3D Metal Printer

Project Plan:

December 2018 - Team 3

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1.1 Project statement

Our team is tasked with continuing the creation of a 3D metal printer. The scope of the project includes creating a printer that utilizes lasers to melt metallic powder to create objects. We are also tasked with choosing and implementing sensors to monitor and evaluate the construction of the object during and after the printing process. The sensors that will be used are Eddy Current scanners, temperature and pressure sensors to ensure that the entire process is done under vacuum (this is so that the metal powder is less volatile) and that the lasers do not cause an excess amount of heat in the chamber. We will also use ultrasounds to scan each layer of the object while it is being printed.

1.2 Purpose

This 3D metal printer will be used for testing on how print quality correlates with the part's performance. That is why the sensors for the non-destructive layers are used. Those sensors will be scanning and evaluating each layer that is created for a part. This will be for testing for defects or any problems in the creation of the part. Industry is making 3D printing more of a standard, so creating 3D printers that can print high quality components is becoming simpler and more standardized. Even though this 3D printing is not built for high speed, it focuses on the quality of printing parts.

1.3 Goals

Our main goal at this point in time is to create a functioning 3D metal printer which is able to create a cube. We also hope to implement a camera in order to monitor the creation of objects, as well as temperature and pressure sensors to make sure that the environment remains oxygen-free and that the printer is not putting out too much heat. We also hope to have Eddy Current sensors implemented to find flaws on and below the surface of objects being created. Lastly, we will implement two extra lasers to perform in-line evaluation of the parts.

2 - Deliverables

Deliverable	Description
Physical Printer	The CAD design of the printer was created and the physical printer was started by the previous group working on this project. Our goal is to complete the physical design of the printer using these design files
Software interface	There should be some way to interface with the printer without having to directly create code for the motors. We will create a program that will convert CAD files into code which can be fed into the printer.
Safety System	The main goal of the project is to ensure safety and monitor any possible safety issues. The safety issues we will be monitoring the most closely are the temperature of the printer and environmental box, the radiation from the printer, and the oxygen content inside of the vacuum, which should be zero.
Quality monitoring	Our team will implement other sensors in order to monitor the quality of the objects being printed. Some possible sensors which we will use to monitor are eddy current sensors and infrared cameras to ensure even heating on the object.

Embedded system	The printer will be operated using a laptop or desktop computer. There will be alerts connected to the computer concerning the safety system and quality monitoring.

3 - Design

3.1 Previous work/literature

Our printer will use the process of Additive Manufacturing to create objects, rolling out a layer of powder and melting it with each repetition of the process. Additive manufacturing (AM) is a process through which 3D printing can be done with materials which are harder to work with or to create shapes which cannot be created through other methods. Additive manufacturing is done by creating an object a single layer at a time. There is a small amount of material rolled out, and then the shape of the object wanted is created. This method creates much less waste than other methods of manufacturing, and allows for much more flexibility in building prototypes by allowing dynamic production (Brand 2017).

Additive manufacturing technology is quickly growing in both the consumer and corporate spheres, and the market for AM is expected to grow from $4 billion in 2014 to $21 billion by 2020 (Thompson et al 2016). Because of the explosive growth of AM technology, there is a lack of generally accepted standards among the industry (Ghao et al 2015). This is also made difficult by the fact that there are so many different ways to go about completing a task using additive manufacturing, making it much harder to make one set of overarching standards. While there is a dramatic lack of standards, we will attempt to follow any standards that are currently in use while creating and testing our printer.

Another essential issue currently facing the world of additive manufacturing is that fact that there is a lack of quality assurance due to the fact that in-process monitoring during additive manufacturing is not up to par (Everton et al 2016). Due to this fact, companies are less likely to use additive manufacturing for expensive items or items where failure cannot be tolerated (Everton et al 2016). Although research has been expanding on in-situ monitoring of AM technology, the level of monitoring is still unacceptable for any critical parts. One organization on the forefront of this is NASA, which hopes to use non-destructive evaluation (NDE) for spacecrafts and instruments (Waller et al 2014). NDE involves the use of many different kinds of sensors to evaluate the printing process and sense defects during and after printing. The key in NDE is to ensure that the sensors being used do not affect the printing process in any way. By using NDE, we ensure that the structural integrity of the parts is sound.

While NDE is a good way to monitor additive manufacturing before, during, and after the printing process, there are still major gaps in NDE technology for additive manufacturing. Some examples of issues that NDE currently has are the monitoring of creation of complex geometric shapes and a lack of algorithms to automatically detect defects during the printing process (Waller et al 2014). Since complex geometry is one of the main attractions of additive manufacturing, and lack of waste is another, these are critical problems. This lack of NDE is the main problem that our printer hopes to address. By using lasers to evaluate the structural integrity of parts while the printer is working, we can ensure that the objects being made are of the highest possible quality and hopefully aid in the acceptance of standards for non-destructive evaluation.

Despite the fact that there are no true standards for NDE and that the technology is lacking, additive manufacturing still has boundless opportunities for individuals and corporations. Some possible uses for additive manufacturing in the future are printing using multiple materials, creating objects based off of sketches, and even printing organs using human tissue (Brand 2017, Ghao et al 2015).

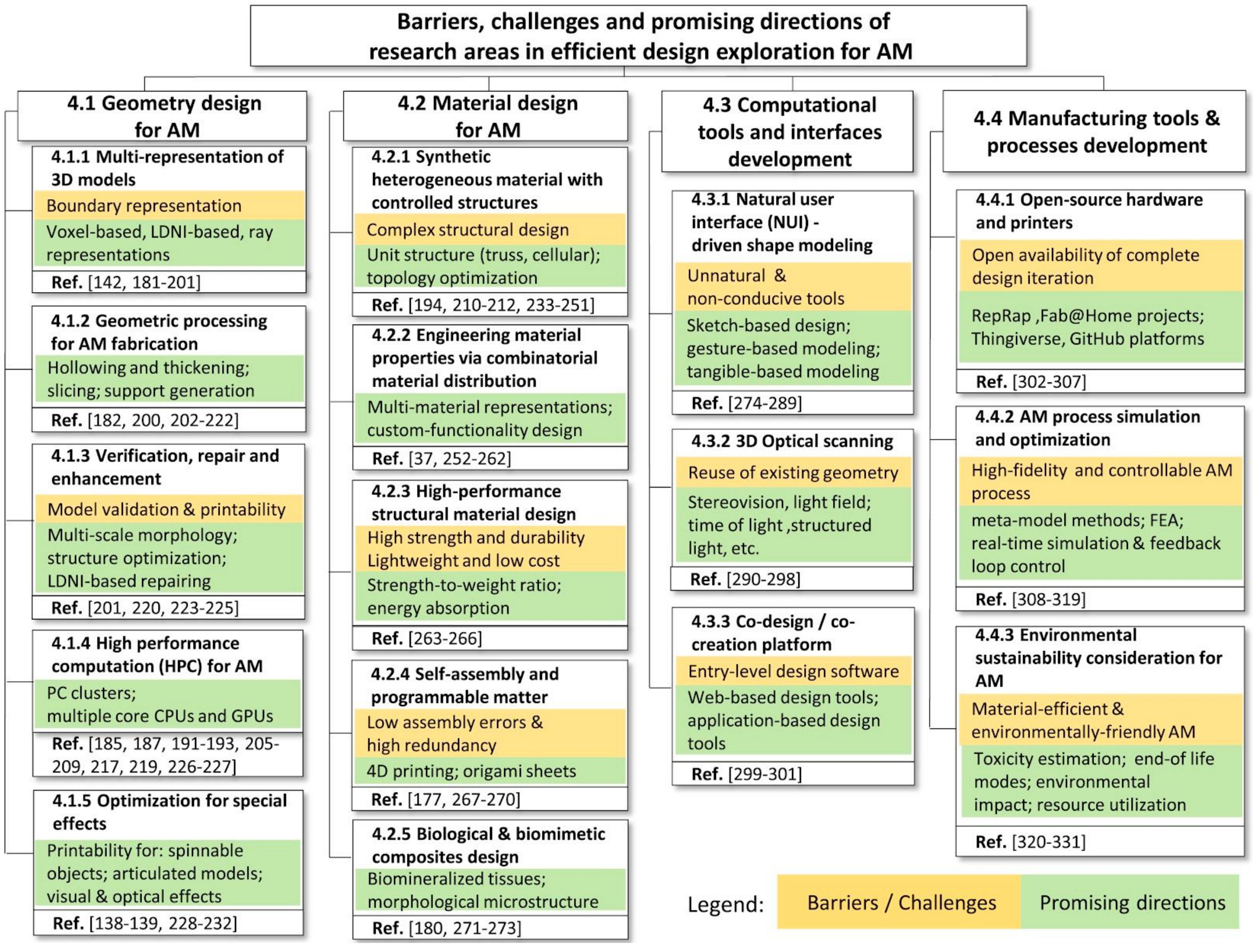

Figure 1: Possible applications and challenges coinciding with the growth of additive manufacturing (Ghao et al 2015).

3.2 Proposed System Block diagram

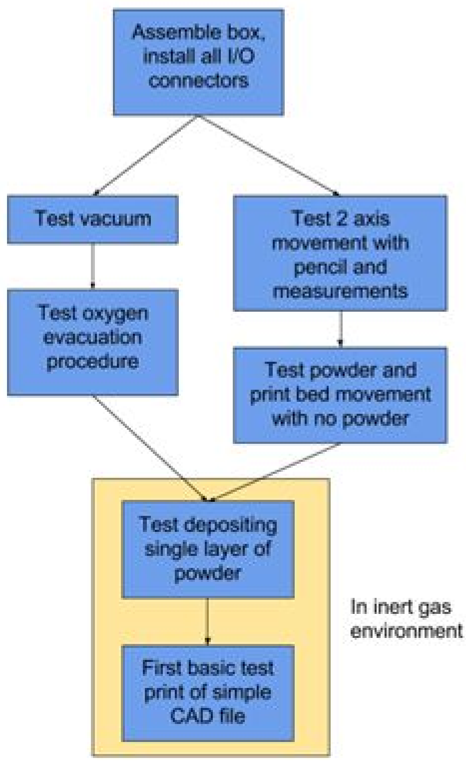

Figure 2: Block diagram of 3d Printer Phase II design

In Figure 2, this is the part of the project that the following group had left for our group. This shows the phases that need to be completed. The first step is completing the vacuum sealed chamber and installing all the inputs/outputs of the connectors. The vacuum sealed chamber needs to be finished for the wire connections, contact sensor, temperature sensor, and sealing the chamber. The I/O will be the barometer, temperature sensors, contact sensor, stepper motor input connectors, Eddy Current, ultrasound connector, and camera connector. These connectors will be used to give power and send commands to each component. All of these components will be tested for the their expected operation.

The second step is testing the vacuum sealed chamber. This will be testing to see if it is actually truly sealed. This testing will require using the oxygen and pressure sensor to be used to evaluate if the chamber is sealed. That would lead into the next part for the vacuum sealed chamber, which is testing for how much oxygen and creating the argon environment in the chamber.

The third step is evaluating and calibrating the two stepper motors for how the accuracy of the stepper motors. This would test how the laser would be working for the printer. Basically, how accurate the laser will be when melting the metal powder. The metal powder will be tested later on.

The next step is testing the print bed for accuracy with the laser stepper motors. This evaluates how the print bed will move and how it will move with the laser. This will test for the angles and accuracy of how the laser would melt the powder.

The final step for testing the components is placing the 3D metal printer in the vacuum sealed chamber. This will be testing the printer to see if a single layer of metal powder can be melted properly, basically making a simple sketch with the metal powder If the metal powder is melted, then the next step is creating a part with a CAD file. This will test the safety and material evaluation of the part, basically evaluating how the part is being made by each layer. Depending on the quality of the completed part, the printer may have to be calibrated to increase the quality of the printed parts.

The past group completed the main construction of the 3D printer. This would include the base, the stepper motor placement, the stepper motor controllers, and the stepper motors for the print bed. For the coding side, the previous team had coding for the stepper motors for the lasers, coding for the barometer, and the vacuum sealed chamber was built. The vacuum sealed chamber was built and is just waiting for the printer to be done to test it out. This group selected this option for creating the 3D printer because they went for accuracy and not for speed. It will take longer for an object to be created but it would be more accurate for the building process. This is where are group started with. This shaped are design proposal based on what the previous group setup the 3D printer. The previous group even had block diagrams and their timeline showed what and how they wanted to finish the project. So, we are just continuing the project on with extra sensors and calibration techniques that Dr.Bigelow suggested.

3.3 Assessment of Proposed methods

The strengths of this project include in-line monitoring for laser ultrasound. There will be oxygen sensors, temperature sensors, contact sensors and cameras to monitor the 3D metal printer. However, there are challenges that we have to face when considering the sensors and camera placement. Since the 3D printer will be operating in a vacuum chamber, the sensors and cameras must be able to withstand the difference in pressure. Taking this into account, we need to consider the material of the camera, the temperature limit it can stand, etc. Another alternative will be creating our own camera that meets the specifications.

The weakness of in-line monitoring include the slow operational speed of the stepper motors. Just printing a simple cube will take a while to complete and the stepper motors might even deviate from its path. This cause inaccurate in-line monitoring, which defeats the purpose of our goal.

To make the workload even and efficient, the team discussed an option to accomplish this. The plan that was discussed was having three pairs. Each pair would include each major. So, there would be one pair of computer engineers, one pair of software engineers, and one pair of electrical engineers. We thought this would be beneficial so that the pairs could discuss between each other to generate ideas or solutions. This method also helps with group communication, as there is 3 collaborative groups instead of 6 completely separate solo workers.

As shown above in Figure 2, our 3D printer was planned and discussed with our advisor, Dr. Bigelow. We will finish both the nitrogen/argon sealed chamber and the 3D metal printer. Each of those components then will be tested to properly test the sensors and the functionality of the componentents. After both components pass, then the two components can be built together. This means that the 3D metal printer will be placed inside the sealed chamber to test the laser and the layer of powder. If that test is successful, then the final step would be to convert CAD drawings into the printer and construct those drawings. This would be the true test to see if the printer can complete a task and to see if the CAD drawing is made correctly.

3.4 Validation

With the project on a budget, we will discuss the construction of the 3D printer with Dr. Bigelow. This would include the purchasing of camera, sensors, stepper motors, and other necessary components. Each component will go under testing to make sure each component can survive a vacuum and still operates under those conditions. This would include software to operate the components, which would attached or added on to produce a safe operating 3D metal printer. To assist with the mechanical side of the project, Dr. Bigelow hired some mechanical graduate students that will assist us with the mechanical components that need to be created.

The Software testing , will have multiple steps. The first step would be connecting and operating the metal printer from a computer. This will help establish that the code is working as well as the printer working. Next, would be programing the oxygen, pressure, and temperature sensor to either operate the printer or shut down the printer. Each sensor would be tested and debug in a vacuum sealed chamber to achieve the proper coding for functionality.

Hardware testing will be testing the two main components, the sealed chamber and the 3D metal printer. The sealed chamber will be tested for a nitrogen/argon environment. This would include the absence of oxygen in the sealed chamber. The 3D metal printer will be tested for the functionality of how it will operate the laser mount. The laser mount is used to position the laser in the proper spot for melting the powder, which is used to create the object. The laser mount will have to be tested for efficiency as well as functionality. This will require some debugging in the coding and calibrating the stepping motors. To test the laser mount outside of the vacuum, we will use a pen to draw out for where the pen is going. This will help us to visually see the operation of the laser mount so that we will be able to calibrate the laser mount properly.

The final testing would be testing the 3D metal printer in the sealed chamber. This will be the first test to see if the powder will be melted properly in the sealed chamber. Testing this will be a good way to make sure that the laser is working properly as well as the code for the laser mount. If the testing proves positive, then the last test would be printing a CAD drawing. This may have multiple problems but it would provide sufficient information about what needs to be fixed.

4 - Project Requirements/Specifications

4.1 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.

4.2 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.

4.3 Standards

Engineering standards assist with the creation of constraints for designing a technical product. Constraints allow for a group of engineers to critical think for a solution or goal for a project. Projects/devices are held to these standards to be easily transferable between platforms. The standards we will be following are the industry and IEEE standards.

All code generated will be written with supporting documentation in Javadocs style comments. This follows the software standards that are present in the industry standards. Meeting these requirements will allow easier understanding of the coding and how to modified the software.

Using a high power laser requires several safety standards to be followed. All of our team members will take the EHS Laser Safety training, and will work with EHS to ensure that the system and its environment is safe for testing.

The following are IEEE standards that pertain to our project:

270-2006 - IEEE Standard Definitions for Selected Quantities, Units, and Related Terms, with Special Attention to the International System of Units (SI).

This standard defines the physical quantities, units, and the systems of measurements that are used in applied science and technology. The standards emphasizes the use of the International System of Units. This is relevant to the team's project because half of our project is mechanically designed. We need to confirm that the parts of the printer are compatible with the design of the printer. Therefore, our team must be aware of the measurements/units for each part.

1100-2005 - IEEE Recommended Practice for Powering and Grounding Electronic Equipment.
This standard is a collection of best practices for powering and grounding electronic equipment used in commercial and industrial applications. The best practices are designed to enhance equipment performance and maintain safe installation. This is relevant to our project because we will essentially be building a device that needs proper powering and grounding. We will be using several lasers, implementing a sensor system, and powering a printer. We need to be able to properly distribute power and ground these systems for safe handling.

299-2006 - IEEE Standard Method for Measuring Effectiveness of Electromagnetic Shielding Enclosures.
This standard describes uniform measurement procedures and techniques to determine the efficiency of electromagnetic shield enclosures. This includes welded, demountable builds of materials such as steel plate, aluminum, and copper. This is relevant to the project because we will be using several lasers, including a high beam melt laser. We need to be able to have an enclosure that helps prevent any radiation and reflection to the user. This standard will help ensure that our device is safe to handle

754-2008 - IEEE Standard for Floating-Point Arithmetic
This standard specifies interchange and arithmetic formats and methods for binary and decimal floating-point arithmetic in computer programming environments. This standard is geared toward the software part of our project. Our printer will be controlled by a program that will control the movement of our printer by pushing coordinate values via arrays. We want to be able to store precise values as possible to maintain accuracy of the 3D printed product.

There are also some other standards by the International Organization for Standardization (ISO) for additive manufacturing that we will be following:

ISO/ASTM 52901:2017 - Additive manufacturing -- General principles -- Requirements for purchased AM parts
"Gives guidelines for the elements to be exchanged between the customer and the part provider at the time of the order, including the customer order information, part definition data, feedstock requirements, final part characteristics and properties, inspection requirements and part acceptance methods." (Naden 2018)

ISO 17296-2:2015 - Additive manufacturing -- General principles -- Part 2: Overview of process categories and feedstock
"Explains how different process categories make use of different types of materials to shape a product's geometry. It also describes which type of material is used in different process categories." (Naden 2018)

ISO 17296-3:2014 - Additive manufacturing -- General principles -- Part 3: Main characteristics and corresponding test methods
"Specifies main quality characteristics of parts, specifies appropriate test procedures, and recommends the scope and content of test and supply agreements." (Naden 2018)

ISO 17296-4:2014 - Additive manufacturing -- General principles -- Part 4: Overview of data processing.

"Specifies terms and definitions which enable information to be exchanged describing geometries or parts such that they can be additively manufactured. The data exchange method outlines file type, data enclosed formatting of such data and what this can be used for."

ISO/ASTM 52900:2015 - Additive manufacturing -- General principles -- Terminology
"Establishes and defines terms used in additive manufacturing (AM) technology, which applies the additive shaping principle and thereby builds physical 3D geometries by successive addition of material."

ISO/ASTM 52910:2018 - Additive manufacturing -- Design -- Requirements, guidelines and recommendations
"General guidance and identification of issues are supported, but specific design solutions and process-specific or material-specific data are not supported."

ISO/ASTM 52921:2013 - Standard terminology for additive manufacturing -- Coordinate systems and test methodologies
"Terms included cover definitions for machines/systems and their coordinate systems plus the location and orientation of parts. It is intended, where possible, to be compliant with ISO 841 and to clarify the specific adaptation of those principles to additive manufacturing."

5 - Challenges

Some of the challenges we will have this semester will be working with a vacuum environment and making sure various components are able to function. Some examples of this will be a barometer, a thermometer, and most difficult likely being a camera that will not crack under high pressure. Another challenge will be getting software to interact properly with our roller used for depositing the metal powder on the bed and controlling various velmex motors to function in accordance with our predefined software and CAD files at a later date. These challenges will be difficult to solve but we should be able to overcome them and accomplish our goals as outlined in the below timeline.

The risk for this project can be high if we do not handle it correctly. We will be using class 4 lasers, the most dangerous, and so we must ensure that we do not operate the lasers unless they are in the correct environment. The lasers can cause eye damage even without direct contact, so they should only be operated in a closed environment with no opportunity for any eye contact. The metal powder can be volatile in an environment with oxygen, so we need to ensure that the chamber is kept oxygen-free, and use nitrogen in the chamber instead. Since nitrogen is an inert gas, it will not react with the metal powder being melted.

The cost for this project from our group should be low. Most of the parts needed, including the lasers and stepper motors, have already been purchased by the previous group. These purchased parts have come out to a cost of $21,286. The temperature and pressure sensors have already been purchased, along with an oxygen sensor. The parts that we currently see ourselves needing are a camera to monitor the printer and a contact sensor for the vacuum sealed box. We hope to use a cheap camera, around 20-50 dollars, and will drill a hole in it to equalize pressure. As for the contact sensor, the average price seems to be anywhere from 25 to 50 dollars. We will also have to purchase a laser lens, of which the average price is around 300 dollars. Overall, with the parts we currently plan on buying, our cost should be no more than $400 to complete the project.

6 - Timeline

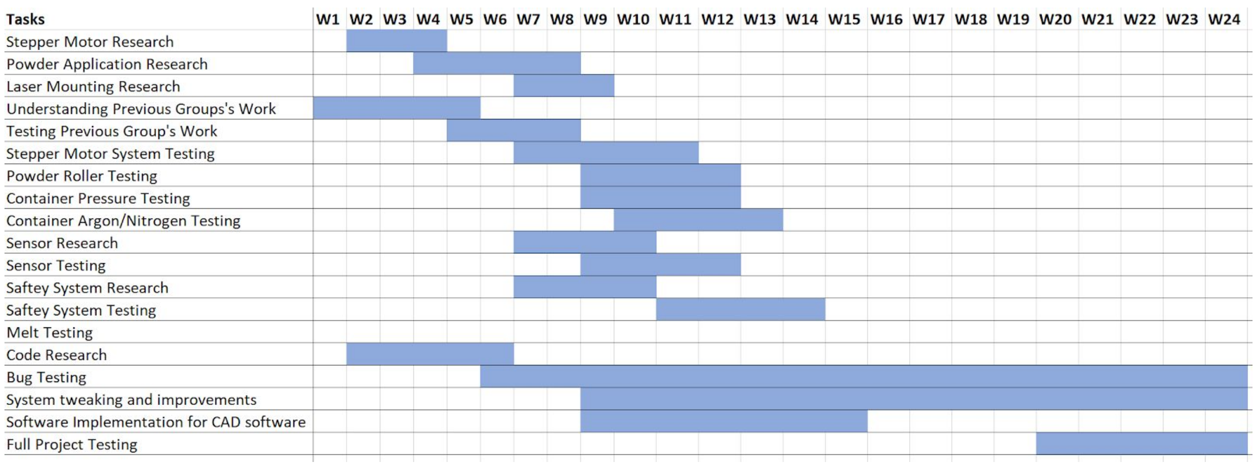

Figure 3 : Gantt Chart of Senior Design Fall and Spring Semesters

6.1 First Semester

The first semester will consist of research, design, purchasing of parts, understanding where the previous group left off and implementing the improvement we make on the individual aspects of the printer. Before starting any work on the printer, all members of the group will complete safety training on emergency lab procedures along with laser safety training. In the beginning each member will research and understand the aspect of the project that they are most comfortable with. The software engineers will focus on expanding and improving on already created software. The computer engineers will focus on achieving proper roller and dispenser functionality. The electrical engineers will focus on adding sensors and monitors for collecting data on the printer. The team will fully analyze the previous group's choices and implementations of features. The team will complete the final assembly of the laser, as well as having a functional vacuum chamber to place the laser into. Completing the vacuum chamber will include many steps. Additional wiring holes may need to be added, and wire organization will be important. To do this, we will be working with two mechanical engineers who will handle the completion of the chamber along with the building of the roller and physical construction of the printer. The printer will be installed without the laser originally, to ensure proper sealing conditions and inert environment. During this time, we will also need to find and purchase a cheap camera, which we will then drill a hole in so it is able to handle the low-pressure, oxygen-free environment in the vacuum chamber. We will also have to purchase a lens for the printing laser.

6.2 Second Semester

During the second semester, we will have a running prototype where the roller will be able to roll out powder and the laser will be able to melt it together. Once the vacuum chamber is complete, we will test the chamber extensively before moving the final pieces of the printer and installing the laser onto the printer. The last step before testing the printer with the laser will be for EH&S to test the chamber and ensure that the proper safety procedures are in place. Once our team has verified that the chamber will safely contain the radiation and the laser, we will begin testing the printing software and hardware performance. We will need to make sure that the chamber is fully oxygen free, and that the laser does not overheat while running. There will also be software expansion for the printer. The software will take CAD files and translate them into instructions for the printer to follow in order to print an object. Other expansions to the project would be installing additional sensors to monitor various aspects of the print, such as eddy current readings and infrared imaging.

6.3 Personnel Effort Requirements

Task	**Description**	**Estimated Time**
Research lasers and 3d printers	Research needed to understand the components we will be working with	20 hours
Understand previous group’s work	Understand what previous group’s work so we can add on to it and make improvements.	90 hours
Test previous group’s work	Make sure that the stuff they had is working and working how they intended	30 hours
Learn how to use C#	The previous group was using C#. To fully understand the code and add on, learning C# is necessary	120 hours
Research gcode	The printer takes gcode as instructions to move. Understanding how gcode can be translated can will help give the printer directions for the model.	10 hours
Research how to convert 3d model to gcode	The goal is to take a 3d model and print it out. This requires the	10 hours

	model to be translated into gcode instructions for the printer	
Test Software	This will require the developers that the model is being converted to gcode properly and will require the hardware be functional	60 hours
Research sensors and cameras	The sensors and camera need to be able to work in a vacuum	10 hours
Create program to run the laser	Laser needs to be controlled so it is not constantly on.	90 hours
Test entire system	Need to make sure the entire system is working properly by printing out models and monitoring the sensors	90 hours

7 - Test Plan

To test the printer for its completeness and effectiveness we will be using an array of sensors.These sensors include barometer, camera, and temperature sensors. These sensors will be used to regulate the printer to make sure that there are no injuries or no defects in objects. The testing for the barometer will be tested to now the amount of pressure in the vacuum sealed chamber, this will allow us to know if it is low pressure or high pressure. If it is low pressure, then we can use the camera for a visual aid in seeing an object being printed. The temperature sensor will be tested for the temperature inside the sealed chamber and the outside of the chamber. The temperature that will be looking out for is 122℉, which is the operation temperature of the camera. If the temperature reaches that high, the camera that we selected may have to be changed out for a different camera. These tests for these sensors and the testing for the printer and sealed vacuum chamber cannot be tested until EH&S approves that they do their function. The sealed vacuum chamber has to be tested to make sure that it does not leak or release any rays, so that there would be no laser injuries. The printer cannot be tested for creating objects until the sealed vacuum chamber is approved by EH&S. The only testing that would could complete was the stepper motor guidance with a pen, which is shown below in Figure 4.

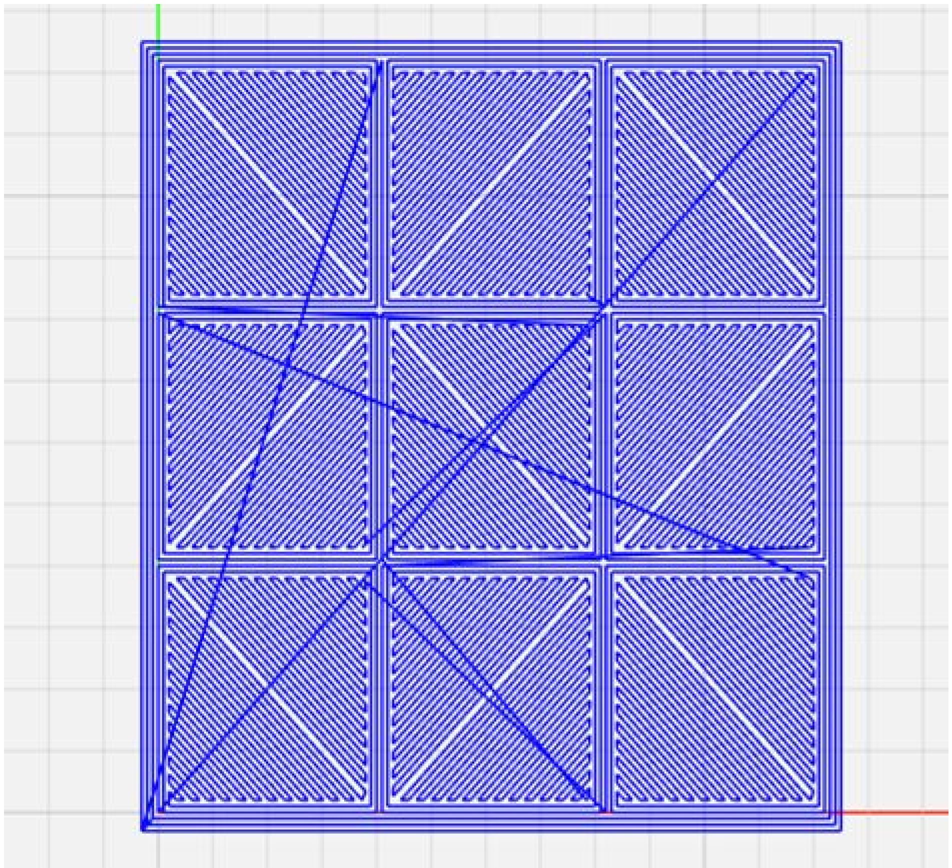

Figure 4: Laser movement with pen

This shows that the stepper motors can be tested for accuracy of the laser. This may need to be calibrated again, when the laser can actually be tested. When the laser is actually tested, the first test will be to see if the print bed coding works and too see if the laser can melt the metal and create an object. Depending on those results, the print bed or the laser might have to be recalibrated for accuracy. The last thing that would be tested, if everything else works, is the implication of a CAD file and printing the CAD file.

8 - Conclusion

This semester and next semester we will be working on a 3D Metal printer that will hopefully be functioning by the end. The project was already started in previous semesters and although there is a good start on some of the beginning design we still have quite a few challenges and decisions we will need to make in order to complete everything on time. The group from last year left us with a prototype that can take in some input and makes the motors draw a grid on a piece of paper as substitute for a laser. Our current goals are to get the printer working as intended with the ability to create a metal cube by the end of the semester. The laser will need to be functional as well as the roller that will be used to lay down the metal powder. We also hope to implement sensors to ensure that the environment for the printer is safe. These sensors will run through an Arduino and send an alarm to the user's computer if there is any issue. These sensors will include temperature and oxygen sensors. Our main challenges during this semester will be getting the program to interact correctly with a CAD file and to find a camera which is within our budget that will work under the high-pressure vacuum that we will create for the printer.

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