Design and Fabrication of a Radiant Heating and Ignition Apparatus for Fire Testing

Submitted to:

Ofodike A. Ezekoye, Ph.D, Professor
The University of Texas at Austin, Mechanical Engineering
Austin, Texas

Prepared by:

Benjamin R. Kobe, Team Leader
Daniel I. Pineda
Rachel D. Purvis
Bryan W. Stockberger

Mechanical Engineering Design Projects Program
The University of Texas at Austin
Austin, Texas

Spring 2012

Design and Fabrication of a Radiant Heating and Ignition Apparatus for Fire Testing

Submitted to:

Ofodike A. Ezekoye, Ph.D, Professor
The University of Texas at Austin, Mechanical Engineering
Austin, Texas

Prepared by:

Benjamin R. Kobe, Team Leader
Daniel I. Pineda
Rachel D. Purvis
Bryan W. Stockberger

Mechanical Engineering Design Projects Program
The University of Texas at Austin
Austin, Texas

Spring 2012

ACKNOWLEDGMENTS

The team would like to acknowledge the assistance of Dr. Richard Crawford, Ms. Becky Harrison, Mr. Erik Felthauser, and Mr. Scott Marshall for guidance and support related to the senior design course throughout the semester.

In addition, the team would like to thank Dr. Raul Longoria for his advice regarding data acquisition in RS-485, and Dr. Thomas Krueger, for his review of the graphics and layout of this report. The team also acknowledges the entire Department of Mechanical Engineering at the Univeristy of Texas at Austin for the valuable instruction received over the years, from the faculty providing knowledge through courses to the staff supporting the operations and needs of the faculty and students.

In particular, the team acknowledges the administrative assistance provided by Lori Holloway in making purchases for this project. The team would also like to acknowledge the assistance and labor of our shop staff; Scott Allen, Danny Jares, Aaron Frost and Eric Pak, who helped manufacture crucial components of our final device.

Lastly, the team acknowledges Dr. Ofodike Ezekoye for his leadership in our group, as well as his group of graduate students who provided valuable insight on how the device we constructed would be used. Additionally, Dr. Ezekoye aided the group with design decisions to cater to the needs of his research team, and was always available when the team needed him.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

EXECUTIVE SUMMARY

A team of engineering students designed and manufactured a conically shaped radiant heater system called a mass loss calorimeter (MLC). This system is capable of producing nearly uniform heat fluxes up to approximately 40 kW/m^2 on a specimen. This heater system will be used to gather important fire hazard data on various materials, including woods and polymers. The purpose of this project was to design and build a low-cost and customized alternative to a commercially available mass loss calorimeter. The MLC can measure the mass loss versus time of a specimen as it is heated. An ignition system ignites and starts the combustion process of the sample, which generates the mass loss data. From this data, the heat release rate (HRR) can be calculated, "the most significant prediction of fire hazard" [2]. A control system and easy to use interface was also constructed to facilitate the use of the heater system and record important data.

The team compiled a comprehensive set of requirements and constraints that were defined by the ASTM E1354 standard and the laboratory environment. Requirements included, but were not limited to, the power rating for the conical heater element, the load cell weight and accuracy, the spark ignition system voltage and frequency, the chassis material and size, and the control system interface. Constraints included budget, available space, electrical requirements, and laboratory safety. This chassis system went through three design phases. Easy manufacturing, stability of the heater, and safety were the driving factors for changing the design from a cantilever setup to a simply supported design. The heating element was made from incoloy alloy capable of temperatures up to 800 Celsius. The heater shielding was designed to insulate the heating element and allow for the K-type thermocouples to be removed and replaced through Swagelok compression fittings.

A temperature and power control system interfaces with a LabVIEW™ VI to control the temperature and operation of the heater. This VI is also responsible for recording all of the temperature and mass loss data into a single file.

The load cell measures the mass loss versus time of the burning sample and is attached to the chassis. The load cell has a 20 kg capacity and accuracy within 0.1 g. An adjustable sample mount sits on top of the load cell to hold the sample below the heater. To protect the load cell and sample from any negative effects from the heater, calcium silicate shielding was used. The sample is shielded in order to prevent any preheating prior to the experiment. The load cell is shielded to protect its thermally sensitive components. An exhaust hood ensures that all fumes and smoke released from the sample during testing are vented safely out of the laboratory.

The team has completed all of the necessary hardware requirements for a functioning mass loss calorimeter at one quarter the cost of a commercial MLC [7]. This complex system will record data critical to the research that Dr. Ezekoye and his team conduct, and will advance the safety of materials used throughout society. The solid design and construction of the MLC promises to provide reliable data for years to come.

1 SPONSOR BACKGROUND

It has become increasingly important in modern society to understand the flammability characteristics of all materials used in everyday products. This allows for various industries to ensure the safety of their products and characterize how they are affected by extreme heat and fire. Fire safety officials can also use this data to better fight fires in an urban or rural environment. The senior design team's sponsor, Dr. Ezekoye, is head advisor of the Society of Fire Protection Engineers at The University of Texas at Austin. His current research involves fire dynamics and polymer thermal decomposition that will assist industries and firefighters in understanding the fire hazards of various materials [1]. Dr. Ezekoye has contracted a K-team to assist in his fire science research goals and further understand the physical properties of a variety of materials. A mass loss calorimeter (MLC) is to be designed and constructed by the end of the semester to assist Dr. Ezekoye in understanding the potential fire hazards present in a variety of materials. The MLC will heat a sample material at a specified uniform heat flux and record the mass loss of the sample over time. From this data, Dr. Ezekoye will be able to obtain the heat release rate (HRR) for the sample material. The HRR is described as "the most significant prediction of fire hazard" and will help Dr. Ezekoye in fire research [2].

Building a mass loss calorimeter will involve a number of technical skills. These skills include SolidWorks™ (a 3D CAD modeling software), LabVIEW™ (a visual programming software), an in depth understanding of control systems, and machining.

Ben Kobe has spent the last three summers as a research assistant for Dr. Todd Ditmire at The Center for High Intensity Laser Science. As a mechanical engineering student, Ben was responsible for designing and constructing parts for experiments and the laser setup. These apparatuses included multi-axis film holders, translations and optics stages, and protective enclosures for experiments. He was able to further develop his CAD and machining skills here, and is well qualified to design and fabricate any custom parts needed to build a working MLC.

Daniel Pineda has been an undergraduate research assistant for Dr. Janet Ellzey at the University of Texas at Austin, working in her combustion lab since October 2010. His primary duties include designing and constructing experimental equipment to gather specific data, calibrating instrumentation, running combustion experiments, and recording and analyzing data from those experiments. In his courses, he has taken Career Gateway Electives in Intermediate Heat Transfer, Turbomachinery and Compressible Flow, and is currently enrolled in Radiation in Participating Media, a graduate course. Based on these credentials, particularly those associated with building experimental equipment for combustion research, Daniel is well qualified to work on this project.

Bryan Stockberger has worked as an undergraduate research assistant in the ME machine shop for three years. As a machinist, he made laboratory specimens for the materials science lab, as well as one-off workpieces for various research projects. Bryan has enjoyed the thermal fluids and heat transfer classes completed during college, including the fire science class taught by the project sponsor, Dr. Ezekoye. Bryan will bring a fundamental knowledge of machining as well as an understanding of the physics principles involved in this design project.

Rachel Purvis has participated and led many group projects, which include reverse engineering a Furby toy, emulating a cogeneration power plant on MATLAB™, and building a prototype for a consumer gardening product. She has also interned with a steel pipe company named Tenaris. During her internship, she designed and built a working prototype that put different colored paint bands onto various steel grade pipes. Rachel has also taken a Career Gateway Elective in Biomechanics, and is currently taking Corrosion and Materials Selection. Rachel has more than sufficient qualifications to work on a design team to design and build a mass loss calorimeter.

This report includes a discussion of the basic principles of fire science, why this project is significant to the field of fire science and to Dr. Ezekoye, the requirements of the project, the constraints the team will have to work around, and ultimately the deliverables that the team will be responsible for providing at the end of the semester.

2 PROBLEM STATEMENT

For this project, this team will design and build a low-cost and customized alternative to a commercially available mass loss calorimeter for the purpose of investigating the heat release rate and flammability of various materials in fire testing.

2.1 Problem Background

The need for a standardized tool for measuring heat release rate has led to the development of the mass loss calorimeter. Previous incarnations of the mass loss calorimeter were plagued with problems associated with antiquated machinery that produced errors of measurement and difficulty of operation. Designs based on the sensible enthalpy principle, the energy indicated by a thermometer, were demonstrated to show large systematic errors. Instruments based on other measurement principles were capable of good accuracy, but were cumbersome and difficult to install and maintain. Due to these shortcomings, the oxygen consumption principle became the successful bench-scale HRR apparatus. Several years of research on various instrument designs led to the development of the cone calorimeter that was first described in a report in 1982 [3].

Current versions of the MLC are commercially available, but they are expensive and have extraneous instrumentation. There is also an expressed interest by the sponsor to integrate this device into a computer system to record all of the data of interest. As such, the team will provide a data acquisition system tailored to his research needs.

2.2 Project Detail

The purpose of the project is for the team to design and construct an economical version of a MLC to collect experimental data from fire testing a 100mm x 100mm x 25mm sample of a combustible material. An image of a commercially available mass loss calorimeter is depicted below in Figure 1. Guidelines for conducting calorimetry experiments are specified by the ASTM E1354 standard. This standard gives detailed plans for the construction of a mass loss calorimeter, including extra instrumentation for smoke density measurements, exhaust temperatures, and gas samples [4]. The group's intent is to fabricate a working MLC, tailored to Dr. Ezekoye's research, that will take into consideration some simplifying assumptions to alleviate design requirements. This MLC will experimentally determine the heat release rate, HRR, and the mass loss rate for a given sample [4]. The MLC will employ the use of a conical radiant heater, heater controller, thermocouples, heat flux sensor, a spark ignitor, a load cell, and a data acquisition system. The design will incorporate shielding where needed to protect data acquisition equipment, as well as protect the sample from preheating before conducting any testing. More detail over the requirements for this project is detailed in Section 3.

Figure 1. Commercially available mass loss calorimeter [5].

2.3 Project Significance and Impact

Building an MLC is important to Dr. Ezekoye's research in high heat flux polymer degradation. This tool will be useful in predicting the thermal degradation rates of thermoplastics, wood, and other polymeric materials. The acquired data from this machine will aid in modeling plastic ignition and flame spread for fire applications. Before the MLC became widely accepted, models developed for polymer thermal degradation were based on curve fits to thermogravimetric analysis (TGA) data. This type of analysis takes into account a sample's change in weight in relation to a change in temperature. For a given set of fitting parameters, it is possible to model the TGA data at the specified conditions. In general, however, when the data is used to extrapolate to other conditions (e.g. higher heating rates) it becomes much less accurate. With an MLC, different experimental conditions can be investigated and the resulting data can be catalogued, providing the means to empirically fit the TGA data for a wide range of fitting parameters [1].

Completion of this project will provide Dr. Ezekoye with a less expensive and customized alternative to purchasing a commercially available MLC from a specialty manufacturer [6], which can cost upwards of $20,000 even without any custom configuration [7]. By constructing an affordable and customized MLC, important fire hazard research can be conducted by Dr. Ezekoye's lab. The team's MLC will also have room for additional equipment, such as a controlled atmosphere wind tunnel setup. This research will lead to a better understanding of flammability properties of assorted materials, and will help industry specialists design safer products. Additionally, this research will help fire fighters better understand and react to fire hazards.

2.4 Prior Art

The device Dr. Ezekoye wants the team to construct is meant to be used for fire testing materials in his group's research. Research applications which involve obtaining very specific data often have a variety of methods to obtain that data, and these methods are vetted over many years in academic journals until the scientific engineering community comes to a general consensus on the best method to obtain the aforementioned data, and develops a standard for it. It turns out, as mentioned previously, that there is such a standard that exists for obtaining the heat release rate of various materials, the ASTM E1354 [4]. Because a standard exists for this overall device (and hence, testing method), it is freely available for use to anyone who wants to construct the device and sell it on their own. However, individual components that make up the device (or drastically different testing methods) are subject to patents of their own.

Dr. Vytenis Babrauskas, an instrumental figure in the fire science community, pioneered the current design of the mass loss calorimeter. Dr. Babrauskas offers a walkthrough [3] of the development of the cone calorimeter, a more featured version of a mass loss calorimeter, as a method of determining the HRR of materials. This paper details the history of the development of his method from the early 1970s to the late 1980s. The device as a testing method was finally standardized in 1993, and subsequently updated over time to make the device easier to use [3]. Dr. Babrauskas himself holds patents related to selective laser sintering (but not directly to calorimetry), which lead the team to the first patent discussed in this report.

This first patent that proved useful was the radiant heating apparatus for providing uniform surface temperature [8]. One of the requirements of the ASTM E1354 standard is that the sample be irradiated with a uniform heat flux. The device is ring-shaped, similar to the design chosen by the team, to accomplish heating the sample. The patent differs from the design project in that it pertains to the application of selective laser sintering, whereas the design project falls under the scope of heat flux degradation. Although the application differs, the similarity in the heater geometry reinforced the team's decision to use a conical heater to irradiate the sample.

More recently, patents related to microscale calorimetry have been filed and published as the research community moves to smaller scales to determine heat release rate. A 2002 patent was located which describes a calorimeter that is able to determine the heat release rate for samples weighing 1 to 10 milligram [9]. This particular patent is interesting because it stipulates that the mass loss measurement of this small sample is not required in order to obtain precise and accurate heat release rate data, since all of the necessary reactions occur nearly simultaneously. The device depicted consists of a pyrolysis chamber, a combustion furnace, and an oxygen analyzer in series connected by a single tube. While the method is interesting, Dr. Ezekoye is not interested in small-scale experiments (or gas analysis), so the team does not plan to use the technical information in this document to design the mass loss calorimeter.

The patent offers insight into various criticisms of traditional fire testing methods, most notably the claim that heating rate across samples is not uniform. As a result of this, the team will closely investigate the ability of the mass loss calorimeter specified in ASTM E1354 to provide uniform heat fluxes on the sample. This investigation is carried out in Section 5.2.1 of this report.

3 REQUIREMENTS

In order to make a custom MLC, the team must first solve several key issues in three main areas of the device: functionality, manufacturing, and controlling. However, to begin solving these issues, the technical requirements need to first be understood. The requirements set forth by the ASTM E1354 standard and Dr. Ezekoye can be seen in Table 1 below. This table lists the technical aspects required for each component of the MLC.

Table 1. Requirements for Dr. Ezekoye's Mass Loss Calorimeter.

ASTM Guideline Requirements	
Conical Heater	Rated for 240 V and 5 kW Supply uniform heat flux of 0-100 kW/m^2
Preheat and Heater Element Shielding	Replaceable Prevent preheating of sample Prevent damage to components Ceramic wool packing density of 65 kg/m^3 Calcium silicate density of 100 kg/m^3
Temperature Controller/Power Controller	Integrates with DAQ system PID control type Change set-point remotely Supply 240 V to heater
Thermocouples	Withstand 1000 C K type, sheathed, exposed junction Quick connect to heater
Heat Flux Meter	Measure 0-100 kW/m^2 Water cooled Withstand temperatures up to 870 °C Interact with DAQ system
Load Cell	Minimum 5 kg capacity Total weighing range of 3.5 kg 500 g accessible for direct monitoring 0.1 g accuracy
Sample Pan	106mm x 106mm x 33mm volume Stainless steel Prevent spillage Insulated by ceramic wool
Exhaust System	Vents to UT laboratory vents Withstand high temperature fumes Blower provides constant flow Accessible for maintenance
Spark Ignition	10 kV spark at 60 hertz 3 mm spark gap Adjustable height
DAQ System	10 channels for input/output GUI interface
Chassis	Stainless steel Minimize welding Less than 0.5m x 0.5m x 1m Capable of retrofitting future testing equipment/ shielding

4 CONSTRAINTS

4.1 Location Based Constraints

Before continuing with the project, it is important to understand a number of constraints on the system. The system will be located in ETC 7.160, pictured below in Figure 2. First, the system must fit on a standard optical lab table. With this in mind, the MLC will be confined to an overall volume constraint of 0.5m x 0.5m x 1m. The second constraint to consider is ventilation. The MLC must vent toxic gases and smoke to the main laboratory vent system. The next constraint involves the power supplied to the heating coil. The heating coil must run on a 240V outlet, and this must be available within the lab. The final constraint is the availability of a coolant source for the heat flux meter. A 35 psi source is required in order to cool the heat flux meter and achieve consistent heat flux measurements.

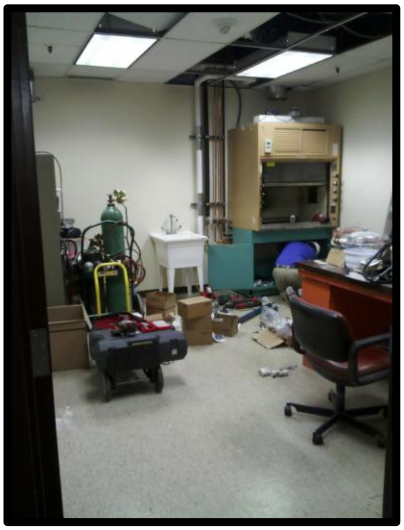


Figure 2. The current state of ETC 7.160, the future location for the MLC.

4.2 Budget

The initial budget for this project was $4,000. An itemized budget can be seen in Appendix A: Budget. The current cost for this project is $4,742.39. The team was unable to adhere to the $4,000 budget primarily due to the unforeseen costs associated with such an ambitious project. The high accuracy load cell, custom heating coils, and the stainless steel materials required to resist the high temperatures from the heater accounted for the majority of the high cost for this project. The team was able to reduce costs by doing the majority of the machining themselves and by acquiring discounts on the load cell and heater control hardware.

5 PROGRESS AND CURRENT WORK

This section includes a thorough analysis of the essential parts needed to construct a mass loss calorimeter. Some of the design specifications were outlined by the ASTM E1354 standard [4], but many components required custom solutions in order to make a simple-to-build MLC. The design process for each component of the MLC is discussed in detail in order to describe the steps necessary to assemble a working MLC.

5.1 Chassis System

The chassis system is the skeleton that holds all of the components of the mass loss calorimeter together. This system consists of a base for support, a sliding heater assembly that contains the heater coil and shielding, and a mid plate to protect the load cell from the heater. The chassis is made from stainless steel in order to resist the high temperatures produced by the heater. The chassis system has gone through three distinct design changes that are listed below.

Version one of the chassis system consisted solely of the heater mount assembly. This version is based largely on the ASTM E1354 standard [4] and uses a cantilever setup. This first version of the heater mount assembly had complex geometries, difficult bends, and required some welding to accomplish the design. Because of these difficult manufacturing hurdles, the version one chassis was completely redesigned in the second version. Version one can be seen in Figure 3 below.

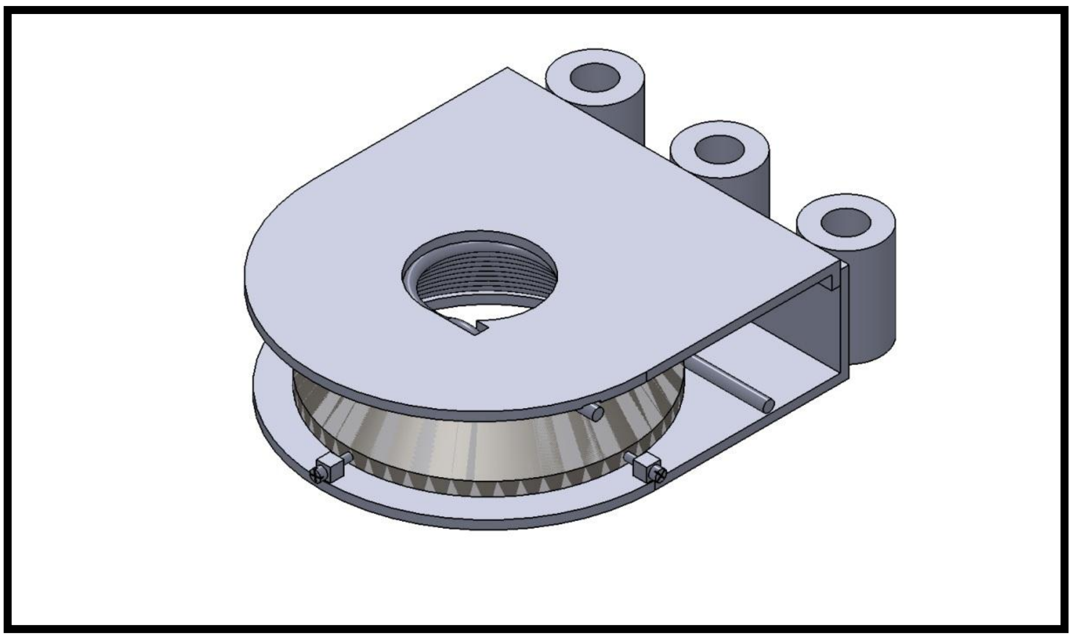


Figure 3. Version one of the heater mount assembly.

Version two of the chassis system involved a complete redesign of the version one heater mount assembly. First, the second version uses a simply supported setup rather than a cantilever setup. This increased the stability of the heater assembly, which is necessary for safe operation while the heater is running. This new setup system also ensures that the heater element is parallel with the sample being tested. Second, the entire assembly was constructed from flat stainless steel plates with simple geometries. This reduced the number of manufacturing steps and required no welding. Third, all parts can be removed and replaced in case a part is broken or is adversely affected by the extreme heats produced by the coil. Fourth, the entire setup was designed so that the number of tools needed to assemble is reduced. This was accomplished by using the same bolt sizes for as many components as possible. Last, the whole assembly can be assembled along the vertical axis in order to reduce the assembly time of the chassis system. Version two can be seen in Figure 4 below.

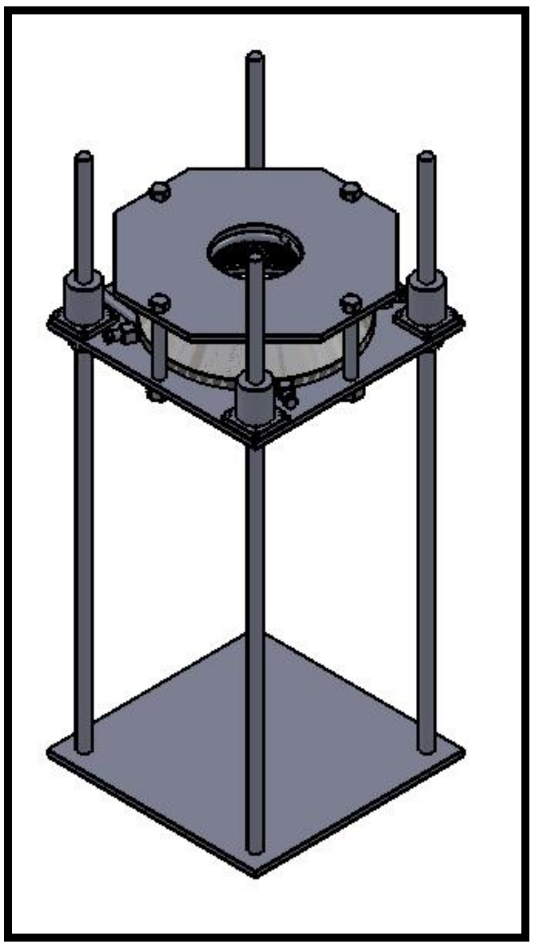


Figure 4. Version two of the chassis system.

The final version, version three, consisted of three primary changes to version two. The first change was to increase the dimensions of the square plates to reduce machining and better deal with the high heat fluxes produced by the heater. Figure 5 below shows that by increasing the plate dimensions from version 2 (9"x9") to version 3 (12"x12"), the heat flux on the bearing posts is significantly reduced. By reducing the heat flux on the posts, we reduced the thermal expansion that would cause problems for the linear bearings. This increase in plate dimension also allowed for proper shielding of the large load cell. The details of these heat flux calculations are presented in Section 5.2.1.

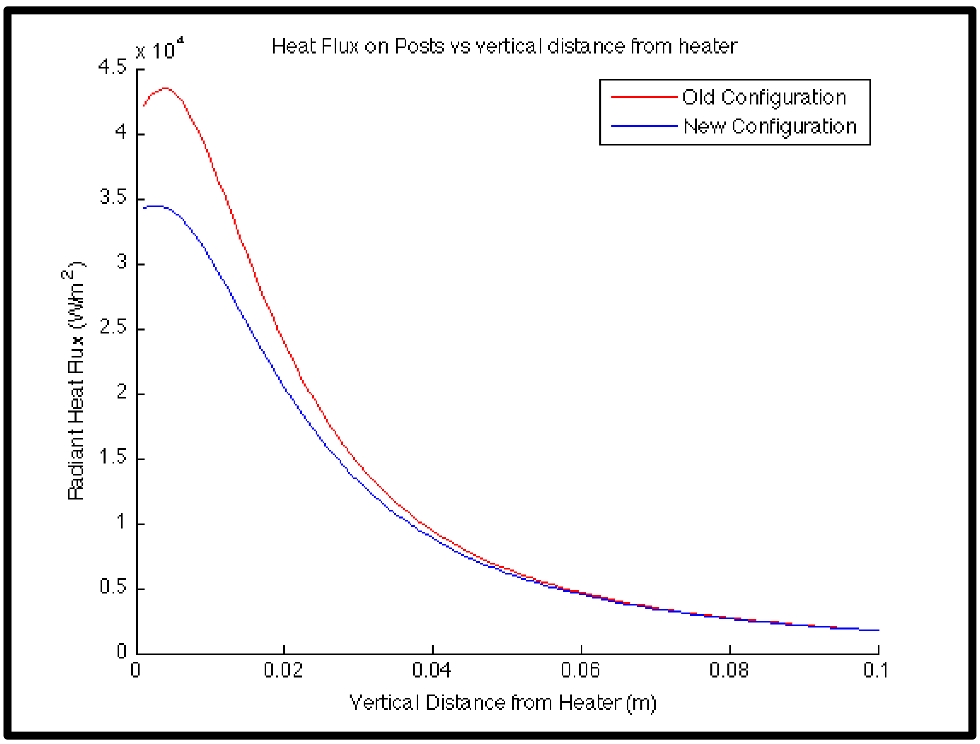


Figure 5. Radiant heat flux on both setups as a function of vertical distance from heater plotted in MATLAB™.

The second major change made to version three was the addition of a middle plate that would support heat shielding and protect the thermally sensitive load cell. The third major change was to the heater element shielding. By changing the outer heat shield from a conical shape to a cylinder, the time to manufacture this piece was reduced and Swagelok fittings for the thermocouples could be attached to the vertical surface. A standardized bolt hole pattern was also added to the base of the chassis so that the team would have more time to choose the correct load cell at a later date. Version three can be seen in Figure 6 below. Figure 7 below shows a labeled exploded view of the version three chassis.

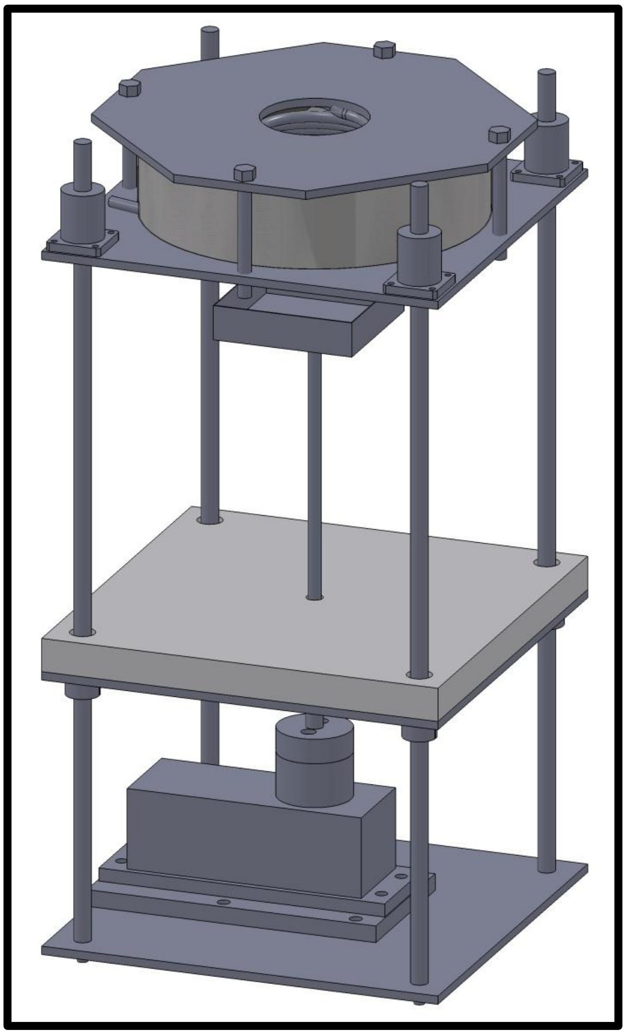
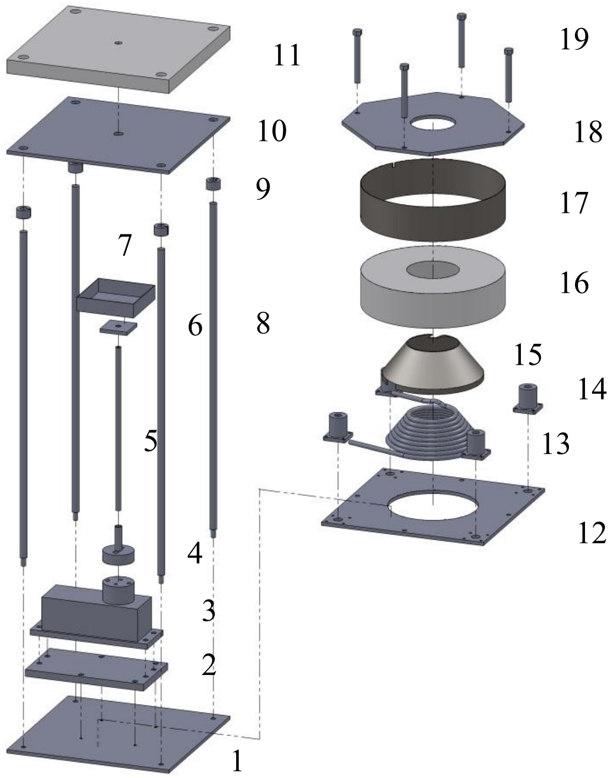


Figure 6. Version three of the chassis system.



#	Part
1	Base Plate
2	Load Cell Mount
3	Load Cell
4	Flange
5	Load Cell Guide Rod
6	Square Mount
7	Sample Pan
8	Heater Guide Rods
9	Shaft Collars
10	Middle Plate
11	Calcium Silicate Shielding
12	Lower Heater Plate
13	Conical Heater
14	Linear Bearings
15	Inner Shield
16	Ceramic Fiber Packing
17	Outer Shield
18	Upper Heater Plate
19	Compression Bolts

Figure 7. Exploded view of the version three chassis system.

After cutting the plates to size, it was necessary to plane the surfaces in which the bearings and support rods sat. This ensured that the guide rods sat perpendicular to the base and interfaced with the bearings correctly. To ensure that everything was machined to acceptable tolerances, a CNC machine was used to machine the large holes in the middle of the two upper plates as well as the bolt hole patterns for the bearings. Figure 8 below shows the finished chassis assembly. The design drawings for the chassis system can be seen in Appendix B: Chassis.

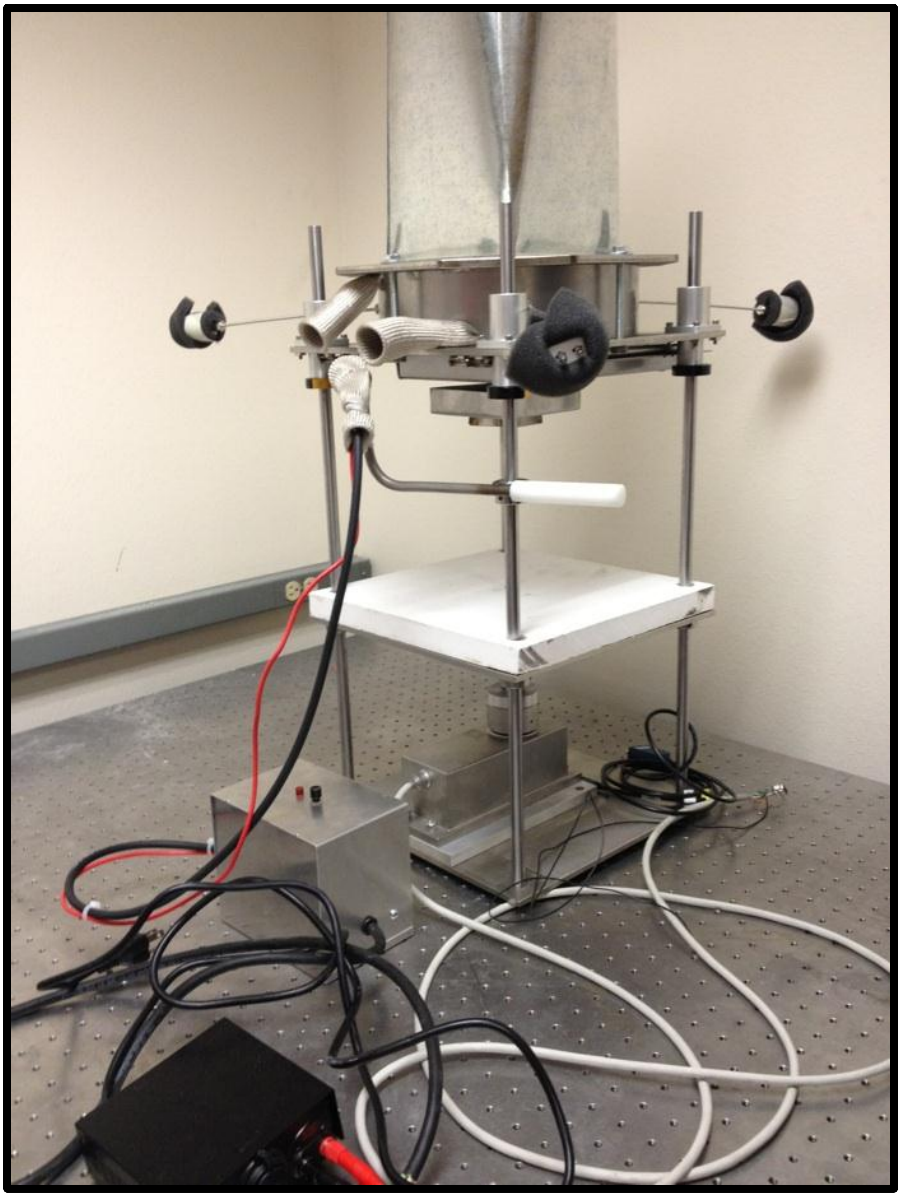


Figure 8. Completed MLC Chassis

5.2 Coil and Coil Shielding

The heating coil and coil shielding comprise the conical heater assembly of the mass loss calorimeter. The coil, shielding, and heater assembly are discussed in further detail below.

5.2.1 Coil

Resistive heating elements are available in a variety of different materials; this provided the team with many options and restrictions. Some of the coil materials, like stainless steel, have high hemispherical emissivities that can produce high heat fluxes, but are unable to operate at the high temperatures required to achieve those heat fluxes. Others, like Inconel, have emissivities that vary significantly with temperature, but are ultimately able to achieve higher temperatures.

The temperature and heat flux of the heater element are related by the following equation, from Howell et al [10]:

$$q" = F\epsilon\sigma(T_c^4 - T_w^4) \qquad \text{(Eq 5.1)}$$

Where q'' is the heat flux, specified by the researcher (most often a constant 40kW/m^2 in the literature [12, 13]). F is the configuration factor associated with the geometry of the experiment, ε is the emissivity of the heater surface, σ is the Stefan-Boltzmann constant (given as 5.67E-8 Wm-2K-4), T_C is the temperature of the conical heater, T_W is the temperature of the sample being fire tested, in units of Kelvins (K). F has been calculated to be 0.74698 for a sample located 25 mm from the base of the conical heater, based on configuration factor relations given by Wilson et al [13] in Equation 5.2, diagrammed in Figure 9 below.

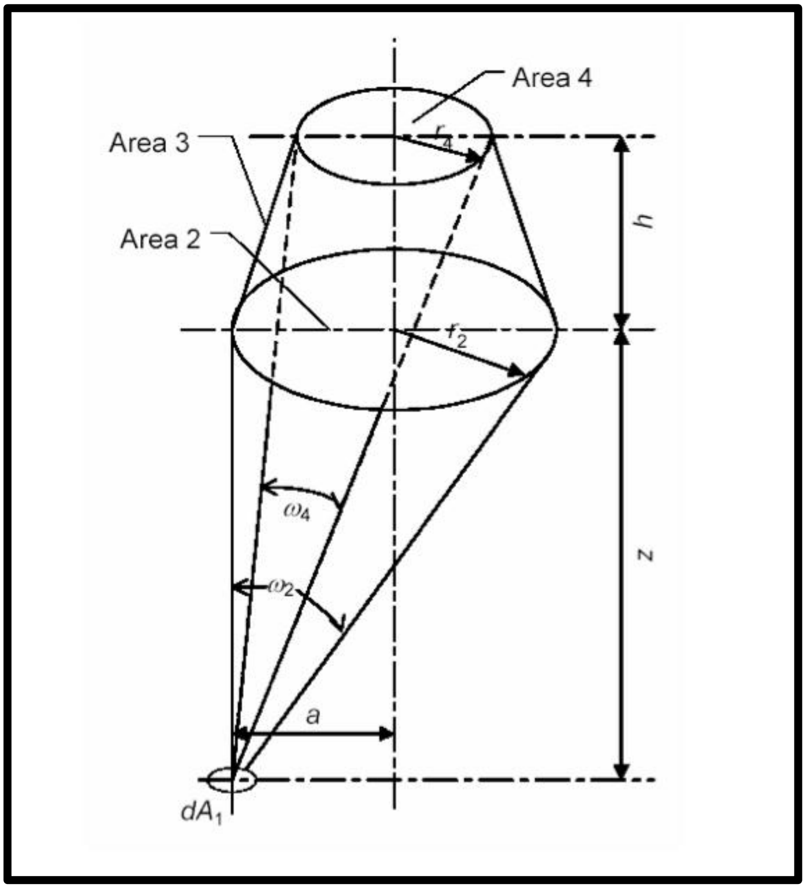


Figure 9. Diagram reproduced from Wilson et al for Shape Factor Calculation in Equation 5.2 [13]

$$F = \frac{1}{2}\left[\left(1 - \frac{1 + H_2^2 - R_2^2}{\sqrt{Z_2^2 - 4R_2^2}}\right) - \left(1 - \frac{1 + H_4^2 - R_4^2}{\sqrt{Z_4^2 - 4R_4^2}}\right)\right] \qquad \text{(Eq. 5.2a)}$$

Where:

$$H_4 = \frac{(h+z)}{a} \qquad \text{(Eq. 5.2b)}$$

$$R_4 = \frac{r_4}{a} \qquad \text{(Eq. 5.2c)}$$

$$Z_4 = 1 + H_4^2 + 4R_4^2 \quad \text{(Eq. 5.2d)}$$

$$H_2 = \frac{z}{a} \qquad \text{(Eq. 5.2e)}$$

$$R_2 = \frac{r_2}{a} \qquad \text{(Eq. 5.2f)}$$

$$Z_2 = 1 + H_2^2 + 4R_2^2 \quad \text{(Eq. 5.2g)}$$

A comparison of the heat flux from the different element materials as a function of temperature is plotted below in Figure 10 for the heater configuration. It can be seen that Incoloy is capable of the highest fluxes at the maximum material temperatures (800ºC for incoloy, 700ºC for SS).

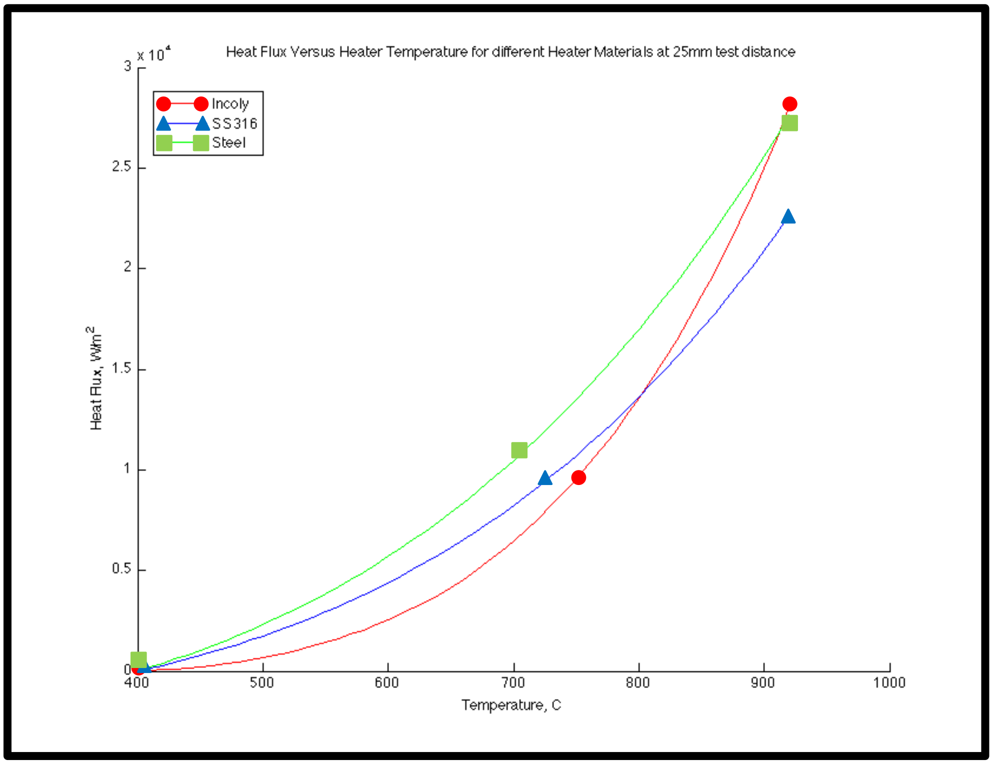


Figure 10. Heat Flux vs. Temperature for different heater materials at 25mm sample distance plotted in MATLAB™.

There are different methods to calculate the heat flux on the sample, based on Equations 5.1 and 5.2. The heater can be assumed as a blackbody, which would result in an overall higher heat flux. The sample temperature can also be assumed constant at room temperature or it can be assumed to have an absolute temperature of zero, also resulting in a higher q”. While the most realistic assumptions (nonblack heater surface, finite sample temperature) yielded lower overall fluxes, they were important to consider so that the team could purchase the best possible components to meet the design requirements, even in a worst-case scenario.

Since Incoloy can handle the highest temperatures [14] and achieve the highest fluxes at those temperatures, as seen in Figure 10, the group chose to go with this material. Emissivities for different industrial materials as a function of temperature are very sparse in the literature, and detailed data are typically a rare find. Data was located in the literature for Inconel [11], and included in the models to estimate the overall heat flux on a fire testing sample, in Figure 11 below. In addition, the fluxes were calculated for various distances between the sample and the heater. Surprisingly, based on the configuration factor determined by Huynh et al and Wilson et al [12, 13], the heat flux on a sample actually increased when the sample was moved farther away from the heater. In Figure 11 below, the rate at which the fluxes increase with sample distance appears to decrease, suggesting that there is a limit to the heat flux based on how far away the sample is from the heater. This intuitively makes sense, since if the sample was infinitely far away from the heater, the heat flux would approach zero.

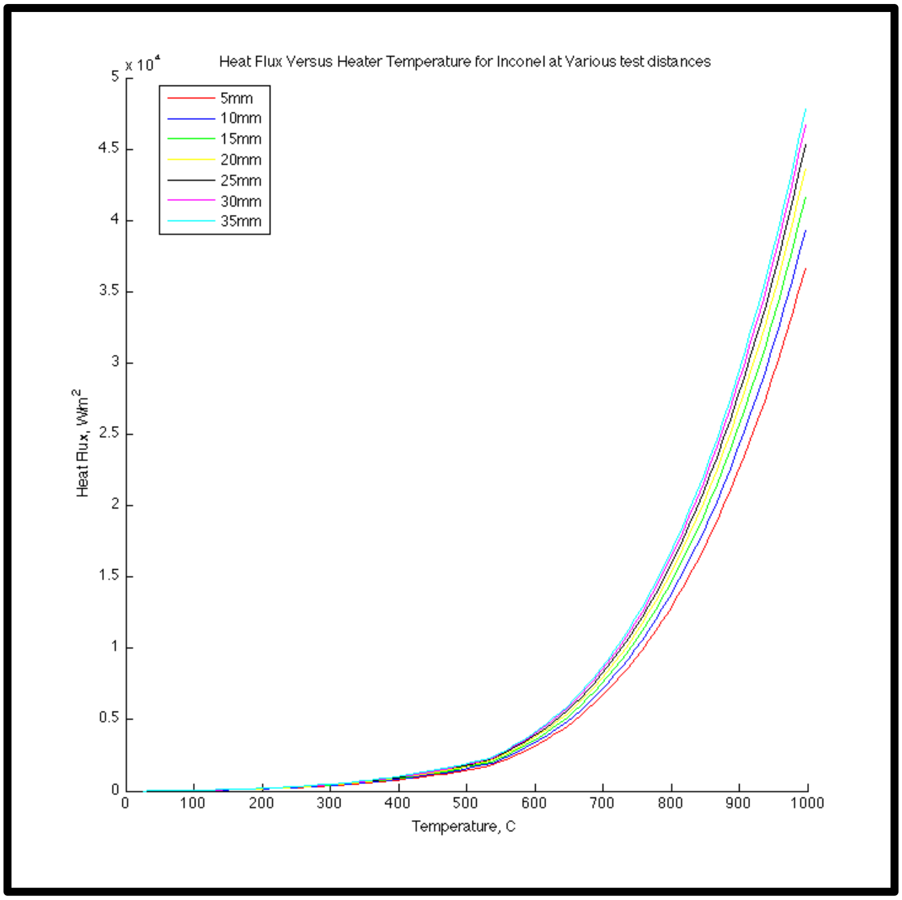


Figure 11. Heat Flux vs Heater Temperature for Inconel at various sample distances plotted in MATLAB™.

After researching flexible coil that can be wound in house versus a custom made coil, the team has decided to have the incoloy heater elements custom made by ASB Heating Elements Ltd. The custom made coils are precision manufactured, cheap to buy, and can withstand a higher temperature in comparison to the flexible coil (800C vs. 700C). Automobile spark plug sleeves were used to cover and insulate the exposed heater leads from electrical and thermal effects. The approved drawing for the coil can be seen in Appendix C: Coil [15].

5.2.2 Coil Shielding

The heat shielding consists of two primary parts: the outer shield and the inner shield. The outer shield is a strip of sheet metal that was formed into a hoop. The shape of the outer shield was chosen to reduce fabrication time over the previously designed conical shape, and so that the thermocouples could be attached to the outer shielding using Swagelok compression fittings. The inner shield is a sheet metal cone that contacts the surface of the heater coil. The pattern for the cone was first mathematically determined and etched onto the surface of the metal. The pattern was then cut out and formed using a roller. The heat shielding for the conical heater was made from .029" thick stainless steel that is quarter-hard. This allowed the sheet metal to be easily formed into a hoop and cone shape. Stainless steel is used because it can withstand high temperatures and corrosion. A picture of the outer shielding fabrication process can be seen below in Figure 12. The drawings for the cone patterns can be seen in Appendix D: Shielding.

Figure 12. Fabrication of outer shielding.

Once the custom coils arrived, the conical heater shielding was custom fit to the coils. This included holes for the heating element leads, Swagelok compression fittings, and thermocouples. Once the shielding has been fit to the coils, ceramic fiber was packed into the void between the inner and outer shielding. Figure 13 below shows the coil and shielding assembly with fiber packing.

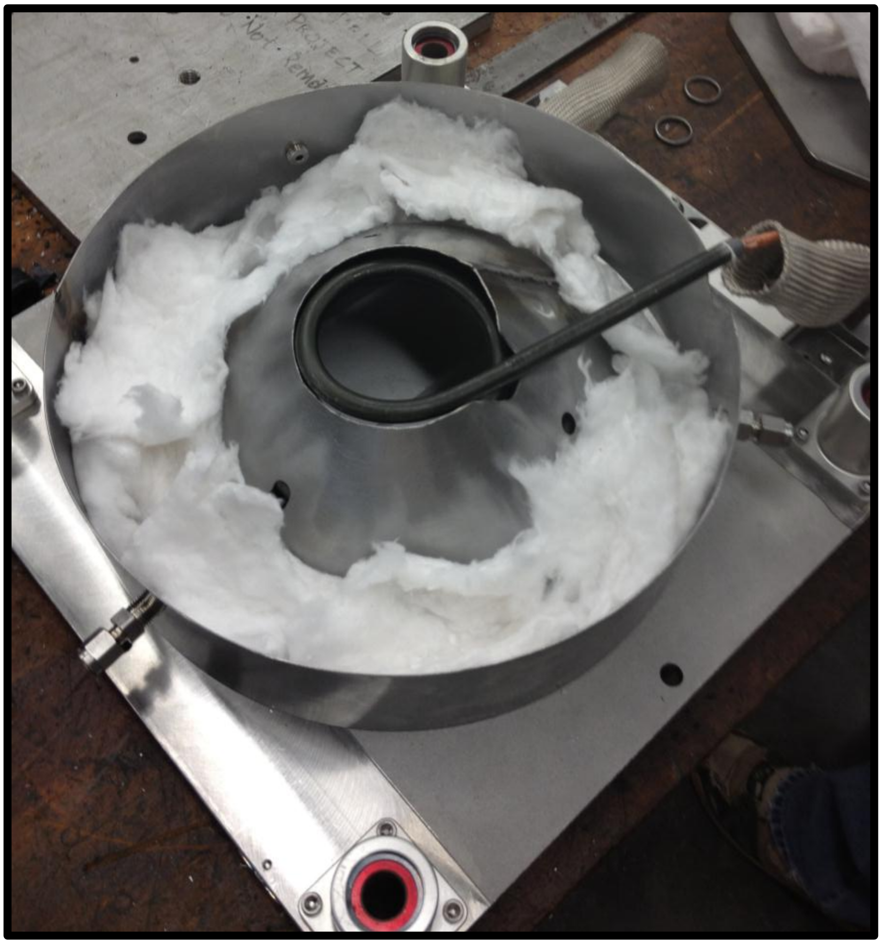


Figure 13. Inner and outer shielding with packing.

5.2.3 Heater Assembly Mount

The heating coil and protective shielding are securely mounted on a heater assembly that will slide vertically and lock into place. The upper plate sandwiches the heater cone and shielding assembly, keeping it firmly in place. Four compression screws ensure even pressure while securing the top and bottom mount plates. Ceramic fiber insulation is used between the inner and outer shield to maximize the heat transfer to the sample and protect sensitive components.

5.3 Thermocouples

The thermocouples were implemented into the design as per ASTM E1354 standards. The ASTM standard states that there are three type K sheathed thermocouples used to measure the temperature of the heater element, so there is not a broad avenue for design. However, the group has decided to anchor the thermocouples to the conical heater using Swagelok compression fittings so that they can be securely attached during a test and easily replaceable if and when they fail. The thermocouples are in contact with the heater element, but are not permanently attached to the coil. The team also chose thermocouple connectors made of ceramic material in order to withstand the high temperatures associated with the heater. The ASTM standard [4] stipulates that the three thermocouples be wired in parallel prior to connection to the heater control system. However, in order to monitor and record the individual voltages of each of the three thermocouples, separate thermocouple wires were connected from each of the thermocouples to the data acquisition system. This will assist in troubleshooting problems in the event of a thermocouple failure.

5.4 Load Cell and Sample Mount

According to the ASTM E1354 standard [4], the load cell for the MLC requires an accuracy of 0.1 grams, a minimum weight capacity of 3.5 kilograms, and a testing range of 500 grams. A calcium silicate board will be used to insulate the load cell from the heater. This will prevent any error or damage to the thermally sensitive load cell. The load cell will also have the sample mount stand attached to the measuring platform.

A 1-FIT1/1SB31/20KG load cell was purchased from HBM, a company that manufactures measurement devices for industrial purposes. This particular load cell is manufactured out of stainless steel, has a weight capacity of 20 kilograms, a standard RS-485 interface, and an accuracy class of C3. A standard RS-485 interface provides an input, output, and two other ports that allow for trigger functions or various switch applications for the load cell. The C3 accuracy class ensures that the load cell will have an accuracy of 0.1 grams [16]. The load cell will be calibrated with precision weights in order to reduce non-linearity errors and further improve accuracy.

The sample pan and guide rod were designed to allow the sample to easily adjust in the vertical direction and properly center on the load cell pedestal. The sample pan is made of stainless steel sheet metal formed into two boxes. The upper box will hold the sample and the lower box, which is welded to the upper box, will center the sample on the square mounting bracket. This bracket is attached to the guide rod via a screw. This guide rod slides into a flange attached to the load cell. This flange will allow the sample to be adjusted in the vertical direction and is secured using a grub screw. All parts above the heat shielding are made of stainless steel to resist the high temperatures of the heater. The flange and load cell mount are located below the heat shielding and are made from aluminum to facilitate machining. Figure 14 below shows the construction of the sample mount. The drawings for the guide rod and flange can be found in Appendix E: Sample Mount.

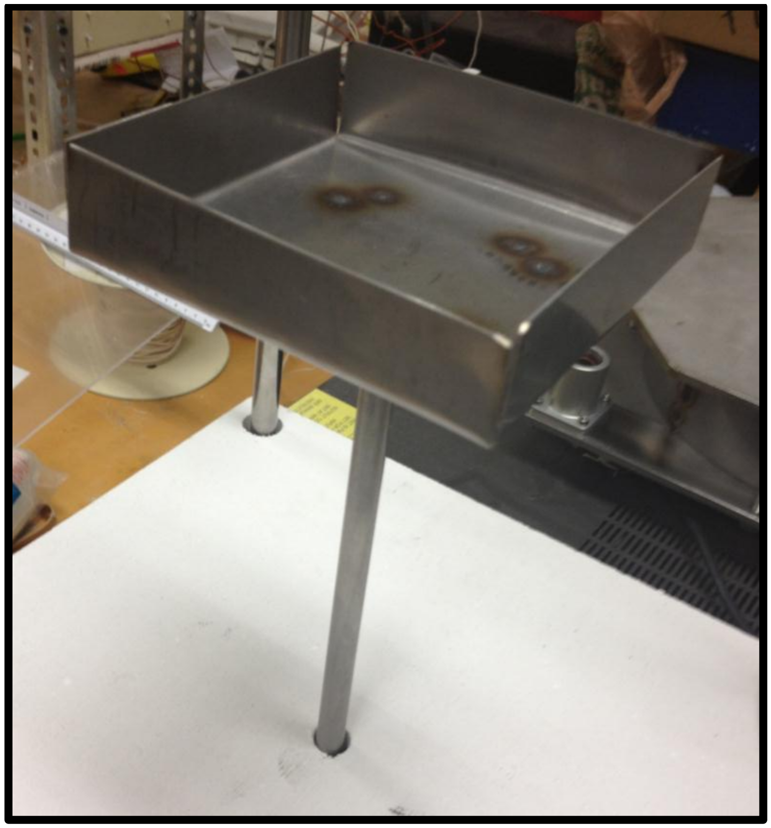


Figure 14. Sample mount.

5.5 Sample and Load Cell Shielding

It is important to shield the sample and load cell from the thermal effects of the heater to avoid any adverse effects from the high temperatures. The sample is shielded in order to prevent any preheating prior to the experiment. The load cell is shielded to protect its thermally sensitive components.

A half inch thick piece of calcium silicate board is used to protect the sample from being preheated. This calcium silicate board has a maximum allowable temperature of 930 Celsius, well above the maximum heater temperature of 800 Celsius. The calcium silicate is mounted to a sheet of stainless steel which is in turn mounted to two stainless steel slides. These slides are then mounted below the opening of the heater. This allows the operator to slide the preheating shielding away from the heater opening when the experiment is ready to be run. Figure 15 below shows the preheating shield.

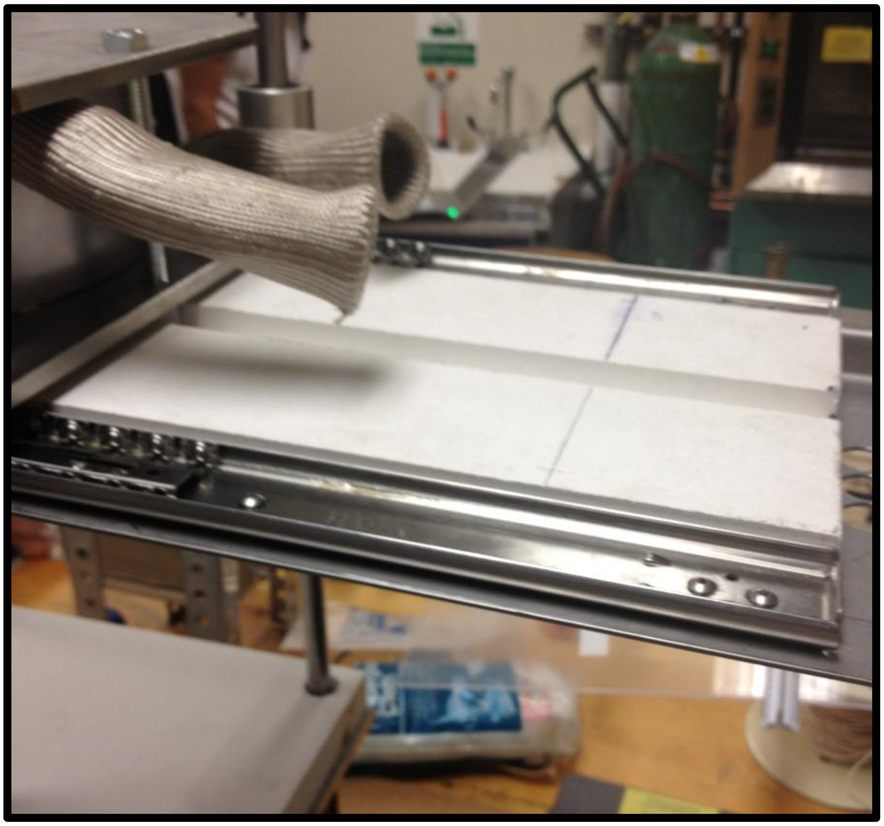


Figure 15. Sample shielding to prevent preheating.

A 1” thick layer of calcium silicate is also positioned on the top of the middle plate to protect the thermally sensitive load cell. The middle plate is ¼” thick stainless steel supported at each corner using shaft collars; this allows for easy adjustment of the middle plate as desired. Figure 16 below shows the load cell shielding.

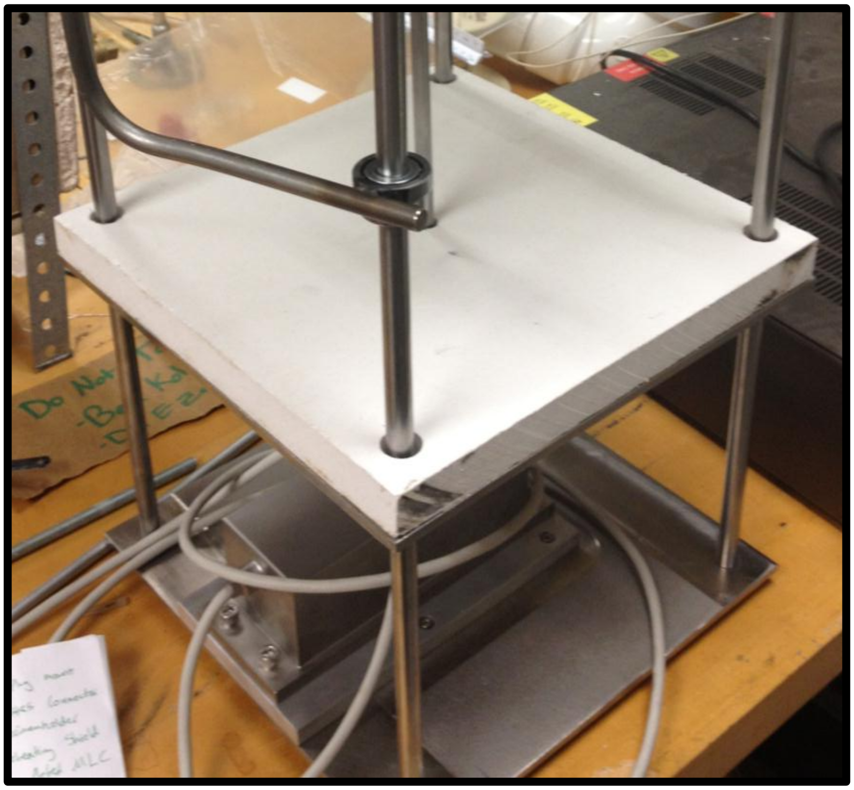


Figure 16. Shielding on middle plate to protect load cell.

5.6 Heater Control System

One of the critical requirements of the project is that the conical radiant heater must supply uniform heat fluxes to the sample surface during experiments. Based on a review of the literature [11, 12, 13], as well as the team’s own estimated calculations (based on Equations discussed in Section 5.2.1, and depicted on the next page in Figure 17), the heat flux being supplied to the sample from the conical heater design presented in ASTM E1354 [4] is not entirely uniform. According to Dr. Ezekoye, once a sample is ignited, it stays at a relatively constant temperature of around 400ºC during combustion [7]. Making this assumption, along with the assumption that the heater is a black surface emitting at a maximum temperature of 1000ºC, the relationship in Figure 17 emerges.

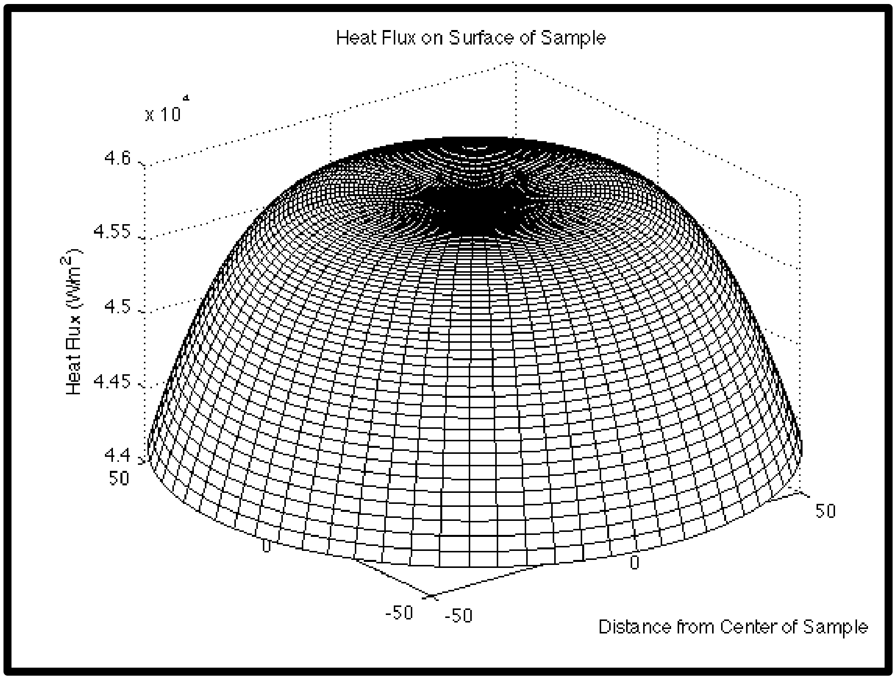


Figure 17. Radiant Heat Flux curve as a function of distance (mm) from the center of the sample surface. Plotted in the technical computing software MATLAB™.

As can be discerned from the plot, the predicted heat flux is not completely uniform over the sample surface. While the variation is small for lower heat fluxes (approximately 100W/m^2 for a specified flux of 10kW/m^2), the variation grows as the specified heat flux grows (up to approximately 400W/m^2 for a 40kW/m^2 setting); however, such a difference in variation is on the order of 1% of the total heat flux, and is not believed to impact the overall results of the fire testing experiments.

5.6.1 Temperature and Power Control

In order to provide these nearly-uniform heat fluxes to the samples, the heater needed to be controlled precisely and safely, via computer. The heater control system must monitor the temperature of the heater and adjust power to the heater to meet the specified temperature when given a specific set point. The team created a closed loop control diagram to show how the heater would be controlled to provide a constant heat flux based on the monitoring of the temperatures of the system. The group initially planned on using the PID control methods learned in LabVIEW from the Mechanical Engineering Department's dynamic systems and controls courses, coupled with a data-acquisition system (To be discussed in more detail in Section 5.7) and a solid state power relay to control the power being supplied to the heating coils [17]. However, safety concerns were raised associated with computer or software failures in the presence of high voltage equipment, so the team decided to purchase a temperature PID control system that would operate separate the computer system. Separating these two delegated the control of the heater to a dedicated device, reducing the risk associated with a heater burnout in the event of a computer freeze or crash.

The PID Temperature controller was purchased from Omega Engineering, a model CN8241. The most important features that the team looked for in the product were the remote setpoint and ability to output a 4-20mA signal [18]. The remote setpoint will allow for the heater temperature to be set by the computer, without any user interaction, satisfying the sponsor's design requirement of the device being as automated as possible. The CN8241 also offers manual temperature control of the heater through a front panel accessible to the user, if desired. The 4-20 mA current output signal from the CN8241 is a common signal that is used by many different power relays from various manufacturers. For the power relay, the group ultimately decided on a 30A Phase Control Power Relay from USA Shinko. While a 5000W heater running on 240VAC would only consume around 20A, the group purchased a 30A relay so that heater upgrades could be made more effortlessly if required at a later date.

5.6.2 Control Tower

The PID temperature controller and the power relay run off of the high 240VAC voltages, and needed to be safely isolated from users while still remaining operational and accessible for manual heater control. The team discerned that a control box was necessary for these requirements; it would need a main power switch for total user control of the high voltage operations, a switch to delegate manual/automatic control, as well as accessible fuses for the internal components. The power relay, as a result of being a high voltage/high amperage device, gets very hot under normal operation. To prevent overheating, a 240VAC computer fan was needed to provide adequate airflow for the internal components. A wiring diagram is shown below for reference in Figure 18 [19].

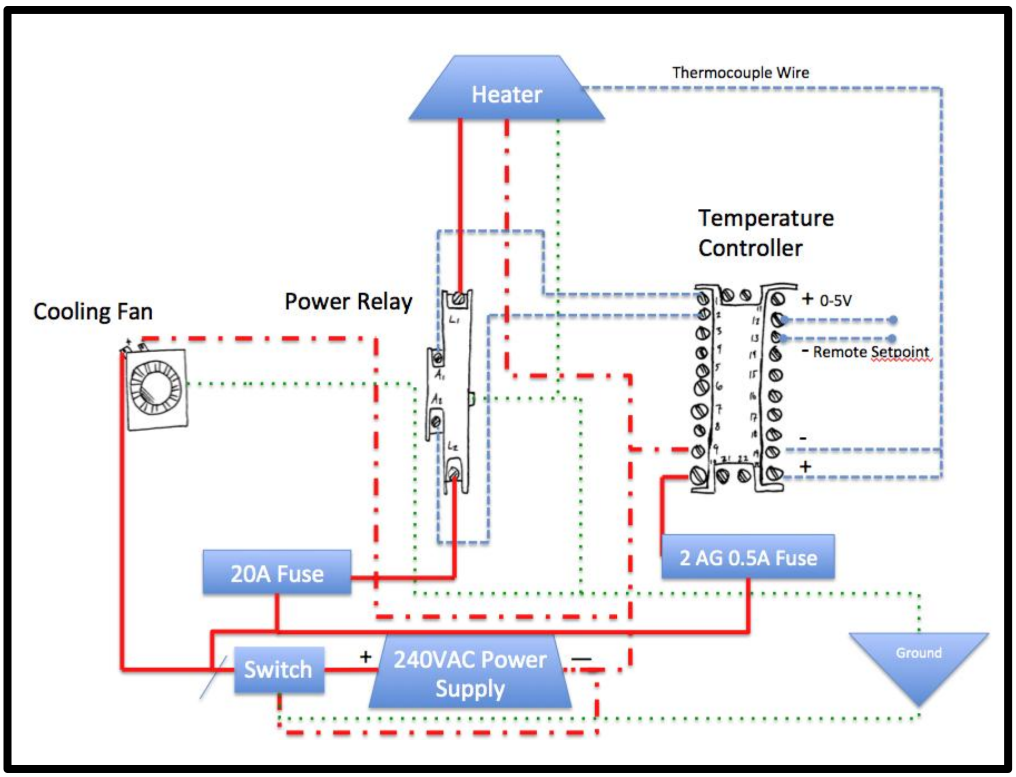


Figure 18. Heater Controller wiring diagram.

In this diagram, the red bolded solid lines are hot AC power lines, the red dot-dashed lines are return AC power lines. Blue dashed lines are signal wires, and green dotted lines are ground wires. To facilitate construction and maintenance, a large control tower (Personal Computer case) was chosen to house the temperature and power controllers, as well as the switches and fuses. During initial construction, it was thought that the spark ignitor controls (To be detailed in Section 5.8) were also going to be incorporated into the tower, which would inhabit the extra space. However, it was later decided that the spark ignitor should be available for other projects, and was separated from the heater control tower.

The wiring to the temperature controller was completed before any other components. This was to ensure that the temperature controller could be programmed in the proper units and inputs (Display in Kelvins, Input K-Type Thermocouple). This also ensured that the Remote Analog Setpoint parameters could be specified before the heater was actually hooked up to any power. Instructions for how to program the temperature controller are included in the Omega documentation that arrived with the controller [20].

After programming the temperature controller, the rest of the wiring was completed and the box was assembled. Due to the high voltages involved for the components, the signal wires were electromagnetically shielded using a metal conduit, so that no noise or erroneous temperature settings or measurements would occur. A photograph of the control box is shown below in Figure 19.

Figure 19. Control Tower operational. PV number represents Present Value for heat temperature. SV number represents Set Value for heater temperature.

5.7 Data Acquisition and Programming

For this project, Dr. Ezekoye is providing a USB-interface data acquisition system made by National Instruments (NI USB-6225), shown below in Figure 20 [21]. This particular board has more inputs and outputs than is required for this particular project (80 inputs, 2 outputs) [21].

Figure 20. NI USB-6225 [21].

The setup for this project required significant design centered around a LabVIEW™ oriented program, especially considering the requirement for the operation to be customizable. For this design, the group utilized a functional diagram to determine how information would flow through the overall system, highlighting what LabVIEW™'s role would be. The functional diagram can be seen below in Figure 21.

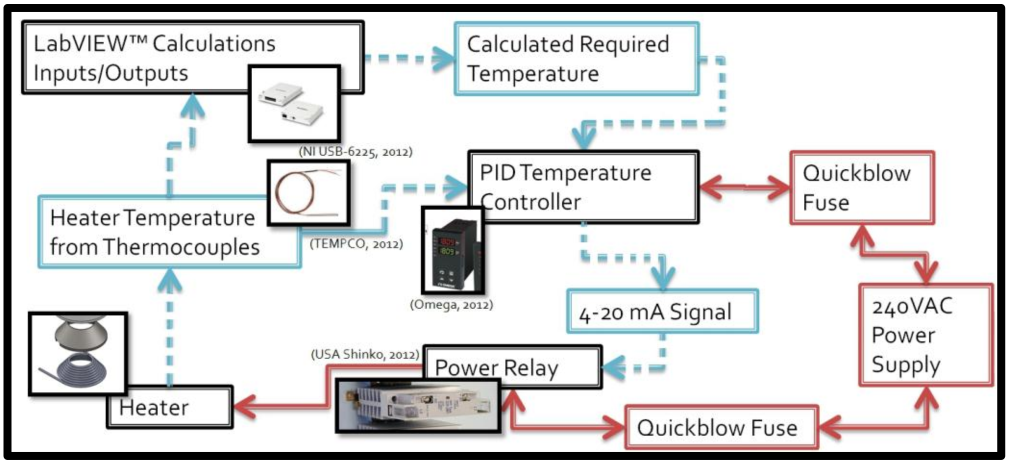


Figure 21. Functional diagram for LabVIEW™ programming.

Blue dashed lines are information, red bold lines are power, and the black outlines are for hardware components. This functional diagram was created based on a scenario in which the user requested a constant heat flux on the fire testing sample. According to Equation 5.1 (reproduced below for convenience), as the sample increases in temperature, the heater will have to also increase in temperature by a specific amount so as to maintain the specified heat flux on the sample for the experiment.

$$q" = F\epsilon\sigma(T_c^4 - T_w^4) \qquad \text{(Eq 5.1)}$$

By calculating the heater temperature, $T_{C,}$ required to maintain a constant flux, *q"*, based on a live feed of the sample temperature, $T_{W,}$ the control system can send the remote analog signal for T_C to the temperature PID controller, which will adjust the heater to the new required temperature. Based on this scenario alone, the LabVIEW™ program needed to constantly perform calculations and send information to the temperature controller. The team determined at that point that the program would need to run on a loop that executes with a high enough frequency to maintain good control of the heater, but a low enough frequency that the computer would have time to perform the heat flux calculations required of it. Designing the program to calculate the flux at every iteration allows for the user to alter the flux calculation methods with little effort.

The system also needed to be robust and have safety features in place so that the control system would not overshoot the heater and damage it. If there is such an overshoot, a quick-blow fuse will protect the equipment from damage.

5.7.1 LabVIEW™ VI Operation

The driving factors for design decisions regarding the LabVIEW™ VI have been to reduce troubleshooting, acquire and record all data, and to simplify calibrations. While the literature often calls for a constant heat flux to be subjected to a fire testing sample [12, 13], in planning the LabVIEW™ program, the team decided to incorporate two different modes of operation into the control system: constant heater temperature and constant heat flux. By including both of these modes, calibration procedures and troubleshooting were made simpler. In addition to various modes of operation, the team decided that every raw input voltage, constant, shape factor, and temperature would be saved to a measurement file during experiments. This will allow the user to manipulate data independently of the program and have a record of the raw data from experiments.

The VI uses the NI-DAQmx drivers to communicate with the USB-6225 and runs inside a while-loop that can be terminated at any point during an experiment. All of the data streams are labeled using the Set Dynamic Data Attributes VI for identification in the Comma Separated Value (CSV) file post-experiment. The shape factor calculations, the emissivity calculations, the heat flux calculations, and the required heater temperature calculations are all located in Formula Nodes. Data is recorded on a voluntary basis (determined by the user); when it is recorded, the VI uses a conditional node to prompt the user where to save the CSV file. The VI uses conditional comparison VIs throughout the block diagram to select the operation modes based on user inputs into the front panel. The NI-DAQmx outputs, which go to the temperature controller, are coerced to values between 273K and 1073K — the control system will never allow the heater to be set to a temperature above 800ºC, the max temperature of the heating element. A screenshot of the current incarnation of the front panel is shown below in Figure 22.

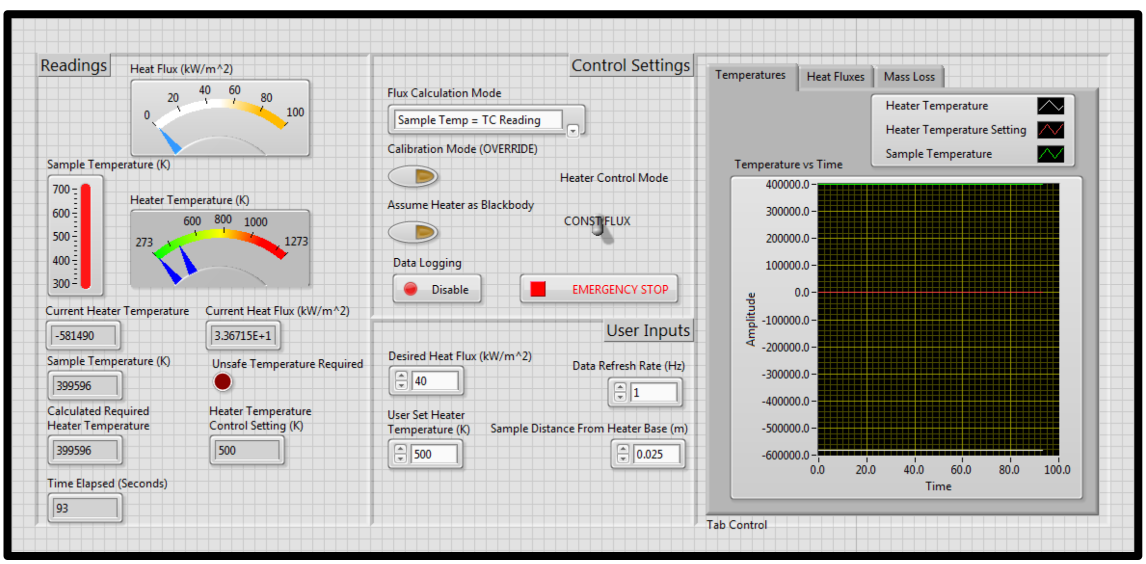


Figure 22. Front Panel of LabVIEW™ control VI.

In addition to temperature readouts for the sample and the heater (given in both numerical and graphical form), the front panel displays the estimated heat flux on the sample, the temperature setting being output by the formula nodes, as well as a warning indicator informing the user when an unsafe heater temperature is required to achieve a specified heat flux. Under the Control Settings section, the user can select methods to calculate the heat flux on the sample (For example, should the sample be considered 0K, 300K, or the sample thermocouple reading?). An option for a user to input a calibration curve from the heat flux meter is also available. The user can also tell the system whether or not to treat the heater as a blackbody for its flux calculations. The control method for the heater can toggle between CONST FLUX and CONST TEMP. Under the user inputs section, the user can input the desired heat flux (for CONST FLUX operation) or the desired temperature (for CONST TEMP operation), in addition to the data refresh rate in Hz. The team recommends running the VI at 1Hz unless greater load cell accuracies are required. The user has the option for inputting the sample distance from the heater base, which influences the result of the shape factor (Equation 5.2). The literature standard is 25mm [4, 12, 13], but this can be adjusted for other experiments.

5.7.2 Load Cell Programming

While the load cell came with free software from HBM in order to set up the parameters for the experiments, there were significant challenges in order to get the device to function. This software provides the abilities to calibrate the scale, select bus address and baud rate, enter four limit values including hysteresis, and graphically view the results of an experiment. It also includes filtering options to isolate and control noise in the outputted data.

However, the load cell communicates through a digital signal due to its high accuracy requirement. The Mechanical Engineering curriculum at UT Austin does not offer extensive training in digital data communication, so the team required some extra time to learn and understand how to transfer data from the load cell to the computer. The digital interface also offers great robustness against electromagnetic interference, which is present in the high voltage heating system.

The HBM load cell also communicates through an RS-485 interface, which is a digital serial communications standard. Most modern computers, especially portable ones belonging to students, do not have RS-485 or RS-232 serial communication ports, so an adapter was necessary to convert the RS-485 serial communication interface to a Universal Serial Bus (USB) interface. For this purpose, the team purchased a USB-RS485 Adapter from National Instruments, and installed NI-Serial software which came with the adapter. This adapter consists of a male USB connector and a female DB-9 connector. This combination of hardware and software "tricks" the computer into believing that the USB port is now a COM port used for serial communication, and the load cell can now communicate with the computer.

The wiring from the load cell, however, does not arrive with a DB-9 connection. The team had to split apart the cable and solder the connections to a DB-9 male connector based on the wire diagram below in Figure 23, reproduced from the HBM documentation [22]:

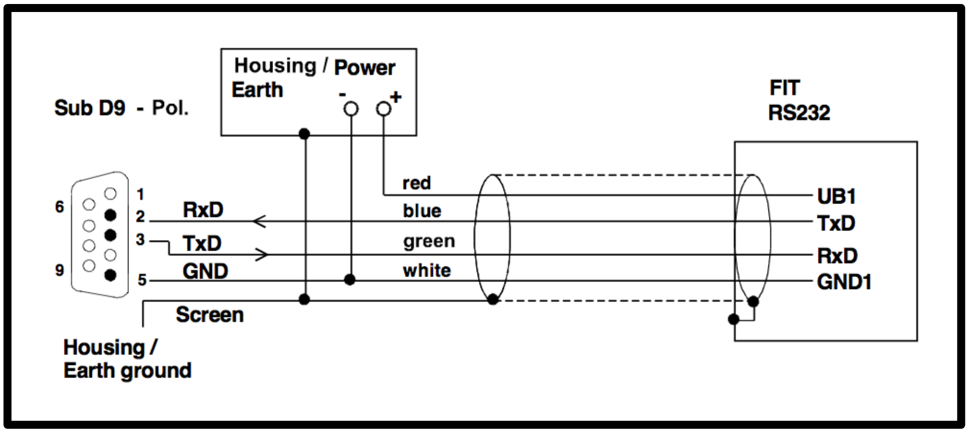


Figure 23. Load cell wiring for RS232 connection [22].

The diagram listed in the documentation is for an RS-232 connection, but the RS-485 connection is very similar. In the wiring according to Figure 23, the computer shares a ground with the load cell and the power supply, which is crucial according to the FIT/1 manual [22]. The manual also stipulates that the load cell power supply be between 10 and 30 DC volts. The team had initially planned to use Dr Ezekoye's NI USB 6225 DAQ board to supply 10 volts of power to the load cell, because the National Instruments DAQ devices can produce incredibly steady voltage outputs. However, when completing the wiring, it was discovered that the DAQ could not provide enough power to the load cell to activate it. Power was supplied to the load cell using a separate, dedicated 13.8V, 3A power supply. At this point, the software for the load cell supplied from HBM recognized the Fit1 Load Cell, and was able to retrieve some information from it. A screenshot of the software GUI is shown below in Figure 24.

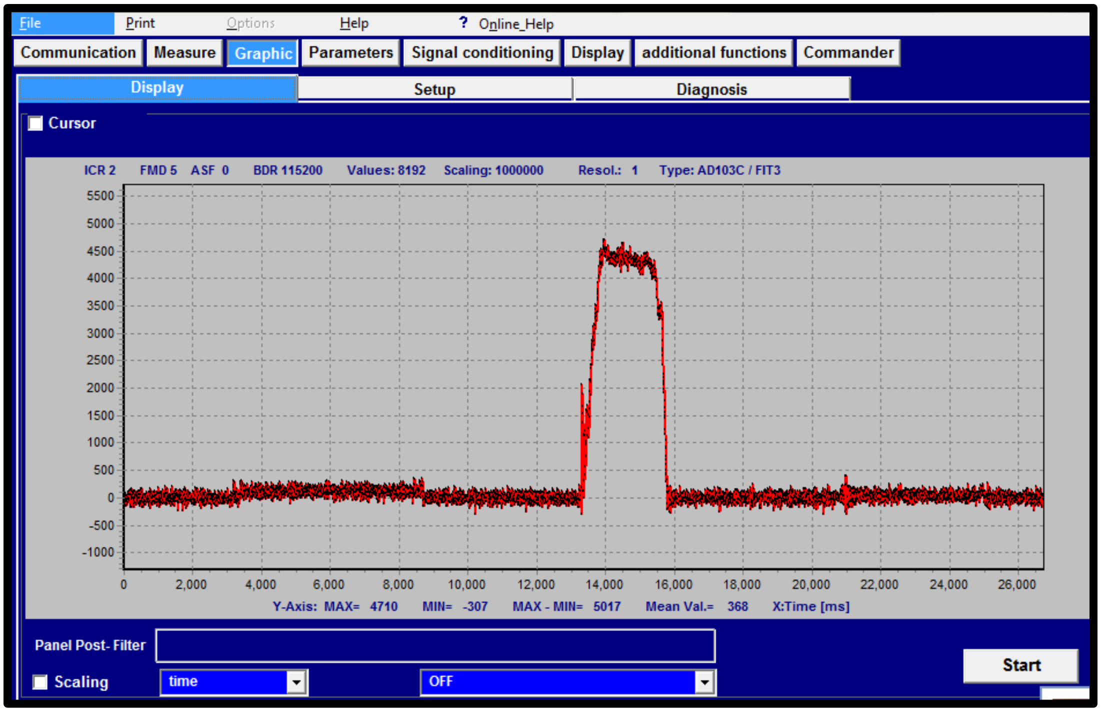


Figure 24. Load cell GUI using HBM software. The spike corresponds to a weight being placed on the load cell and then taken off.

Figure 24 depicts the response of the load cell over time to a weight being placed on it, and then taken off. It is clear that there is some noise in the data and that some signal processing will be required to get good data. At the moment, the team has not yet implemented a software solution to carry the data from the load cell into the LabVIEW™ VI; some advanced serial communication protocols will be required (the load cell uses the UART protocol), and the researchers may opt to use the HBM software to separately record the load cell data. The HBM software includes signal conditioning functions, settings, and measurement options which would have to be reverse engineered and reconstructed in order to function completely in LabVIEW™, a process that could take a lot of time and effort.

5.8 Spark Ignitor

A spark ignitor was constructed to start the combustion of samples being tested by the MLC. This will allow the experimenter to record data, such as time of combustion, for various samples. Initiating the combustion process is where the mass loss of the sample begins. From this point on during the experiment, the recorded mass loss data will be used to find the heat release rate. The spark ignitor uses an automotive spark generator to generate a 10kV spark at 80Hz. Initially, a spark ignition circuit used by the UT Formula SAE (Society of Automotive Engineers) team was going to be constructed to generate a spark above the sample. After contacting an expert electrical technician [23], it was determined that an ACDelco ignition coil and spark plug could be used to generate the spark. This setup would provide a consistent and controlled spark. A circuit diagram for the spark ignitor can be seen in Figure 25 below.

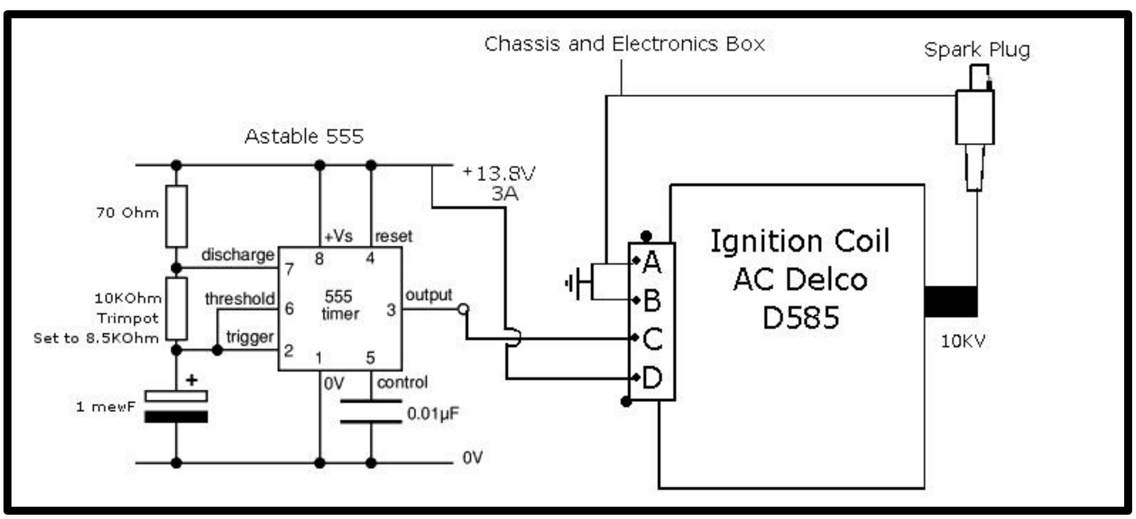


Figure 25. Spark ignition circuit diagram.

An astable 555 timer was used to ensure proper charging and triggering of the spark ignition coil. After researching ignition coils, it was determined that the ignition coils will need 6 milliseconds to charge [24]. The 555 timer characteristics were tuned to have a 6 millisecond charge time and a 6 millisecond discharge time (50% duty cycle) [25].

The mounting bracket for the spark ignitor consists of a bearing, shaft collar, and stainless steel rod. The spark ignitor bracket allows the user to rotate the spark plug over the sample and trigger the spark ignitor. A nylon handle was fitted to the end of the spark ignitor to allow the user to easily swivel the ignitor in place. Figure 26 below shows the mounting hardware for the spark ignitor.

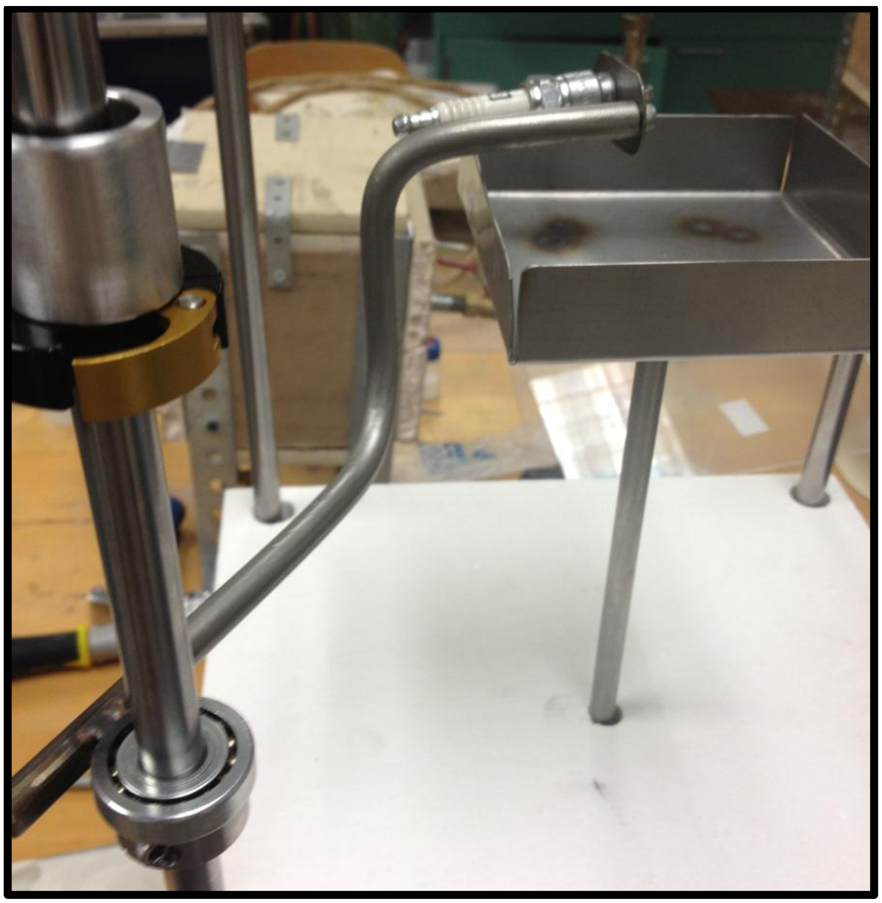


Figure 26. Spark ignitor mounting hardware.

5.9 Exhaust Hood

Since Dr. Ezekoye is not interested in smoke density or corrosion measurements, the design of the exhaust system for this project is allowed to deviate from the ASTM E1354 standard by a much greater amount than many of the other components in the calorimeter. The exhaust vent attaches to the top of the MLC via a flange. This flange is attached to the top of the heater assembly mount using the four compression bolts that keep the heater assembly together. The flange is made from 8 inch diameter steel ducting that is used in home construction. This ducting was used to ensure that the flange could attach to the 8 inch vent opening in the ceiling of the laboratory. Figure 27 below is a picture of the attached exhaust hood flange and laboratory exhaust vent.

Figure 27. Left: Exhaust hood flange attached to the MLC.
Right: Laboratory exhaust vent.

6 FUTURE WORK

This section will discuss the components of the MLC that still need to be constructed and implemented in the final design. These components are not likely to be completed by the end of the semester or by the time this report is submitted for completion. The remaining components are not enough work to necessitate another K project; as such, it is the opinion of the team that Dr. Ezekoye's graduate students will be able to tie up any loose ends in the project. It should be noted that all of the hardware and wiring for the MLC is complete and ready, and all relevant purchases have been made; all that remains is the integration of the load cell software with the rest of the system, as is discussed in the following sections.

6.1 Heat Flux Meter

Some background research was conducted regarding what kind of instrument would be necessary to calibrate the heat flux data for the MLC. The parameters defined by ASTM E1354 eliminated all but the high-temperature meters that were selected as a feasible option. After meeting with Dr. Ezekoye, it was decided that a heat flux meter from a previous experiment would be sufficient for this project. Although the ASTM standard stipulates that the heat flux meter be water cooled [4], Dr. Ezekoye has since indicated that this is not necessary for his specific heat flux meter to get accurate measurements [26]. The heat flux meter in question uses two thermocouples on either side of a plate from which data is recorded and analyzed post-process in a finite element analysis (FEA) MATLAB routine. The recursive nature of FEA precludes the possibility of using the heat flux meter to calibrate the heater within the main LabVIEW™ routine.

The team expects that the heat flux meter can be used in a calibration run of the heater, the data can be processed to reveal the heat fluxes, and a calibration curve can be generated to be put into the main LabVIEW™ VI for controlling the heater.

6.2 Load Cell

The load cell is powered and communicating with the computer software. The only work left is to calibrate the load cell and then integrate the data with LabVIEW™. Also, the HBM software provided will need to be further investigated since it is not very intuitive, but it has many applications that will allow the operator to adjust the load cell dependent on the application. It is understood so far that the load cell can be commanded using ASCII commands, and that the filtering and noise reduction functions are complex. The help files provided with the HBM software are an excellent resource, and the team will be sure to provide adequate directions to Dr. Ezekoye's students on where to look for this information and how to use it.

6.3 Exhaust Hood

The last task to complete concerning the exhaust hood is to connect the flange from the MLC to the vent duct in the ceiling. This will be accomplished once the MLC is positioned in its final location in the laboratory.

6.4 Testing and Calibration

Once the MLC is constructed and operational, a protocol will need to be developed for how an operator should run the device to conduct fire tests and extract the data. More importantly, the device will need to be kept in regular calibration, so that the data yielded is consistent and reliable. The team is anticipating that the calibration method will be as follows: First, the user will calibrate the heat flux meter or have it professionally calibrated. Once the heat flux meter is calibrated, the team will use it to correlate the thermocouple temperature readings with the heat flux meter. This will allow the user to monitor heat flux rates based on temperature readings rather than a heat flux meter, which will not be able to operate reliably in a combustion environment. Samples can now be tested and data recorded.

A more thorough experimental procedure will need to be established once the MLC software is completed.

7 CONCLUSION

The team has completed all of the necessary hardware requirements for a functioning mass loss calorimeter at one quarter the cost of a commercial MLC [7]. This includes the chassis, heater element, heater shielding, preheating shielding, load cell, control box and spark ignitor. All of the hardware and software components meet the stated requirements and constraints in sections 3 and 4 above. The final step in completing a working MLC is to have the load cell integrate with the current LabVIEW program. After completing the hardware and software components of the MLC, calibration and functionality testing will be required. The calibration will be used to determine the link between the heat flux specified and the coil and sample temperatures. It will also be necessary to calibrate the load cell with class 3 weights to increase the accuracy of the system. Next, functionality tests will be run to ensure that the heater control and load cell are operating as expected. This can be done using a material with a known HRR value. This will give a comparison point to confirm that the system is producing consistent fire hazard data. Once this is completed, the calorimeter will be able to determine the mass loss versus time as the sample is heated, and in turn the important heat release rate value for any desired samples.

In order to build upon the design, the team will leave the option of adding a controlled atmosphere wind tunnel to the mass loss calorimeter. This will allow variables to be further isolated to obtain more data variations. Additionally, the exhaust duct may be substituted for one that collects data on the exhaust gases from the combustion process. This design avenue is left open to Dr. Ezekoye and his research team, pending their need for exhaust analysis.

Over the course of this semester, the team effectively used design methods to create a solution to an open-ended engineering question. Through cohesive teamwork and creative problem solving, a highly complex system was engineered to provide the fire science department at the University of Texas a productive research apparatus. The team believes that the MLC will provide researchers the ability to create materials less susceptible to fire hazards to be implemented into consumer and industrial products.

REFERENCES

1. Ofodike A. Ezekoye. (n.d.). Retrieved January, 2012, from The University of Texas website: http://www.me.utexas.edu/~ezekoye/

2. V. Babrauskas et al., "Heat Release Rate: The Single Most Important Variable in Fire Hazard," Fire Safety Journal 18 (1992) 255-272.

3. Babrauskas, V., 1993, "Ten Years of Heat Release Research with the Cone Calorimeter," Heat Release and Fire Hazard, 1, Building Research Institute, Tsukuba, Japan.

4. Standard Test Method for Heat and Visible Smoke Release Rates for Materials and Products Using an Oxygen Consumption Calorimeter. (ASTM E1354 – 11b, n.d.).

5. MASS LOSS CALORIMETER ISO 13927. (n.d.). Retrieved January 25, 2012, from Laborund Analysen-Technik GmbH website: http://www.latonline.de/index.php?option=com_content&view=article&id=132:mass-loss-calorimeter-&catid=41:brandtest&Itemid=81

6. FTT, Cone Calorimeter (2012). Retrieved January 28, 2012 from http://www.firetesting.com/cone-calorimeter-dual

7. Personal Communication with Dr. Ezekoye, February 8, 2012.

8. Grube, Kris W. Radiant Heating Apparatus for Providing Uniform Surface Temperature Useful in Selective Laser Sintering. DTM Corporation, Austin, TX, assignee. Patent 5155321. 13 Oct. 1992. Print.

9. Lyon, Richard E. Heat Release Rate Calorimeter for Milligram Samples. The United States of America as represented by the Secretary of Transportation, Washington, DC, assignee. Patent 6464391. 27 Jun. 2002. Print.

10. Howell, J. R., Siegel, R., & Mengüç, M. P. (2011). Thermal Radiation Heat Transfer (5th ed., p. 208). Boca Raton: CRC Press.

11. Greene, G., & Finfrock, C. (2000). Total hemispherical emissivity of oxidized Inconel 718 in the temperature range 300 - 1000°C. Experimental thermal and fluid, 22.

12. Huynh, V.C.M., 2003, "Flame Spread Measurements Of New Zealand Timber Using an Adaptation Of The Cone Calorimeter Apparatus", Master's Thesis, University of Canterbury School of Engineering, New Zealand.

13. Wilson, M.T., Dlugogorski, B.Z., Kennedy, E.M., 2002, "Uniformity of Radiant Heat Fluxes in Cone Calorimeter." Process Safety and Environmental Protection Group, The University of Newcastle, Callaghan, Australia, 7th Symposium in Fire Science in Worcester, USA

14. Hotwatt, Tubular Heaters: Straight and Formed. Retrieved March 25, 2012 from http://www.hotwatt.com/tastraight.htm.

15. Ben, J. (2012, April 25). ASB1-41866_SPIRAL_SPRING_U_OF_TEXAS_AUSTIN [Electronic mailing list message]. Retrieved from Personal Email

16. Hattinger Baldwin Messtechnik GmbH, FIT/1 Data Sheet (B1712-2.0 en).

17. University of Texas at Austin, August 2010, Undergraduate Catalog 2010-2012, pp.232

18. Omega Engineering, ⅛ DIN Vertical and ¼ DIN Universal Input Temperature/Process Controllers, P-61 - P-62. Retrieved March 25, 2012 from http://www.omega.com/pptst/CN8240_CN8260.html

19. USA Shinko, Single Phase Power Controllers. Retrieved March 25, 2012 from http://www.usashinko.com/FPT

20. Omega Engineering, "CN8240 & CN8260 Series Temperature and Process Controllers: User's Guide." 2004.

21. NI USB-6009. (2012). Retrieved February 13, 2012, from National Instruments website: http://sine.ni.com/nips/cds/view/p/lang/en/nid/201987

22. HBM, "FIT Digial Load Cells User Manual: Hardware and Functions; RS232 / RS485 4-wire interfaces (UART)." p. 41.

23. Personal Communication with Mark Phillips, April 12th, 2012.

24. Draper, D. (2005). *Electronic Ignition Capacitive Discharge Ignition (CDI) Transistor Controlled Ignition (TCI)*. Retrieved April 26, 2012, from http://www.jetav8r.com/Vision/Ignition/CDI.html

25. Hewes, J. (2011). *555 and 556 Timer Circuits*. Retrieved April 26, 2012, from The Electronics Club website: http://www.kpsec.freeuk.com/555timer.htm

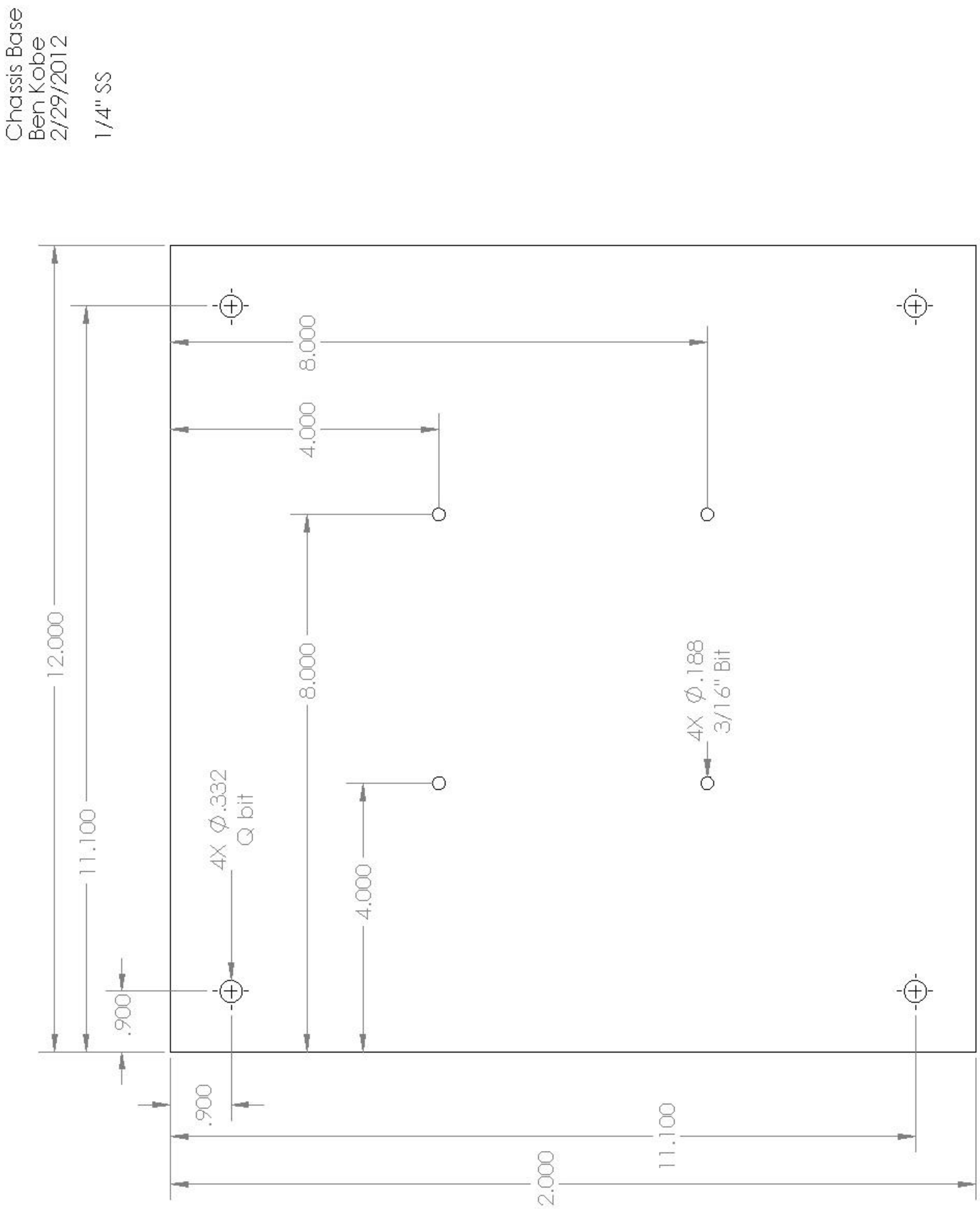
26. Personal Communication with Dr. Ezekoye, April 18th, 2012.

APPENDIX A: Budget

MLC Part	Description	Vendor	Part#	Quantity	Price/unit	Total
Vertical guides rails	24" long, 1/2" D smooth rod with threaded end, 5/16"-18 thread	McMaster	8350t91	4	$ 52.34	$ 209.36
Guide bearings on heater top	Vertical axis, 1/2" D, self lubricating, .0015" clearance	McMaster	64825k11	4	$ 59.51	$ 238.04
Guide lock to keep steady height	Quick unlock guide lock	McMaster	1511k12	4	$ 17.72	$ 70.88
Lock to keep mid plate secure	Screw actuated guide lock	McMaster	6435k34	4	$7.60	$ 30.40
Metal for heater mount top and bottom, chassis bottom	SS plate 1/4"x12"x12"	McMaster	6620k21	4	$81.49	$ 325.96
Vertical guide rail base nuts	5/16"-18 bolt, heavy, 100 count	McMaster	95045a030	1	$8.61	$ 8.61
Heater compression bolts	3.5" Length, 5/16"-18 full thread, 5 count	McMaster	92865a597	1	$4.31	$ 4.31
Bolts for guide bearings, heater centering screws	3/4" Length, 8-32 screw, 25 count	McMaster	92185a197	1	$ 4.09	$ 4.09
Nuts for guide bearings, heater centering screws	Square 8-32 SS nut, 100 count	McMaster	94785a009	1	$ 9.05	$ 9.05
Inner/outer shielding	1/4 hard, 12"x36"x.029"	McMaster	1217t23	1	$56.16	$ 56.16
Shipping						$ 36.12
McMaster Order 0215BKOBE (20447100)					**TOTAL**	$ 992.98
Insulating board	1" Thick Calcium Silicate, 12"x12"	McMaster	9353k33	2	$17.97	$ 35.94
Sample Stem	3/8" D x 12" L ss Rod	McMaster	9200k121	1	$10.85	$ 10.85
Adjustable rod mount	2.5" D x 3" AL	McMaster	1610T61	1	$14.42	$ 14.42
Load Cell Mount	5"x12"x.5" AL	McMaster	8975k436	1	$21.94	$ 21.94
Load cell mount screw	3/4" L 5/16"-18 SS bolt	McMaster	92185a581	1	$6.26	$ 6.26
Adjustable rod screw	18mm M6 screw	McMaster	92290a323	1	$6.45	$ 6.45
Shipping						$ 12.23
McMaster Order 0320BKOBE (2696255)					**TOTAL**	$ 108.09

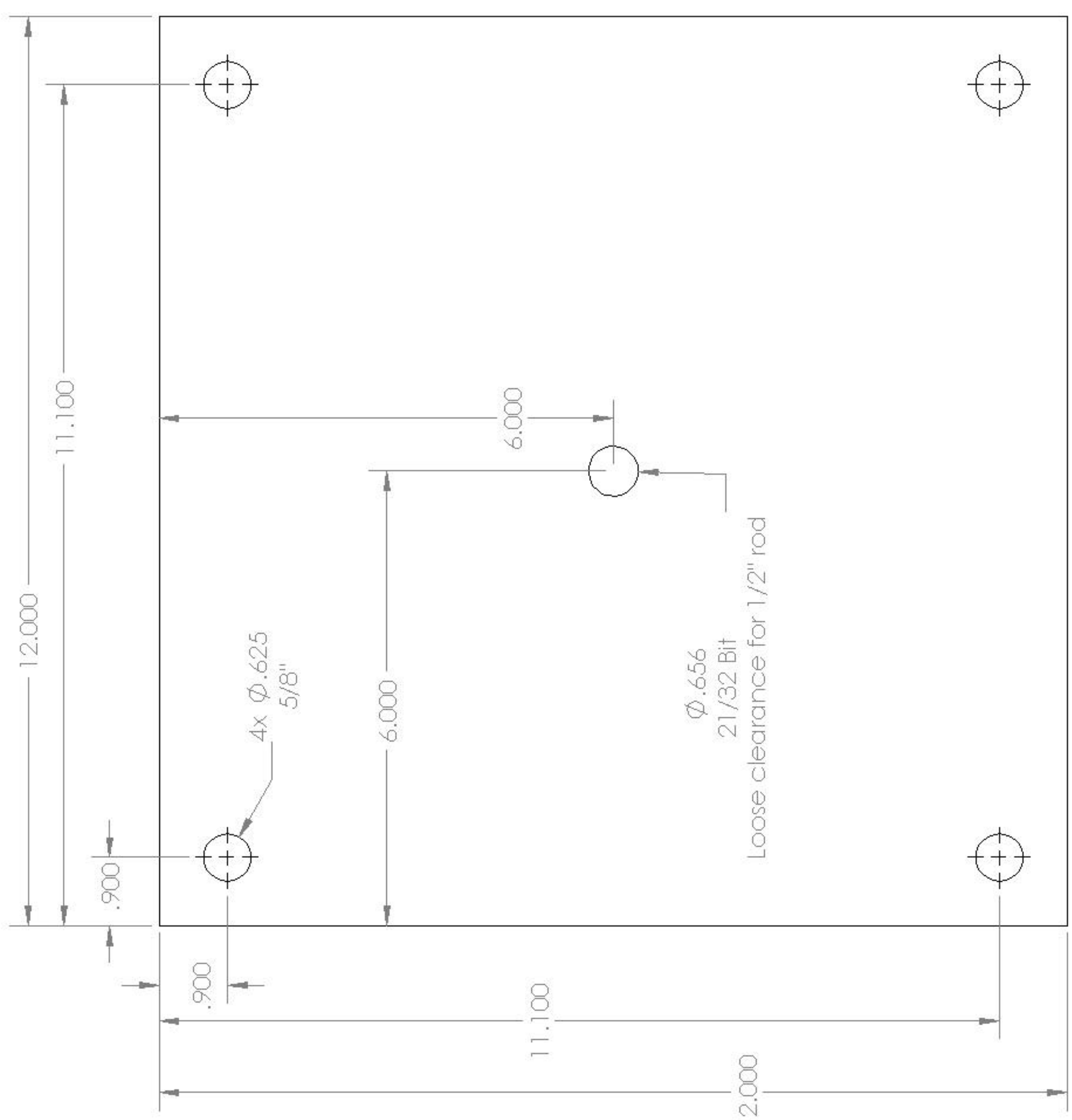
Temperature Controller	Remote Setpoint, 240VAC	Omega Engineering		1	$414.00	$ 414.00
Power Controller/Relay	>20A, 240VAC	USA Shinko		1	$260.85	$ 268.65
Load cell				1	$1,000	$ 1,014.00
CNC Machining						$ 450.00
Drawer Slides for radiant heater	Radiant heater shield	McMaster	12155a22	1	$29.14	$ 29.14
Heater Shielding	SS, 1/4 hard, 12"x36"x.029"	McMaster	1217t23	1	$56.16	$ 56.16
Spark ignitor rod	3/8" SS Rod x 12"	McMaster	9200K121	1	$10.85	$ 10.85
Shaft Collar for spark ignitor	1/2" Clamp	McMaster	6435k34	1	$7.60	$ 7.60
Bearing for collar	1/2"	McMaster	6383K39	1	$6.08	$ 6.08
Shipping					$17.05	$ 17.05
McMaster Order 0404BKOBE					**TOTAL**	$ 126.88
Ceramic packing fiber	Free				$ -	$ -
Heating Elements	ASB Heating			2	$269	$ 613.58
Heater Thermocouples	K Type	Omega Engineering		3	$37	$ 109.50
Shipping				1	$10	$ 10.00
Spark Plug / Insulation		O'Reilley's Auto				$ 22.98
Spark Plug Holder Welding		ME Shop				$ 60.00
Wiring/Switches/Plugs	Control Box Parts	Home Depot		1		$ 135.01
USB RS485 Adapter	Single Port RS-485-USB	National Instruments				$ 151.73
Spark Ignition supplies	555 electronics and coil	Frys, Radio Shack, O'Reiley's Auto Parts				$ 138.31
Enclosure/Fuses	Control Box Parts	Fry's Electronics		1		$ 33.97
Spark Ignitor Power Supply	3A, 13.8V	Radio Shack				$61.18
Wiring	Heater element wiring and spark ignitor	Home Depot				$31.53
					TOTAL	$ 4,742.39

APPENDIX B: Chassis



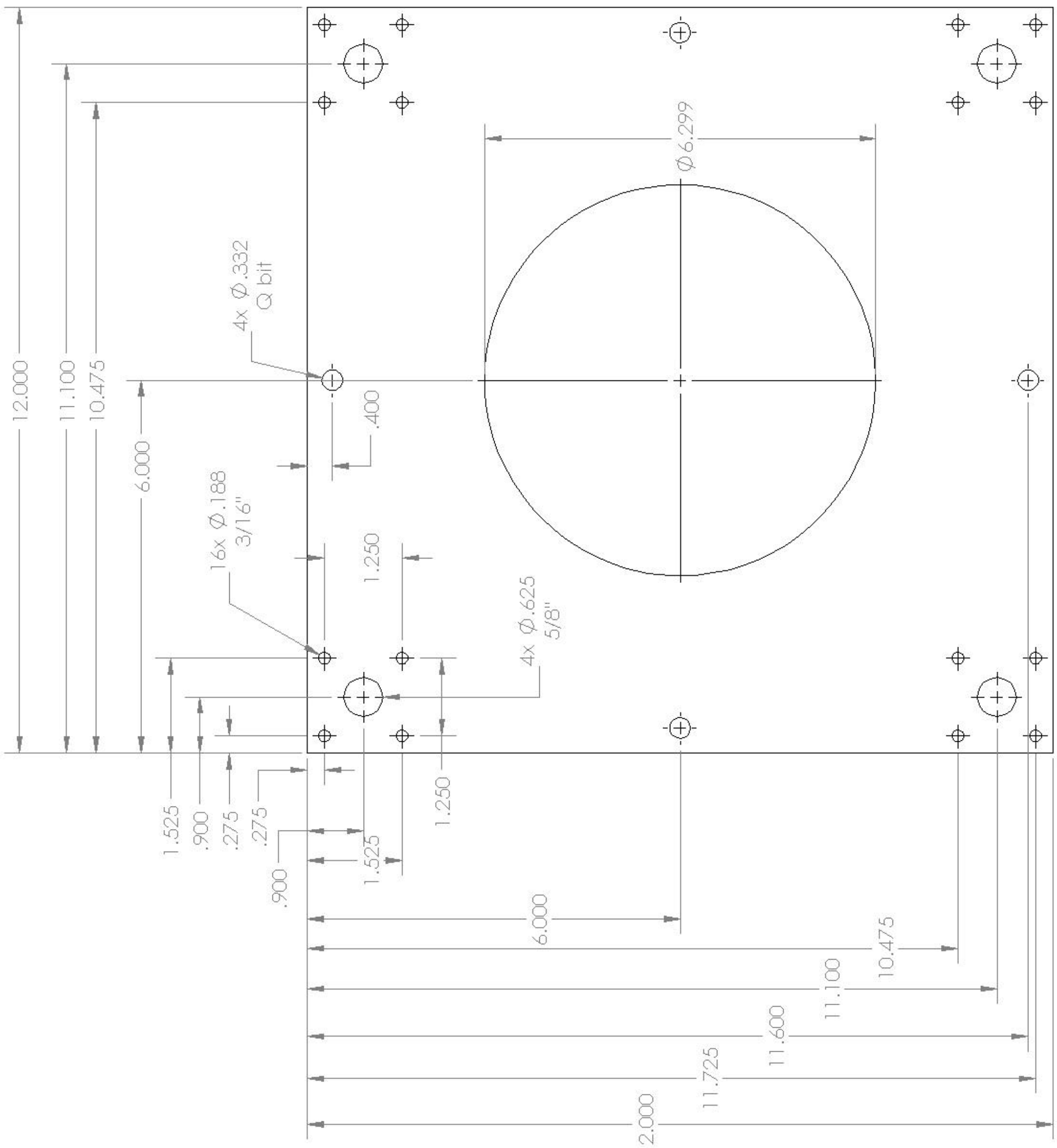
Mid Base
Ben Kobe
2/16/2012

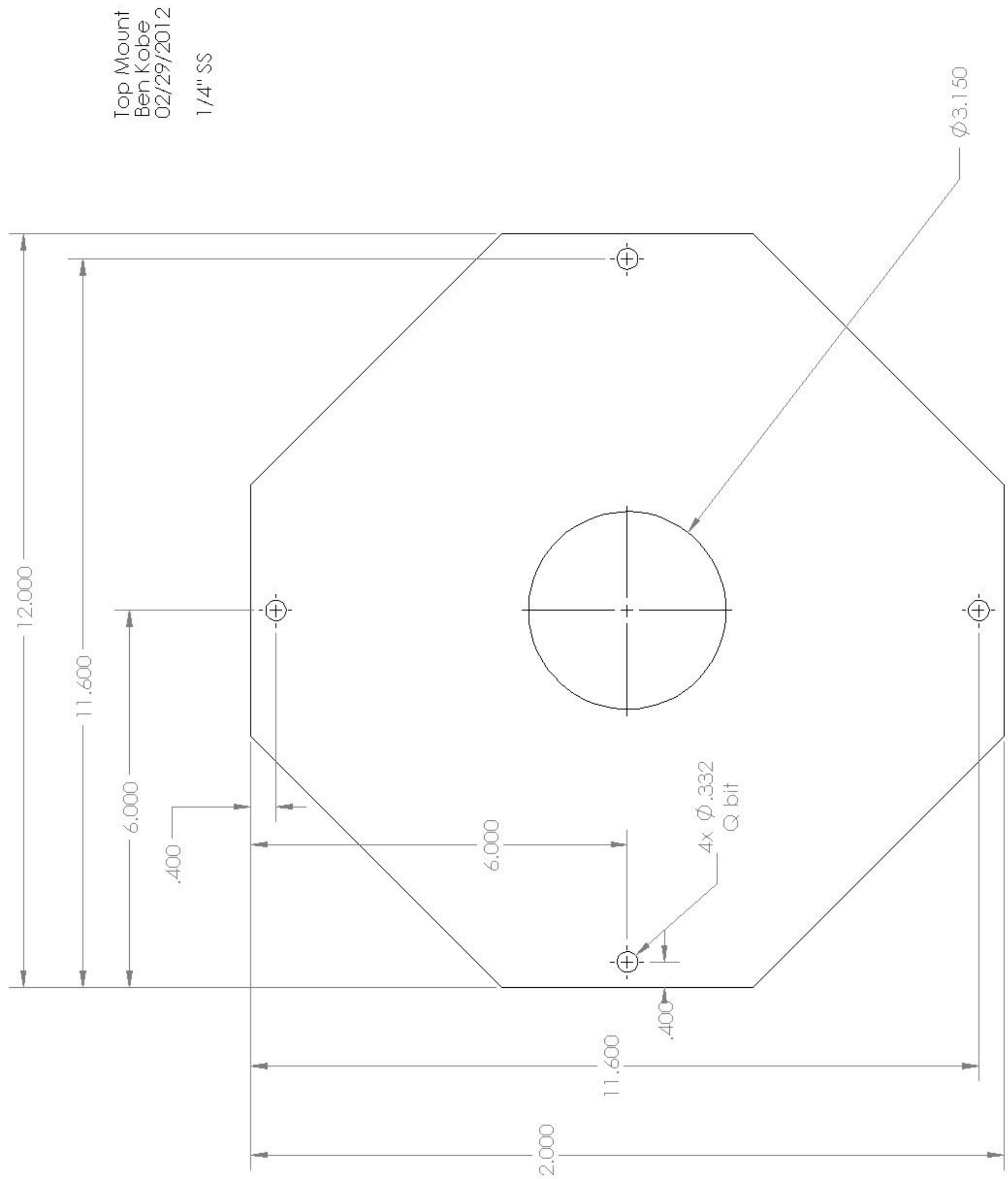
1/4" SS



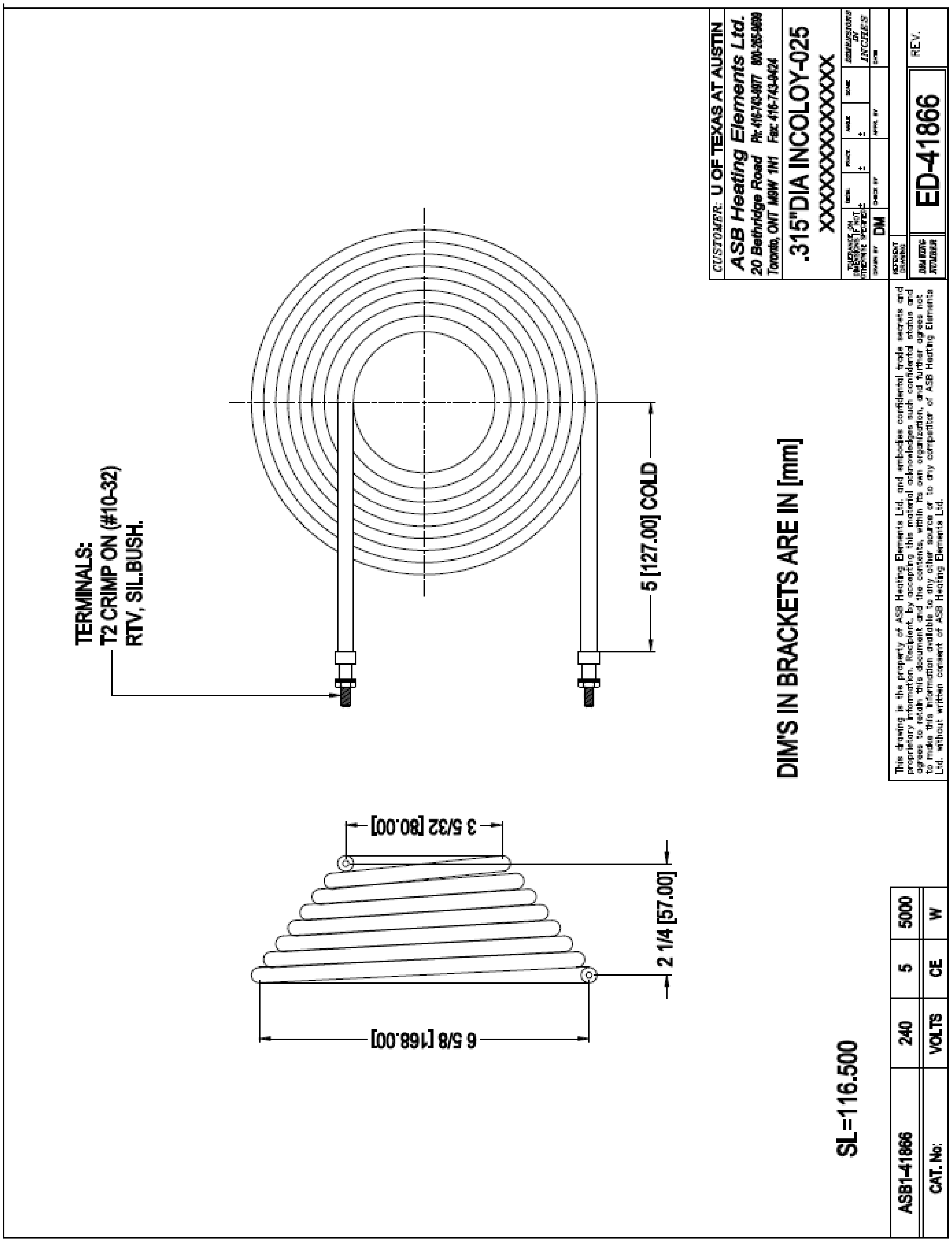
Bottom mount
Ben Kobe
2/29/2012

1/4" SS



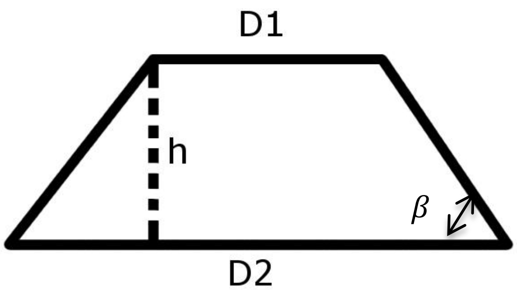

Top Mount
Ben Kobe
02/29/2012
1/4" SS
Ø3.150
12.000
11.600
6.000
.400
6.000
4x Ø.332
Q bit
.400
11.600
12.000

APPENDIX C: Coil



APPENDIX D: Shielding

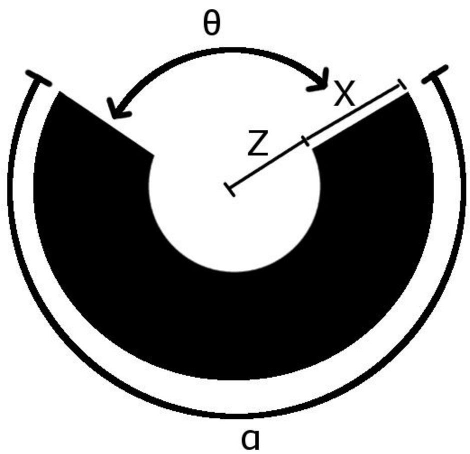
Inner Shielding



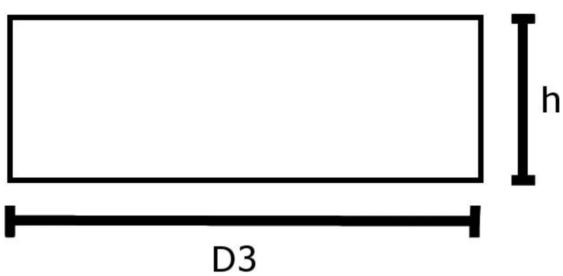
$$L_1 = \pi D1$$
$$L_2 = \pi D2$$
$$X = h/Sin(\beta)$$

$$L_1 = (2\pi - \theta)Z$$
$$L_2 = (2\pi - \theta)(Z + X)$$

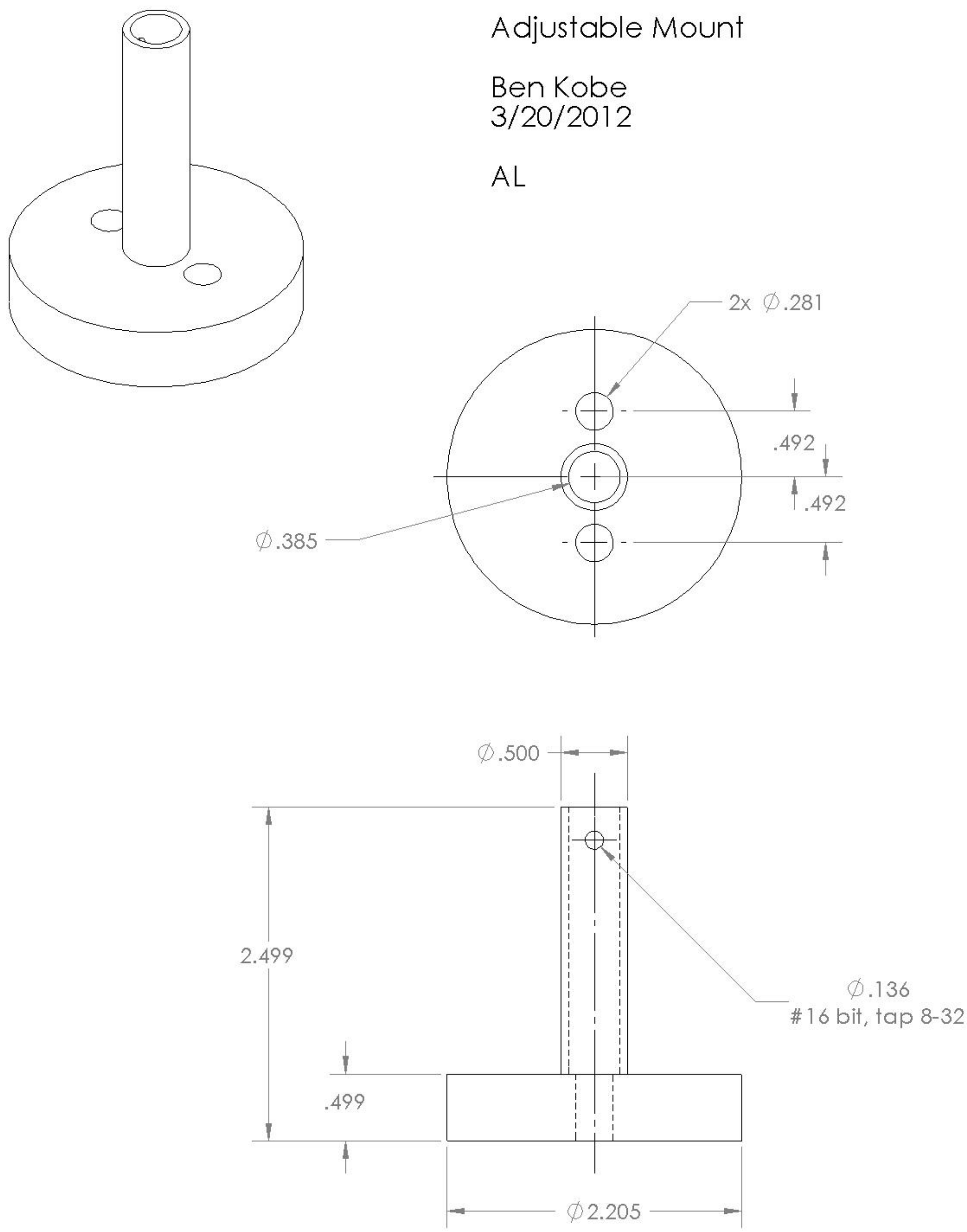
Solve for Z and θ

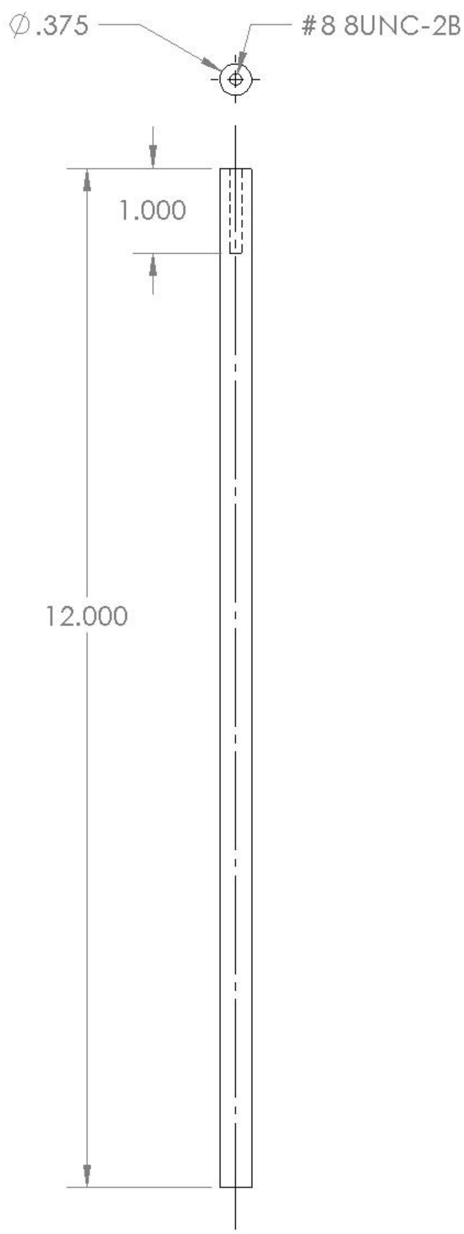


Outer Shielding



APPENDIX E: Sample Mount

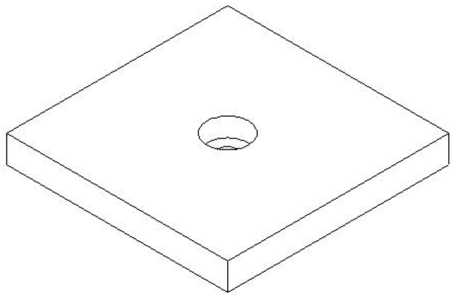




Through Rod

Ben Kobe
3/20/2012

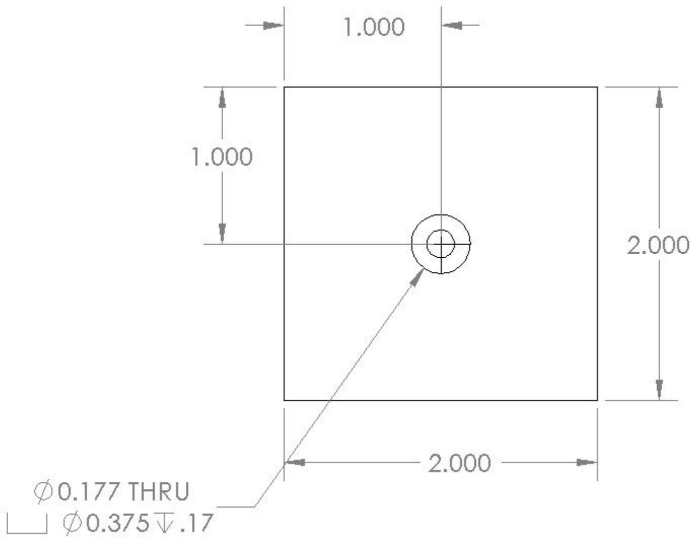
Stainless Steel

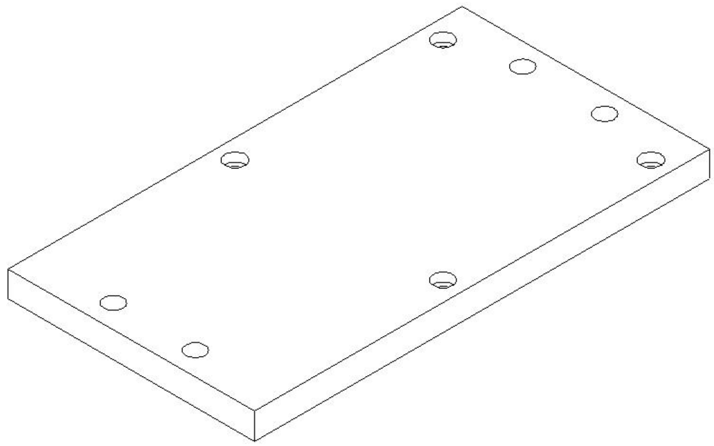


Bracket

Ben Kobe
3/20/2012

1/4" Stainless Steel





Load Cell Mount

Ben Kobe
3/20/2012

1/2" AL