Design and Fabrication of 3d Printer (Control Mechanism)

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Abstract- In modern printing, the 3D printers play a vital role in making models of additive manufacturing technology. The creating of 3D models saves the time and costs eliminating the needed design. The 3D printer is a wide spread application in the producing models. Thus, the 3D printer would serve as a safe and the versatile method for material modeling operations. Creating complete models in a single process using 3D printing has great benefits. This innovative technology has been proven to save companies time, manpower and money. Companies providing 3D printing solutions have brought to life an efficient and competent technological product.

Indexed Terms- force necessary to push the melt, the power of motor, Pressure drop for liquefier, the travel length

I. INTRODUCTION

3D printing is a form of additive manufacturing technology where a three dimensional object is created by laying down successive layers of material. It is also known as rapid prototyping, is a mechanized method whereby 3D objects are quickly made on a reasonably sized machine connected to a computer containing blue prints for the object. The 3D printing concept of custom manufacturing is exciting to nearly everyone. This revolutionary method for creating 3D models with the use of inkjet technology saves time and cost by eliminating the need to design; print and glue together separate model parts. Now, you can create a complete model in a single process using 3D printing. The basic principles include materials cartridges, flexibility of output, and translation of code into a visible pattern.

3D Printers are machines that produce physical 3D models from digital data by printing layer by layer. It can make physical models of objects either designed with a CAD program or scanned with a 3D Scanner. It is used in a variety of industries including jewelry, footwear, industrial design, architecture, engineering and construction, automotive, aerospace, dental and medical industries, education and consumer products
The technology for printing physical 3D objects from digital data was first developed by Charles Hull in 1984. He named the technique as Stereo lithography and obtained a patent for the technique in 1986. While Stereo lithography systems had become popular by the end of 1980s, other similar technologies such as Fused Deposition Modeling (FDM) and Selective Laser Sintering (SLS) were introduced. In 1993, Massachusetts Institute of Technology (MIT) patented another technology, named "3 Dimensional Printing techniques", which is similar to the inkjet technology used in 2D Printers. In 1996, three major products, "Genisys" from Stratasys, "Actua 2100" from 3D Systems and "Z402" from Z Corporation, were introduced. In 2005, Z Corp. launched a breakthrough product, named Spectrum Z510, which was the first high definition color 3D Printer in the market. Another breakthrough in 3D Printing occurred in 2006 with the initiation of an open source project, named Reprap, which was aimed at developing a self-replicating 3D printer.

1.2 Types of 3D Printer

There are four types of 3D printer. They are

1. Extrusion type
- Fused deposition modeling (FDM)

2. Granular type
- Direct metal laser sintering (DMLS)
- Electron beam melting (EBM)

- Selective heat sintering (SHS)
- Selective laser sintering (SLS)
- Powder bed and inkjet head 3d printing, Plaster-based 3D printing (PP)

3. Laminated type

- Laminated object manufacturing (LOM)

4. Light polymerized

- Stereo lithography (SLA)
- Digital Light Processing (DLP)

1.3 Application in 3D Printer

A method of manufacturing known as ‘Additive manufacturing’, due to the fact that instead of removing material to create a part, the process adds material in successive patterns to create the desired shape. Main areas of use are Prototyping, Specialized parts – aerospace, military, biomedical engineering, dental, Hobbies and home use, Future applications– medical (body parts), buildings and cars.

This technology is used to manufacture direct parts for a variety of industries including aerospace, dental, medical and other industries that have small to medium size, highly complex parts and the tooling industry to make direct tooling inserts. With a build envelop of 250 x 250 x 185 mm, and the ability to ‘grow’ multiple parts at one time, SLS is a very cost and time effective technology. The technology is used both for rapid prototyping, as it decreases development time for new products, and production manufacturing as a cost saving method to simplify assemblies and complex geometries.

1.4 Capabilities of 3D Printer

As anticipated, this modern technology has smoothed the path for numerous new possibilities in various fields. The list below details the advantages of 3D printing in certain fields.

Product formation is currently the main use of 3D printing technology. These machines allow designers and engineers to test out ideas for dimensional products cheaply before committing to expensive tooling and manufacturing processes.

In Medical Field, Surgeons are using 3d printing machines to print body parts for reference before complex surgeries. Other machines are used to construct bone grafts for patients who have suffered traumatic injuries. Looking further in the future, research is underway s scientists are working on creating replacement organs.

Architects need to create mockups of their designs. 3D printing allows them to come up with these mockups in a short period of time and with a higher degree of accuracy.

3D printing allows artists to create objects that would be incredibly difficult, costly, or time intensive using traditional processes.

1.5. Components of 3D Printer

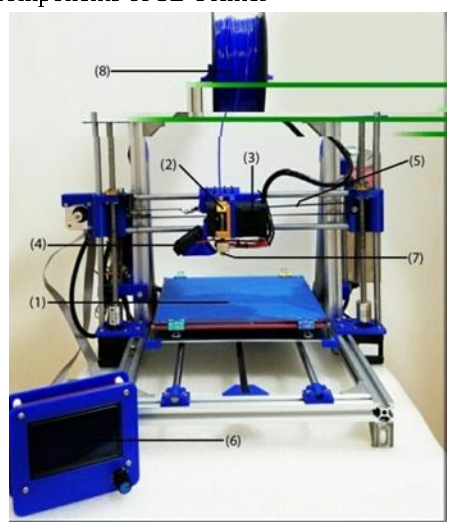

Figure 1. Components of 3D printer

1. Print-bed
2. Extruder Head
3. Stepper Motor
4. Lead Screw
5. Timing Belt
6. Adriano-mega
7. Nozzle
8. Filament Pla 1.75mm

II. DESIGN CONSIDERATION OF THE CONTROL MECHANISM

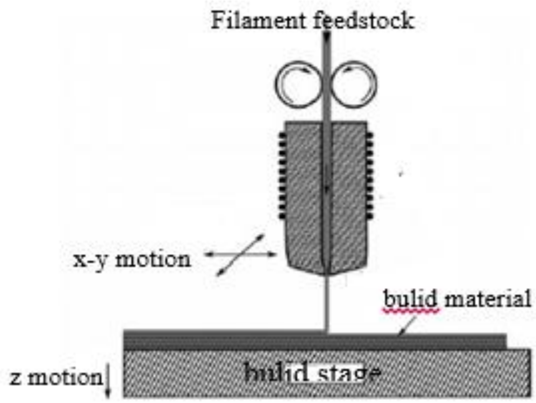

Figure2. Illustration of a typical extrusion-based AM process

Key elements of the melt extrusion AM system include a material feed mechanism, liquefier and print head, gantry, build surface and build environment. Components of a generic system are illustrated in Figure 2. The typical design features for each of these systems components are discussed in this section.

A pinch roller mechanism is used to supply material to the liquefier in FDM-like processes. The filament feedstock is in tension above these rollers, which pull the filament from its source. Below the rollers, the filament is in compression, being pushed against the constricted opening of the print nozzle at the end of the liquefier. The feed rate is controlled so as to maintain a constant volumetric flow rate of material from the print nozzle, Q. For a desired road width (W) and slice thickness (H), the linear feed velocity of the filament (*v*) can be approximated as

$$\upsilon = \frac{Q}{WH} \qquad (1)$$

The feed velocity can be most simply related to pinch roller parameters by assuming perfect adhesion between the filament and rollers, i.e. no slip. In this case, the feed velocity can be expressed as:

$$\upsilon = \omega_r R_r \qquad (2)$$

Where ω_r the angular velocity and R_r is is the radius of the rollers, respectively.

Accounting for this slip has been found to be particularly important to accurately control the roller motor when sudden changes in the flow rate are made. The force necessary to push the melt through the liquefier can be determined if the pressure drop (ΔP) through the liquefier is known,

$$F = \Delta PA \qquad (3)$$

WhereAis the cross-sectional area of the filament, it is assumed to be equal to the cross-sectional area of the liquefier. This in turn allows the required torque (Γ).

$$\Gamma = \frac{F}{2} \qquad (4)$$

And power (P_{mot}) to be calculated:

$$P_{mot} = \omega_r \Gamma \qquad (5)$$

The critical pressure (P_{cr}) that can be placed on the filament can be obtained from an Euler buckling analysis,

$$Pcr = \frac{\pi^2 E d_f^2}{16 L_f^2} \qquad (6)$$

Where Eis the elastic modulus of the filament, $d_f$is the filament diameter and L_f is the filament length from the rollers to the entrance of the liquefier.

$$\eta = K(\gamma)^{n-1} \qquad (7)$$

Where η is the viscosity, **γ**is the shear rate and Kand nare power-law fit parameters.

$$\eta = H(T)\eta_{T_0}(\gamma) \qquad (8)$$

$$H(T) = \exp\left[\alpha\left(\frac{1}{T} - \frac{1}{T_0}\right)\right] \qquad (9)$$

Where, α is the activation energyis 1 at the reference temperature. The required heat flux to the liquefier is given by the familiar equation,

$$q = \dot{m} c_p (T_2 - T_1) = \left(\frac{\rho \upsilon A}{2\pi\left(\frac{D}{2}\right)}\right) c_p (T - T_i) \qquad (10)$$

Where $\dot{m}$ is the mass flow rate of the polymer through theliquefier, $c_p$is the heat capacity of the polymer and Tand $T_i$are the temperatures of the polymer at the exit and entranceof the liquefier, respectively.

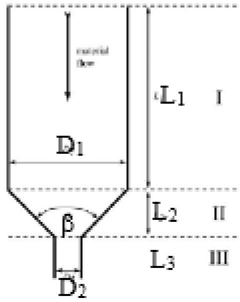

FIGURE (3) LIQUEFIER DIVIDED INTO THREE ZONES FOR MODELING

This model include that the melt is incompressible, a no-slip boundary condition applies at the walls of the liquefier and that the flow is fully developed, steady state and laminar. The pressure drops in each section of the liquefier according to this model are given respectively by:

$$\Delta P_1 = 2L_1\left(\frac{\upsilon}{\emptyset}\right)^{1/m}\exp\left[\alpha\left(\frac{1}{T}-\frac{1}{T_\alpha}\right)\right] \quad (11)$$

$$\Delta P_2 = \left(\frac{2m}{3\tan\left(\frac{\beta}{2}\right)}\right)\left(\frac{1}{D_2^{\frac{3}{m}}}-\frac{1}{D_1^{\frac{3}{m}}}\right)\times\left(\left(\frac{D_1}{2}\right)^2(m+3)2^{m+3}\times\exp\left[\alpha\left(\frac{1}{T}-\frac{1}{T_\alpha}\right)\right]\right. \quad (12)$$

$$\Delta P_3 = 2L_3\left(\frac{\upsilon}{\emptyset}\right)^{\frac{1}{m}}\left(\frac{(m+3)\left(\frac{D_1}{2}\right)^2}{\left(\frac{D_2}{2}\right)^{m+3}}\right)^{\frac{1}{m}}\exp\left[\alpha\left(\frac{1}{T}-\frac{1}{T_\alpha}\right)\right] \quad (13)$$

Where the dimensions L_1, L_3, $D_1$and D_2correspond to Figure 3, β is the nozzle angle of the conical section of the liquefier, and m and φ are power-law fit parameters. The total pressure drop in the liquefier is the sum of the pressure drops in each section,

$$\Delta P = \Delta P_1 + \Delta P_2 + \Delta P_3 \quad (14)$$

If flow through the print nozzle, region III in Figure 3, is modeled as a simple Hagen-Poiseuille flow, the volumetric flow rate, Q, is Radius of the rollers, r

$$Q = \frac{\pi\left(\frac{D_2}{2}\right)\Delta P}{8\eta L_2} \quad (15)$$

The cross-sectional area (A) of the bead will be inversely proportional to the velocity of the print head (υ_{print}).

$$A = \frac{Q}{\upsilon_{print}} \quad (16)$$

If the print head velocity is sufficiently large, the bead will become unstable and discontinuous. As the maximum velocity for which the bead remains stable and continuous is approached, the deposition has been described as similar to an axisymmetric liquid bridge, allowing the maximum velocity of the print head to be estimated

$$\upsilon_{print} < \frac{Q\pi}{h^2} \quad (17)$$

As well as the minimum cross-sectional area.

$$A_{min} = \frac{h^2}{\pi} \quad (18)$$

Here, h is the height of the print nozzle opening above the print surface.

This simplified the governing equations to a 1D transient heat transfer equation,

$$\rho C A \upsilon \frac{\partial T}{\partial x} = A\frac{\partial\left(k\frac{\partial T}{\partial x}\right)}{\partial x} - hP(T - T_\infty) \quad (19)$$

The analytical solution of which is:

$$T = T_\infty + (T_0 + T_\infty)\exp\left(\frac{1-\sqrt{1+4\alpha\beta}\,\upsilon t}{2\alpha}\right) \quad (20)$$

$$\alpha = \frac{k}{\rho C_\upsilon}, \text{and } \beta = \frac{hP}{\rho C A \upsilon} \quad (21)$$

III. DESIGN RESULTS

T_i = 30° C + 273 = 303 K

D = 13 mm

$$m^{\cdot} = \frac{Q}{A} = \frac{16752}{\frac{\pi}{4}(13)^2} = 126.208 \text{ mm/s}$$

Heat flux for liquefier Diameter of nozzle = 13 mm

= 4 mm

Revolution per minutes, N = 200 rpm

Thickness of road, H = 10 mm

Width of road, W = 20 mm

Torque, τ = 2000 g-cm
Filament diameter, d_f = 1.75 mm
Filament length, L_f = 35 mm
Power-low fit parameters, K = 1
Power-low fit parameters, n = 1.4
The shear rate, γ = 100/s
Specific heat, C_p =1.085J/KgK
Density, ρ = 1.25 Kg/m^3
Thermal conductivity, K = 0.22 W/mK
Reference temperature, H(T) = 1
The temperature of the polymer at the entrance, T_i= 30° C
For pinch roller feed mechanism

$$\omega = \frac{2\pi N}{60} = \frac{2\times\pi\times 200}{60} = 20.94 \text{ rad/s}$$

$$\upsilon = \omega_r R_r = 20.94 \times 4 = 83.76 \text{ mm/s}$$

$$Q = \upsilon WH = 83.76 \times 20 \times 10 = 16752 \text{ mm}^3/s$$

Torque for roller

Γ = 2000 g-cm = 20 Kg mm

$$\Gamma = \frac{F}{2} R$$

$$20 = \frac{F}{2} \times 4$$

The force necessary to push the melt

F = 10 N

d_f = 1.75 mm

$$A = \frac{\pi}{4} d_f^2 = \frac{\pi}{4} \times (1.75)^2 = 2.405 \text{ mm}^2$$

$$\Delta P = \frac{F}{A} = \frac{10}{2.405} = 4.1575 \text{ N/mm}^2$$

The power, $P_{mot} = \omega_r \Gamma = 20.94 \times 20 = 418.8$ W

L_f = 3.5

$$Pcr = \frac{\pi^2 E d_f^2}{16 L_f^2} = 462.64 \text{ N/mm}^2$$

n= 1.4, K= 1, γ= 100/s

$$\eta = K(\gamma)^{n-1} = 6.309$$

$$H(T) = \exp\left[\alpha\left(\frac{1}{T} - \frac{1}{T_o}\right)\right]$$

$$\infty = \frac{K}{\rho C_v}$$

T_o= 200°C
H (T) = 1
K = 0.22 W/mK
ρ = 1.25 Kg/m^3
C_p = 1.085 J/KgK

$$\infty = \frac{0.22}{1.25 \times 1.085} = 0.1622$$

T_∞ = 30° C + 273 = 303 K

T_o = 200° C + 273 = 473 K
H(T) = 1

$$1 = \exp[\, 0.1622 \left(\frac{1}{T} - \frac{1}{473}\right)$$

T = 473 K

$q = m^{\cdot} c_p (T_2 - T_1)$ = 23.279 Watt

m= 1.3, Ø= 0.8

$$\Delta P_1 = 2L_3 \left(\frac{\upsilon}{\emptyset}\right)^{\frac{1}{m}} \left(\frac{(m+3)}{\left(\frac{D_1}{2}\right)^{m+3}}\right)^{\frac{1}{m}} \exp[\alpha\left(\frac{1}{T} - \frac{1}{T_\alpha}\right)]$$

Pressure drop for liquefier

For L_1= 42 mm

$\Delta P_1 = 2.77\times10^5$ Pa

For L_2= 10 mm

$\Delta P_2 = 4.252$ Pa

$\Delta P_3 = 1.253 \times 10^3$ Pa

$$\Delta P = \Delta P_1 + \Delta P_2 + \Delta P_3 = 2.7 \times 10^5 \text{Pa}$$

$$Q = \frac{\pi\left(\frac{D_2}{2}\right)\Delta P}{8\eta L_2}$$

η = 0.1265 Ns/mm

d = 3 mm

$$A = \frac{Q}{\upsilon_{print}}$$

υ_{print} = 23.69 mm/s

$$\upsilon_{print} < \frac{Q\pi}{h^2}$$

$$\upsilon_{print} = \frac{Q\pi}{h^2}$$

h = 4.712 mm

$$A_{min} = \frac{h^2}{\pi} = 7.068 \text{ mm}^2$$

Checking heat temperature

t = 5 min

$$T = T_\infty + (T_0 + T_\infty)\exp\left(\frac{1 - \sqrt{1 + 4\alpha\beta})\upsilon t}{2\alpha}\right)$$

T = 303 K
Power = 1.8 W
Required force = 15 lb
Time to achieve travel = 5 s
Desired cycles = 1,000,000
Convert to Newtons,

30 lb/ (0.225 lb/ N) = 133 N

Mechanical power in watts,

P = 133 N × L

the travel length L = 0.0135 m = 13.5 mm
Linear velocity = 13.5/5 = 2.7 mm/s

IV. CONCLUSION

3D printing is one of the main drivers of innovation in the manufacturing technology field worldwide. It is a generic term used to define any kind of additive or layered manufacturing process, that is, a group of techniques used to obtain final parts or prototypes in a short period of time from a CAD file by progressive addition of a raw material. Stereolithographic, laminated object manufacturing or fused filament fabrication are some of these processes. They differ mainly in the state of the raw material and the way it is introduced into the system. The main advantage of these systems is the possibility of manufacturing customized parts for specific applications in a relatively short period of time.

In modern printing, the revolution per minute is used in 200 rpm, the printer runs in 2.7 mm per second of linear velocity. Power usage is 1.8 Watts and the travel length is 13.5 mm. These data are obtained by the calculation of 3D printer after analyzing and studying.

Maintenance of the 3D printer are check the deposit molten filaments along the nozzle tip, clean and remove the remain molten filaments immediately after the model had been produced, all program had finished for working duration at individual parts will need to check error for safe, be always clean and place the print bed neatly after the model had been produced and check individual parts and trays before and after working.

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