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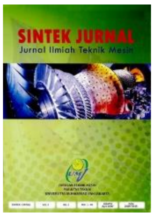

DESIGN OF A SINGLE SCREW EXTRUDER MACHINE FOR 3D PRINTING FILAMENT PRODUCTION APPLICATION

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ABSTRACT

This study aims to determine the optimal 3D Printer filament extruder machine design, to determine the design of the extruder components for filament production, to determine the single screw design used for filament production. The research method used is creating flow chart, the result of the research is the calculation of the diameter of the 3D Printer filament of 1.77 mm, by measuring the diameter of the filament by taking a 2 meters long sample to be measured every 10 cm. the most influential components in this research are diameter, length of single screw extruder, length of filament winding process, production capacity and total electric power. With a screw speed of 5 RPM, 1.5 kg of ready-to-use 3D printer filament is produced within 1 hour of production. So there, is an error between the calculation and the real condition of 15%.

Keywords: 3d printers; extruders; film waste

1. INTRODUCTION

The waste plastic processing system has several methods and processes, one of which is the extrusion process. Until now, the process of treating plastic waste with an extrusion machine is considered the cheapest and most efficient method. Extrusion machines are widely used to produce plastic products with long and simple shapes such as pipes, straws, plastic hoses and filaments for 3D printing machines.[1] [2]. Therefore this machine is very effective and widely used for plastic recycling processing. [3]

In the industrial field, 3D printing is very popular because for prototyping, which usually requires a long time, it can be maximized in a shorter time. [3]. The manufacturing process using the 3D printing method is currently growing very rapidly. This technology provides the advantage of being able to create environmental geometries of various types of materials, ranging from plastics, ceramics, to metals, using this method. There are many types of filaments that are used as materials for forming 3D models, such as Polylactid Acid (PLA), Acrylonitrile Butadiene Stryrene (ABS), Polyethylene Terephthalate (PET), Thermoplastic Elastomers (TPE). Currently, the type of filament for 3D printing is indeed dominated by thermoplastics and their derivatives.

Materials or raw materials from 3D printing technology or commonly called filaments can be made using polymer type materials. The process of making filament can be done by extrusion process, using an extruder machine. The application of filament feed in the 3D printing process, experiments were carried out using the extrusion process by running a screw extruder to obtain continuous filament. In its manufacture it will produce waste goods called waste. Plastic waste is inorganic waste which is composed of chemicals that are harmful to the environment and take a long time to decompose in the soil. In the process of making prototypes with 3D printers, failures often occur and there is leftover filament from the main form of the prototype during finishing so that it piles up as waste. Filament waste from the support section and filament from the print that ran aground, is reprocessed because the process of using the goods is the same. Polylactic acid (PLA) waste processing equipment or commonly called an extruder machine aims to be able to reuse 3D printing machines.

Based on this problem, after that the design of an extruder machine was attempted which was intended to process recycled plastic pellets into filaments. The purpose of making this extruder is to recycle plastic waste so that it can reduce plastic waste. Therefore, in responding to this case, a trial will be carried out to design the maximum extruder machine for creating 3D Printer filaments.

2. METHODS

In this study the method used is in accordance with the order in the flow chart starting from a literature study used to find data about anything related to the components and materials produced by the extruder machine. This study formulates the process of designing a single screw extruder machine in Figure 1:

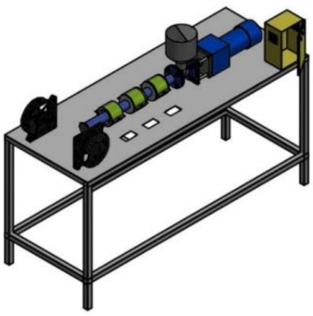

Figure 1. Single screw extruder machine design

This extrusion machine has a main part in the form of a threaded shaft (screw) which functions to push and press the pellet material out of the die. In the process, the polymer raw material in the form of pellets is put into the hopper and moved through the barrel using a threaded shaft in the form of a helical (screw conveyor) and then conveyed to the mold (die). Such a threaded shaft consists of three main parts. [4] The design concept of the single screw extruder which will be designed into three areas or zones as shown in Figure 2.

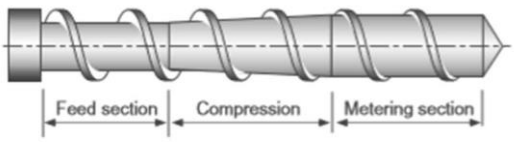

Figure 2. Section of the single screw zone

The screw on the single leescrewwin machine as a whole has a conical shape which continues to be close to the hdies, so that the core of the iscrew continues to enlarge to create compression after the plastic changes from solid to liquid have taken place. The expected goals and targets of this screw modification are to obtain optimal outflow quality and minimize product defects/failures without having to change the length and diameter of the screw itself. [4]

3. RESULT AND DISCUSSION

3.1 Basic design

As a basis for extruder machine design, the calculation of the rate of production of a single screw extruder is used and then direct experiments are carried out to validate the calculation results and the actual product produced after the machine is in operation [5].

$$\text{Rate} = 60 \,.\, \rho_b . N . \eta_{F.} \pi^2 . H . Db . (Db - H) . \frac{W}{W + W\,Flt} . \sin\theta . \cos\theta \quad (1)$$

In Equation (1) the calculation of the required barrel diameter is carried out based on all the data previously obtained so that the required barrel diameter value is obtained.

Where: Rate = 1.5 kg/hour, Rate = 1.5 kg/hour, Fl = 800 mm, S = w + wflt = 18.93 mm, Wflt = 1.18 mm, w = 17.75 mm, H = 0, 8 mm, ηF = 0.2565 (ABS), Pb = 0.773, N = 8.88 rpm, Design Db = 58.70 mm.

Application of equation (1) to determine Barrel diameter (Db).

$1{,}5 = 60.\ 0{,}773\ .\ 8{,}88\ .\ 0{,}2565\ .\ (3{,}14^2)\ .\ Db\ .\ (Db-0{,}8).\ \frac{17{,}75}{18{,}93}\ .\sin 9°\ .\cos 9°$

$1{,}5 = 105{,}64 \times 9{,}86 \times Db\ .\ (Db-0{,}8) \times 0{,}937 \times 0{,}412 \times -0{,}91$

$Db^2 \times (0{,}8 + 0{,}003) = Db$

$Db^2 \times 0{,}803 = Db$

From these calculations it is found that the diameter of the barrel needed to produce 1.5 kg of 3d printer filament in 1 hour is 1.77 mm.

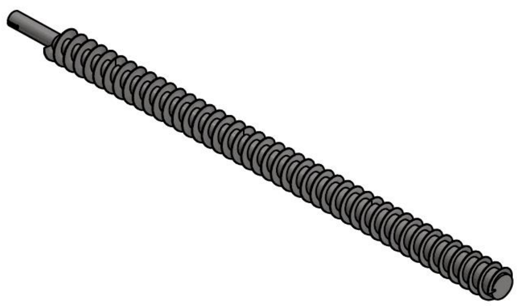

Figure 3. 2d design single crew

3.2 Single Screw Design

With the data obtained from the single screw extruder design [6] previously as well as from the data obtained on the basic single screw extruder design, it is known that the L/D ratio of the new screw is 600/37.1 or L/D = 16.17, by scaling down from the data in Table 1, the new screw design data is obtained as follows:

Table 1. *Screw design data*

Diameter	37.11 mm
Flighted Length	800 mm
Feed Section Length	184.62 mm
Compression Section Length	207.69 mm
Metering Section Length	207.69 mm
Compression Ratio	3 : 1
Constant Screw Pitch (Flight lead)	37.11 mm
Channel Depth Feed Section	8.30 mm
Channel Depth Metering Section	2.50 mm
Channel Width	33.40 mm
Flight Width	3.71 mm
Flight Angle	17.65
Screw Tip Angle	120 ~ 150

The scaling down of this design is carried out based on a comparison between the barrel diameter obtained from the basic design and the size of each screw section. Then from the data table 1, a 2-dimensional and 3-dimensional design of the screw is made using the Inventor application shown in Figure 3 for a 2-dimensional image of a side view screw and Figure 4 for a 3-dimensional image of a single screw.

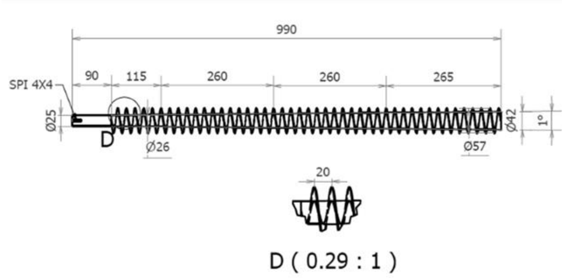

Figure 4. Dimension single screw design

After carrying out the 3D design of the new screw, to find out how the screw behaves when given a torque load, a mechanical simulation is carried out with the specified conditions, namely the screw material is AISI 4140 which is a material commonly used as a screw extruder, with a number of nodes 27550 and with material assignment Structural Steel [7] then determines the fixture or pedestal, namely on the screw face, a load of 500 Nm, it is obtained that the amount of deformation that occurs when a torque load of 500 Nm is given is a minimum of 0 mm and a maximum of 0.001 mm so this design is considered safe. Figure 5 shows the deformation of the object when given a torque load.

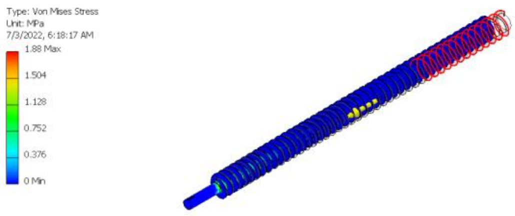

Figure 5. Deformation when loaded

3.3 Barrel Extruder Design

Extruder barrel is a tube that covers the screw extruder.[7] Feed Throat is the part of the extruder where the material first enters the screw channel. Generally, the feed throat has a watercooling system which functions to prevent the temperature rise in the feed throat which causes the polymer to stick to the surface of the feed throat thereby preventing the entry of material into the screw channel. Extruder barrel is just a tube with a flange. The extruder barrel must be able to withstand a pressure of 70 MPa and must have good structural strength to avoid deflection. In addition, the screw extruder must have current resistance on the inner wall of the barrel so that the material used in conventional extruder barrels is bimetallic steel which is produced by centrifugal casting. In this design, the barrel material used is stainless steel 304. The diameter of the barrel used is 37.1 mm according to calculations with a thickness of 10 mm.

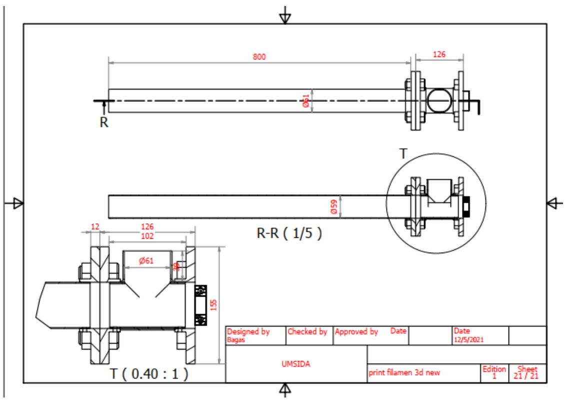

Figure 6. Barrel design and location of the thermal barrier

In the barrel of the feed section, the material entering the feed section must be in solid condition so that the feed section must be kept low so as not to interfere with the process such as blockage in the hopper section due to partially melted material or blockage in the screw feed section due to reduced root depth so that To overcome this, the barrel in the feed section is made separately with a screwing connection mechanism and with the addition of empty space at the connection as a thermal barrier as shown in Figure 6.

3.4 Die Components

The die component consists of 3 parts, namely the breaker plate, the die, and the die housing. The breaker plate is one part of the die which functions to ensure that all polymer before entering the die is in a melting state and also to change the melted polymer flow from a rotating flow due to the thrust generated from the screw extruder into a straight flow in the direction of the die. The breaker plate geometry design is shown in Figure 7.

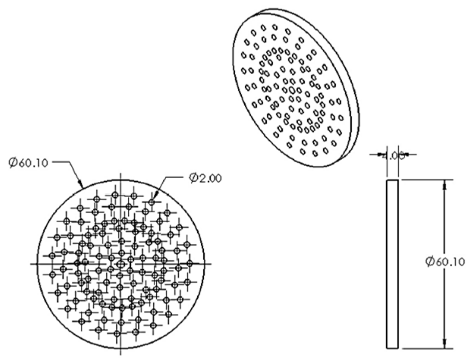

Figure 7. Breaker plate geometry

Dies are the part that will form the final product of a single screw extruder machine which in this study is to produce 3D printer filament.[9] The geometric design shown in Figure 8 in this design, the output of this die is a filament with a diameter of 3 mm die end. filament with a size of 3 mm is then pulled using a filament puller so that the diameter will decrease. The final size of the filament depends on the speed of the filament puller motor.

The expected size is in accordance with the standards used in 3D printers, which are 1.75

mm in diameter, so adjustments are needed to the speed of the filament puller motor.

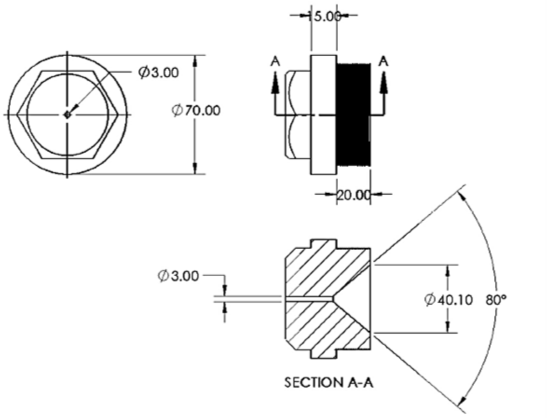

Figure 8. Die geometry

Dies housing is the part that connects the barrel and the die as well as a place to place the breaker plate.[8] The function of the die housing is also to make it easier to change the type, shape or size of the die. Dies housing can be seen in Figure 9, the material used in this component must have good thermal conductivity because it is a component that is in direct contact with the heating element and the die so that this component is selected Aluminum material.

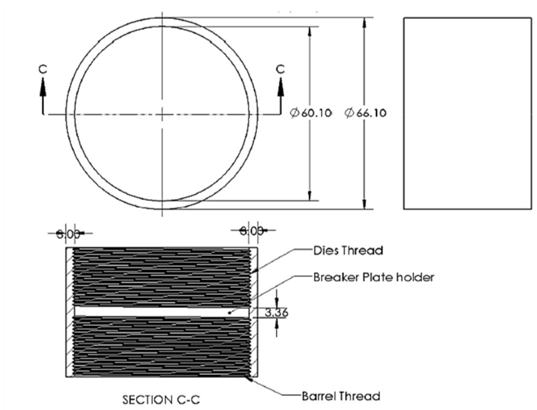

Figure 9. Geometri dies housing

3.5 Filament Spool Guide

After the polymer material comes out of the extruder die in the form of a wire, then the spooling process is carried out, namely the process of winding the filament on the filament holder to form a cylinder. [9] So that during the spooling process the filament does not accumulate at one point, then a system is designed that functions to direct the filament to be regular on the cylinder holder. So that during the spooling process the filament does not accumulate at one point, a puller system is designed to direct the filament. Figure 10 provides an overview of the design of the filament control coming out of the die which is able to adjust the mechanism of rolling filament without being damaged.

Puller is a tool using a microcontroller system. The method used in this system is to drive a DC motor to carry out the towing function. Similar to pullers, rollers are tools with a microcontroller system. In the roller component the method used also uses a DC motor[10].

3.6 Electric motor

The electric motor used is a DC electric motor with a power of 350W and a working voltage of 12 – 36 vdc. The general characteristic of a DC electric motor is that it has the greatest torque at 50% RPM, namely for the electric motor used, namely at 1283 RPM. The torque obtained at that speed is 0.8 Nm. To adjust to the rpm requirements of the extruder machine, the gear ratio calculation is carried out [11].

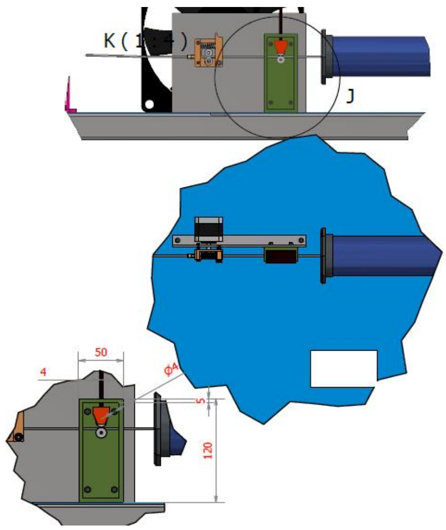

Figure 10. Design of filament size regulator that comes out of the die

$$Gear\ Ratio = \frac{driver\ gear\ speed}{driven\ gear\ speed}$$

$$Gear\ ratio\ = \frac{1283\ rpm}{6.66\ rpm} = 192.64 : 1$$

Then this ratio is used as the basis for obtaining the sprocket gear requirement in the sprocket and chain speed reduction mechanism. The number of sprockets on the electric motor / sprocket driver is determined in advance, namely 6 so that the need for driven sprockets on the screw extruder can be determined by calculation.

Driven Sprocket = *Gr* × *Driver Sprocket*
Driven Sprocket = 19.69 × 6
Driven Sprocket = **118.4 *teeth***

So that the torque is obtained after the gearbox reduction mechanism

$$T1 = T0 \times Gr0 \times E\%$$

$$T1 = 0.8 \times 9.78 \times 96\%$$

$$\boldsymbol{T1 = 7.511\ Nm}$$

Torque after chain and sprocket reduction mechanism

$$T2 = T1 \times Gr1 \times E\%$$

$$T2 = 7.511 \times 19.69 \times 98\%$$

$$\boldsymbol{T2 = 115\ Nm}$$

So, the torque obtained at Rpm 6.66 after going through 2 speed reduction processes is 115 Nm. Total Electric Power Requirements are determined in table 2.

Table 2. Electrical components and total power.

Components	Amount	Power (W)
DC Electric Motor	1	350
Band Heater	2	200
DC Geared Motor	2	12
PID	1	50
Total Power		**612**

So that the total electric power needed by this machine to operate is 612 Watts.

E_A **= 1,5 – 1,3**
E_A **= 0,2 kg**

$$E_r = \frac{E_A}{result}$$

$$E_r = \frac{0,2}{1,3}$$

Er= 0,15

Er= 15%

Filament products can be applied to 3D printers, so the diameter of the filament is measured by taking a 2 meter long sample to be measured every 10 mm. Then get the results of 1.77 mm diameter on the 3D Printer filament.

4. CONCLUSION

The design of an ABS pellet extrusion machine as an input material, based on the design carried out, it is known that the proper operation for the production of ABS filament is extrusion at a temperature of 198.191 oC with a screw speed of 5 rpm to produce 1.5 kg of ready-to-use 3D printer filament within 1 hour of production. . So there is an error between the calculation and the real condition of 15%.

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