3D Metal Printer

Design Document

December 2018 - Team 3

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1.1 Acknowledgement

Dr. Timothy Bigelow, Associate Professor of Electrical and computer Engineering at Iowa State, serves as the faculty advisor for this project. He provides guidance, technical advice, and design constraints in our weekly Thursday meetings. The funding for this project is from a research grant that Dr. Bigelow obtained. His support and guidance will help ensure the completion of the project.

1.2 Problem and Project Statement

This senior design team is tasked with completing a Metal 3D Printer with safety systems. This is phase two of the Metal 3D Printer. The main body of the printer has been built. Our task for phase two is to design and build the roller, calibrate the stepper motors, complete vacuum sealed chamber, test printer with the roller in vacuum chamber, testing safety systems, and building a CAD drawing with the 3D printer. The safety systems are systems that make sure the printer is operating in a safe temperature to produce CAD drawings and preventing harm from the pure nitrogen gas environment. Components included in the safety systems are cameras, temperature sensors, and barometer.

The goal of this project is to use this printer to perform non-destructive evaluation (NDE) on the parts that it is printing. It will be use to test how a part's quality correlates with print performance. As 3D printing is becoming more popular for industrial and personal use, it is important that the parts printed are high-quality. By using NDE during and after the process of printing, we ensure that the quality of parts is high and is kept consistent.

The first phase of this project was mostly focused on the actual construction of the printer. The previous group mostly completed the printer physically, building the frame and placing all the motors where they needed to be. They also created simple software to print a square, which can fairly simply be expanded to create a cube. The sensors that we will be using for NDE were also purchased, but not set up, by the previous group.

To complete this project, we first plan on designing the roller with a stepper motor. This roller is very important for laying out the metal powder for the metal printing. As the roller is being designed, the

safety systems will have the components researched for the appropriate function and cost. That would include the camera's, temperature sensors and the barometer. The sealed chamber will be tested for a proper nitrogen environment with no oxygen gas present. All three of those components will be programmed together to go to the last stage of testing. The last stage of testing will be testing the roller and see if it can complete an accurate 3D CAD drawing. The printer will be monitored at all times by the camera and by the sensors to ensure the printer is still functioning and can operate at the appropriate temperature.
The team plans to complete the 3D printer that was explained above. With it completed, the 3D printer can be used for researchers to create simple objects safely and effectively.

1.3 Operational Environment

The operating environment for the printer will be in a laboratory setting. The laser requires a specific environment as well. The printer needs to be sealed in a chamber filled with nitrogen or argon gas to evacuate all the oxygen. If the chamber leaks, there may be risk of of suffocating people in the room as well as the laser not functioning properly. We will be communicating with EHS at Iowa State to ensure that all the proper safety measures are being taken to keep the users safe.

1.4 Intended Users and uses

The intended end users of our printer are researchers in the area of nondestructive evaluation and materials. They will use this printer to produce and evaluate several simple shapes. This printer must be able to be adapted and easy to operate. In other words, the technical portions of this project is to have very well documentation to adapt the code for future projects. Hence, it is not supposed to be a sealed, non modifiable, end consumer product. This means that the end users should be kept in mind for the hardware and programming language used. Most likely, none of the researchers using the printer will not be software engineers so simple and well documented Java or Python code would be preferable to make efficient and easy use for the researchers.

1.5 Assumptions and Limitations

Assumptions

The project is to develop a 3D Metal Printer that uses a laser based nondestructive evaluation system for monitoring of additive manufactured parts. Thus, the build speed and complexity of the printed parts is not a concern. The end product will not be used for commercial use but for research purposes.

Limitations

The budget for this project is approximated at $10,000. The end product will fiber-couple 3 lasers to focus on the same spot. The three lasers (client requirement) will be 200 watt fiber lasers (spi lasers), Nd:YAG laser at 1064 nm wavelength, 50 mJ (Quantel), at 20 Hz; and the last laser will be a laser interferometer (OPTECH) at 1550 nm wavelength, 50 mW. The fiber-coupled laser will be housed in an optical head and would need to be in a vacuum chamber of 10^{-3} to 10^{-6} torr. Dust protection from the powder bed will be needed.

1.6 Expected End Product and Deliverables

The end product will provide researchers the access to analyze additive manufactured parts. The mechanical design of the 3D printer includes five steppers motors for the powder bed, the roller, and the laser optical control head. The short term plan for the first semester is the complete the construction and the coding for the print bed. This would allow us to have a chance to actually test the 3D printer in the vacuum sealed chamber. So, the long term plan would be the actually testing of the laser and testing to see if an object can be created in the vacuum sealed chamber. The plans for the second semester is to have the 3D printer be able to upload CAD files and print the object. That would be the long term plan but the short term plan for the second semester would be to be able to actually print an object, it might not be a CAD file. This means that the printer could at least melt and print something, it might not be perfect but it would be a functioning printer.

In addition, a sensor system will be used for the overall safety requirements. The sensor system will be comprised of an external oxygen sensor, an internal oxygen sensor, temperature sensors, and a barometer. The external oxygen sensor will be a device that will warn the user if the oxygen levels are not sufficient in the room. The internal oxygen sensor and barometer will be an Arduino based system that will allow the users to monitor the oxygen and pressure within the chamber of the 3D metal printer. The temperature sensors will be used to measure the inside temperature and outside temperature of the sealed chamber. This is to ensure that the chamber is not too hot to touch and that the printed CAD drawing is printing properly. This system shall be expected to be finished at the end of the first semester of Senior Design.

2. Specifications and Analysis

Since we are working on part two of the project, many of the parts have already been ordered and the printer has been mostly assembled. The plan of the last group was to use a mechanically controlled laser head to print along with two lasers, one ultrasound and one interferometer, to perform non-destructive evaluation while the printer is working. The design is currently able to draw a 2D design, and our goal is to implement a roller for the metal powder and design the software to allow for full 3D printing.

2.1 Design Specifications

Functional

- The printer shall have 3 lasers- a 1064 nm 200 W melt laser, a 1064 nm ultrasound generating laser, and a 1550 nm laser interferometer.
- The printer shall have a powder bed which moves up in order to deposit a new layer of powder.
- The printer shall have a roller to deposit powder from the powder bed to the print bed.
- The printer shall have a print bed which moves down after each layer is sintered by the laser.
- The printer shall have a collection bin which collects any excess powder that is not deposited on the print bed.

- Any component or device that deals with powder must be enclosed in a vacuum sealed chamber that is filled with a nitrogen/argon gas.
- All lasers shall be able to be adjusted to any point within the print bed using some sort of servo control system.
- There shall be a pressure and oxygen sensor inside the sealed powder chamber to check for safety hazards.
- There shall be an oxygen outside of the printer, to alarm the user if oxygen levels in the room are unsafe or low.
- The system shall use an interlock or locking system to prevent the laser to turn on unless the chamber's door is sealed.
- A camera will be added to provide eyesight in the sealed chamber and to visually see if there are any problems.
- Two temperature sensors will be used to measure the temperature of the inside of the sealed chamber as well as the temperature of the sealed chambers' walls. This is for checking to make sure that the powder isn't getting too hot and to know if the sealed chamber is safe to tough.

Non-Functional

- The vacuum chamber should use space efficiently.
- All code should be well documented and understandable to allow future users to edit easily.
- The printer should work as quickly as possible without affecting quality or causing safety issues.

2.2 Proposed Design

Since the project has already been partially completed, we have very clear goals for the project. The physical design of the printer is almost complete, and we need to add a roller for the metal powder as well as install the three lasers. A figure showing the final physical design of the printer is included below. We also hope to control the printer using the provided PC through a serial connection. Finally, we will expand the software interface to allow expansion to 3D printing from 2D printing. The second figure below shows how we plan to implement the user interface as well as the interaction between the software and hardware. Figure 1 also shows the placements of the lasers and the stepper motors that will be used to control their movement.

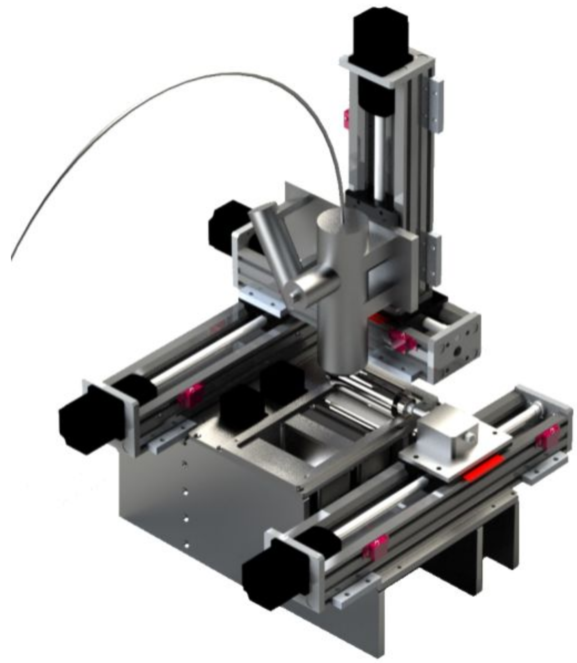

Figure 1 - Rendering of final 3D printer

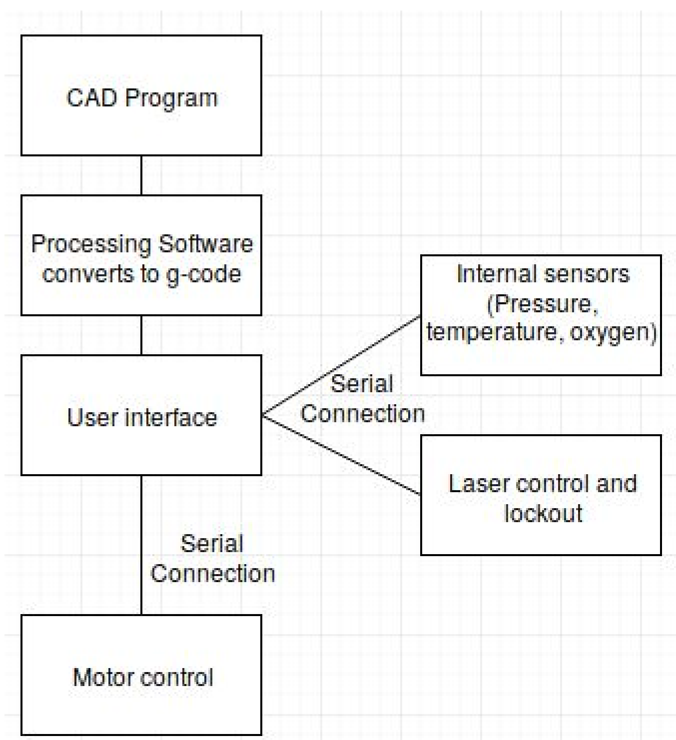

Figure 2 - Block diagram of software and hardware interaction

For Figure 1, this shows a rendering of what the 3D printer would look like in its final state. This would include having the components of the print bed, stepper motors, and the laser. The stepper motors will control the movement of the laser's position and the position of the print bed. The laser will be used to melt the metallic powder to create an object. And the print bed is used for placing the metallic powder on the bed so that it can be used for creating objects.

Figure 2 is representing the block diagram between the hardware and the software. The first block of "CAD program," is representing the CAD program for creating the objects in CAD. This CAD file is then sent to the next block of "Processing Software converts to g-code." The processing software is using C# to convert the CAD file into g-code. The conversion to g-code is needed so that the printer and the CAD file are using the same software and that the CAD file can be created through the printer. This conversion of the CAD file to g-code goes to the next block of "User Interface." This block is used to determine if the printer can continue operations of to discontinue operations. This depends on the two blocks of "Internal Sensors" and "Laser control and lockout." The block for the internal sensors is the input of the sensor values. Depending on these values, this will set the printer to continue operations or discontinue operations. The block about laser control and lockout will be used to identify the controls for the laser. This would include the operation of lasers position and to lock the laser in place for melting a certain location on the print bed. Depending on the inputs of the sensors and the laser control and lockout, will determine the motor controls. The motor controls would be the last block called, "Motor Control." This block dictates the motor controls of how far or what motors get moved to accomplish the task from the previous block. This entire block diagram explains how the code will work overall and implement the motors to create the CAD file.

2.3 Design Analysis

Much of the physical design of the printer has been completed, so we are already locked in on a design. The group previous to us considered two options for the design of the printer: the window method and the mirror method. In the mirror method, the laser travels through a window and bounces off a mirror onto the print surface. This method would have used less total space to make, but also would be much more prone to error since the mirror could be accidentally shifted slightly. This method is shown in figure 3. In the window method, which the previous group decided on, the laser points directly onto the printing surface (Credit to the phase I group for the figures). This figure uses more space, but is simpler and less prone to errors.

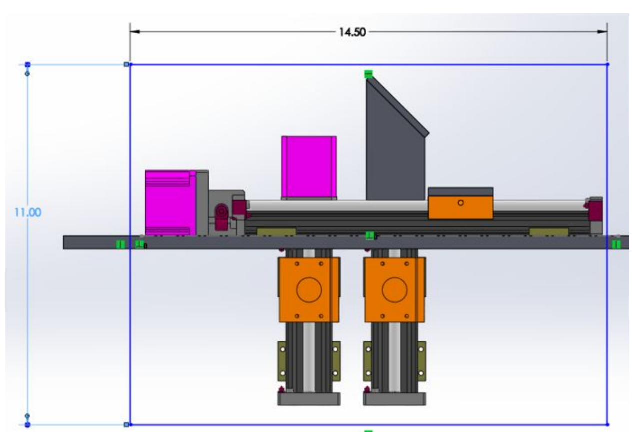

Figure 3: The mirror method

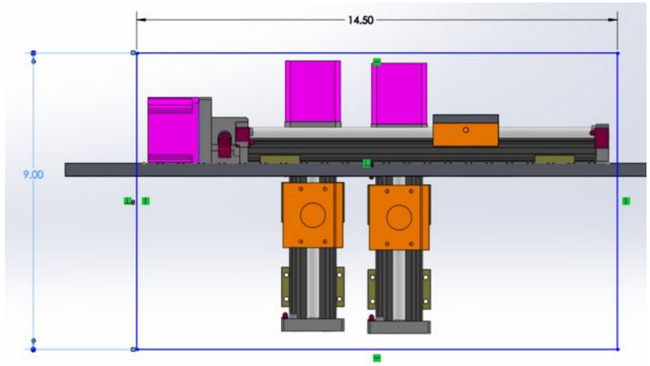

Figure 4: The window method

There are several large safety concerns for this printer. Since the printer needs to be atmospherically controlled, keeping a sealed chamber is a concern. There is another cause of concern with the class 4 lasers, which have serious radiation and exposure hazards. Both of these issues will be controlled by the chamber that the printer will be housed in. This is good because it keeps the printer in an isolated environment, but any leak will push oxygen out of a room as it gets filled with pure gas. It is critical for us to use a safe chamber due to this.

The other two designed components, the roller and the dispenser have no safety concerns. The roller needs to be made of a material that does not allow for sticking of the aluminum powder to the roller. The dispenser needs to constantly output an evenly dispersed layer of powder. The roller will also push down the layer of powder after it is dispensed, to minimize air gaps in the metal. The Roller design is shown here, in Figure 3.

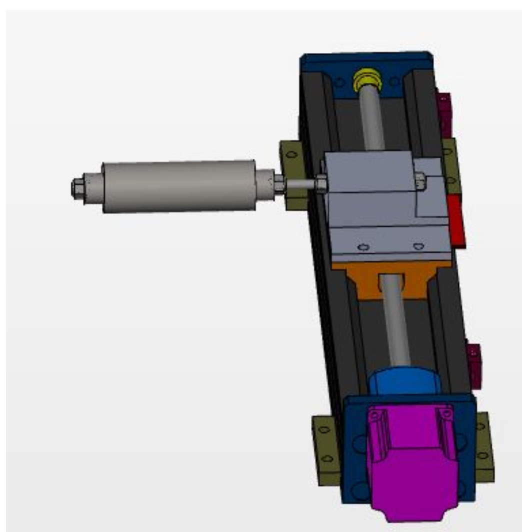
Figure 5: Design of the roller assembly

The print bed, on which the roller will function, has gone through several stages of design. The bed needs to remain flush with the walls, as well as be able to travel up and down using stepper motors. The final design for the print bed is included in the figure below. There is a powder collection bin directly adjacent to the print bed, for the roller to push all excess powder into for recollection. The design for this is shown in Figure 4, below.

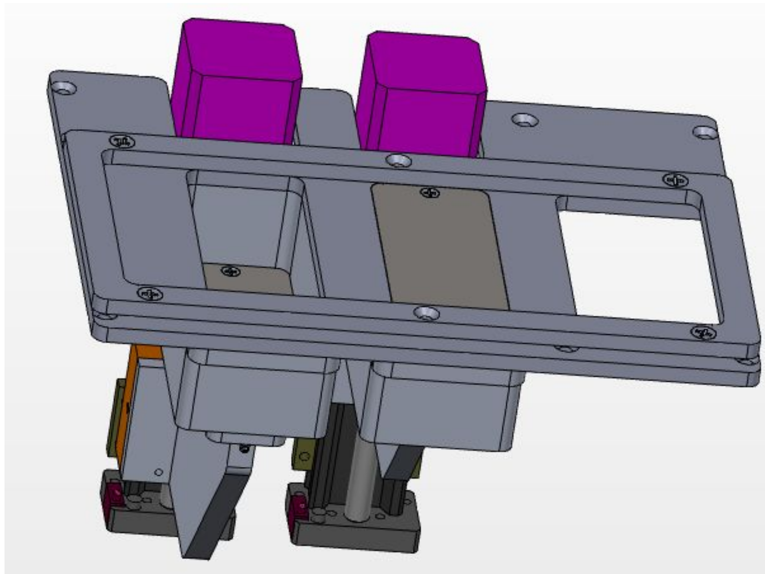

Figure 6: Print and powder bed design

The plan for depositing the powder is to have two stepper motors which will control the print bed and the powder bed. With each layer of powder deposited and melted, the print bed will move slightly down and the powder bed will move slightly up. The roller will then roll over the powder bed, collecting powder as it does. The roller will then roll over the print bed, depositing a thin layer of powder on top of the previous sintered metal. Finally, the roller will roll back, the powder will be melted, and the process will repeat. The figure below shows a visual representation of how the powder depositing process will work.

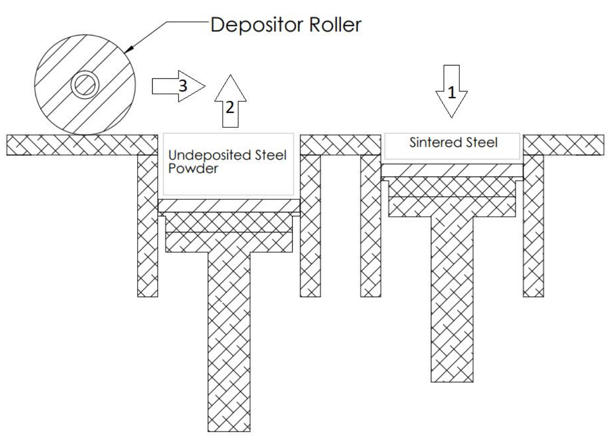

Figure 7: Representation of how the roller will deposit powder

This is the final design, of which most has been implemented. The print bed and dispenser need to be manufactured, which should be done soon. There is no other components of the printer that we need to design, our next step is implementation and testing.

3 Testing and Implementation

For this project there will need to be a significant amount of testing before the project will be approved. Before testing the system as a whole, each aspect of the project will need to be test. Both the software aspects and the actual machine needs to be tested. Some of the functional items that need to be tested include the laser-guiding stepper motor, oxygen sensor, powder system, laser, software interface, oxygen alarm, and cameras. Some of the nonfunctional items that need to be tested include, the speed of printing, print accuracy, powder efficiency, temperature, and oxygen level.

3.1 Interface Specifications

Our testing interface will be done through a pc connection. We will use this interface to send commands to the machine and also use it to take input data from the sensors and camera. The temperature, pressure, and oxygen levels will all be displayed on the user interface to ensure that the environment remains stable and conducive to printing. There will be a camera in the box, which we will feed to the computer, in order to visually monitor the printing process. We will also include an eddy current sensor, which is meant to be used by the more advanced users, in order to perform NDE. The output of the sensor will also be put on the user interface.

Success in this area will be defined as streamlining the information into one easy-to-navigate user interface. The data previously mentioned from the sensors will be used to ensure that the sensors are correct by testing in a normal, oxygenated environment (other than the oxygen sensor, which cannot be used in this environment without making future readings inaccurate).

3.2 Hardware and software

The project uses an iowa state desktop computer that will run the printer program. The printer itself will be in a chamber that will have a specific environment to run under. The main program is done in Visual Studio using C#. The main printer program, when run, will have a user interface that allows the user to search for a gcode file. When the user selects the gcode file the printer will then use that gcode as instructions to move to control stepper motors that will be moving a powder roller and a laser about it its axis to move and shape the metal powder to what we want. The program will eventually allow for the user to input a 3d model in the form of a .stl file and convert that to gcode. The program will take that 3d model and take cross sections at regular intervals and so that it will be a 2d instruction. The printer will then run through all these cross sections to make the final model. We will also be using a temperature sensor, pressure sensor and the program will monitor the values that are being taken from these sensors. If the program sees the temperature reach an unsafe temperature for the equipment or users the program will stop. If the pressure is not low enough, the program will stop. The camera that is in the chamber will also be connected and show us he live feed the printer inside the chamber. The laser will also be controlled by the program to ensure that it turns on at the correct time and not constantly running.

3.3 Functional Testing

The functional testing will be done for the individual units, both hardware and software, along with the complete printer once it is finished.

There has been a large amount of testing already done by the previous group. The software to load a CAD file and convert it to 2D slices has been completed and tested previously. There is also software which was tested by the previous group which is able to print a 2D square on a piece of paper. On the software side, we have a few things to design and test. First, we need to expand the software which prints a square to be able to print a 3D cube. We also need to take the 2D slices created by the previous software and convert them into gcode which can be read by the printer program. We will test this software separately to start, and if it works we will implement it into the printer program.

On the hardware side, not much testing has been done. The printer itself, as stated above, is currently able to print a 2D box. In order to test the actual printing capabilities, however, the vacuum sealed box must be completed. This is being worked on by the mechanical engineers that we are working with. Once the box is completed, we will run several tests in order to ensure correct operation, using the temperature, pressure, and oxygen sensors to ensure that the box is able to vacuum seal and finding the optimal environment for printing. Once this is complete, we can test the ability of the printer to roll out metal powder. With this test complete, we can test the full system by printing basic shapes. This will test both the software and hardware along with the interaction of the two.

3.4 Non-Functional Testing

There are a few non-functional parameters which could help with ease of use for the printer. One of these parameters is the speed of printing. This is important, but it was also made clear to us that this is not top priority, and that the structural integrity of the parts is the most important. Ease of use is a very important part of the printer. There should be an easy to understand GUI which gives the user all information gathered by the sensors. This will also be used by people with backgrounds in computer and electrical engineering, often for very specific tasks, so it should be simple to modify the settings of the printer and change parameters for these tasks. We will test this by bringing in outsiders who did not work on the printer in order to perform tasks.

3.5 Process

The process of testing the printer will be done by using our various sensors and cameras to monitor the system as it runs and make sure everything is looking the way it should be. The motors should be moving the roller and laser the correct distance which will be tested by using measurements and the video from a camera. The oxygen sensor should show none in its vacuum state, and the pressure should read low. The temperature sensor will be used for safety involving the box and the environment by ensuring things do not get too hot. Finally the printed result will also need to be what was intended and should match the design that was sent to the printer.

3.6 Modeling and Simulation

Almost all of our current design work is being modeled in CAD software. This would include the CAD modeling of the 3D printer and the test parts that will printed, when the printer is functioning. This is key as it allows us to visualize how the printer will look before doing any manufacture. Furthermore, it allows us to identify potential interferences or complications with the way the parts are put together. Since the printer components need to be machined and manufactured by professionals, we do not have a lot of room for building a second revision without dramatically increasing cost, thus it is very important that our design is sound.

3.7 Implementation Issues and Challenges

Our greatest implementation issues and challenges lie in the mechanical nature of the project. In order to implement our printer design, we must manufacture the physical hardware of the printer. We are in collaboration with the graduate mechanical engineers that Dr.Bigelow selected for this project. Like right now, we are waiting for the mechanical engineers to finish building the print bed so that we can finish the coding for it. The other challenge is the completion of the vacuum sealed chamber. This chamber is still being built, which is taking time away from actually testing the chamber. This is turn is holding up on the testing of the laser since the sealed chamber has to be approved by EH&S.

3.8 Results

So far we have not done any testing as we are still in the process of assembling the printer. As of now the motors are working and we are able to move a placeholder pencil that will later be replaced by the lasers. We also have all the sensors working, but seeing as the vacuum chamber is not yet complete, we have not been able to test under the conditions that we will be printing in.

4 Closing Material

4.1 Conclusion

Our project is to complete the 3D Metal Printer for Dr.Bigelow. Our goals for the project is to finish up phase two of the 3D printer. By the end of this semester, our goal is to have the printer to run and communicate with the software. Ideally we want to start testing by the beginning of the second semester. This means we have to be done designing the safety concerns including the placement of oxygen sensor, temperature sensor, contact sensor, and cameras. Our plan to achieve this goal is to work together as a team throughout the entire project, have consistent weekly meetings as a group as well as with Dr. Bigelow, and always contributing to the sharing of ideas and problems. The printer will be controlled by a pc where to pc will send instructions to a set of stepper motors and the powder system that will be laying out the stainless steel powder. Another computer will be used for sensor data and cameras to monitor the printer and making sure it is safe throughout the process. Some of our biggest challenges include the safety of laser, the limitations of the interferometer, limitations of the camera due to temperature and pressure, and the preciseness of the laser.

4.2 References

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4.3 Appendices

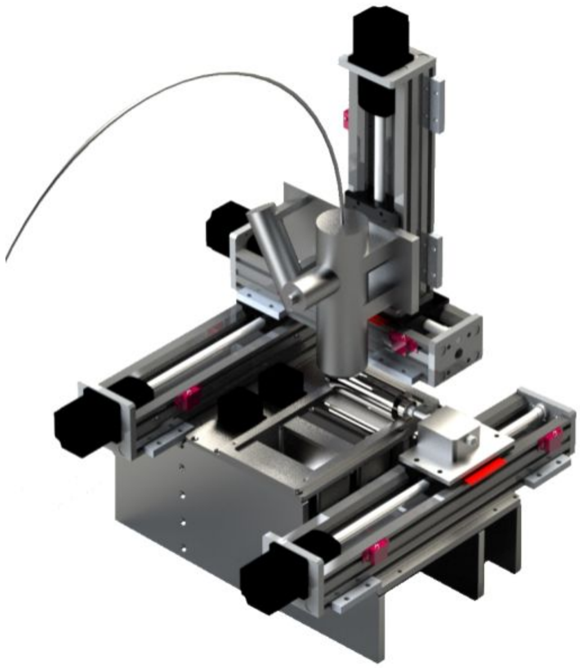

Figure 1: Rendering of final 3D printer

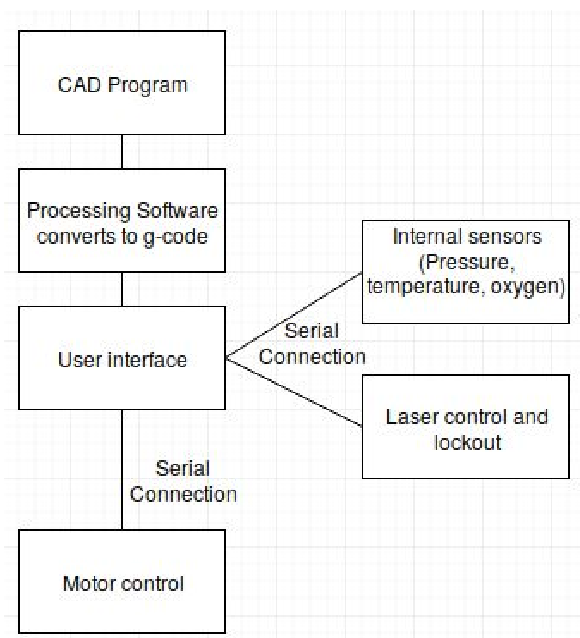

Figure 2: Block diagram of hardware and software interaction

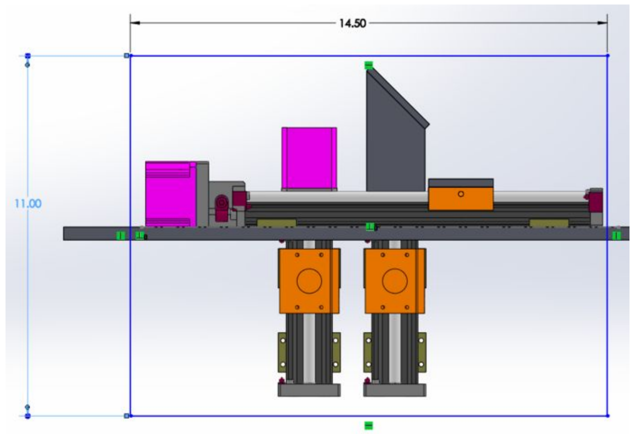

Figure 3: The mirror method

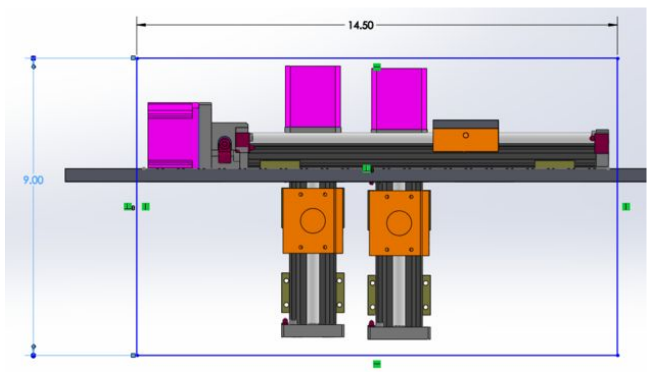

Figure 4: The window method

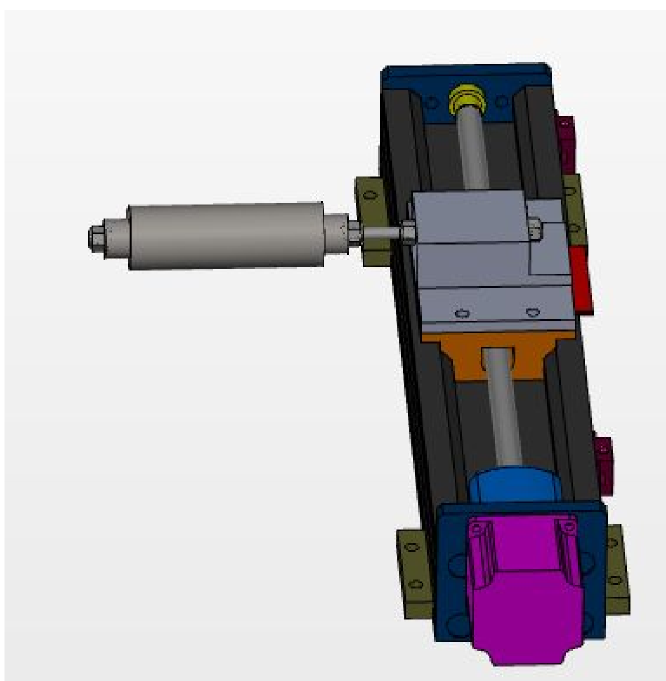

Figure 5: design of the roller assembly

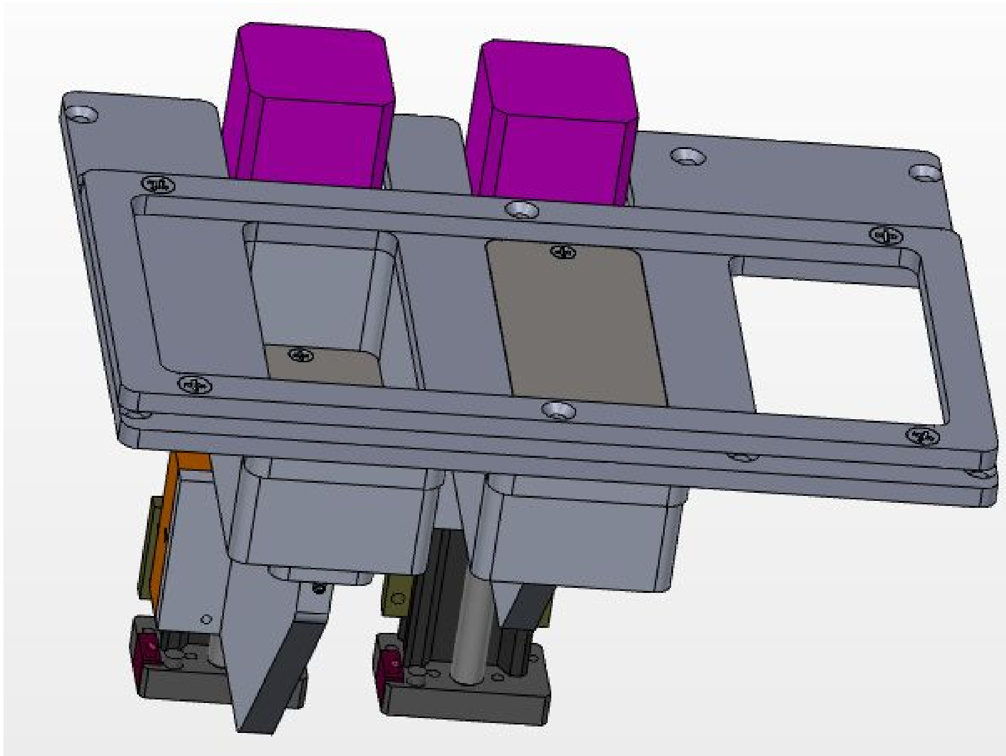

Figure 6: Print and powder bed design

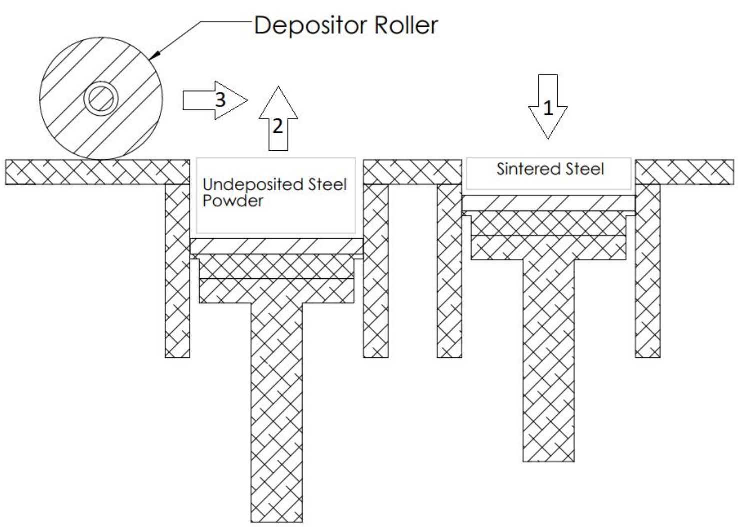

Figure 7: Representation of how the roller will deposit powder