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Design of Metal 3D Printer Using CO2 Laser and Cooling System For Laser Tube

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Abstract **Conventional methods of manufacturing pose a number of difficulties like skilled labor requirement, difficulty in manufacturing intricate components, low speed of prototyping, need for pattern making, etc. Rapid Prototyping processes over come these manufacturing problems. Selective Laser Sintering (SLS) process is a type of RP processes that directly 3D prints metal or thermoplastic components using metal powder or thermoplastic powders. This is achieved by melting powder and fusing it with successive layers using a laser. Information of 3D model is converted in X Y,Z co-ordinates and provided to mirror gantry mechanism to print the required model. High grade metals like Titanium, Aluminum can also be printed using this process. Components manufactured using SLS process are used in automobile and aerospace industries. Selective Laser Sintering machines are large in size and very costly, thus cannot be used in small manufacturing facilities and laboratories. Hence, we are making this project to try to reduce the size and cost of this process and make this technology available to all.**

Keywords —Selective laser sintering, CO2 Laser, mirrors, laser gantry, iron powder, cooling system, metal printing.

I. INTRODUCTION

Selective Laser Sintering (SLS) is an Additive Manufacturing (AM) technique that uses a laser as the power source to sinter powdered material (typically metals, nylon, poly-amide) aiming the laser automatically at points in space defined by a 3D model, binding the material together to create a solid structure. It is similar to Direct Metal Laser Sintering (DMLS); the two are instantiates of the same concept but differ in technical details. Selective Laser Melting (SLM) uses a comparable concept, but in SLM the material is fully melted rather than sintered, allowing different properties (crystal structure, porosity, and so on). SLS (as well as the other mentioned AM techniques) is a relatively new technology that so far has mainly been used for rapid prototyping and for low-volume production of component parts. Production roles are expanding as the commercialization of AM technology improves.

Problem Statement

To manufacture intricate components fast, easily, in low cost and without the need of skilled labor using SLS process. Generally this type of machines are large in size and are costly and thus cannot be used in small manufacturing facilities and laboratories.

II. METHODOLOGY

Complex components can be manufactured using the process known as selective laser sintering. It is actually part of a broader category, commonly referred to as a Granular Based Technique. All granular based additive manufacturing techniques start with a bed of a powdered material. A laser beam or bonding agent joins the material in a cross section of the part. Then the platform beneath the bed of material is lowered, and a fresh layer of material is brushed over the top of the cross section. The process is then repeated until a complete part is produced.

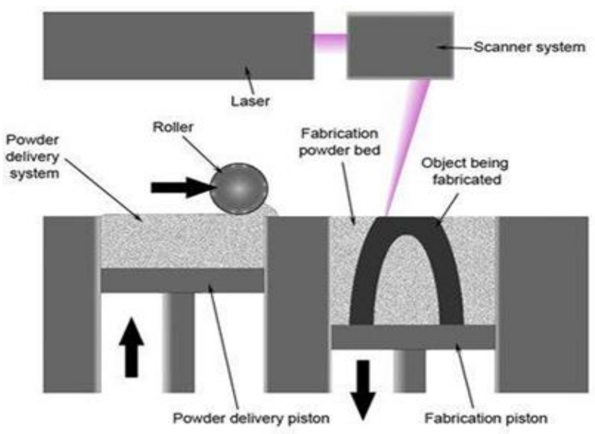

Figure 1: Basic working of SLS Machine

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III. DESIGN

1.1. Laser

The carbon dioxide laser (CO_2 laser) was invented by Kumar Patel of Bell Labs in 1964, and is still one of the most useful. Carbon dioxide lasers are the highest-power continuous wave lasers that are currently available. They are also quite efficient: the ratio of output power to pump power can be as large as 20%. The CO_2 laser produces a beam of infrared light with the principal wavelength bands centering on 9.4 and 10.6 micrometers (μm).

1.2 Metal Powder

The focus of this design is to understand the current state of research and progress mainly from the perspectives of the SLS/SLM of ferrous (e.g. iron powder Ferchim MT), non-ferrous (e.g. aluminum) powders.

The melting point of Aluminum is lesser than that of iron. However, the thermal conductivity of aluminum is more than that of iron. Hence the heat is conducted faster and thus it becomes difficult to sinter aluminum in a single spot. Rather than melting the powder, the heat is conducted away. Iron powder is easily available as compared to aluminum powder. Cost of iron powder is also less than aluminum powder. Hence, Iron powder is selected for the application.

The thermal expansion coefficient is lower than for pure aluminum and decreases almost linearly with increasing oxide content, to reach values of the order of 20x10- 61/K for the 300-600 K range at 15% oxide. Thermal conductivity decreases by approximately 1% for every 1% of oxide present, but is higher in the direction of extrusion. Repeated pressing with intermediate vacuum annealing gives the maximum conductivity. The Lorentz constant is 23 x 10-6W/Ω/K2.

1.3 Cooling System

The performance of high-powered lasers depends on effective cooling. High-powered lasers generate a significant amount of heat that must be removed from the laser system to avoid overheating critical components. Carbon dioxide (CO_2) lasers, excimer lasers, ion lasers, solid-state lasers, and dye lasers all use liquid cooling to remove excess heat. Laser liquid cooling can help accomplish three goals: maintaining a precise laser wavelength and higher output efficiency, achieving desired beam quality, and reducing thermal stress on a laser system.

Water chiller are suggested as the cooling system when you use the laser tube more than 80 watt. Since the water chiller has the refrigerating capacity and can adjust the temperature intelligently to keep the temperature within a certain range, thereby to ensure the stability of laser working, reduce the air leakage and slow down the aging speed so as to improve the life of laser tube.

DC excited glass CO_2 laser tubes (as well as some high-power RF exited metal tubes) are water cooled. The typical coolant is distilled water. This is important because the conductivity of distilled water is much lower.

The power of the selected laser tube is 80W. However, the efficiency of the laser is about 15% to 20%.

Hence, the required power input is 80/0.15=533.33W. Therefore the total heat developed is (Power input-Power used in laser tube) 533.33W- 80W=453.33W. To compensate for heat developed due to the water pump, we use the multiplication factor of 1.2. Hence, total heat to be removed is 453.33*1.2=543.996W. For safety, we choose total heat to be removed as 600W. Accordingly we selected the 0.5TR capacity compressor. 1 TR=3517 W

0.5 TR= 1785 W > 600W

The cooling water temperature recommended by the laser manufacturer is 10°C to 14°C.The refrigerant used is R22 for the required temperature range.

The condenser is selected from availability criterion. The evaporator consists of coils of copper tube, which is sized according to the size of the water reservoir. The copper tubes are soldered using a lead solder wire and butane torch (blue flame). The system is checked for leakage using froth test using soapy water. Then the refrigerant was filled using a pressure guage at a recommended pressure of 10 psi. The evaporator consists of 9 coils of a ½ inch diameter copper tube. For controlling the temperature, The W1209 thermostat is selected. The temperature is set at 12°C. With upper and lower limits as 110 to 5°C and a hysteresis of 2°C.

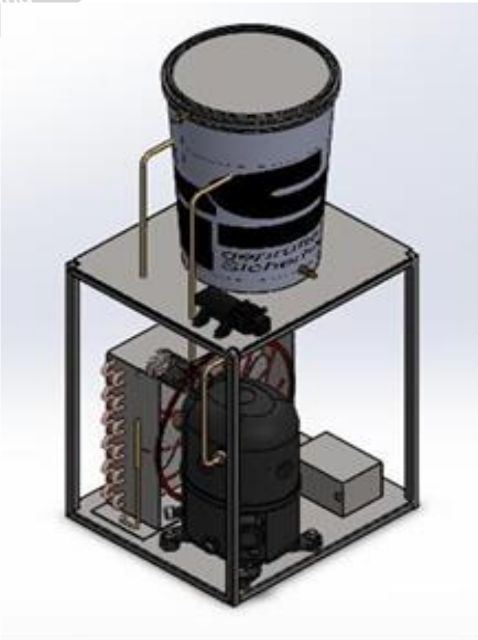

Figure 2: Cooling System for Laser

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1.4 Gantry System

In 3D printers, the gantry is the frame structure that supports the printer head along the X/Y axis as the printer head moves around to print the part on the build platform. The gantries are moved by stepper motors, which use digital pulses to move and track the gantry. The stepper motors allow for high resolution movement by allowing the pulses to move the motor at a small fraction of a rotation. The gantries hold up the printer head as it moves along the build platform.

Ultimaker type gantry system uses two stepper motors (one for X axis and one for Y axis). There are two horizontal parallel rails used in X direction and two horizontal parallel rails in Y direction on either sides of the main head. These rails are used as a sliding guide for the main head as well as the rails rotate to transmit power to pulleys from stepper motor.

IV. DESIGN OF RAILS

Design of horizontal linear rails is crucial in the gantry system. Rails should be designed to minimize the deflection. Deflection in rails adds up to the main head. This may cause errors in the 3D model and actual printed part. To avoid this rails should be strong and rigid. Horizontal rails take bending loads. For the application chrome plated smooth ground EN-8 induction hardened rails are used. 8 mm diameter rails are most commonly used and thus are easily available. Design is done based on rigidity criteria. Analysis is done to ensure minimum deflection. ANSYS APDL is used to perform Finite Element Analysis (FEA) on a rail. End supports are fixed and load is applied in the center of the rail.

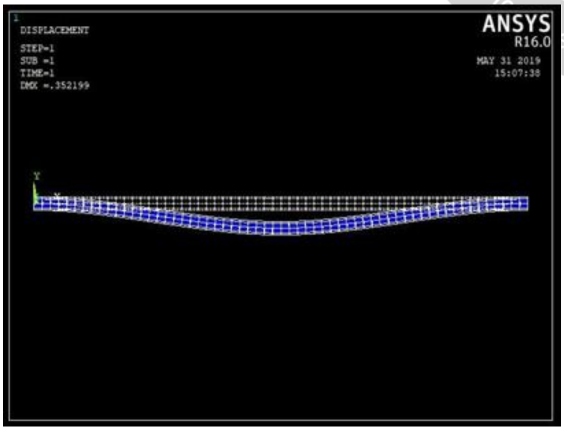

Figure 3: FEA of Horizontal Rails (Deflection Plot)

Design of Gantry Base

Gantry base is designed to mount the rail supports. Gantry is made up of MS sheet metal and laser cutting process. Deflections in the gantry base plate must be as minimum as possible. Any deflections in the base plate may add up to create error in the 3D model and actual printed part. Thus, gantry is designed based on Rigidity criteria. Analysis is done to ensure minimum deflection. SOLIDWORKS 18 is used for simulation and FEA of the base plate. Remote load of the head assembly is applied on rail support points. Fixture is given at the bolting points of the base plate to the main frame.

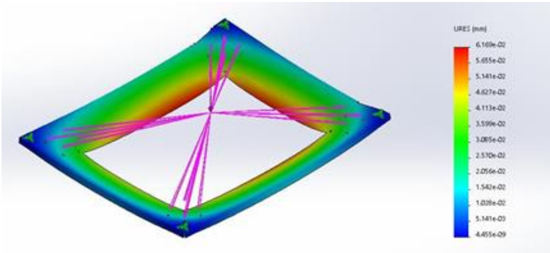

Figure 4: FEA of Gantry Base (Deflection Plot)

Design of Rail Supports

Rail supports are designed to give adequate support to the horizontal rails to ensure minimum deflection. Rail supports are made from 3D printed ABS. Brass bushes are fitted inside the 3D printed parts to provide smooth interface.

Design of main head

Head is designed slide on horizontal rails in X and Y axis. Lens mount assembly is mounted on to the head such that it also moves along with the head. Head is made from 3D printed ABS. Brass bushes are fitted inside the 3D printed parts to provide smooth interface.

Lens Mount

Lens mount is used to hold convex lens in correct place. Lens mount is an OEM part made by aluminum. Whole assembly is mounted on ABS 3D printed head. The 3D printed head is fitted with the brass bushes and it slides on the horizontal rails. Brass bushes are used for smooth interface.

Arrangement is provided to adjust the lens in Z axis. This is achieved with the help of a grub screw. Lens is adjusted according to its focal length and then grub screw is tighten to secure the lens in that position. The mirror mount is integrated with this lens mount. Mirror mount is used to hold and securely place the mirror in right position and orientation. Positioning of mirror in correct orientation is important to ensure that ray of laser beam is perpendicular to the print bed surface. Orientation of the mirror can be adjusted in all directions with the help of two spring returned bolts and three positioning pins. The positioning pins are turned such that mirror is adjusted to required orientation and then nuts are tightened to secure the mirror in that place.

Mirror Mount

Mirror mount is used to mount and adjust the mirror in all directions to reflect to laser ray in desirable direction. Due to the less availability and high cost, the decision was made

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to design and manufacture our own mirror mounts for the application.

Mirror mount was reverse engineered with the help of one available mirror mount. Custom mirror mount was designed according to the needs of height adjustment and availability of space. Mirror mount was designed such that it can be manufactured easily with Mild Steel by laser cutting and welding. Reference plate was integrated with the mount to be able to adjust the orientation of the mirror easily.

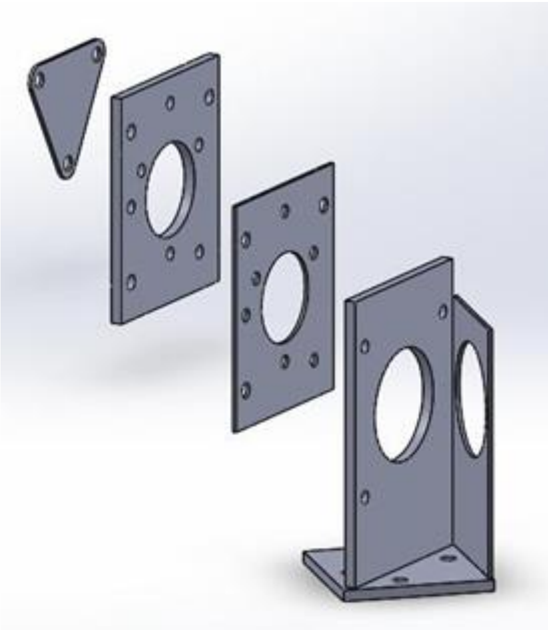

Figure 5: Exploded View of Mirror Mount

Bed Assembly

Bed assembly consists of Feed bed mechanism, Print bed mechanism and Wiper blade mechanism. Feed and Print bed assembly is a sliding cylinder piston mechanism. Feed bed is slightly larger than Print bed to accommodate with the spillage of powder. Piston is powered by stepper motor and power screw.

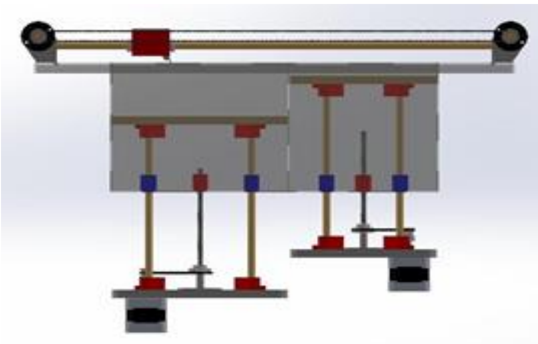

Figure 6: Bed Assembly

400 step stepper motor is used for this application with reduction on 2.5 with the help of pulley and belt.

For constrained movement of the pistons vertical rails with brass bushes is used. For mounting rails and motors, MDF routed plated are used. Print bed has an additional sacrificial plate is used and is need to be replaced after few prints.

Main structure is designed to withstand the forces due to weight of the powder. Design is based on rigidity criteria such that deflection is reduced. Analysis is done to ensure minimum deflection.

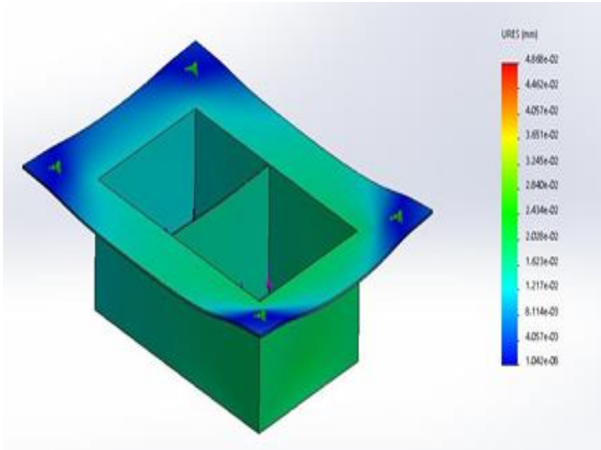

Figure 7: FEA of Main Bed Structure (Deflection Plot)

Wiper blade mechanism is made of MS sheet metal laser cut and welded. Doctor blade (used is printers) is used for the application of wiper blade. Wiper blade is used to transfer powder from feed bed to print bed after each successive layer is printed. Wiper is blade slides with DC motor and pulley-belt system. Feed bed in initially filled with powder and print bed is at its top most position. Feed bed piston moves slightly upward and print bed piston mover downward by the same amount. Wiper blade slides to transfer the powder and then metal powder is sintered in that layer and the cycle continues until whole part is printed.

Frame

A frame in general may have to deal with the following loads or a combination of them : Axial Loads (Tension/Compression), Shear Loads, Bending Loads.

For simplicity we will consider separate and singular application of each load on different cross section beams. To calculate the effect of axial loads on the beam the factors to be considered are applied Force/Load and cross section area of the beam. Considering same weight sections and same material beam means the cross section are is same for all and hence for axial load purpose all sections are equally effective. Considering all the factors we have used rectangular section for side members, L section for top members and rest all the frame is made of square section.

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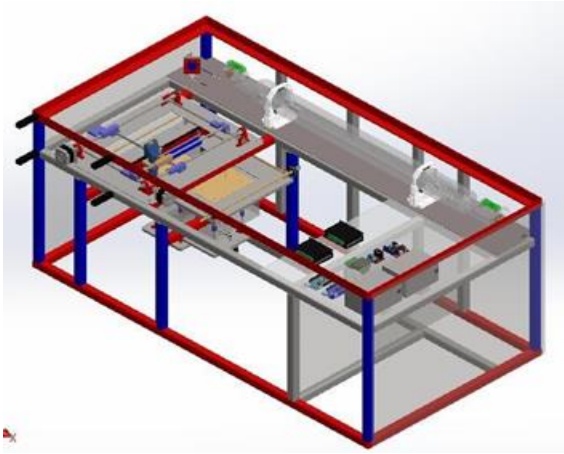

Figure 8: Full CAD Assembly of the Machine

V. ELECTRONICS

3D printers, like any other printers, require some form of interface between the communication channel that allows a computer to operate the printer, and the mechanical and electromechanical parts that make up the printer.

Arduino is well suited to that task, since it can be readily programmed to do communications as well as drive and sense the machinery that makes up the printer. Arduino is one that gets chosen because of it's ease of programming, low cost, ubiquity, high degree of support, and because it tends to have reasonable ways to interface to the kinds of devices that make up a printer.

Component list

a) Arduino Mega X 2
b) L298 motor driver X1
c) A4988 motor driver X2
d) CNC Shield V3 X1
e) TB6560 motor drivers
f) W1209 Thermostat

Testing

During the testing phase various parameter of the machines were adjusted to achieve the required result. Machine parameter are as follows:

a) Layer thickness
b) Laser power
c) Head travel speed

Layer thickness (µm)	Laser power (%)	Remark
100	60	Oxidation
100	80	Oxidation and Warping
100	100	Puddle formation
200	60	Oxidation and Warping
200	80	Oxidation and Warping
200	100	Oxidation and Warping
300	60	Oxidation and Warping
300	80	Oxidation and Warping
300	100	Oxidation and Warping
400	60	Oxidation and Warping
400	80	Oxidation and Warping
400	100	Successful layer bonding

Result Table

Figure 9: Initial Testing Result

Thus adjustments in head speed and laser power are done for different layer thickness. Trial and error method was used for this experimentation. Laser power is adjusted using a potentiometer whereas layer height and head speed is controlled with the help of program.

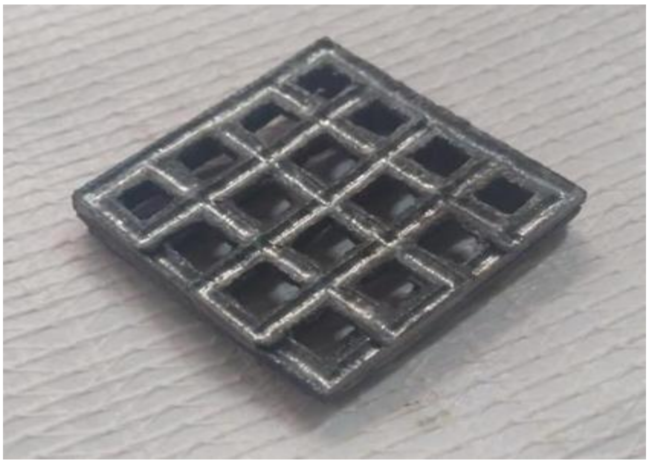

Figure 10: Successful Print Result

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Figure 11: Cooling System Assembly

Figure 12: Full Machine Assembly

VI. CONCLUSION

Concluding Remarks

Thus, we can conclude that selective laser sintering process can be used for 3D printing and rapid prototyping of metals and non-metals. Size and cost of the machine is considerably decreased.

Scope for the Future Work

Increase the machine power by replacing the CO_2 laser with a fiber laser in order to be able to manufacture different metallic components requiring higher temperatures. Increase the print bed size of machine to manufacture larger metallic and non-metallic components.

Flush the complete printing bed in Argon chamber to avoid the oxidation of the melting metal, thus quality of the print can be increased. Print the standard testing specimen in different orientations and test the part in Universal Testing Machine (UTM) to determine the mechanical properties.

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