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Design of Plug and Print Extruder for 3D Printer

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ABSTRACT
3-dimensional printing, generally known as 3-D Printing is an AMT - Additive manufacturing technology that applies successive layers of material to create a 3D object. It is a mechanized method of rapidly producing 3D elements using a medium-sized machine connected to a computer that contains designs for the object. As 3D printing becomes more popular and product development accelerates, 3D printing companies must be able to consistently meet printing demands and maintain an adequate inventory of filament. The cost of 3D printing is increasing as manufacturers have to source these filaments from numerous sources. The 3D filament making machine is designed to solve the difficulties faced by manufacturers and small workshop owners. Desktop fabrication is the term for 3D printing. The 3D model is used in the process to create a structure. 3D model is saved in STL format and then transferred to a 3D printer for printing. It is capable of printing with a wide range of materials including ABS, PLA and composites. The 3D printer creates something real by printing the CAD design layer by layer.3D printing will pose a significant threat to mass manufacturing processes in the future. This type of printing is expected to impact industries such as automotive, medical, education, equipment, consumer goods and other businesses.
This project focuses on the design and development of a plug and print extruder and 3D printer nozzle to solve the difficulties encountered with traditional extruders and nozzles.

Keywords: *3D Printer, Extruder, Nozzle*

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I. INTRODUCTION

Additive manufacturing (AM) is a technology based on layer-by-layer manufacturing from CAD models and integrating raw materials, computers, and machines to create a product. [2] AM enables faster creation of products and allows for dynamic design and process adjustments. It also allows for creative flexibility and accurate material and time prediction for finishing sections. AM's economic appeal also comes from recycling and environmental friendliness, both of which contribute to corporate growth and pollution reduction. prototyping has been around for two decades, beginning with the notion of Rapid Prototyping, which was first patented by Charles W. Hull in 1984which further evolved into rapid prototyping 3D systems in the year 1986. [3]

With the progress of NC and CNC machines, additional AM technologies with broader application areas have evolved. While there are numerous methods to categorise AM technologies, the simplest method is to categorise them based on the kind of raw materials utilised or the type of process, such as laser technology. summarises the AM categorization. Non-Metals & metals in solid, liquid, semi-solid forms can be processed Traditional manufacturing processes suffer from metal-on-metal machining, which affects accuracy, quality, and cost. With all of the relevant dimensions and functional criteria met in one production stage, AM provides great precision and quality. [1]

Many research groups from many nations developed technical road maps for additive manufacturing, outlining the obstacles to its commercialization and quick replacement of traditional production processes. AM has the ability to reduce direct & indirect expenses such as capital investment, machine impression, labour, material inventory & handling, product – finishing followed by assembly, & other processes, compared to traditional techniques. While the initial investment in an AM system would be significant, its long-term use might be cost-effective [4] The many stages of the AM process are depicted in Figure 1.In this, first the 3D model is generated using suitable and standard software. It is then converted to the STL file format and saved with the '.stl' extension. This is conversion is necessary as the CAD will be undergoing the slicing operation when transferred to the am machine. Prior to this, the filament material is selected as per the need and demand of the consumer; Even the manufacturer's cost constraints are taken into account. Once the material is selected and the STL file is transferred to the AM machine, the various process parameters are set to initiate the manufacturing operation. After manufacturing, post processing operations are performed on the final product and then it is sent out for the delivery.

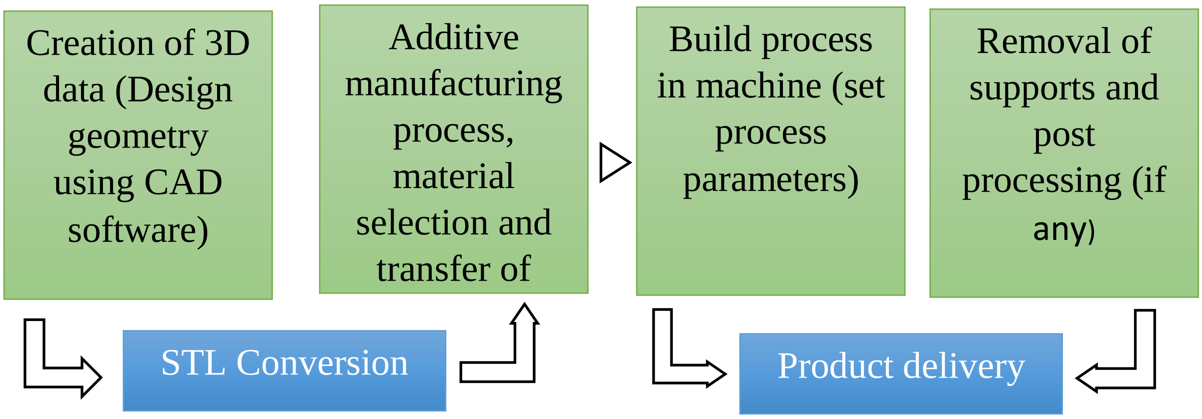

Fig 1**:** AM process phases

1.1 Problem Statement

This project is based on Design and Development of Plug and Print 3D printer extruder and Nozzle. Conventional 3D printer extruders and Nozzle have different problems like maintenance of extruders. For maintenance we need to remove whole extruder assembly and it is very time consuming. Also, conventional 3D printer nozzles have problems like clogging of the nozzle, overheating of nozzle and also problem like not extrusion at start. To design the extruder in order to come up with feasible solutions to eliminate the problems like energy loss on the heat bed, to make it economical for general purpose usage, nullify clogging damage and to aim for universal fitment of the extruder.

1.2 Objectives

a. Extruder design modification in accordance with industrial requirements;
b. Design of Plug & Print Extruder for 3D-Printer;
c. Redesigning the nozzle to eliminate the clogging

1.3. Scope of Study

a. Prototyping (complex geometries)
b. Biomedical engineering
c. Aligning the Indian market with Industry 4.0 and upcoming manufacturing-based possibilities supported by automation and robots.
d. The less material utilized, the greater the strength, so that it may be used to create Aerospace Components.

1.4 Methodology

1.4.1 Identifying the need

The extruder is one of the component of a 3D printer which carries out the function of ejecting the liquid or semi-liquid material in order to carry out successive layering within the 3D printing volume. In other circumstances, the extruder solely serves to deposit a bonding agent required to solidify a powdered substance. Clogging, fracture propagation, and filament leakage due to overheating are some of the issues encountered when utilising conventional nozzles in a 3D printer. Identifying these consequences ensures the requirement for a sophisticated nozzle.

1.4.2 Analysis

Analysing the problems of standard nozzles, other nozzles were examined which can either eliminate or alleviate the negative effects and provide positive results.

1.4.3 Selection of Materials

After referring various research papers and journals and also going through some hands-on experiences, manufacturing of Nozzle was finalized that will be used in the extruder. It is considered that the nozzle will be made of either nickel or tungsten, whichever is economical.

1.4.4 Numerical Treatment

Numerical treatments were done to find the flow rates, heat transfer rates, and other values using analytical methods. Experimental validation will provide the data for CFD.

1.4.5 Detailed Drawings

Rough sketches were prepared before commencing the numerical treatments and analysis. After selection of materials, software's like SolidWorks were aided to prepare the detailed drawings.

1.5 Background of 3-D Printing

3-D printing is an additive manufacturing (AM) process used to create structures and geometries. AMP is widely used in various fields like prototyping, construction of structures, biomechanics, etc. Recent technological advances have alleviated the costings of 3D printing processes, allowing them to be utilised in schools, homes, libraries, and laboratories. The accuracy of the printing method utilised, as well as the size of printing, determine the precision of the printed pieces. 3D printing eliminates the extra costs associated with creating a mould and tooling for a custom product.

There is still scope for research in 3D printing for obtaining better mechanical strength. Bulk production of identical items can be as cost-effective as mass production. FDM is one of the most common type of 3D printing that is generally employed.

1.6 Introduction to Extruder

As seen in Figure 2, an extruder is a machine that melts plastic polymer into molten form before converting it to a certain shape. Plastic is widely employed in the modern world, and many forms are produced using plastic extrusions and blown film extrusion. The polymers are heated either externally or inside. Though the internal warmth is created by the friction caused by the plastic polymers, some external heating is induced to the extruder. When the plastic granules adhere to the screw, it aids in the forward movement of the molten plastic. [23] Feed transition and metering zones are the common features of film extrusion screws. The polymer melt is forced through the die to obtain the desired form. When the polymer has reached the correct form, it is cooled to produce the finished product. [40]

1.6.1 The History of Extruders

Paul Troester of Germany invented the first thermoplastic extrusion machine in 1935. The extruder machines were traditionally facilitated for rubber extrusions. The ram steam heated screw extruders with a small length to diameter ratio was among the first machines. Electrical extruders with expanded length and double cams were developed as technology advanced. LMP's Roberto Colombo found the twin extruders having co-rotating twin screws. Roberto got a patent for this product in a number of countries, however he permitted certain corporations to exploit the patent right. The earliest details concerning extrusion were about the melting and pushing processes. By the early 1950s, there was a surge in scientific research into the expanding extrusion techniques. The researchers and employees in the plastics sector were the first to do research on extrusions. The study, on the other hand, drew academics, widening the gap between extrusion theorists and practitioners of extrusion technology. [39]

1.6.2 Uses of extruders

There are several types of extrusion processes. Plastic extrusion involves melting raw plastic and transforming it into a melted state, which is then used to mould various goods such as rods, seals, plastic tubes, sticky tapes, and sheets, among other things, using extruders. Plastic materials that are often utilised include nylon, polycarbonate, polyethene, acrylonite butadiene, and acrylic. The blown method of extrusion is used to make shopping bags and related things. Except for the die, this is quite identical to normal extrusion. In this procedure, the die is shaped like a tiny cylinder with a circular aperture ranging in size from a few centimetres to several metres. The most important significance of this technology is the variety of quality variations it delivers. Sheet/film extrusion-The materials are chilled by drawing them through a succession of cooling wheels in this form of extrusion. The materials can attain the required texture and thickness using this procedure. This is followed by thermos shaping, which involves heating the plastic until it is flexible enough to create a specified shape. When a vacuum is employed during this procedure, the technique is known as vacuum forming. Extrusion of tubing This procedure is used to manufacture tubes and straws. Except for the die used, there is little difference between this procedure and others. This method is used to create medical tubes and drinking straws. Different / multiple lumens can be utilised according on the number of holes required. Composite extrusion is a method that mixes various polymers to form a plastic compound. Injection moulding and extrusion can opt for powder, liquid, or pellets. Equipment are highly useful in this sort of procedure; they can be little laboratory machines or massive industrial machineries for moulding large things. The extrusion methods described above are the most regularly utilised nowadays. Each has a distinct edge over the others. Each procedure demands for a unique set of machinery and equipment. [40]

Fig 2:- Extruder

II. LITERATURE REVIEW

3D printing is an Additive Manufacturing process that is now used to fabricate a broad variety of structures as well as complicated geometries using 3D model data. Almost every industry is using 3D printing. Engineering, architecture, Aerospace, medicine, arts are some of the examples. This method employs a material with low waste, lowering the cost of complicated geometries to a bare minimum.

According to **Tuan D. Ngo,** there are several advantages to employing Additive Manufacturing (AM) or 3D Printing technology, including design flexibility, waste minimization, and the capacity to build complicated structures. Metal additive manufacturing is expanding rapidly. The Aerospace industry has experienced massive growth in the recent years. At the same time, this technology is utilized to create and deliver answers to structural, protective engineering, and insulating concerns. Metal 3D printing involves melting of a metallic feedstock with an energy source such as a laser or electron beam further transforming that material to print layer by layer solid parts. Polymers are the most often used material in the 3D printing industry owing to their versatility and ease of incorporation into various 3D printing processes. Polymers are commonly encountered as thermoplastic filaments, reactive monomers, resins, or power for additive manufacturing. Polymers and composites have been utilized in industry for many years to produce a variety of industrial applications such as toys, medical implants, and so on. Furthermore, it may be less expensive than traditional procedures such as moulding and extrusion.

According to **Joel C. Najmon,** additive manufacturing parts in the aerospace sector can be classified as metallic or non-metallic. Non-metallic components, on the other hand, are largely polymers and composites, which are used in major and minor, critical and non-critical aircraft parts. New applications are constantly appearing as new materials and Additive Manufacturing technologies are created. Printers have become less expensive as a result of their advancement. As a result, the use of additive manufacturing technology is spreading to schools, households, labs, workshops, and enterprises. Because of its speedy and cost-effective prototyping potential, 3D printing technologies are frequently employed in the early stages for manufacturing aesthetic and functional prototypes.

3D printing, according to **Amal Nasar,** is a procedure in which a solid model is built layer by layer with automated control. Any shape or geometry may be represented by a 3D CAD file in digital format. The data in the electronic control unit consists of an Additive Manufacturing File (AMF), which instructs the extruder on the path to take while adding filament layer by layer to create an item. There are several varieties of filaments on the market, and they are classed according on their mechanical qualities, fused temperature, and diameter. Filaments like Acrylonitrile Butadiene Styrene (ABS) and Polylactic Acid (PLA) are some of the most prevalent in the industry. ABS offers a high level of impact resistance, strength, and flexibility. ABS has a high melting temperature (210-250° C).

According to **Taoufik Hachimi**, almost every industry uses Thermoplastic Polymers for their industrial activities, such as automotive, agriculture, aerospace and aeronautical, logistics and other industrial applications. For those industries are using different types of processes like injection, extrusion and 3D printing. 3D Printing is a new type of technology which works on CAD based model and for production of parts the raw material is in the form of powder and filaments. By using this technology wastage of material gets reduced.

According to **Md. Hazrat Ali,** 3D printing or three-dimensional printing or additive manufacturing is the process in which solid objects get produced from 3D CAD model. This model is designed in the design software. Relatively low fabrication speed and material limitation are the major drawbacks of this process. For that purpose in this paper 5 nozzle extruder model designed, just to print the model in multi-colors and multi-materials.

III. CAD MODEL

3.1 Cad Model (Solid Works)

The cad model for a typical nozzle, which is now utilised in modern extruders, is shown in Fig. 3. The dimensions for the standard nozzles are shown in front view section A and cut section A-A. A top image is also offered, which includes the diameter and size of the hexagon's side. On the top view, the diameter of the nozzle exit is also shown. The counter bore is provided by the cut portion. Finally, if the conventional nozzle is on the extreme right, one below the other, a skeleton as well as three-dimensional structure is apparent.

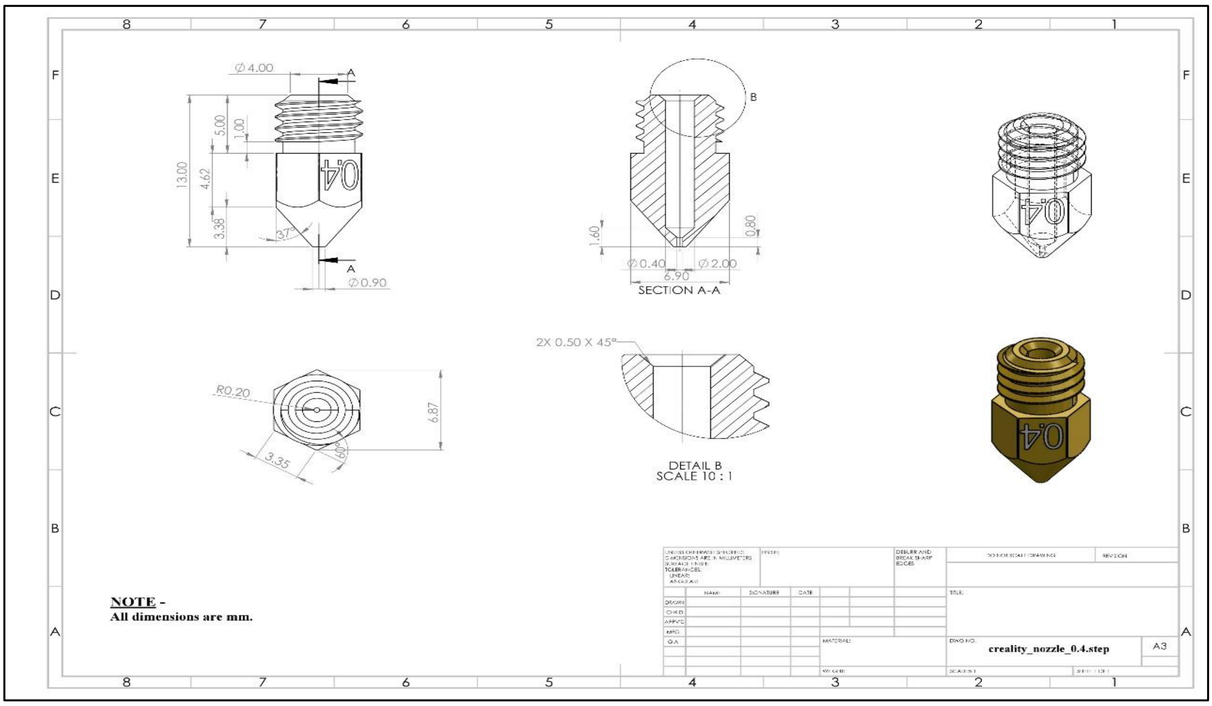

Fig No. 3: Standard Nozzle

The cad model for the modified nozzle, shown in Fig. 4, is now being reviewed for the project and will be utilised to replace the normal nozzle as well as with the extruder. Front view section A and cut section A-A show the dimensions for the Modified nozzles. The diameter of the triaxial drilling and the angle between the axes are also shown in the bottom image. The diameter of the nozzle exit is also given in the bottom image. The length of the Modified nozzle as well as the distance between the three axes are specified in the cut section. Finally, if the ordinary nozzle is present on the extreme right, one over the other, there is a skeleton as well as a 3D structure.

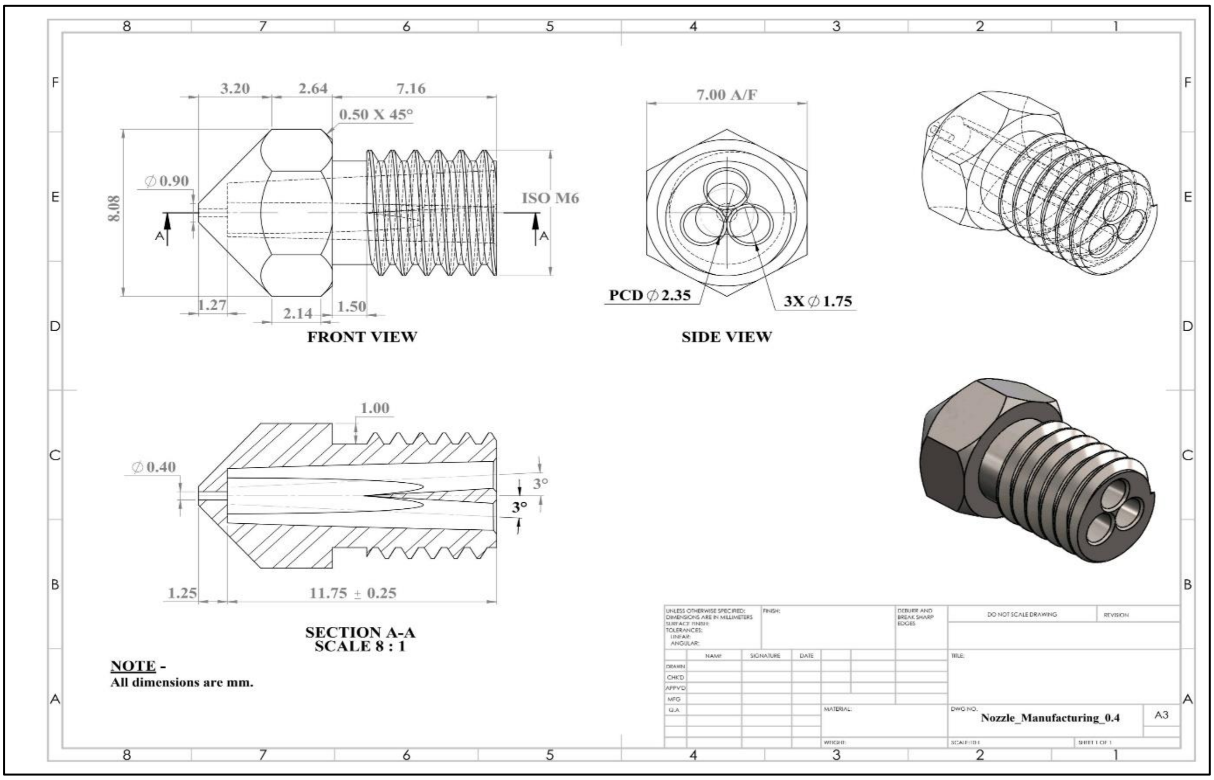

Fig. No. 4: Modified Nozzle

IV. CALCULATION

4.1. Flow rate of the filament (Q):

$Q = A*V$ …………………………………………………………………………………………………..….(i)

Where,

A= Area of Cross Section (mm^2)

V = Velocity (mm/s)

We estimated the area and velocity in order to calculate the flow rate of the filament, as the look of the 3D printed model is dependent on the flow rate of the filament.

The diameter of the nozzle (D) is 0.4 mm.

We took the diameter of the nozzle as 0.4 mm, because the 0.6 mm and 0.8 mm diameter nozzles are already available in the market and we are designing the nozzle of diameter 0.4 mm as per market need.

Area of cross section = $\pi D^2/4$

Area (A): **0.12 mm^2**

Velocity: **8.378 mm/s**

Therefore,

$Q = A*V = 0.12 * 8.378$

$=$ **1.005 cu.mm/s**

4.2. Nozzle: STAINLESS STEEL 304(SS304)

As per the standard requirements nickels is an alloy, we cannot use alloy for manufacturing. Instead of that we use "Inconel". Which is so costly, & use for Aerodynamics components.

So, we have to use SS304 we can get it for very low cost & Manufacturing is also very careful. Following that, we must supply a surface treatment technique.

Thermal coefficient of expansion **(α): 16 * 10^{-6} / ^{0}**C

Thermal expansions **(δ)** for different heights of nozzle considered: **$\delta = \alpha*T*L$** ………………………………..(ii)

Because the nozzle operates at high temperatures, thermal expansion must be taken into account. Because different filament materials have varying melting temperatures, the temperature of the nozzle is always fluctuating.

Where,

T = Temperature Difference (^{0}C)

According to the usual charts, the temperature is 4 degrees Celsius.
L = Length of Nozzle (mm)
For L=13mm
$L_{13} = \alpha * T * L$
$= 17.3*10^{-6}*4*13$
$L_{13} = 9*10^{-4}$mm

Similarly for
$L_{14} = 9.688 * 10^{-4}$ mm
$L_{15} = 71.038 * 10^{-4}$ mm

4.2.1. **Select thread type:** (BSP, ISO metric etc)
(As per design profile of Nut & Bolt)
H= 0.86603p =0.86603x1 =0.86mm
D1= d-1.0825p =6-1.0825x1 =4.95mm
H1= 5H/8 =5x0.86603/8 =0.54mm
D2= d2 =d-0.6495p =5.35mm
d3= d-1.2268p =4.78mm
h3= 17H/24 =0.60mm
r= H/6 =0.143mm

(d= Diameter of nut ; D= Diameter of bolt)

According to ISO 64, M6 x 1 (External threading's)
Major Diameter= 6mm
Pitch= 1mm (Coarse)
Pitch= 0.75mm (Fine)

4.2.2. **Select across flat hex profile according to thread size**
HEX NUTS - BASIC DIMENSIONS
METRIC BASIC DIMENSIONS FINISH NUTS
Basic Size = 4
Width Across Flat = 7

4.2.3. **Material of Nozzle** = SS304

4.2.4. **Surface Treatment process** = En8 Nickel electrolysis Plating

We will be manufacturing the nozzle for 3 different lengths 13 mm, 14 mm and 15 mm respectively as to study and analyse the working of the nozzle and to select the length which best suits the AM process further

4.3 Heat Block:

Heat will be transferred by the mode of conduction as the molecules are close in contact
Heat transfer by conduction ($Q^{\cdot}$): -K*A*(dT/dX)…………………………………………………..(iii)
Where,
K = Thermal Conductivity
Thermal Conductivity is the material property, hence standard.
A = Area of Cross Section
As per the positioning of the heat block on the extruder assembly, the cross sectional area is obtained by using the dimensions of 12 mm and 16 mm
(dT/dX) = Temperature
It measures the effect of temperature across the length perpendicular to the cross section Aluminium and brass are shortlisted and one will be finalized, as per the cost Constraints.

4.3.1 for heat block (made of Aluminium)

Given, K (Al) = 205 W/mK
Area = 12 *16 = 192 sq.mm.
Length = 23 mm
As a result, the length of heat flow perpendicular to the cross sectional area is 23 mm.
Therefore, $Q^{\cdot}$ = 205 * 192 * (4/23) = **$6.84*10^{-3}$ W**

4.3.2 for heat block (made of Brass):

Given, K(brass) = 10W/mK

Area = 12 *16 = 192 sq.mm.

Therefore, Q· = 109 * 192 * (4/23) = **$3.6*10^{-3}$ W**

V. CONCLUSION

We designed the plug and print extruder for 3D printer and we hope that it will eliminate the problems related to clogging. Also, it will be useful in different industries after getting manufactured. With an aim to keep mass production in forefront, we hope the manufacturing process to be economical.

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