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Designing a Bearing System for a Smart Material Filament 3D Printing Extruder Machine

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Abstract

The filament extruder machine is used to produce 3D printing filament made from Thermoplastic Polyurethane (TPU). This final project focuses on the design and analysis of the bearing system on a single screw-type extruder machine. The processing of TPU, which requires high temperatures and stable rotation, makes the bearing's role crucial in supporting machine performance. The machine is powered by a 25watt electric motor operating at 1390 rpm, which is reduced to 12 rpm through a 1:75 gearbox. The bearing used is a KFL000 type with a 10 mm bore. Calculation results show an equivalent dynamic load of 128,34 N and a dynamic load capacity of 283,68 N. The bearing's service life is estimated to reach 4 years, 5 months, and 19 days with a reliability level of 95%. Testing showed that the machine operates properly and is capable of producing Ø1.75 mm TPU filament according to specifications.

Keywords: Extruder Machine; Bearing; Smart Material Filamen; 3D Printing

Introduction

The development of additive manufacturing technology has experienced rapid growth in the last decade, one of which is 3D printing. This technology enables the efficient and precise manufacturing of three-dimensional objects and has been widely applied in the automotive, healthcare, and education sectors. One of the most commonly used methods is Fused Deposition Modeling (FDM), which utilizes filament material as the main ingredient. The quality of the filament greatly affects the print results, in terms of dimensions, mechanical strength, and surface smoothness. Therefore, the need for filament extruder machines capable of producing high-quality products is increasing [1].

The filament extruder machine functions to re-print thermoplastic material into filaments with a specific diameter and high dimensional stability. One of the commonly used materials is Thermoplastic Polyurethane (TPU) [2]. This condition causes mechanical components in the engine, especially those directly involved in rotation and transmission, to operate under heavy loads and high temperatures [3]. However, processing TPU requires high temperatures, ranging from 220°C to 250°C, as well as stable flow rate control to produce filaments with consistent shape and size. This condition causes mechanical components in the engine, especially those directly involved in rotation and transmission, to operate under heavy loads and high temperatures [4].

In many laboratory-scale or small-to-medium industrial extruder designs, the aspects of bearing design and selection are often overlooked [5]. Many designs rely solely on general-purpose bearings without considering critical parameters such as equivalent dynamic load, operating temperature, and the appropriate type of lubrication system. Research results by Kumar, et al. (2025) shows that the tribological performance of TPU-based bearing materials is highly dependent on load and temperature conditions. If not calculated correctly, bearing operating efficiency can decrease significantly [6, 7]. These findings emphasize the need for further study on the design and analysis of bearing systems that are suitable for filament extruder machines that process high-temperature thermoplastic materials such as TPU, in order to maximize operational stability and print quality [8].

This research focuses on the design and analysis of bearing systems for 3D printing filament extruder machines. This study includes identifying the most suitable type of bearing, analyzing the working load borne by the bearing, and estimating its service life based on actual loading conditions. It is hoped that the results of this study can contribute to improving the reliability and efficiency of extruder machines, as well as extending the service life of mechanical components through the selection and design of optimal bearings.

Methods

Previous research related to plastic extruder machines has been conducted extensively, particularly on the manufacture of plastic waste-based filament machines for 3D printing needs [8]. Jiang, et al. (2024) designed a single screw extruder machine with a single heating system and fan cooling used to print filaments from Polyethylene Terephthalate (PET) waste [9]. They highlighted that extrusion temperature stability is a major factor in producing uniform dimensional filaments [10].

Another study by Rashwan, et al. (2023) developed a microcontroller-based recycling extruder system with Proportional Integral Derivative (PID) temperature control. This system enables more accurate multi-point temperature control, which is important for materials with a narrow process temperature range such as TPU [11, 12]. Although the maximum temperature in their study did not reach 300°C, the control system is an important reference considering that the TPU extrusion process requires precise temperature control to avoid thermal degradation [13].

The extruder machine is designed to melt TPU plastic pellets and extrude them into filaments suitable for 3D printing. The melting process is carried out in a heated barrel, while the material is pushed by a screw rotated by an electric motor. The rotational movement of the screw generates pressure that pushes the material towards the nozzle until a filament with a diameter of 1.75 mm is formed [14]. Sketching is necessary to provide an initial overview before making a filament extruder machine. The sketch can be seen in Figure 1.

The names of the components in Figure 1(c) are listed in Table 1.

The working principle of this machine begins with a drive system in the form of a 25-watt electric motor with a rotational speed of 1400 rpm. This rotational power is then transmitted through a gearbox with a reduction ratio of 1:75, resulting in a final rotation of 12 rpm. The electric motor shaft is connected to the screw extruder shaft using a flange coupling.

Next, when the screw shaft begins to rotate, the TPU material is fed into the barrel through a hopper, which serves to regulate the amount of material entering in a controlled manner. The barrel is equipped with a band heater that functions as a heating element to melt the TPU material inside. After undergoing the melting process, the material is pushed by the screw towards the nozzle and comes out in the form of filaments. This extruder machine is designed to process 200g per use.

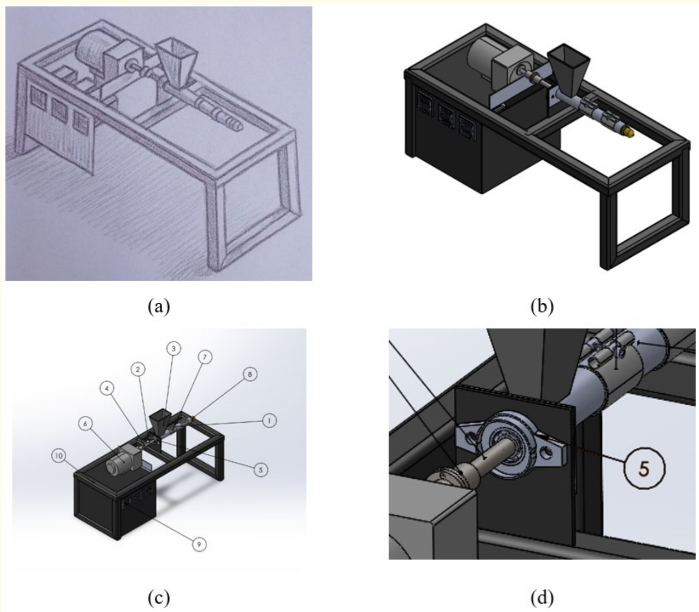

Figure 1: (a) Sketch (b) 3D design, (c) Parts and (d) bearings of the extruder machine.

S. No.	***Components***	***Function***
1	Barrel	The barrel in an extruder machine functions as a place to process materials and melt TPU plastic from plastic pellets into liquid form with the help of a band heater.
2	Screw Extruder	The screw extruder is a component that acts as the shaft in the extruder machine and functions to mix and push the material inside the barrel, which will then be ejected through the nozzle.
3	Hopper	The hopper or funnel functions as a container for the material before it enters the barrel.
4	Coupling	The coupling is a component that functions to transmit power from the electric motor to the screw.
5	Bearing	The bearing is an important component that acts as a shaft support/bearing.
6	Electric Motor	The electric motor used in this 3D printing filament extruder machine has a power of 25 watts with a maximum speed of 1390 rpm, using a 1:75 gearbox ratio to produce a maximum speed of 17 rpm.
7	Band Heater	The band heater used in this system is capable of producing temperatures up to 350°C.
8	Nozzle	The nozzle is a component that shapes the material into filament. The nozzle on this extruder machine produces a final filament size of Ø1.75 mm
9	PID (Proporsional Integral Derivatif)	This component is assisted by a thermocouple to read the temperature in the barrel so that it matches the desired temperature. In addition, PID is also used to regulate the speed of the electric motor so that it rotates the shaft at the desired speed
10	Frame	The frame supports the performance of the extruder machine

Table 1: Names and functions of engine components.

Results and Discussion

Structural static calculations are required in bearing design. The load on the filament extruder machine can be seen in Figure 2.

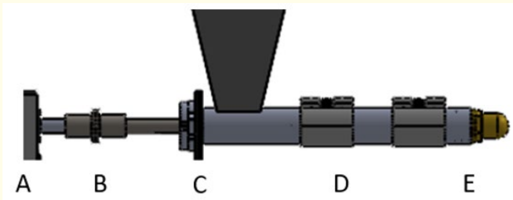

Figure 2: Extruder Machine Loading.

The reactions of evenly distributed loads and concentrated loads can be seen in Figure 3.

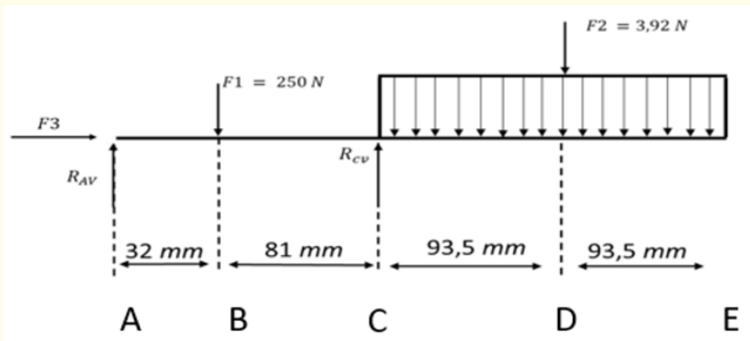

Figure 3: Reaction Support.

Determining the force on the screw extruder (F_{screw})

$W_{screw} = m \times a$

$W_{screw} = 0,2\ Kg \times 9,8\ m/s^2$

$W_{screw} = 1,96\ N$

$W_{plastik} = m \times a$

$W_{plastik} = 0.2\ Kg \times 9,8\ m/s^2$

$W_{plastik} = 1.96\ N$

$F_{Screw} = W_{screw} + W_{Plastik}$

$F_{Screw} = 1,96\ N + 1.96\ N$

$F_{Screw} = 3.92\ N$

Finding the style on the clutch

T = 8 "Nm" = 8000 "Nmm"

R = 32 "mm"

$T = F \times r$

$F_{kopling} = T/r$

$F_{kopling} = 8000/32$

$F_{kopling} = 250$ "N"

Determining the axial load

$T = F \cdot r$

$8000 = F \cdot 280mm$

$F = 8000\ Nmm/280mm$

$F = 28{,}57\ N$

$\Sigma F_X = 0$

$R_{AH} - 28{,}57\ N = 0$

$R_{AH} = 28{,}57$

Determining Radial load
Determining the even load on the screw

$F_{screw} = 3{,}92N$

$q = 3{,}92N/187mm$

$q = 0{,}20\ N/mm$

$W = q \cdot l$

$W = 0{,}02\ N/mm \cdot 187mm$

$W = 3{,}74\ N$

Determining the load at point A

$\sum M_a = 0$

$(R_{CV} \times (X_1 + X_2)) - (F_{kopling} \times X_2) - (F_{screw} \times (X_1 + X_2 + X_3)) = 0$

$(R_{CV} \times (32 + 81)) - (250 \times 81) - (3{,}74 \times (32 + 81 + 93{,}5)) = 0$

$113 \times R_{CV} - 20250 + 772{,}31 = 0$

$R_{cv} = 172{,}37\ N$

Determine the load at point A

$\Sigma M_c = 0$

$R_{AV} + R_{CV} = F_{total}$

$R_{AV} + 172{,}37 = 250\ \text{"N"} + 3{,}74\ \text{"N"}$

$R_{AV} = 81{,}37\ \text{"N"}$

$\Sigma F_y = 0$

-250-3,74 + 172,37 + 81,37 = 0

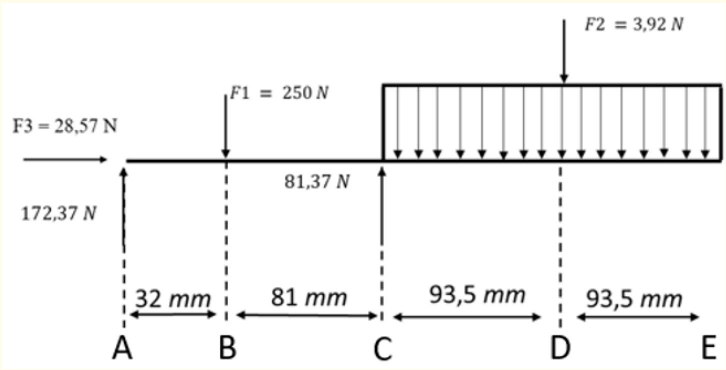

Figure 4: Free Body Diagram.

Design of Bearing Extruder Machine
Dynamic Equivalent Load (W)

$W = (X \cdot V \cdot W_R + Y \cdot W_A)\ K_S$

$W_A/W_R = 28{,}57/81{,}37 = 0{,}35$

The load factor used for radial X = 0.56 and the axial load factor Y = 1,4 because $W_A/W_R > e$. *V* is equal to 1 for rotating inner rings (Khurmi & Gupta, 2005). Meanwhile, the service factor (*KS*) is assumed to be subjected to a light shock load with a value of *KS* 1.5.

$W = (0{,}56 \cdot 1 \cdot 81{,}37 + 1{,}4 \cdot 28{,}57)1.5$

$W = 128{,}34\ N$

Rating Life (L)

$L = 60 \cdot N \cdot L_H$

The shaft rotation (N) used in electric motors is 12 rpm. Meanwhile, *LH* = 15,000 hours.

$L=60 \cdot 12 \cdot 15000$

$L = 10{,}8 \times 10^6\ rev$

Dynamic Load (C)

$C = W(L/10^6)^{1/K}$

Nilai k = 3 for ball bearing

$C = 128{,}34(10{,}8 \times 10^6/10^6)^{1/3}$

$C = 283{,}68$ N

From the above calculations, the dynamic load value of the bearing is 283.68 N. Therefore, the required bearing specifications are needed for comparison. The bearing specification used is KFL000, which has a basic dynamic load of 4,700 N. The dynamic load capacity is greater than the dynamic load of the bearing, so the bearing design is SAFE and meets the service life requirement of L_H = 15,000 hours. Next, the bearing life is calculated below.

Bearing Reliability

$L_n = a_1 \cdot a_2 \cdot a_3 \cdot L_h$

Values α1, α2, α3 using:

$\alpha 1 = 1$ (reliability factor value 90%)

$\alpha 2 = 1$ (steel material factor)

$\alpha 3 = 1$ (working factor under normal conditions)

$L_n = 1 \cdot 1 \cdot 1 \cdot 15000$

$L_n = 15000$ hours = 625 days

Bearing Service Life

$L_B = L_N/8 \times 260$

$L_B = 15000/8 \times 260 = 7{,}21$ years = 7 years 2 month 16 days = 2362 days

From the calculation results for the bearing replacement period above, using a reliability factor of 90%, a maximum operating time of 8 hours per day, and 5 days of operation per week, the bearing life is 7 years, 2 months, and 16 days, or 2362 days.

Conclusion

Based on the results of the design and testing of the filament extruder machine, it can be concluded that the equivalent dynamic load received by the bearing is 128.34 N and the dynamic load is 283.68 N. The bearing used in the filament extruder machine with a speed of 12 rpm on the screw shaft is type KFL000 bore 10 mm. The results of the design for bearing replacement time with a reliability factor of 90% show that under normal working conditions, the bearing has a lifespan of 7.21 years, or 7 years, 2 months, and 16 days, or 2362 days.

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