3D Metal Printer

PROJECT PLAN

May 2018 - Team 5

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1 Introduction

1.1 Project statement

This senior design team is tasked with designing and creating a Metal 3D Printer. The scope includes designing the printer mechanically, designing safety systems to prevent harm from the pure nitrogen gas required for printing, designing software to drive the motors, and developing a user interface to make the printer accessible to researchers.

1.2 purpose

The twist with this printer's design is that there is an interferometer to perform non-destructive evaluation on each layer of the part as it is printed. This is a research component to try to correlate print quality with part performance. The cost of this evaluation is speed. The printer will ideally be able to perform this evaluation as it is printing, without require a second scanning step for every printed layer. As will be discussed later, metal 3D printing is becoming the standard in industry for developing hard to manufacture parts, many of which need to be of high quality for system critical applications. This creates a strong need for new and innovative NDE methods in the area of 3D printing.

1.3 Goals

As discussed with our product owner, Dr. Bigelow, the team should focus on trying to achieve one of two goals: a printer with a functioning NDE scan, or a printer that can print. Both of these will require similar deliverables. The main difference being which function gets more effort to be completed. It is our understanding that this senior design project will be continued in future years. As a team, we are currently focusing getting the printer to print objects first. We feel that this is logical, as it will be much easier to test the evaluation component if the printer is able to evaluate which it is printing.

2 Deliverables

Deliverable	Description
Solidworks Model	This is the virtual design of the printer. We will use this to check space conflicts and estimate costs. The design will be reviewed by the chemistry machine shop for manufacturability.
Manufacturing Drawings	Provide mechanical drawings/parts to the manufacturing lab to create the necessary components to assemble the printer.

Software interface	For accessibility, we need an accessible software interface to coordinate the safety and motor subsystems of the printer. The software will incorporate some standard slicing formats to enable commercially available tools to prepare path planning for our printer.
Safety System	The team will research and integrate sensors to guarantee the system is sealed and operating safely. The two primary hazards are a gas leak and radiation leak from the laser. Appropriate sensors and visual alerts will be provided to the user to ensure safety.
Embedded system	Team will develop an embedded safety system to link sensors into the desktop computer. The embedded system will also operate safety alarms regardless of the state of the PC connection.

3 Design

3.1 Previous work/literature

When we think of 3D printing, we often think of customized toys and parts being built layer by layer with some kind of polymer. The ability to print products in this manner paves way to build more intricate designs such as naturally occurring honeycomb structures or geometrical lattices. This process is known as additive manufacturing (AM), and metal 3D printing is being seen as the emerging technology for these intricate parts. These intricate structures are lightweight and strong, perfect for use in the aerospace industry (see Figure 1). According to NASA, "compared with a traditionally cast part, a printed [part] has superior strength, ductility, and fracture resistance, with a lower variability in materials properties."

(a) GE fuel nozzle [1] (b) SpaceX combustion chamber [2] (c) NASA engine baffle [3]

Figure 1: Example applications of AM to fabricate mission-critical aerospace products (NASA, Albakri et al.)

While the ability of metal printing is praised, there is a lack of in-situ process monitoring as well as a lack of quality control for each part being made (Waller et al., Slotwinski). This is where nondestructive evaluation (NDE) comes into play.

Nondestructive evaluation will make it possible for real-time evaluation of defects and materials characterization (Sorrentino, Slotwinski). NDE can be used to measure the materials before and after a part is made. Possible measurable properties of the powder include particulate size, distribution, and chemical composition. For in-situ sensing, NDE techniques can be used to measure and monitor the temperature and size of the melt pool in powder bed fusion systems. If sensors can be integrated into the build chamber, each layer can be immediately scanned for any defects (Slotwinski).

The need for NDE in 3D metal additive manufacturing is an emerging field of interest. The ability for integration of NDE into the additive manufacturing process fulfills the need for real-time evaluation of defects and the ability for quality control that is much needed to take 3D metal printing into commercial manufacturing.

3.2 Proposed System Block diagram

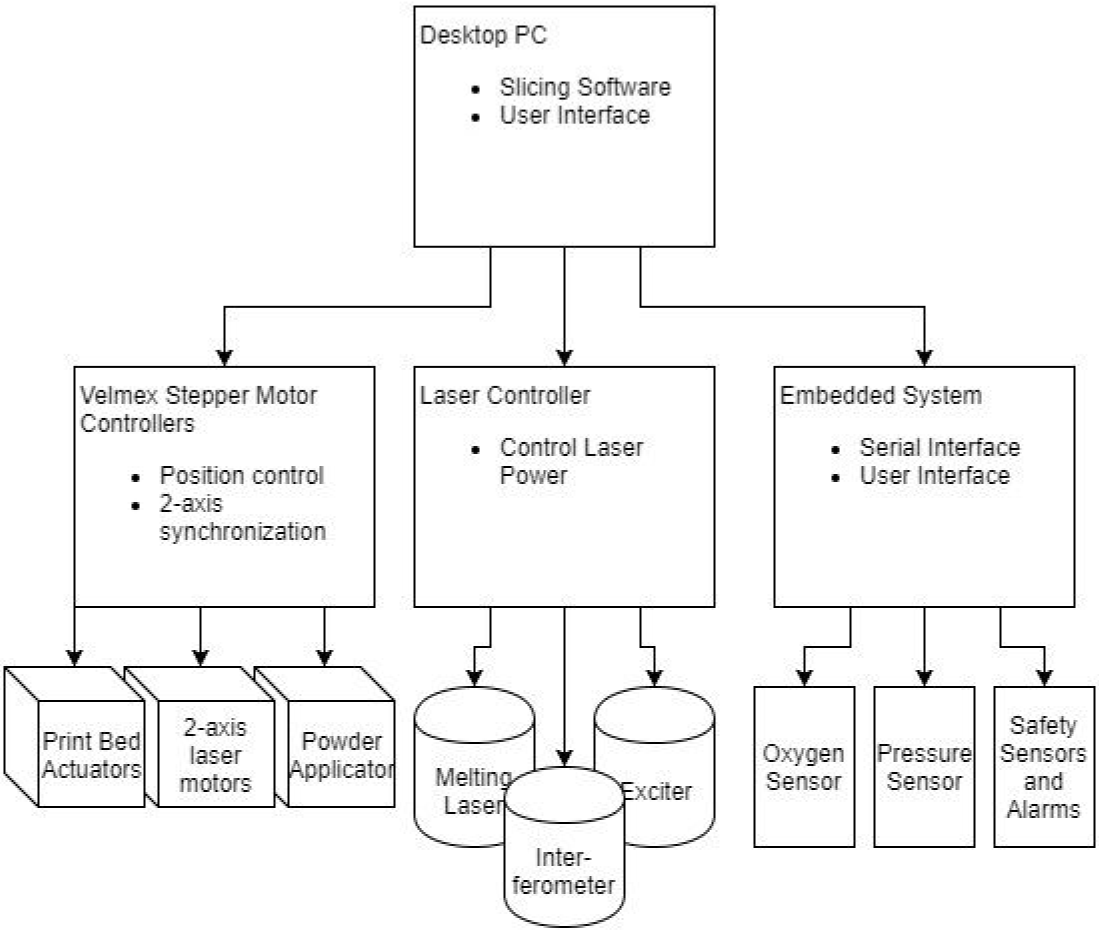

Figure 2: Block diagram of 3d Printer design

3.3 Assessment of Proposed methods

For the overall organization and structure of the project, we considered a few approaches. We thought about splitting into two teams, a powder system team and a laser system team, but decided that there would be far too much overlap between the systems for splitting into two distinct teams. Instead, we decided to stay together as one group and dole out responsibilities as need arises.

As the above diagram illustrates, our system has been planned out and discussed with our advisor at length. Based on the knowledge of Dr. Bigelow and our own engineering work, the fundamental design is sound. We control the printer via a PC. Then we use stepper motors to move the laser heads and powder system. The PC will get data from various sensors and cameras in return. Every part of our design is doable by this team. One of the biggest downsides to this design is that our printer will be very slow. This shouldn't matter for the scope of our project since speed was not a constraint we were given.

3.4 Validation

Due to the expensive nature of a lot of these parts, we really only have one shot. For the most part, we won't be making prototypes. This means that we have to work very carefully to ensure success. To do this we will confirm that Dr. Bigelow is on board with all of the important decisions in the project and carefully check each other's work. If it doesn't work the first time, we will make adjustments via software or swap out some hardware if necessary. The best way to ensure that our solutions will work is taking the time for calculation and analysis prior to action.

That being said, we must have a comprehensive plan on how to test each component of the printer before assembling it, otherwise it will certainly not work the first time. This project has many complicated hardware and software elements, and thus the testing can be dividing into hardware and software testing.

With regards to software testing, there are several approaches we can take. Most of the software we will be writing will be C# code on a Windows PC, so it will be very easy to quickly debug and change. One challenge with the software is that the hardware will not be fully ready and tested for a while. We plan to create a piece of software which essentially emulates the physical hardware of the project. This will be a simple GUI application which listens to the output commands of the software we write, and then draws what 'should' be printed to the screen. This will allow us to validate all of our code before the actual drivers which communicate with the printer hardware.

There will be several elements to the hardware testing of the 3D Metal Printer. One of the first, and most critical, pieces to be tested is the sealed chamber. This chamber or box must be able to handle enough vacuum to be evacuated of air and filled with nitrogen. We plan to test this box well before installing any of the printer assemblies or components, as it will be easier to fix problems with it early on. Another major hardware component which will require extensive testing, particularly because it works closely with the software, is the movement of the laser head. The laser head must move in a precise manner, and it would be preferable to ensure it is operating correctly before actually turning on the high power melt laser. Our current plan is to affix a writing utensil of some sort to the laser head, and having the printer draw paths on a piece of paper. This will allow for a visual verification that the print head is moving in the correct path.

The final test for the 3D Metal Printer will be the printing of a simple CAD model. This will test both the hardware and software of the printer. There could be several problems revealed that were not present in individual component testing.

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 power bed which moves up in order to deposit a new layer of power
- The printer shall have a brush or roller of some sort 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 excess powder not deposited on the print bed
- Any place with powder must be enclosed in a sealed chamber which can withstand a vacuum and be filled with nitrogen or argon gas
- All lasers shall be able to be pointed at any point within the print bed using some sort of servo control
- There shall be a pressure and oxygen sensor inside the sealed powder chamber
- There shall be an oxygen outside of the printer which will alarm the user if oxygen levels in the room are unsafe
- The system shall use an interlock such that the laser cannot be powered unless it is contained

4.2 Non-functional

- The volume of the sealed chamber should be minimized
- It should be easy for future users to modify system software
- The time for printing and scanning should be a small as possible while keeping the printer design simple

4.3 Standards

Our code will be written with supporting documentation in Javadocs style comments. This is considered industry standard for software of this nature, and will be necessary to meet the requirement of easily understandable and modifiable software.

As there is a high power laser, several safety standards must be followed. All of our team members will take EHS Laser Safety training, and will work with EHS to ensure the system and its environment is safe before powering on the lasers.

5 Challenges

The biggest challenge currently facing the team is finding the best way to integrate an interferometer. Ideally, we would use two mirrors for scanning, but most interferometers have a very specific beam length at which it functions. A mirror solution would mean we had a variable beam length which most likely won't work. This is a challenge we are currently working through. Another challenge will be getting the interlock system set so that we can even turn on the lasers at some point. There are a lot of regulations on lasers and it's hard to get regulatory approval to use them. A third challenge is the precise and extreme accuracy necessary for 3D printing to work. While in theory this accuracy should be achievable, it is highly likely that we will face challenges in practice. While it is likely that we will face many more challenges over the course of the project, these are the biggest and most foreseeable issues right now.

6 Timeline

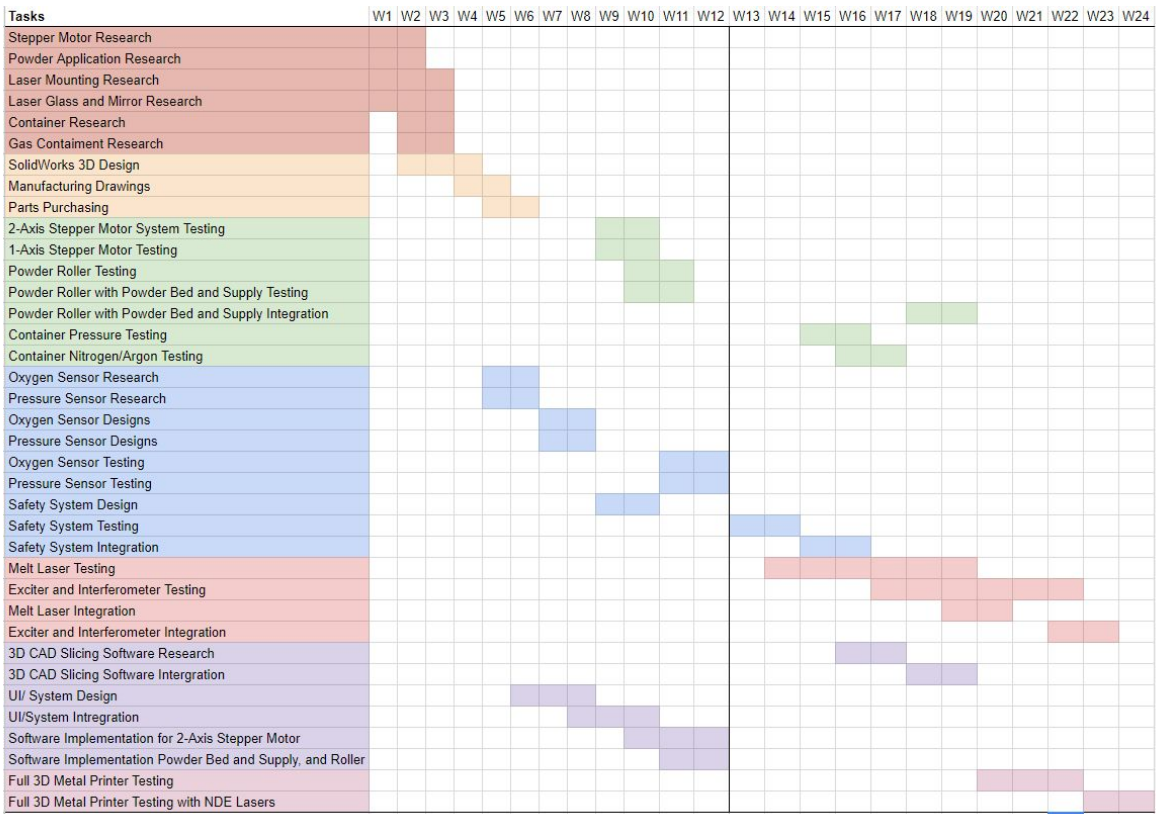

Figure 6.1 : Gantt Chart of Senior Design Fall and Spring Semesters

6.1 First Semester

The first semester will consist of research, design, purchasing of parts, and implementation of mechanical parts and electronic sensors. In the beginning each member is researching different aspects for the design. Around the time parts are being ordered, teams will be formed around sensor creation and software creation. The sensor team will be involved with the research, design, and testing during the first semester. The software team will create a basic application that will integrate with the mechanical parts.

6.2 Second Semester

During the second semester, a safety system based off the sensors will be tested and built in conjunction with container pressure/gas testing. The lasers will be tested in and out of the nitrogen/argon environment, and the software application will be able to splice a CAD file to map points for the 2-axis stepper motor system. A full scale 3D metal printer testing will occur with just the melting laser and, then another a couple of weeks of testing for the NDE lasers too. Teams from the previous semester will continue; however, both teams will also work on laser testing and gas/pressure testing.

7 Conclusions

Our project is to create a 3D Metal for Dr. Bigelow. Our goals for the project is to get as far as possible in the creation of the printer. Ideally, we would at least be able to print parts by the end of the year. We are planning to have much of the parts acquisition done by the end of the semester so that we can focus on implementing functional requirements during second semester. Our plan to achieve this goal includes weekly meetings as a team and with Dr. Bigelow, and constant communication about ideas and problems. Each week we are tackling design and implementation challenges as they arise. The printer will interface with and be controlled by a pc. The pc first takes in a 3d schematic, then slices into layers, then sends instructions to a set of stepper motors for each layer. For each slice, a roller adds a new layer of powder. In return the pc will get data from sensors and cameras. Certain alarms and sensors will run through an Arduino. Some of our biggest challenges include laser safety, dangerous gas volumes, and print accuracy. The implementation of these functions will continue throughout the year as we attempt to overcome the major challenges.

8 References

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9 Appendices

Figure 6.1 : Gantt Chart of Senior Design Fall and Spring Semesters pg