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Research Article

Design and Development of syringe based Extruder for an FDM Printer

M.Karthik Reddy[1*] and V. Phanindra Bogu[2]

[1]M.Tech, Department of Mechanical Engineering, Vidya Jyothi Institute of Technology, Hyderabad, India.
[2]Associate professor, Mechanical Engineering, Vidya Jyothi Institute of Technology, Hyderabad, India.

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Abstract

Additive manufacturing technology as evolved with wide range applications in several fields. Syringe based extrusion is technique of the additive manufacturing technology in which is mainly used for bioprinting, paste extrusions e.t.c. A syringe is used for the extrusion of material or printable inks; the material to be printed is placed in the syringe. The syringe plunger helps the material to extrude out of the syringe with certain diameter. Syringe plunger is moved forward through a gear set up to the stepper motor. Designing and development of the syringe extruder components is done in affordable ways and tested with several printable parameters. The application of these techniques is mainly in medical field (bioprinting) for fabrication of bone tissues, cell tissues. A good quality print is obtained using the parameters (print speed, travel speed, flow rate) and also calculated value of extrusion multiplier. The print quality can further improve using the bionks with good viscosity and some design changes of the setup and also by accurate leveling of print bed and better calibration of the printer after installing the syringe setup on the normal printer setup.

Keywords*: Bioprinting, Hydrogel, Syringe extrusion, Extrusion multiplier.*

1. Introduction

Conventional manufacturing is a subtractive type process. It uses a physical tool to manufacture components by removing unwanted materials. 3D printing is a novel method of tool-less manufacturing. In this process, the materials are added in successive layers to form the final 3D object thereby reducing wastage of material and tooling cost. Additive manufacturing comes under the category of the non-conventional or non-traditional manufacturing process. The wastage of materials is much lower than any conventional manufacturing process. Thus additive manufacturing is more efficient when compared with conventional manufacturing process because of its less tooling requirements and efficient use of material with minimum wastage.

3D printing comes under additive manufacturing technology that involves printing the object layer by layer. Conventional FDM involves melting of the filament that is converted to solid as it is extruded out of the nozzle. In Fdm printers the materials used are PLA or ABS. whereas extrusion printing increases the application range of printing by use of bioinks.

Syringe based extrusion can be classified mainly into two categories one is bioprinters and the other is clay or paste extruding.

*Corresponding author's ORCID ID: 0000-0002-7819-0663
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Bioprinters are used for printing of biological elements, cells and tissues, the low volume and small diameter nozzles are used to print biopolymers and cells. Paste or clay extruders are used for high capacity and nozzles used have larger diameter compared to bioprinters.

1.2 Bioprinting

Bioprinting is a technology in the field of biofabrication. It is a process of printing three dimensional objects by using layer by layer printing method to extrude materials known as bioinks to create structures of tissues which are used in various medical and tissue engineering fields. Currently, bioprinting can be used for printing of different body organs, tissues and also helpful in pharma field like developing of drugs and pills. The process of bioprinting is evolving with new innovations like printing of extra cellular matrix and mix cells with the bioink hydrogels, which will be printed layer by layer to produce the tissue of desired shape. For bioprinting the bioink used mainly is hydrogel, which act as the cells micro environment. Hydrogels are 3D-hydrophlic molecular polymer network has high water content that can be obtained from natural or synthetic polymers.

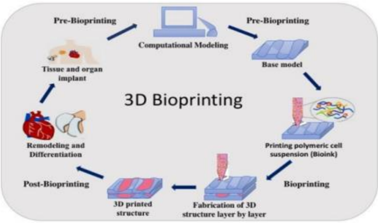


Fig no 1.2(a) schematic representation of bioprinting

Advantages

1. Accuracy in deposition of cells
2. Good control over the rate of cell distribution
3. No wastage of materials
4. Process speed has increased the application of this technology in printing of live scaffolds

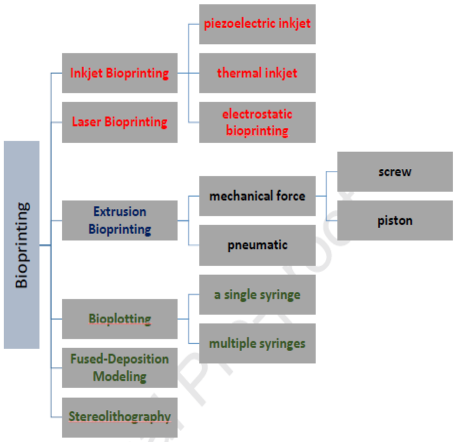


Fig no 1.2(b) classification of bioprinting based on biomedical applications

1.2.1 Material used for bioprinting

A wide range of materials are used for bioprinting with different viscosities and also cells having density can be printed by bioprinting. Several varieties of polymers are tested for the purpose of bioprinting. The most commonly used bioink materials are Natural polymers like **collagen, gelatin, alginate,** and **hyaluronic acid (HA)** and **synthetic polymers** like **PVA**, and **polyethylene glycol (PEG)** for bioprinting. Bioinks are produced by post processing using chemical or UV cross linking to improve the structures mechanical properties. Extrusion based bioprinting has been used for the printing(fabrication) of scaffolds for printing of the bone, cartilage, aroticvalve, skeletal muscle, neuronal, and several other tissues. Even after great success in bioprinting, mechanical strength of the printed object and material selection still remain the major issue or problem for bioprinting. To resolve this issues researcher are watchful on using sacrificial materials which are included inside the structure while 3D printing, and will be removed in the post processing. Viscosity plays a main role while the selection of materials for printing using the syringe-based extruder.

1.3 Syringe based extrusion

Syringe based extrusion is a type of additive manufacturing technology in which syringe is used for the placing the printing material which is to be extruded. In some cases the syringe is filled with the material and heated to the processing temperature. A force is applied to the material in the syringe, by the stepper motor controlled (with the help of gears) plunger that pushes the material out of the syringe according to the 3D model given. The drawbacks of this process include:

- Refilling of material: refilling of material can be an issue for large objects to be printed, because there will be interruption in the printing, which also results in poor printing of the object
- Thermal degradation: Since the material is heated in some cases the syringe will also be affected and it is also possible that the material could suffer thermal degradation thus resulting in poor properties of the final product.
- Air block: this problem arises when the filling of the materials in syringe is not done properly air bobbles will be created, as a result causing air block.

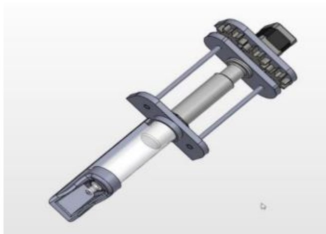


Fig 1.3 Syringe extruder

In this paper the work done is designing the components of the syringe setup and the components are printed using the 3D printer, and assembling of the components is done, material selection process is discussed according to materials required for printing. The calculation is done for calculating the extrusion multiplier, which is the major parameter along with flow rate, print speed e.t.c for 3D printing. Using these parameters mainly 3 experiments of printing is done by varying the process parameters for choosing the best parameters for a desired print.

2. Designing

The different components used in the syringe extruder setup are:

1. Herringbone gear (both driver and driven gear)
2. Gear holders (both top and bottom)
3. Bolt M8
4. Syringe holder
5. Plunger seal cap
6. T joint stepper motor holder

2.1 Herringbone gear

A herringbone gear his similar to that of helical gears the main difference is herringbone gear is a double helical gear which are facing opposite to each other. The helical groves look like V shaped when viewed from top, and forming a herringbone pattern (“resembling the bones of a fish such as a herring”). These gears do not produce any additional axial load as of helical gears. They are mainly designed for transmission of power through parallel or perpendicular axes. The typical pressure angles for herringbone gears is 14.5^{o} or 20^{o}

These gears have better edge over other for transferring of power smoothly same as the helical gear, because there are more than two teeth that will be in mesh at same time. Their main advantage is that the side-thrust of one half is balanced by the other half when compared to the helical gears. This indicates that herringbone gears can be used in “Torque Gearboxes” without needing any substantial thrust bearings. These are the main reason why herringbone gears are an important reason in the introduction of the steam turbine for marine propulsion.

Advantages

- Herringbone gear works quietly or operates quietly.
- Smooth power transmission is offered by the herringbone gears.
- Since the gears are in V shaped the axial thrust which will be produced in helical gears is cancelled out.

The applications of herringbone gear are transmission of high torque, used in heavy machinery, used in gas turbines, heavy duty vehicles and also in torque gearboxes e.t.c.

$$\text{Gear ratio} = \frac{number\ of\ teeth\ in\ driven\ gear}{number\ of\ teeth\ in\ driver\ gear} = \frac{45}{12} = 3.75$$

Therefore, the gear ratio is 3.75 i.e., 3.75 rotation of driver gear is equal to 1 rotation of driven gear. The design of the components of syringe extruder are done using CATIA software.

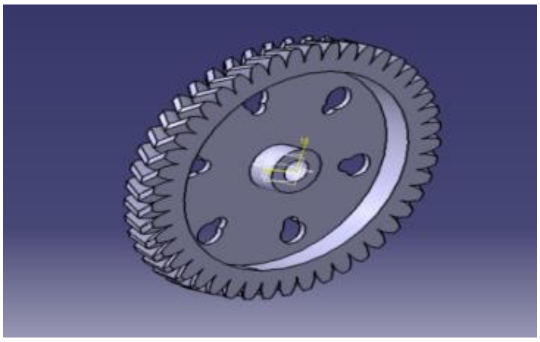


Fig 3.2.1 (b) 3D view of driven gear

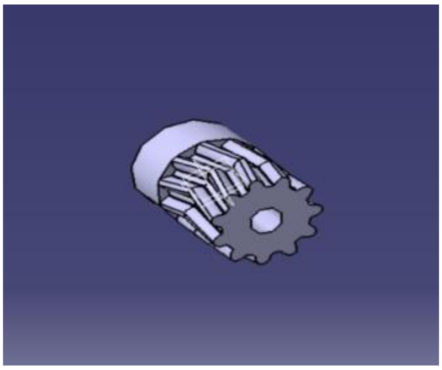


Fig no 3.2.1 (d) 3d view of driver gear

2.2 Gear holders (both top and bottom)

Gear holders or gear covers are used to fix the driven gear connected with the bolt in between top cover and bottom. Bottom cover also as a slot for stepper motor head to which driver gear is fixed. Driven gear is fastened between these to covers as shown in the figure below.

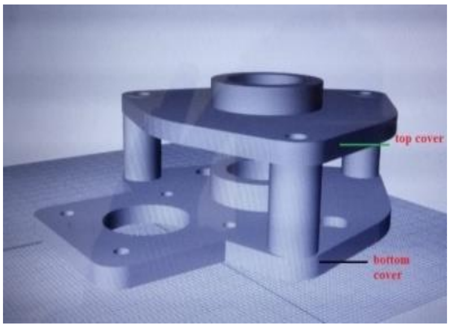


Fig no 2.2(a) gear holder

2.3 Bolt (M8)

M8 bolt is used in the syringe extruder setup for the transmission of rotational motion into linear motion. The driver gear(pinion) is attached to stepper motor shaft .The driven gear is meshed with the driver gear for the transmission of motion. The bolt is connected to driven gear which is used for the extrusion of material from the syringe. The other end of bolt is fixed with a plunger seal. The bolt used is 8 mm in diameter and 150 mm in length.

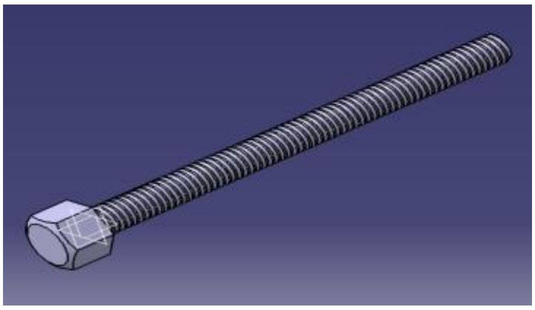


Fig no 2.3(a) 3D view of bolt

2.4 Syringe holder

Syringe holder is used to fix the syringe firmly to the bottom cover with the help of fasteners. Syringe is fixed to the bottom cover so as to get the desired extrusion. The holder is designed according to dimensions of the syringe.

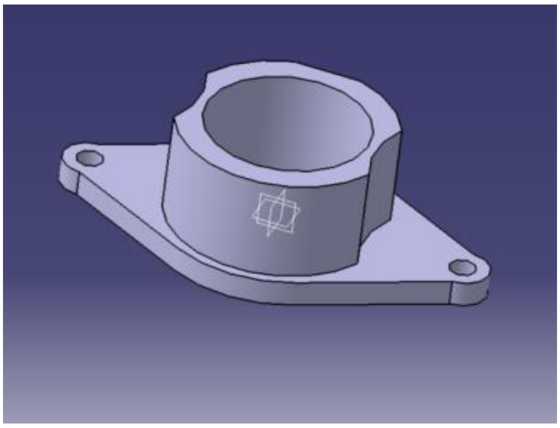


Fig no 2.4(b) Syringe holder 3d view

2.5 Plunger seal cap

Plunger seal cap is attached to rubber seal of the plunger for the better fitment of the bolt to the plunger rubber seal, which allows the better extrusion of the material through the syringe nozzle. The bolt which is fixed to driven gear is attached with this cap and the cap is inserted into the plunger seal.

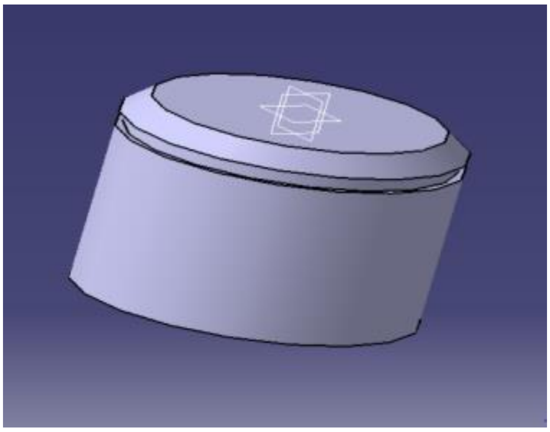


Fig no 2.5(a) plunger seal cap

2.6 T shaped stepper motor holder

T shaped stepper motor holder is used to fix the stepper motor on it. The T shaped holder is fixed to the horizontal x axis beam of the 3d printer. The whole stepper motor and syringe extruder setup is held firmly on this holder using fasteners. The whole weight of the setup is balanced equally on the x axis frame by this T holder. The designed component T holder is shown in below figure.

The syringe extruder setup placed on the T shaped holder is shown in the following figure below.

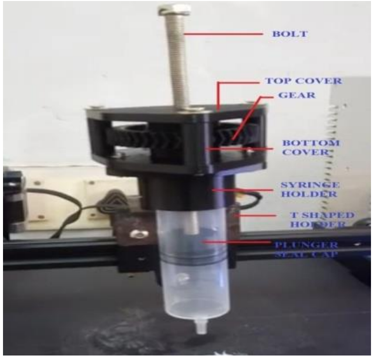


Fig no 2.6(a) Syringe extruder setup mounted on T Shaped holder

2.7 Materials used for bioprinting

There are different types of bio materials which can be used as bioinks for bioprinting. The following materials are some of the bioinks which can be used for bioprinting

a) Hydrogel

Hydrogels are bioinks that are useful in bioprinting due to their properties, which include high levels of hydration and shear thining.Bio-compatible hydrogels are used in bioprinting to show printing properties that are beneficial for cells within the ink. Some bio-compatible hydrogels exhibit a high level of hydration and a shear thining behavior.Hydrogels are used in bioprinting to display properties that are relevant to the printing process. They can maintain a high level of hydration and exhibit low shear. Hydrogels are used in bioprinting to display properties that are relevant to the printing process. They can maintain a high level of hydration and exhibit low shear.

b) Alginate based bioinks

Alginate is a type of biopolymer derived from brown algae, and is also cheap compared to other materials and it is also known as algin or alginic acid. It has two monomers, which are responsible for the production of negatively charged polysaccharides. Although it can trigger an inflammatory response in the body, it is not harmful to the environment. The combination of -L-gluronic acid and -D-mannuronic acid helps in the formation of gels and enhances the flexibility of the material. Combination of different biomaterials such as agarose, alginate and carboxymethyl-chiston are used for printing 3D constructs with stem cells inserted in it. The main advantages of using alginate is alginate biopolymers can trap water and also other molecules by the help of capalliary forces and they still can be used for diffusing from inside out.

c) Collagen based bioinks

Collagen based bioinks are mainly obtained from natural biomaterials; collagen is also one of the main component of ECM. Collagen is used for 3D bioprinting alone and also combined with other because they have excellent biocompatibility nature. This kind of biopolymers can be cross linked with other materials using temperature or also by changing the pH value or also by the use of the vitamins like riboflavin. The crosslinking or gelation of this materials can take minimum of 30 mins for gelation of collagen at a temperature of 37 ^{0}C. Therefore the usage of collagen directly for 3D printing can be tough, so combining with other materials can give good results.

The other materials mainly used as bioinks for 3D bioprinting are fabrin, cellulose, ECM derived bioinks, silks e.t.c. The below figure shows about the important requirements for selection of bioinks for 3D bioprinting.

Fig no 2.7 Important requirements for selecting bioinks for 3D bioprinting

2.8 Extrusion multiplier calculation

Extrusion multiplier is also known as "flow rate".

Filament:

$$\text{Circumference} = 2\pi r = 2\times\pi\times 5 = 31.4 \text{ mm/rev}$$

$$\text{Volume} = \frac{\pi}{4}\times d^2 \times l = \frac{\pi}{4}\times (1.75)^2 \times 31.4 = 75.52 \text{ mm}^3\text{/rev}$$

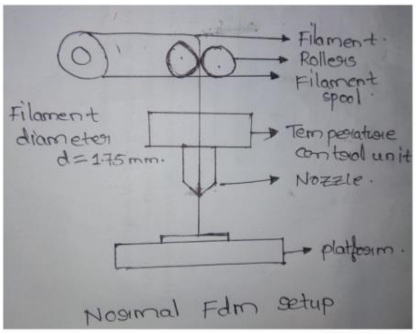


Fig no 2.8.1 2D diagram of fdm setup

Nozzle (syringe):

Outer diameter of syringe = 32 mm
Inner diameter of syringe = 30 mm

Length 90 mm = 60 ml

$$1 \text{ mm} = \frac{60}{90} = \frac{2}{3} = 6.667$$

1 mm = 6.667

Then
1.25 mm = 1.25× 6.667=0.833 ml

=833.33mm^3/rev (since 1 ml =1000mm)

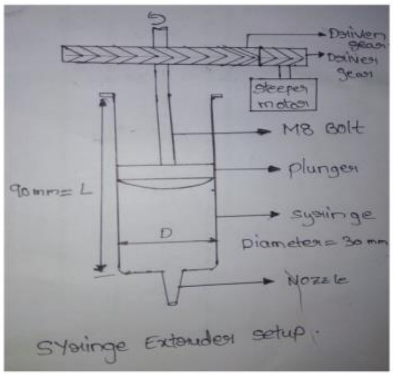


Fig no 2.8.2 2d diagram of syringe extruder setup

$$\text{Therefore extrusion multiplier} = \frac{filament\ volume}{nozzle\ volume} = \frac{75.52}{833.33} = 0.090 = 9.066$$

The extrusion multiplier is 9.066. This multiplier should be set in the cura software for the better print quality along with other parameters like travel speed, flow rate, print speed e.t.c.

2.9 Applications

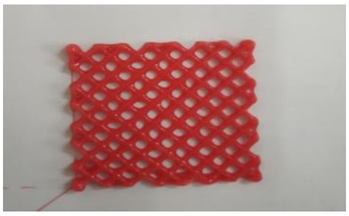
1) Bioprinting of living tissues.
2) This technology (bioprinting) can also potentially be applied to bone, skin, cartilage and muscle tissues.
3) 3d food printing using food grade syringes.
4) Creative food design.
5) By using 3d food printing there can be reduction in food waste.
6) In pharmaceuticals for printing of tablets.

3. Results and Discussions

The main parameters considered in cura software for printing are flow rate, travel speed, print speed. Different experiments were conducted by varying the process parameter. The below table shows the different prints that have obtained by varying the above parameters.

Experiment 1

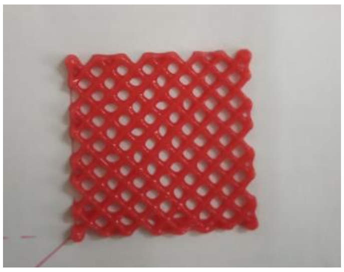
Flow rate - 100 mm/sec
Travel speed - 100 mm/sec
Print speed - 20 mm/sec
Acceleration control - disabled



3.1 image of printed part 1

Experiment 2

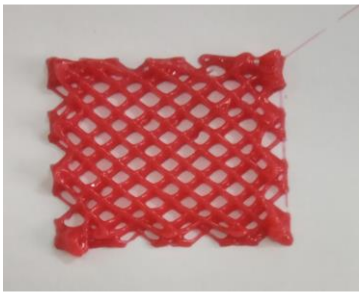
Flow rate - 150 mm/sec
Travel speed - 100 mm/sec
Print speed - 10 mm/sec
Acceleration control - disabled



3.2 image of printed part 2

Experiment 3

Flow rate - 100 mm/sec
Travel speed - 100 mm/sec
Print speed - 10 mm/sec
Acceleration control - disabled



3.3 image of printed part 3

The experiment 1 with the parameter values flow rate 100 mm/s, travel speed 100 mm/s, print speed 20 mm/s as given better print quality when compared to the other experiments. The print quality may be even bettered by varying the viscosity of the printable inks. There are some minute errors like slightly overflow of material that is due to the gravity, it can be reduced by choosing the ideal viscosity and also changing designing errors.

The syringe extruder setup which is mounted on the normal open source fdm printer setup is shown in the figure no 3.2

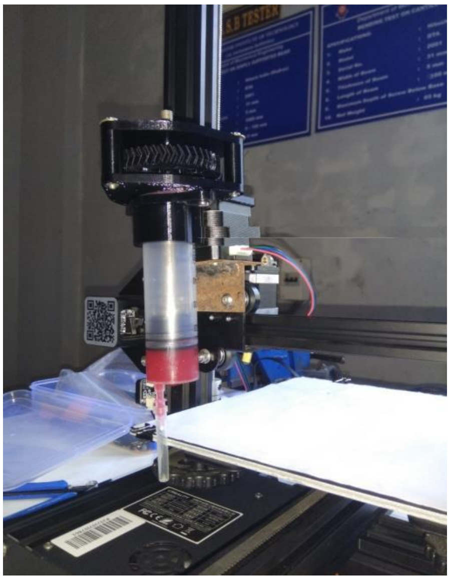


Fig no 3.2 syringe extrusion setup on the FDM printer

4. Conclusion

The main motto of this project is to create (design and develop) a syringe based extruder setup for fdm printer or for any other open source 3d printers in affordable way. The main application is for the use of 3D bioprinting.The setup include the designing of the extruder components (gears, gear holders, syringe holder e.t.c.), assembling the components, calculating the parameters (i.e extrusion multiplier or feed rate) and selection of materials and finally printing of the material with the syringe extruder setup with different parameters.

An ideal print is obtained by using different parameters like feed rate, print speed, and travel speed and infill e.t.c. The print quality main depends on the viscosity and the speed of the material flow. Sometimes print quality may also depend on the environment. A good quality print can be obtained by maintaining good viscosity and the flow speed of material. The extrusion multiplier also plays a major role in quality print. The experiment 1 done as the better results. The print quality can further improve using the bionks with good viscosity and some design changes of the setup and also by accurate leveling of print bed and better calibration of the printer after installing the syringe setup on the normal printer setup

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