

By using the parameters given in the table 5.3 power transmission by the belt is calculated.
Power transmitted per belt = $162.95*10^3$ W.

COST ESTIMATION

The components purchased are at low cost and the quantity of the components purchased are given in the table 6.1.

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Table 6.1 Cost estimation

S No	Materials	Quantity	Cost (Rs)
1	Screw	1	3500
2	Barrel	1	3000
3	Gearbox	1	2500
4	1hp motor	1	3000
5	Hopper	1	400
6	Die	1	1500
7	Pulley (12.5")	2	1000
8	Pulley(2.5")	2	500
9	Belt	2	900
10	Shaft	1	200
11	Temperature controller	3	1500
	Total		18,500

ADVANTAGES

1. Low Cost

Compared to other molding processes, plastic extrusion molding has a low cost and is more efficient. The extrusion molding process uses thermoplastics and they undergo repeatedly melting and hardening, this allows the waste to be reused rather than be discarded. Raw material and disposal costs are lowered. Plastic extrusion machines operate continually and this reduces the chances of inventory shortage. It also allows for 24-hour manufacturing.

2. Better Flexibility

Extrusion molding will provide considerable flexibility in the products being manufactured with a consistent cross section. As long as the cross section stays the same, the extrusion molding can produce complex shapes. Minor alteration to the plastic extrusion process the manufacturers can use it for plastic sheets or produce products that mix plastic attributes.

3. After Extrusion Alterations.

Plastics remain hot when they are removed from the extruder and this allows for post-extrusion manipulations. Many manufacturers will take advantages of this and use a variety of roller, shoes and dies to change the shape of the plastic as needed.

CONCLUSION

Thus the plastic filament extruder is manufactured as per the design and within the estimated cost as mentioned in the table 6.1. Plastic filament extruder manufactured, can be used to make filament from all type of thermoplastic materials except PVC. This machine will be used in small scale production. Produced filament can be used in the Rapid prototyping (FDM) and 3D-printing Machines. Machine can be further digitalized by using digital temperature indicator and controller. Winding of filament may be done by using the DC motor setup.

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