Welding Fixture with Active Position Adapting Functions

A Major Qualifying Project Report

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Abstract

Robotic welding requires specialized fixtures to accurately hold the work piece during the welding operation. Despite the large variety of welding fixtures available today the focus has shifted in making the welding arms more versatile, not the fixture. To address this issue, we designed and constructed a prototype welding fixture with enhanced mobility. The new fixture design reduces cycle time and operator labor while increasing functionality; and allows complex welding operations to be completed on simple two axis welding arms.

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1.0 Introduction

For a manufacturing company to remain competitive in today's market they must produce a quality product at the highest possible efficiency. Over the past century there have been large strides in manufacturing processes. Ever since Henry Ford's introduction of the assembly line, businesses have been focused on using available technologies to manufacture their products at minimal cost. During the manufacturing process there are many different parameters that need to be controlled, such as, limiting waste, assembly downtime, and labor compensation to be able to produce at a minimal cost. In recent years the concentration of the manufacturing community has been on automated processes because they produce higher quality products and higher production rates. In 2003 North America alone spent 877 million dollars on robotics used for manufacturing, a 19 percent increase over the amount spent in 2002 (Pethokoukis, 2004). This increase in spending reflects manufacturers need for greater efficiency from their manufacturing process.

One of the most common automated processes in an assembly line is welding. Robotic welding is used by many companies around the world because the process is easily automated and more efficient than a professional welder. The main benefits of an automated welding process are, improved weld quality, increased productivity, decreased waste production, decreased costs associated with labor. However, an automated welding operation may not be best suited for every application. A company must consider many variables when deciding if a robotic operation is appropriate for their application. The initial cost of a manual welding process is significantly lower than an automated welding process so an automated system must be able to quickly recover the initial investment. Flexibility is also an issue that must be considered because in a manual system the worker can easily adjust to any new tasks, where as it is much harder to adapt a robotic welder to a different job.

One way to increase the flexibility of a robotic welding operation is to improve the fixturing device that holds the work piece. The addition of an active positioning adapting function increases the units' degrees of freedom, allowing for a larger range of possible motions. By increasing the degrees of freedom the welding system can perform more complex movements, thus increasing its adaptability to new work pieces. There are products on the market today that can perform these types of operations. Currently at Huazhong University of Science and Technology (HUST) they have a robot that was built by Motoman, a robotics manufacturer based in Japan. The University uses this fixture to weld a section of an automobile chassis. However this welding fixture has only one degree of freedom. It can only rotate around its x axis. The University needs an automated fixture that can adapt to different size and shaped work pieces, and at the same time have multiple degrees of freedom.

There have been previous attempts by students at HUST to design a similar welding fixture; we will use the information they acquired to help us improve our fixture design. Our main goal is to give the fixture increased versatility, and to do so we will design the fixture with two degrees of freedom. This will allow all of the surfaces on the work piece to be welded without re-fixturing the work piece. This automated fixture will decrease production times compared to those of a stationary welding fixture. Through our knowledge of kinematics and completed background research our team was able to design and manufacture a working model of a welding fixture with adaptive positioning functions.

2.0 Background Research

To understand the challenges of designing a welding fixture, we conducted extensive background research. We researched the basic concepts of automated welding processes to understand their advantages and disadvantages. We have determined that the main challenges faced include providing versatility and at the same time reliability. We also addressed what companies have done to solve these problems, and create their own welding fixture.

2.1 History of Robotics

The study and creation of robotics started in the ancient city of Alexandria around 250 BC where Ctesibius, a Greek physicist invented and built the first water clock with moveable figures (Currie, 1999). However robotics did not advance significantly until the late 1800's, when Nikola Tesla created the first remote controlled robotic vehicle. The vehicle was only a small accomplishment for Tesla; he dreamed of creating full humanoid robots that had abilities comparable to humans (Robotics Research Group, 2007). These inventions did not have a significant impact on society, but they influenced other engineers and inventors to think about the potential robotics have. Two inventions that where influenced by Tesla, and which had an impact on industry in modern society were the Unimate, and the Stanford Arm.

2.1.1 Unimate

The Unimate was designed to do jobs that were too dangerous or too difficult for humans to perform. The Unimate was invented by the 'father's of robotics' (Robotics Research Group, 2007). George C. Devol was a successful inventor and businessman, and Joseph F. Engelberger was an accomplished engineer. They teamed up after World War II after being inspired by the technological boom produced by the war, to produce a commercially available robot for manufacturers. This became a reality when Engelberger started a manufacturing company called Unimation and started to produce and sell Unimate robots. The Unimate made its first appearance on the assembly lines of General Motors, where its primary job was to remove die castings from die casting machines, as well as perform spot welding operations (Robotics Research Group, 2007). By replacing workers, the Unimate made assembly lines more efficient and cost productive. It was an important invention because it showed manufacturers the capabilities a robotic unit could possess.

2.1.2 Stanford Arm

The Stanford Arm was designed in 1969 by Victor Scheinman, a Mechanical Engineering student at Stanford University. The arm was revolutionary because it featured six degrees of freedom and was the first robotic arm to be designed for computer control. The Robot was built so that it could recognize different objects and was able to compute the sequence needed to put them together correctly (Stanford University, 2007). By 1974 the Stanford Arm was able to assemble a Model A Ford water pump and other miscellaneous tasks (Computer History Museum, 2006). Having a computer controlled arm that had optical sensing and that could build simple assemblies had a great commercial appeal. Enough of a appeal that Unimation, the creators of the Unimate, hired Scheinman onto their staff to engineer other robotics used for manufacturing processes. The Stanford Arm became the benchmark for robotic arms, because of its computer controlled joints and optical sensing ability.

2.2 Benefits of Robotic Manufacturing

The introduction of robots into manufacturing operations has increased productivity and quality throughout many different markets. All machines used in manufacturing were designed to increase the profit a company could make. One of the main benefits of using robotics in an assembly line is their ability to perform a job over less time than that of a worker. Not only can robotics perform at a higher rate of speed, they are also more accurate, which allows for less errors and wasted product, thus increasing efficiency. Robotics also do not become fatigued like human workers, which means that they are able to stay operating for longer hours and continue producing profit. As well as having exceptional production rates robotics do not demand a salary nor health insurance. Joe Shoemaker of Allied-Locke Industries states “with the rising cost of health insurance for our employees, the cost of a robot is pretty easily justified” (Pethokoukis, 2004). The only cost of robotic manufacturing is the initial cost of the machine, maintenance, and the electricity to run it.

2.2.1 Benefits of Automated Welding

Being more efficient and increasing productivity is true for all applications of robotic manufacturing. Automated welding is no different than any other robotic manufacturing process. It increases efficiency and lowers the cost of the process. There are four significant benefits to automated welding: increased productivity, higher weld quality, decreased waste produced, and decreased costs associated with labor (RobotWorx, 2007). Other Benefits cited by a member of the Robotics Industries Associated are listed as follows.

- *Weld quality consists of two factors: weld integrity and repeatability.*
- *Automated welding systems ensure weld integrity through electronic weld process controllers.*
- *Combining mechanized torch and part motions with electronic recall of automated welding parameters results in a higher quality weld than can be accomplished manually, offering instantaneous quality control.*
- *Because an automated weld is made only once, defects are readily visible and detectable.*
- *Humans tend to "smooth over" a mistake with the torch, hiding lack of penetration or a possibly flawed weld.*
- *In some cases, leak testing and vision systems can be integrated into fully automated welding systems to provide additional quality control.*
- *Repeatability is a function of the quality of the weld process controller and of the engineering of the machine motions.*
- *Automated welding provides repeatable input parameters for more repeatable output.*
- *Assuming the controller is functioning properly, the question becomes: Can the mechanisms of the machine position the parts or the torch within the specified tolerances for welding automation? The answer to this question will attest to the quality of system purchased.*
- *Semi-automatic and fully automatic welding systems increase output by eliminating the human factor from the welding process.*
- *Production weld speeds are set at a percentage of maximum by the automated welding machine, not by an operator.*
- *With minimal setup time and higher weld speeds, a automated welding system can easily outpace a skilled manual welder.*
- *Automating the torch or part motions, and part placement, reduces the possibility of human error.*
- *A weld takes place only when all requirements are satisfied.*
- *With manual welding, reject welds often increase when welders become fatigued.*
- *Depending on the value of the parts when they arrive at the welding station, the cost savings in scrap alone may justify the purchase of an automated welding system.*
- *Automated welding should also be considered when assemblers need to minimize the risk of shipping a bad part to a customer.*

There are many advantages to having an automated welding process over a manual operation. However not every application is suitable for this type of automation. A company must closely look at their present and future needs before they make a decision to upgrade to a robotic welding operation. A major concern is the ability for the manufacturing process of a company to be able to have the flexibility to accommodate any changes in product that is produced. So a company whose product varies significantly might not benefit from an automated welding operation.

2.3 Current Solutions

At Huazhong University of Science and Technology (HUST) they currently have an automated welding fixture designed and produced by Motoman, a subsidiary of Yaskawa Electric Company. The Japanese company produces robotic automation for many manufacturing processes including welding, assembly, coating, machine loading, and material cutting. "Motoman's product line includes more than 175 distinct robot models and 40 fully integrated pre-engineered 'World' solutions that are complete application specific work cells, including robot, process equipment and safety equipment" (Motoman Inc., 2001-2007).

The welding fixture that HUST has purchased from Motoman is one of their fixture mounting systems, Motomount^{tm} (Figure 1). Motoman lists the advantages that the Motomount^{tm} has over other competitors products, "Reduces stress close to 7x or more as span goes beyond three meters, Increase positioner life due to less stress and wear on bearings, Improved repeatability; Stress from restrained load does not cause warpage, Pinned fixture blocks provide quick, repeatable changeover" (Motoman Inc., 2001-2007). At HUST this fixture is used in conjunction with Motomans' EA1400N robot which is designed to increase efficiency of arc welding. This set up is used to weld part of the chassis of a car. The downfall of the fixture is that is only enables one degree of freedom, the rotation along its x axis. Also the fixturing mechanisms, the clamps, are in fixed locations and are not easily moved to adapt to different shaped work pieces.

Figure 1 - Robotic Welding Fixture

2.3.1 Adaptive Fixturing

An independent fixturing system can allow for more flexibility in the possible size and shapes of the work piece being machined. Puqi Machine, a Chinese company, produces chucks whose clamps operate independently of each other. The 4H and 4HA Through-Hole Power Chuck models both employ this system (Figure 2). All of the mechanical specifications are listed on Puqi Machines website and can be found in Appendix 1.

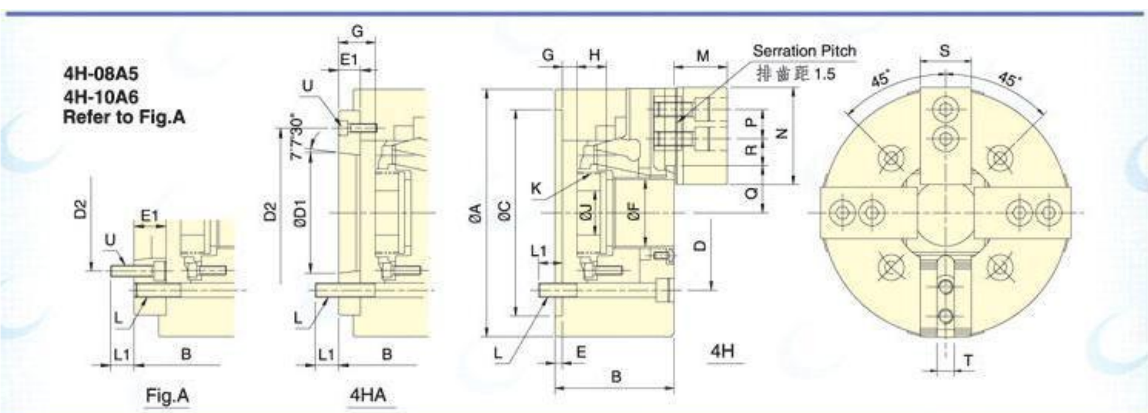

Figure 2 – Chuck Diagram[1]

[1] http://www.pqwy.com/Product/GB/product_detail.asp?catalogid=4&productid=112

Yantai Evergreen Precision Machinery Co., Ltd. Also uses a similar clamping fixture. Like Puqi Machine they use independent motions for their clamps. Yantai Evergreen Precision Machinery is slightly different but still holds the same principles as Puqi Machine's design. They both use a worm gear to adjust the individual clamps. The two diagrams (Figure 2 and Figure 3) show the two different designs from the different companies.

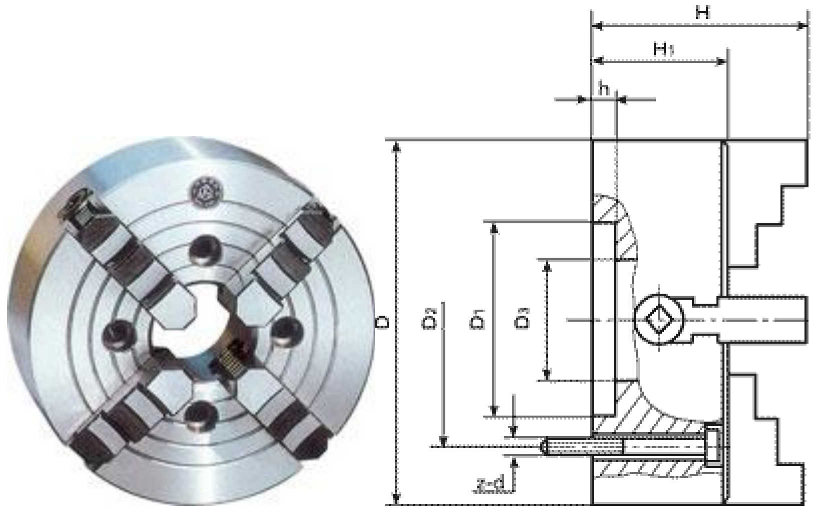

Figure 3 - Lathe Chuck[2]

2.3.2 Robot Controller

Included in HUST's automated welding operation is the controller produced by Motoman used to direct the motions of the individual robots. HUST uses the NX100 robot controller made my Motoman. It features Windows CE operating system on the programming pendant, multiple robot control ability, built in Ethernet, the ability to hold 60,000 steps and 10,000 instructions in its memory, and many other features. This controller allows for simultaneous control over four independent robots. At HUST they use the EA1400N robotic welder, along with an HP6, a high performance handling machine to increase production of

[2] http://www.cn-sanjing.com/ArticleShow.asp?ArticleID=206

parts being welded. These two machines and the Motomount [tm] are controlled by the NX100 controller. It allows for independent coordination with all of the machines in the production line (Motoman Inc., 2001-2007).

3.0 Methodology

After completing research on robotic welders and robotic welding fixtures, we began to plan how the project would be completed. We envisioned four smaller tasks as integral to this accomplishment. This chapter will discuss these goals and what specific actions were taken to accomplish them. The process has been divided into four major phases; Design Brainstorming, Design Formation, Design Selection, and Design Creation. Each of these four phases includes several steps which are vital to a successful project completion. A more detailed description of the methods used is described in this section. A Gantt chart outlining this process is shown in Appendix C.

3.1 Sample Work piece

We first decided to create a sample work piece to be used as a basis for the design. We knew from our background research as well as advice from Professor Yan many of the pieces that will be used with this device have several features that are all different, while also somewhat similar.

3.2 Design Brainstorming

Using the information gathered during our background research, the team began to formulate a list of requirements for the device. At the broadest level of brainstorming, we compiled a list of functional requirements and design parameters. The first step was to compile the list of functional requirements. A functional requirement is a specific requirement that the device must incorporate. Each functional requirement must contain a qualitative specification as to how the device will perform. Functional requirements were vital in keeping the device requirements clear throughout the entire design process.

Once the complete list of functional requirements was compiled, the next step was to assign each functional requirement a design parameter. A design parameter is a possible design concept to address the functional requirement it is matched with. At the first level of brainstorming, design parameters allowed the team to compile a large list of design ideas to solve each problem. The finalized list of functional requirements and design parameters is shown below.

3.3 Design Formation

Once the team had compiled an accurate and complete list of device specifications, the team was ready to move on and begin formulating ideas. Each team member designed their own solution to the problem and came together to discuss the benefits of each design. Once all of these designs were completed, we then analyzed each design for the best design concepts. By formulating several different designs independently, we each had not been influenced by ideas of the others and were able to create many different design features.

3.4 Design Selection and Creation

After each member of the team had finished their preliminary design formation we came together as a group to compare each members results. This process involved lengthy discussions and further brainstorming about how we could use ideas from five different designs in our final design. Once the useful components of each design were extracted, we then began to create our final design. As all of the original design ideas were very different, many features we wanted to use in the final design had to be adapted and customized to all work with each other in the best way.

3.5 Final Design

Our finalized design is a product of the several different ideas and components originally created in the design phase. Our main design components were then divided into three main sub-assemblies that displayed the three different areas of movement. The base is the main sub-assembly, the foundation of the entire mechanism. This feature keeps the entire structure stable as well as provides the tilt rotation along the x-axis. The next main sub-assembly is called the slider assembly, as it provides the sliding movement allowing translation between the different components. In relation to the base, the slider assembly also allows rotation but along the z-axis. This rotation influences the rest of the upper part of the device. Above the rotation, the slider assembly has several components which allows for two axis translational movement in both the x and y directions. The final subassembly is the worktable. The worktable is the main interface between the device and the work piece being welded and must ensure that the work piece is securely fastened and will not allow the machine to interfere with the welding operation. In order to accomplish this task, we created a customized clamping system to accurately hold the work piece in the correct orientation and still not compromise the integrity of the welding operation.

3.6 Prototype Construction

After designing the ideal final design, the next step was to make a realistic prototype. A scaled down version, this model will help us analyze our design and justify the design feature we did correctly. To build the prototype we utilized HUST's manufacturing facilities. We had to work closely with the wood working shop, machine shop, and the local market places to acquire all of the materials and parts we needed. It took a significant amount of effort to coordinate efforts from four different sources, and bring the prototype together.

4.0 Findings

In this chapter we will identify the gaps discovered with robotic welding fixtures today and how we decided to resolve them with our design. Second we summarize our design process and analyze the final design. Finally, we present our prototyping process and what we learned from it.

4.1 Sample Work piece

One of our first steps was to design a sample work piece. The work piece that our team designed is shown in Figure 4 below. It incorporates multiple features that produce different scenarios for our welding fixture.

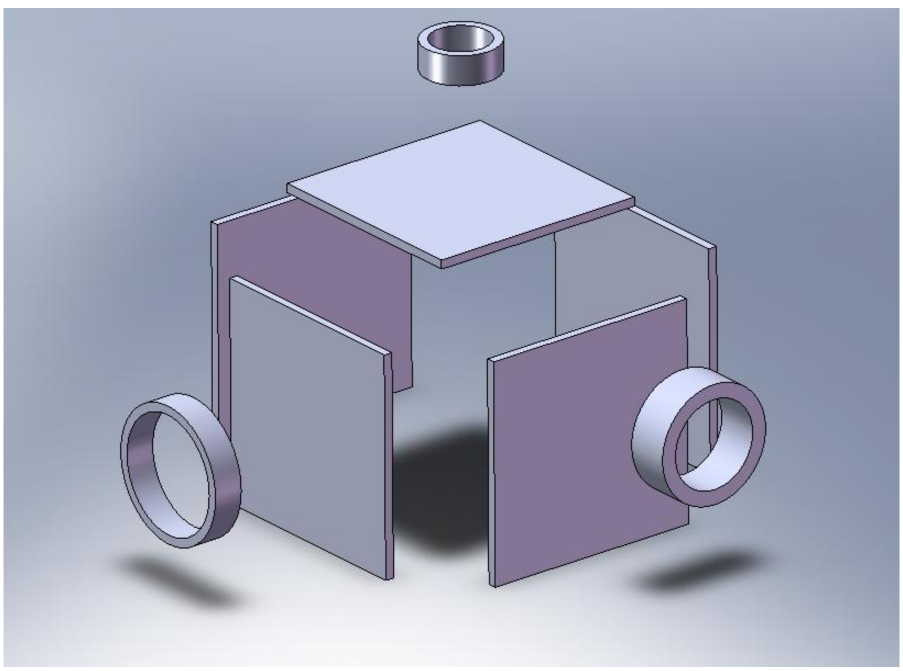

Figure 4 – Unassembled Work piece

As can be seen in Figure 4 above, the work piece will start in five separate rectangular pieces. These pieces will be tack welded together on the corners to hold them together;

forming a cube with one face missing. Once the straight line welds are completed, additional bosses or features may be required. To simulate more complex features, we added some circular features. These circular features are all of different sizes and are not all centered on the central axis of the work piece. By adding a feature off-center, a more realistic work piece is created to simulate many different operation scenarios. Many of these samples will be used to accept pipes of different sizes and locations, and each feature would most likely be in a custom location each time.

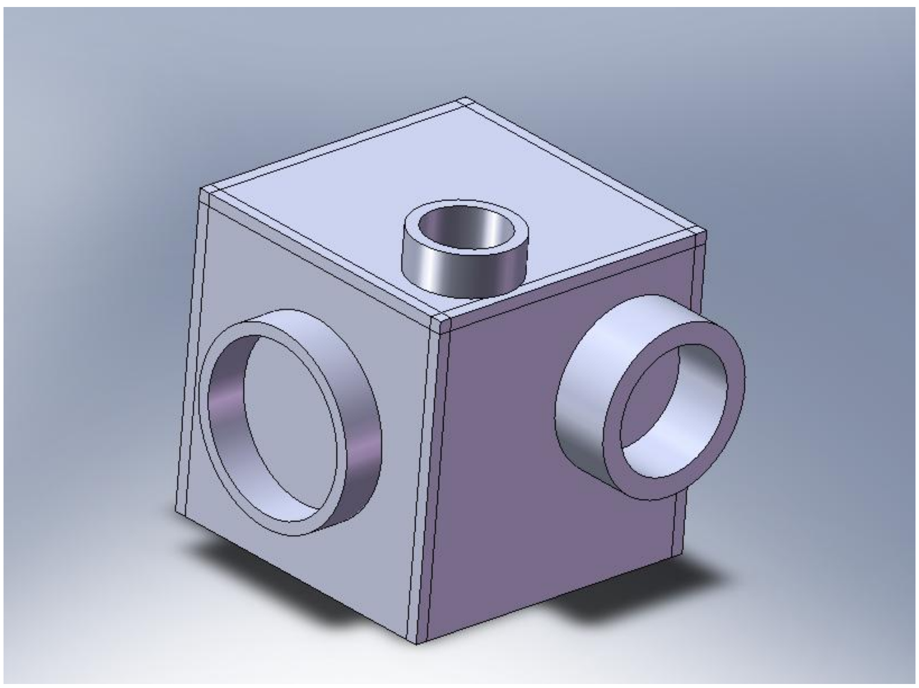

Figure 5 – Assembled Work piece

4.2 Design Brainstorming

During our brainstorming phase we constructed a list of the functional requirements as well as design parameters which spawned from the functional requirements. These parameters guided us to our final design and are listed below.

Functional Requirements

I. *Fixture must not interfere with the welding process*
II. *Setup must be at least 10% more efficient then the current process.*
III. *Fixture must not allow the un-welded part to change its orientation in relation to the welder during the welding operations.*
IV. *Fixture must be compatible with straight and curved faces.*
V. *Fixture must be able to adapt to weld circular features at any point on the work piece surface.*
VI. *Design must not require machine operator to lift more then a 50 lb. or 22.6 kg. load. Design must facilitate a work piece up to two tons.*
VII. *Design must be deliverable via standard tractor trailer truck*
VIII. *Design must be adaptable to different size and shaped workpieces*
IX. *Design must minimize force needed to move work table*

Design Parameters

I. *Fixture is synced to welding program*
II. *Cost benefit analysis must be preformed*
III. *Strong clamping mechanism will be designed*
IV. *Fixture must be able to adapt to weld both straight lines and circular features on the work piece.*
V. *Fixture must be able to adapt to weld circular features at any point on the work piece surface.*
VI. *Design will have enough degrees of freedom to complete all weld operations.*
VII. *Design will be compact and easily assembled*
VIII. *Fixture will have independent clamping system*

IX. Friction between moving parts will be minimized.

4.3 Design Formation

One preliminary design proved to be very similar to a standard lathe chuck on the market today, as seen in Figure 6.

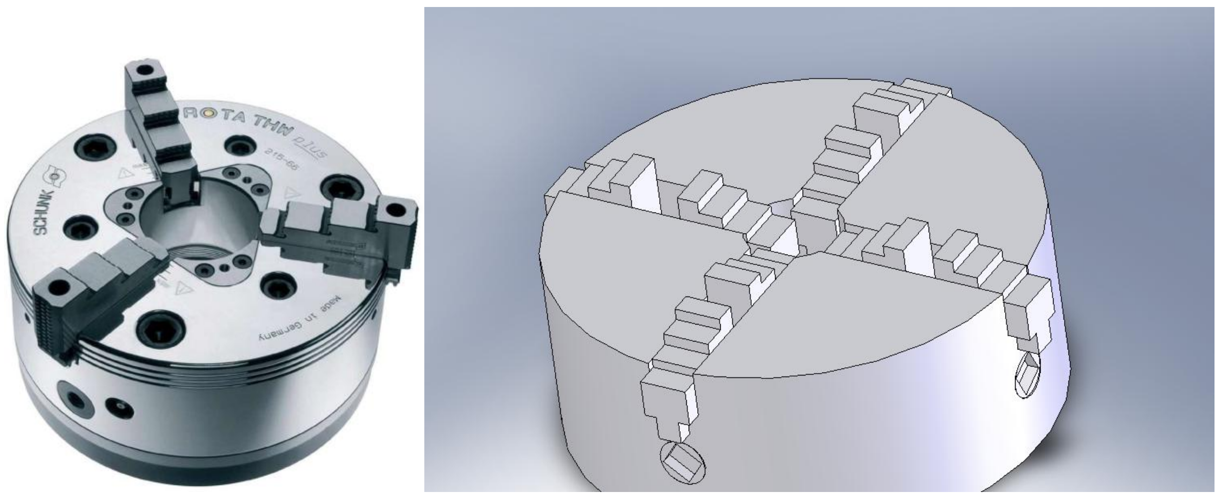

Figure 6 - Preliminary Design Concept (chuck)[3]

This design focused on independently holding the separate pieces of the work piece. Each of the four jaws as can move together to a specified location along the track, and then tighten down on the work piece holding it from both sides. Although this design securely holds the work piece, it does not allow much versatility in work piece size and can only accommodate square work pieces due to the clamping profile.

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[3] http://news.thomasnet.com/images/large/462/462709.jpg

4.4 Design Selection

After discussing all of the different design possibilities and ideas, the team decided to formulate the ideas gathered into two main design concepts. One design concept focused on a more simplistic approach while still keeping up functionality. The second design focused on ease of use for the machine operator as well as precision for faster cycle times. Each design has advantages and disadvantages which are discussed in the following sections.

3.4.1 Design Concept A

The first design concept focused on simplicity in design. We kept the ideas similar to designs and features currently on the market. The design has a main rotation axis in which the entire work surface rotates during circular welding operations. This clamping system is quite effective for operations in which the same features will be welded repeatedly, as in an assembly line configuration. Once the initial welding operation has completed, then if additional operations are required the machine operator would manually unclamp, move, and reclamp the work piece. This requires that a complex fixturing system be designed to accommodate several different shaped work pieces in customizable locations. An example of this clamping system can be seen in Figure 7.

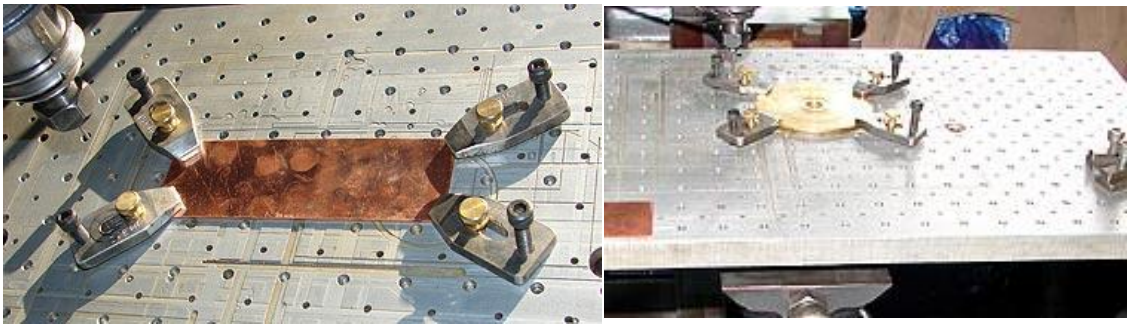

Figure 7 - Example of universal clamping system[4]

Although this design allows for a very adaptable clamping system, this design has several other drawbacks. Firstly, this design requires a crane or other lifting device to move and position the work piece in the correct orientation. The machine operator must lower the work piece onto the table and try to align the piece in the correct position manually which can be very difficult by hand with a very large and heavy object. Once the work piece is positioned in the correct place, it must be fastened down with custom fixturing devices and would require several different clamps in order to accommodate work pieces of different shapes and sizes. This design does however provide a cost effective solution to the problem.

3.4.2 Design Concept B

Design concept B focuses on ease of use for the machine operator as well as faster cycle times for making parts. Taking inspiration from many milling machines currently on the market, this design uses a two axis moving worktable similar to the one seen below in Figure 8.

[4] http://www.jamesriser.com/Machinery/GortonPantograph/Restore.html

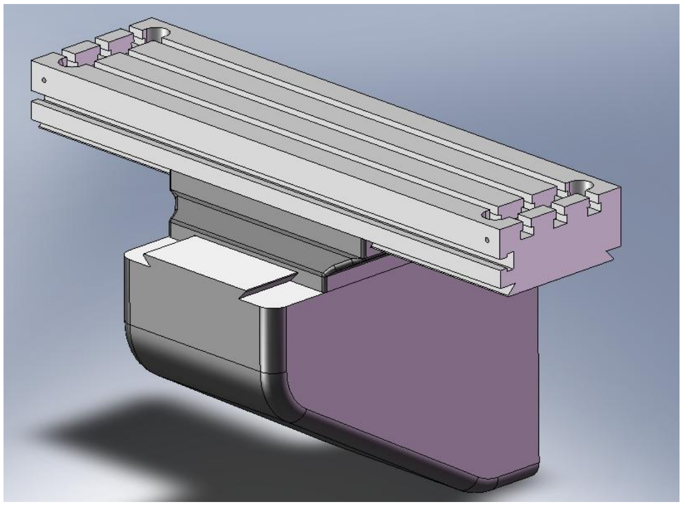

Figure 8 - Two axes CNC Worktable

This design concept allows for the work piece to be mounted in one central location which ensures accuracy and precision for several different setups. A much simpler and more reliable clamping system is possible. Once the work piece is clamped securely, the entire worktable simply moves to the correct location depending on the welding task. This feature allows several features to be welded with only one setup as the worktable can be automatically adjusted. Although this design requires much less physical labor for the machine operator, the machine is much more complex. Increased complexity in the machine design means a much higher cost in design and manufacturing as well as higher maintenance costs.

4.5 Design Creation

After the brainstorming and design formation phases were complete, we had developed a better understanding of the best features to incorporate in the final design. Many good design ideas were taken from each of the two design concepts to combine to one final design. We decided that we would use a two axis worktable design combined with a chuck-like fixturing system. Like many different chucks on the market, all of the clamps move at the same rate, dependant on one another. This is a very useful feature on lathe chucks as it insures that the central axis of the work piece and the central axis of the machine are collinear. This feature is vital in turning operations as it insures that the machined face will be uniform and truly circular. However, our welding fixture will not be used for turning operations. The fixture must accurately keep the work piece clamped in the correct location and not allow any movement that would jeopardize the quality of the weld. To adapt this concept we decided the clamps must be independent from one another. This feature will allow for non-uniform shapes and will keep accuracy with computer control.

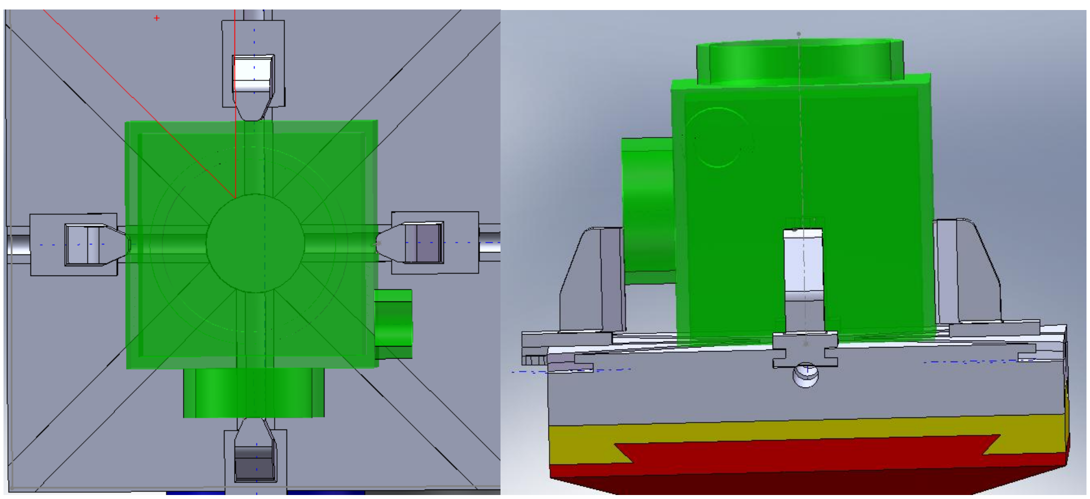

Figure 9 - Clamp Independence

As can be seen in Figure 9 above, depending on the work piece different clamp orientations are needed for each separate clamp. This feature enables items with non-uniform geometries to still be accurately fixtured in the clamps. The entire clamping system is movable via the two axis worktable design. This design consists of three separate parts; the bottom, mid-section, and top worktable surface. The movement in the x-direction is controlled between the bottom and mid-section and the movement in the y- direction is controlled between the mid-section and the top worktable. This combination of design ideas produced a highly adaptable clamping system.

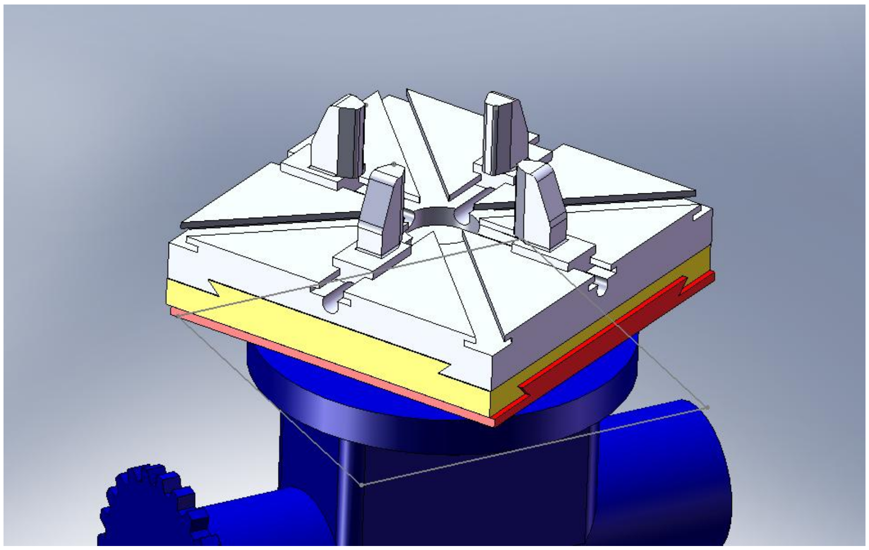

Figure 10 - Preliminary Conceptual Design

Figure 10 displays a conceptual representation of the functionality needed in the final design. The top worktable assembly includes the main three pieces to achieve the two axis movement, as well as a general clamping system. The red part acts as the main rotation axis for the machine and the blue bottom part is the base, providing the final degree of freedom as a tilt function of the entire assembly. This design concept visualizes the combination of the two main design ideas mentioned previously and gave us a good starting point for refinement. As the worktable movement system proved to be the most complex, much of our attention was focused on correctly designing a system which would be practical as well as efficient. The interface between the worktable levels in Figure 10 conceptually makes sense, but practically the design had to be updated. Aside from difficulty in machining the bevels, this design was missing several components related to how it would actually work. Large amounts of friction would be created between the plates making it incredibly difficult to move any of the pieces with all of that surface area. In the next design refinement we addressed the clamping, frictional, and movement issues.

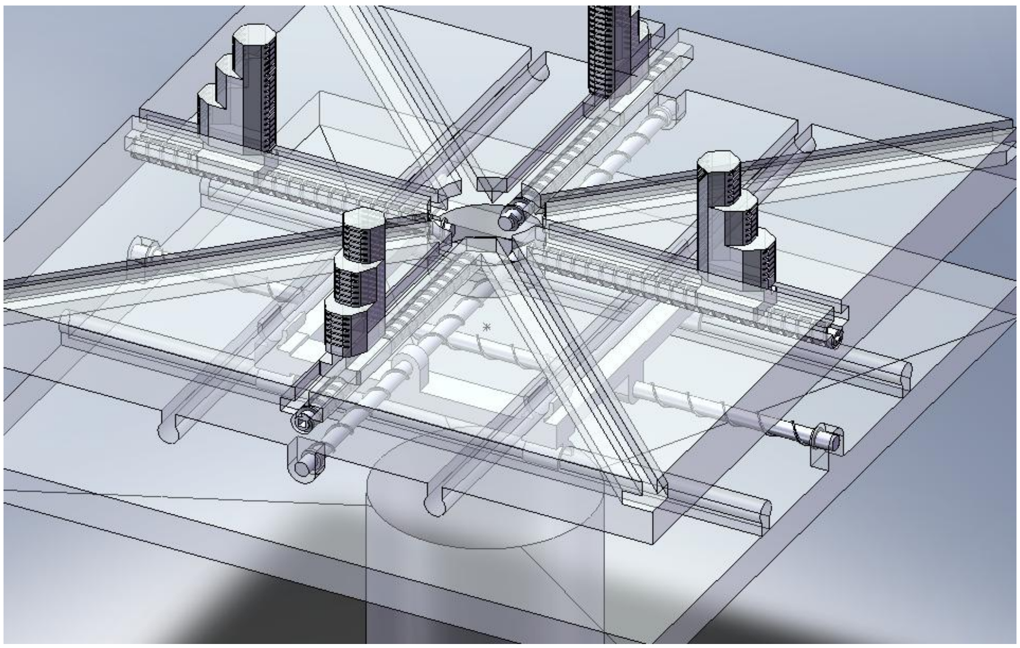

Figure 11 - Design Refinement 2

This next design refinement updated all of the previous issues with respect to friction, clamping and movement. Smooth and accurate movement of the worktable pieces was a crucial part of good design, and was very difficult with the large amounts of friction generated with the previous design. After research of current solutions for this problem we decided on a rod and sleeve system. This system greatly reduces the friction between the pieces as well as ensures smooth and accurate movement. This system consists of a mounted metal rod which matches up with a circular sleeve that allows movement along only one axis.

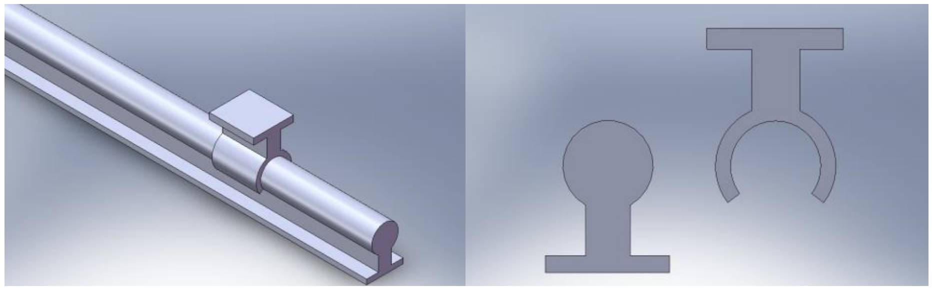

Figure 12 - Rod and Sleeve Slider System

The circular sleeve contains bearings, greatly reducing the friction between the two pieces as well as keeping accurate motion along only one axis. This system is widely used in similar applications, and would be a very cost effective solution. The worktable pieces now had a plausible solution for movement, however still had no way to control that motion. The next step was to design a system which would be able to be computer controlled and would also provide strength when holding the worktable in one spot. Rack and pinion systems were considered as they are also very widely used in the world today, however they would require a very strong motor to drive them due to the high torque put on the pinion. In the tilt position, all of the force of the entire worktable assembly as well as the work piece would be translated to the rack and pinion system, which requires an extremely high torque motor or complex gear reduction system. As an alternative system, we decided to use a drive by screw system. Both the top and bottom worktable pieces have a screw-shaft mounted on the inner side (facing the mid-section) with bearings at both ends allowing rotation of the shaft, but no translation. The female connecter is connected to the mid-section, creating translational movement when the shaft is turned.

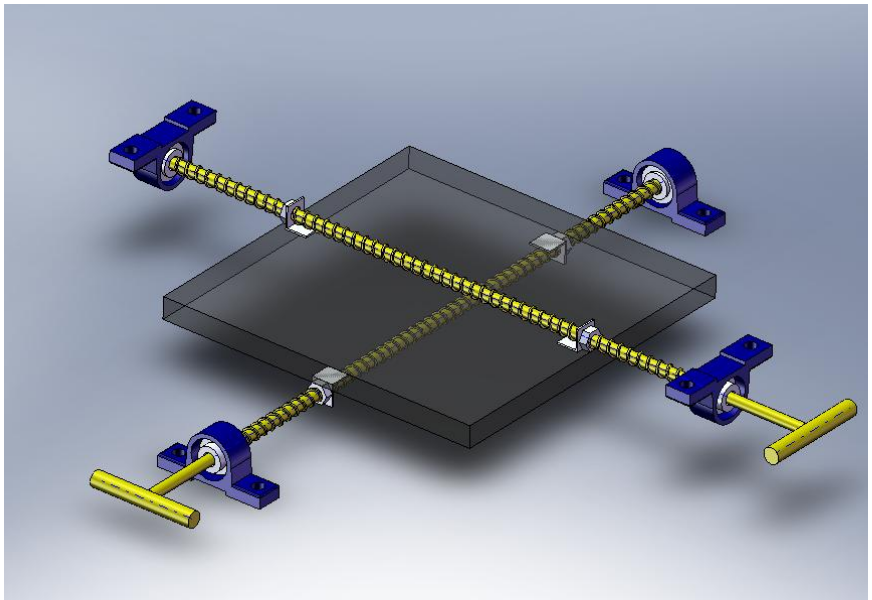

Figure 13- Drive by Screw System

The same principle was applied to the clamping system in the worktable. Each of the four clamps had their own independent drive screw, allowing independent motion. With computer control, each of the drive screws could be driven at the same rate, and therefore the clamps would move at the same rate.

The clamp was the last big improvement in this design refinement. After conducting more background research, we decided to adapt a very universal design for clamps on the market today. Mainly designed after lathe clamps, our design must also be able to be used with odd shaped work pieces not just circular pieces. This design allows for a very wide range of fixturing patterns as well as a reliable clamping surface for many different shapes. The clamp has one large face for most clamping set-ups, however it also has three separate faces on the opposite side for custom clamping applications.

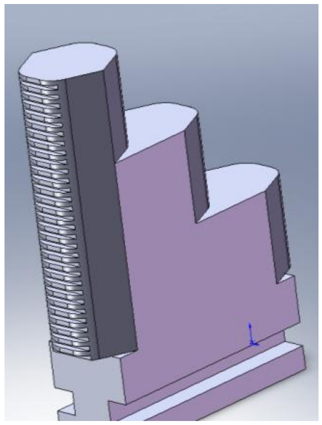

Figure 14 - Clamp Design

All four faces are fitted with not only the flat face but a rounded surface as well. This concept allows more surface area contact between the work piece and the clamp with circular features. In addition to the curved surface, the faces have groves along the entire length of the face. As a common design in clamps today, this feature increase the grip of the clamp on the work piece, keeping the work piece firmly in place.

4.6 Final Design

After several different design steps we finally took our ideas and made them realistic. After spending a long time thinking about the overall design, for the final design we took a step back and handled each component piece by piece. Starting at the top, we decided to keep the clamp pretty much the same with some dimensioning changes. This design is very similar to a widely used design in the market today, and we didn't feel there was much room for improvement from the last design refinement. The next step was dealing with the worktable. Keeping most of the design the same as in the previous refinement, we only made two major changes. We first decided to change the overall shape of the worktable from a square to a hexagon. This shape will be better suited for the rotational motion that the worktable will encounter. We also changed the translation system to a rack and worm gear system as it will be a better solution for this application. The rack half of the system is located on the underside of the worktable along with a new track system.

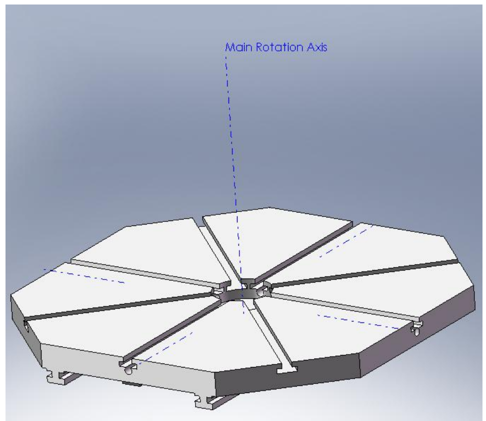

Figure 15 - Final Worktable

The mid-section was the next piece to be redesigned. A stronger and more reliable track system than the rod and sleeve system was needed to support the worktable. This new system has a profile similar to a "T" and provides a much more sturdy construction, and is essential when dealing with increased loads on the worktable. The mid-section also includes another major change from the previous refinement. As discussed earlier, a rack and worm system has been put in place in the final design. The mid-section houses the two worm gears as well as their motors, 90 degrees out of phase to provide movement of the worktable pieces.

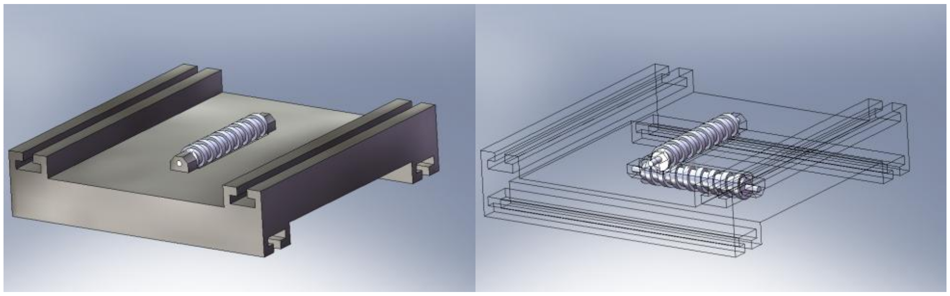

Figure 16 - Final Mid-Section

The main rotation axis remained relatively the same as in previous design refinements, just updated with the new track and translational movement system put in place. The final piece to upgrade was the overall base of the device. Modeled after many of the devices found in our background research, our base looks similar to many other robotic fixture bases. However, it contains the drive components to turn the main rotation axis as well as provide a stable working environment for the entire structure as a whole. The base was designed such that no matter what position the worktable is in during the welding operation, the machine will not move and jeopardize the integrity of the welding operation.

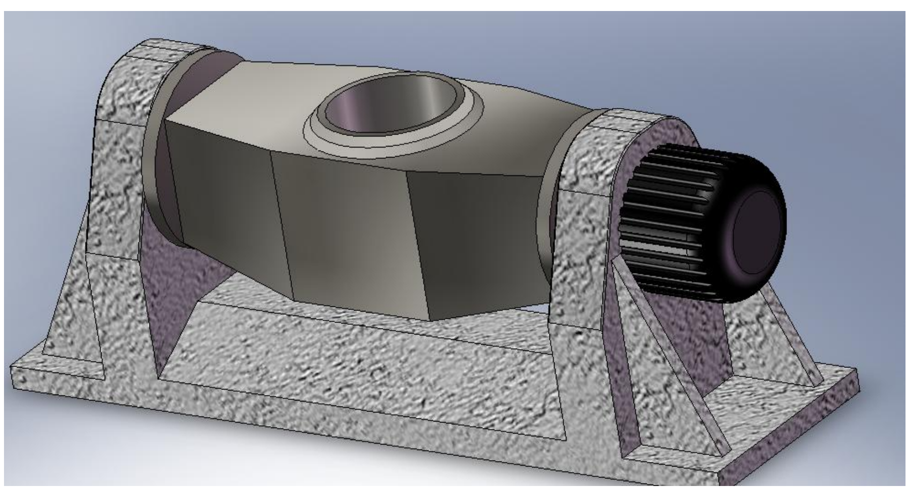

Figure 17 - Final Machine Base

All assembled together the machine closely resembles many different welding fixtures available today, however incorporates many additional features making it a much more powerful tool for today's welding industry.

4.1 Final Design Analysis

Through our team's research we identified shortcomings in the designs of automated welding fixtures available in today's market. We recognized two major hold backs in the process, each of these hold backs are associated with the design of the welding fixture. The first deficiency we identified was the lack of motions the fixture could perform, most fixtures on the market rely on one axis of rotation. The second deficiency was the lack of adaptive positioning functions.

4.1.1 Active Positioning Functions

The number of degrees of freedom in an automated welding process determines the complexity of weld lines that are able to be achieved. By increasing the number of degrees of freedom in our welding fixture, we create more options for the possible weld lines that we wish to make. The current Motoman fixture that HUST uses in their robotics facility only allows for rotation around its x axis. This is suitable for their current application; however there are other applications in which this single axis rotation will hinder the ability of welding other work pieces. Active positioning functions are the solution to this problem.

Increasing the degrees of freedom of the entire system allows for the work piece to be in the active position without refixturing. To do this we added another axis of rotation to the machine. We designed the fixture to be able to also rotate around its main axis (z axis) (Figure

18). This allows for the work piece to be in the active position without refixturing. Combining the movement of both rotations gives the fixture the desired motion required to be able to weld straight and circular weld lines.

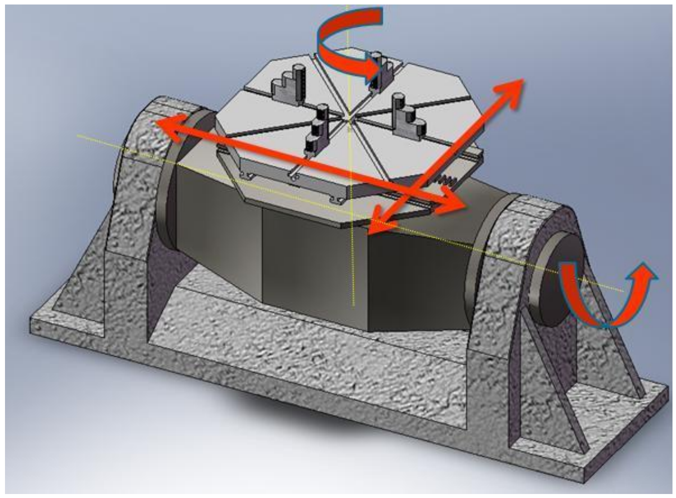

Figure 18 - Axes of Rotation

The addition of a second axis of rotation allowed our fixture to be more versatile in the movements it could make. However work pieces can vary significantly, and our design needed to accommodate pieces that when clamped the circular welds were not located over the center of rotation of the main axis. To allow for this situation, we designed a translational movement system.

4.2 Prototype Construction

After designing the ideal final design, the next step was to make a realistic prototype. A scaled down version, this model will help us analyze our design and justify the design feature we did correctly. Although a seemingly easy task, redesigning and constructing the solid model proved to be a much greater task for us.

4.2.1 Dimensioning

The full scale conceptual model is designed to be a very large device, with a worktable of 4 square meters. This would be incredibly expensive as well cumbersome at best for us to construct. Dimensioning down became a vital step as the entire model had to be rethought and re-dimensioned to successfully model the actual design. Bringing the model down to a reasonable size for demonstration purposes as well as functional purposes we decided to dimension the worktable to be seventy five centimeters square. Using this reduction ratio, we scaled down the entire assembly to a more realistic prototype size.

4.2.2 Purchased Parts vs. Manufactured Parts

Although almost all of our required parts could be manufactured by ourselves, we had many limitations with time, money, and access to tooling. In an ideal situation, all of our parts would be constructed from a soft metal, probably aluminum which would remain relatively lightweight and also strong. All metal parts also allows for parts to be welded together which makes fabrication much easier. Although metal would prove to be the best material for most of the parts, we had to adapt the model and make it suitable for different materials. As we had found in our research, many different rod and bearing systems were available for purchase and would make a good fit to provide the translational movement required in the worktable assembly. As this is also a fairly complex part, we decided that it was much more cost efficient to purchase a four rod and bearing system; two for each direction of movement. Along with the rod and bearing system, the only additional part we found we needed to purchase was the drive screw to move the worktable pieces. We found several different solutions for our problem, many screw systems designed specifically for the purpose we needed it for. Due to financial restrictions however we were unable to purchase the more expensive systems and settled for a very simple screw shaft and nut system. Although not as accurate or reliable as the more expensive system, the screw shaft and nut still provides enough movement for demonstration purposes for the prototype.

After budgeting for all of our expenses, we realized that we would be unable to realistically construct a prototype of our entire mechanism and stay within our financial boundaries. As a result, we decided we would model all of the worktable pieces as well as the main rotation axis, demonstrating three of the four degrees of freedom. We would also redesign the machine to be manually driven as opposed to computer/motor control in the real design. This prototype will still demonstrate the overall advantage to our design and highlight the worktable system.

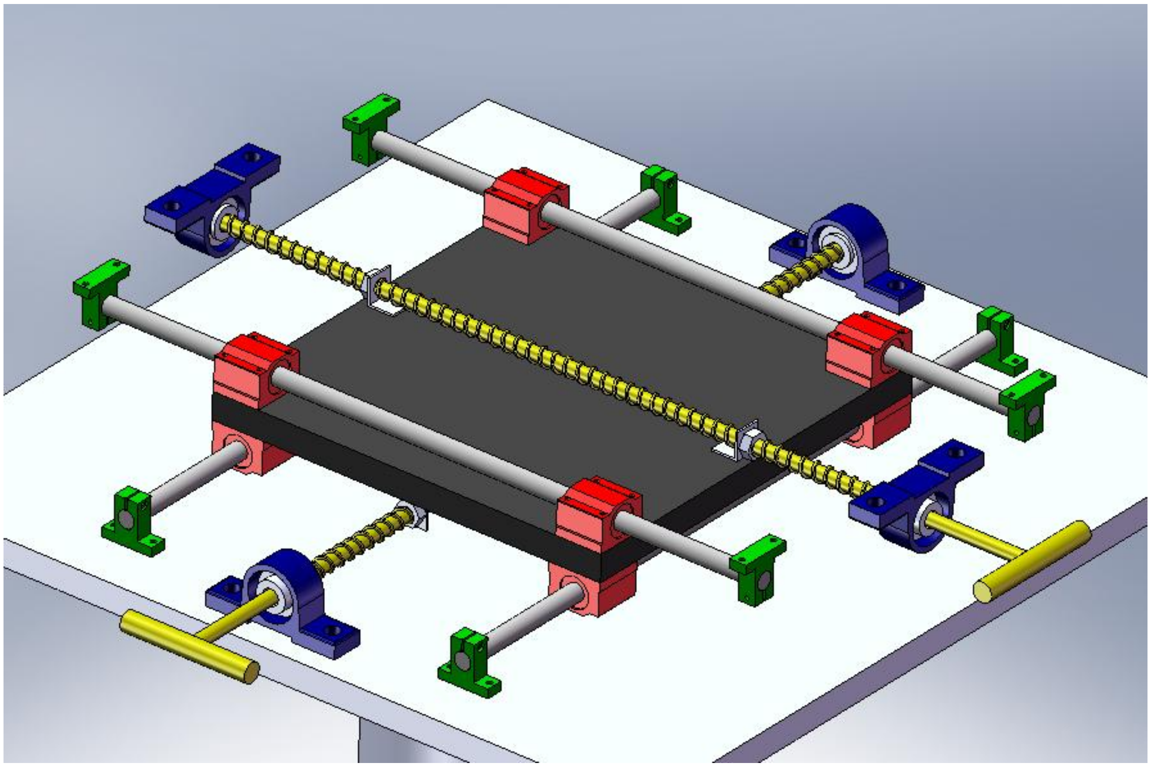

Figure 19 - Redesigned Prototype Model (worktable hidden)

4.2.3 Prototype Issues

In constructing the prototype we encountered a few minor issues during the construction process. As we had to purchase some of the parts from the local markets, they were not designed to our specifications and therefore were not easily integrate able into our prototype. Firstly, we had to manufacture custom brackets to fixture the nuts in the screw drive system so they would be mountable to the mid-section. This issue was easily fixed as it required a very simple part to be designed and machined. A more complicated issue arose when we first took a closer look at the parts we had purchased from the market. The “sleeve” section of the slider system had to be mounted 90 degrees out of phase of one another in order to achieve the correct orientation as could be seen in Figure 20.

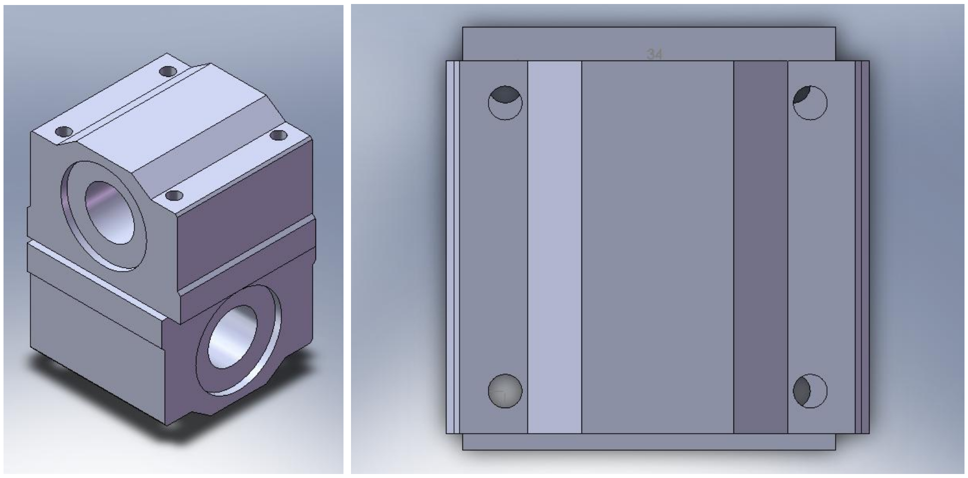

Figure 20 - Hole Alignment Issues

When the two parts are out of alignment like in this way, the predrilled holes in the bearing housing do not match one another. One simple solution would to just redrill some of the pre-existing holes making them bigger so they will match the adjacent hole. Unfortunately, due to the bearing mechanism inside the part, we were unable to use a drilling method.

Our last option was to manufacture a new part, which would allow for the parts to be aligned correctly and still be securely fastened to the mid-section. To achieve this, we designed an interface plate which would be directly mounted to the part, and then mounted separately to the midsection and the opposing interface plate.

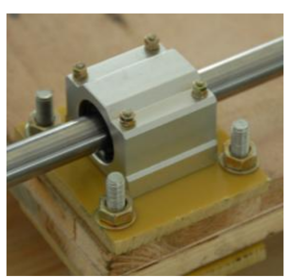

Figure 21 - Interface Plate

4.3 Final Design Analysis

The machine has been designed as described in the previous sections. After completing the conceptual final model as well as the prototype, we were able to step back and take an objective look at our design to analyze it correctly. Many features in the design provide a reasonable solution as well as improvements to many little details that would otherwise be overlooked, but improve the quality of the machine even more. This section will discuss each of the design components features.

4.3.1 Worktable

The uppermost part in the assembly is the worktable. The worktable provides a uniform surface for the work piece to rest as well as houses the clamp guides which hold the work piece firmly in place. As the worktable will almost always be rotating, a square shape does not make the most sense as it may interfere with some parts as the assembly rotates. A circle would provide a better solution to this issue; however a very large size circle would be required to accommodate the same size work piece. This would increase the size and weight of the worktable assembly, and subsequently the entire machine increasing overall cost. To solve this problem the worktable has been designed with an octagonal shape, still allowing a large size work piece as well as a more suitable design for rotation.

4.3.2 Clamps

Our clamps appear very similar to many standard clamps on the market, but they have a few added features. All of the four separate faces on the clamp have a flat edge, as well as a rounded off area. This allows for flat edged work pieces to be accurately fasted as well as circular work pieces. With circular work pieces, they can be fastened either from the outer face or if the boss has a inner radius, the clamp can be fastened on the inside, keeping the clamps out of the way of any additional welding operations. This rounded off section provides additional surface area when used on the inside of a circular surface and therefore provides a more secure grip. The clamps have one large face, and three additional smaller faces all off-set by 5 centimeters each. The large surface provides the general clamping surface for most applications. If a very large or unique work piece is being used, the clamps can be taken out of the worktable and turned around 180 degrees making the three off-set faces point inward. This allows an increased work piece size of up to 20 centimeters in each direction while still securely holding the work piece. Finally, each face of the work piece is grooved, forming small teeth along the length of the face. This feature is common on many clamps today and increases the clamps ability to hold the work piece securely.

4.3.3 Mid-Section

The mid-section transitions the movement between the pieces of the worktable. It is the central location for movement and stability of the structure. The two main feature of the mid-section are the tracks on which the different pieces move and the worm gear which controls the movement. The tracks are a key part of the overall design as they allow the two axis movement of the worktable section. After studying and testing different track shapes, the final design utilizes a "T" shaped design. The "T" shaped design provides much more strength then the rod and slider system used in the prototype. With increased weight, the rod begins to bend and would not support large loads. The T shaped design provides direct contact between the two faces, spreading the force across the entire track and decreasing deformation. The worm gear system makes all of the worktable movement possible. Each gear is mounted in the center of the mid-section, parallel to the tracks on the adjacent face. A worm gear was selected as the preferred drive method due to its low speed and high torque gearing advantage. If a rack and pinion system was utilized, all of force of holding the worktable in the correct place would put an extremely high stress on the drive motor or may result in back drive, causing the worktable to move. A worm gear system allows for a less expensive motor as well as minimizes the chance of back drive occurrence.

5.0 Conclusions and Recommendations

As we examined our findings, we drew conclusions based on the information we collected about each aspect of our project. These conclusions led us to recommendations that we believe will, if applied, create an even better machine then we have designed.

5.1 Concluding Remarks

The process of conducting background research on robotic welding to physically designing helped us gain a deeper understanding of the robotic welding field as well as an effective project process. During the prototype construction we were able to analyze the process for its potential as a finished product.

In today's market all large manufacturers are automating as much of their production line as possible. Automated processes have been in high demand, in 2004 North America witnessed a 19 percent increase in spending on robotic devices compared to the previous year 2003 (Pethokoukis, 2004). Robotic welding is a process that has been developed extensively in the past two decades, but there is still room for improvement. Our welding fixture closes the gap in the engineering of automated fixturing mechanisms.

Throughout the entire project we followed our project outline which was developed within the first week. Although planning a project may seem a relatively easy task, we had a few slight issues to overcome. Coming from different schools of thought, we all had a different approach to how we would approach the project. While some partners insisted on beginning to create designs, the others were firm believers in carefully mapping out phases of the project which were time specific. Creating a set project plan at this point was especially difficult since we were still trying to understand the problem definition. We were finally able to create a realistic project outline, and as a result, it was accurately followed throughout the duration of the project.

Our next main challenge was in the design process. As computer skills throughout the group varied, some members of the group lacked the ability to accurately visualize their design ideas. For those who could speak to each other it was easy to come up with an idea, however conveying that idea to the rest of the group with the language barrier proved to be a problem. We were able to understand general ideas quite quickly, however the important details that matter took more time. Our design process may have been stronger had we not had the communication issues we faced.

The prototyping phase proved to create the most hassle for our group. Taking a conceptual design and making it real is quite the task in itself, and with limited resources the task became incrementally harder. Firstly, finding a resource to research materials other then word of mouth was non-existent. Design updates had to me made after the parts were purchased, which caused the task of accurately prototyping the real design very difficult. Aside from selection, the market to purchase these materials was quite far away and proved to be another unavoidable obstacle as we lost a large amount of engineering and design time. Once we had most of the hardware, the only disappointment was to construct many of the machine parts from wood and not aluminum due to cost requirements. Luckily, all of the engineers and factory managers at the wood shops were very helpful and really made the fabrication of some parts very easy for us.

In spite of all the obstacles and difficulties we faced, we created a very realistic final design concept. The design satisfies all of the functional requirements and design parameters which were outlined at the start of the project. While we were unable to do an in-depth analysis of the fixture components, we did produce a complete conceptual solution to the problem at hand. Of course, more customization is possible if a part does not meet the requirements of the fixture, and our clamping system is practical for various sizes and geometries.

5.2 Recommendations

Throughout our project we faced issues which may be avoided in the future. This section will discuss our recommendations and possible solutions addressing these issues.

Mechanical Properties

After completing our research and solid model construction, the team reflected on the results that the project produced and found a few areas in which further research would benefit project. One of the areas where further work needs to be done is in determining mechanical properties of our welding fixture with active position adapting functions. Our team had concerns with the amount of friction placed between certain moving parts of our system. There were two locations which we believe would experience a large amount of friction was between the main rotation axis and the mid-section, similarly with the mid-section and worktable. The other location was between the housing for the main rotational axis and the main rotational axis itself. These two locations are susceptible to high forces of friction that could potentially cause complications with our design. The force of friction in these two locations needs to be kept at a minimum, and calculations to figure their exact values would help improve the design of the welding fixture.

A few other considerations for calculations that would ultimately improve the quality of the welding fixture are stress analysis and cost benefit analysis. Stress analysis and friction analysis would both help in the selection of material to be used for each part of the machine. Thorough stress calculations could not be done without knowledge of the material being used for each part, because of different materials physical and mechanical properties. By also knowing the material selection a cost benefit analysis could be conducted to determine how cost effective the product is. All of these calculations would greatly add to the significance of the research already conducted.

Control Systems

In our current design all of the kinematics for the motions of the moving parts has been implemented. However, there is no system in place to drive and control the motions of the worktable and clamps. This is a necessary process that needs to be done to finalize a fully functional working model of our design. To see the mechanism working under computer control, as how it was designed to function, would help improve the system. Having the machine as close to fully functional as possible is a excellent way to trouble shoot any unforeseen problems, because test runs can be preformed with different kinds of work pieces that would require unique motions. But because building a to scale working model of our design was out of the question, further research needs to be done in the way of a fully functional model. We could not complete this step by ourselves during the timetable given to us because of time restrictions and more importantly financial restraints.

5.3 Benefits to our Academic Community

Our research on welding fixtures with active position adapting functions aided the academic community in several ways. The first, and maybe most obvious benefit was the added research and thought into different solutions to the current problem. Our research opened our minds to the intricacies of designing a robotic welding fixture, and we became saturated with the possible design options. The more researchers and engineers there are working to solve one problem the better the end solution will end up being, because the people working on the problem can benefit from others work. The more research that can be done and made public, the more educated other engineers can be on any particular topic.

We believe that we have pushed the ideas and concepts associated with automated welding. Our design shows creativity through innovation and reflects what we have learned through our background research of other current products. This is a great asset we have bestowed on our academic community. Without mental saturation of a topic and innovation, engineering new ideas and concepts would not push processes like automated welding to better solutions.

Apart from the technical aspect of the project, our team learned a significant amount about how to operate in an industry. We gained the most experience when we were manufacturing our model. Working with the people at the local market, the wood factory at HUST, and at the engineering training center, we learned how to manage multiple resources to reach one goal. This experience will help benefit our academic community because now there are five more confident engineers in the world who have proven capable to coordinate efforts of outside resources to complete a project.

From working with our Chinese counter parts, and the various manufacturers, we learned a great deal about the Chinese culture. The most important part of the culture we learned was how to communicate with people that did not speak English as their native language. This posed problems for us at the beginning of the project, and our project suffered from it. However, once we learned how to communicate with one another the effects were obvious, and the problems we were having were more manageable. This experience will be able to aid us in any future work we venture into because of our ability to collaborate with other engineers from different backgrounds.

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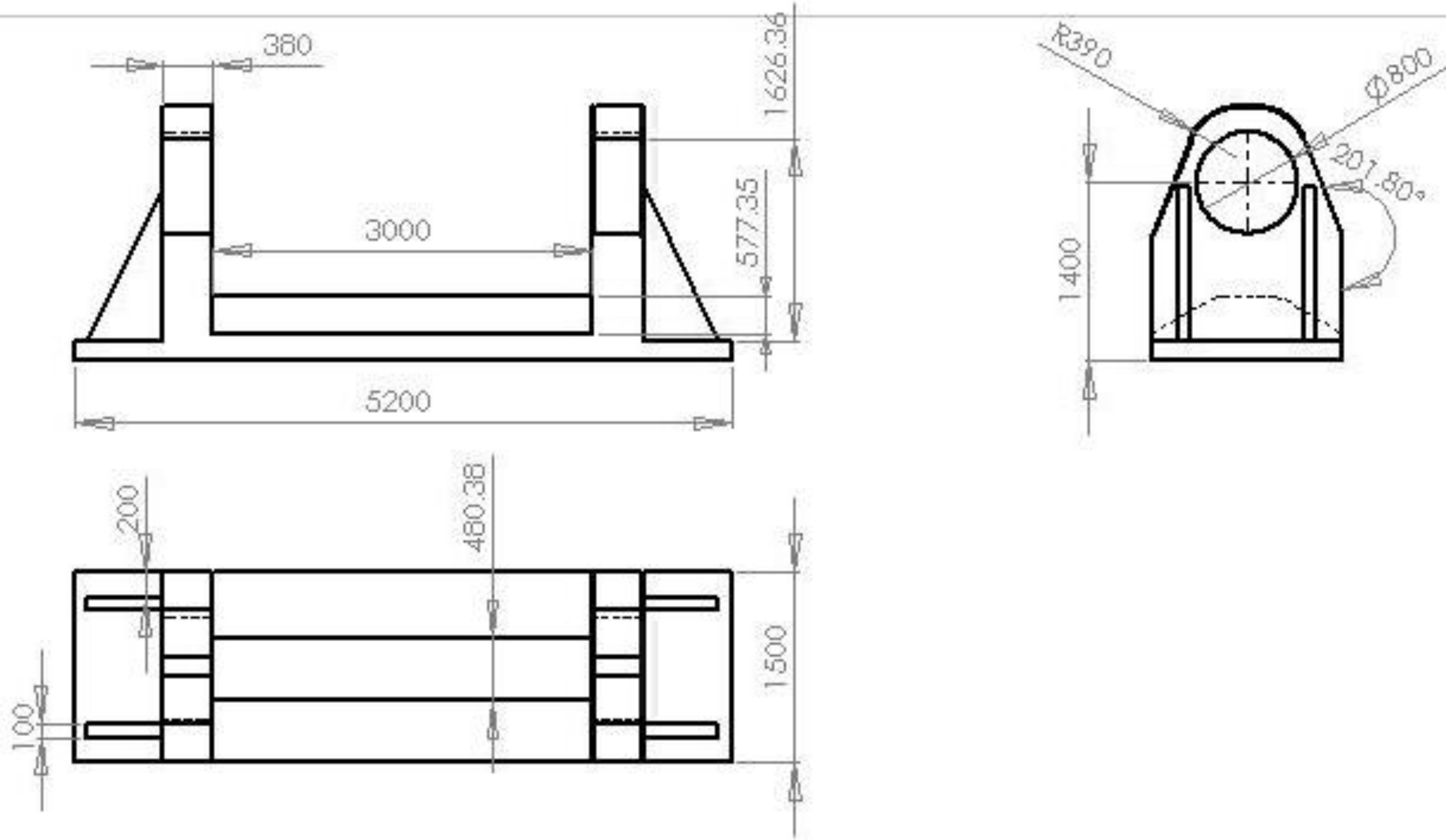
Appendix A – Machine Part Drawings

The following section contains the dimensioned drawings for the finalized design concept. The main design components are featured here, excluding smaller parts such as nuts, bolts, motors, electrical wiring, hydraulic hoses, etc…



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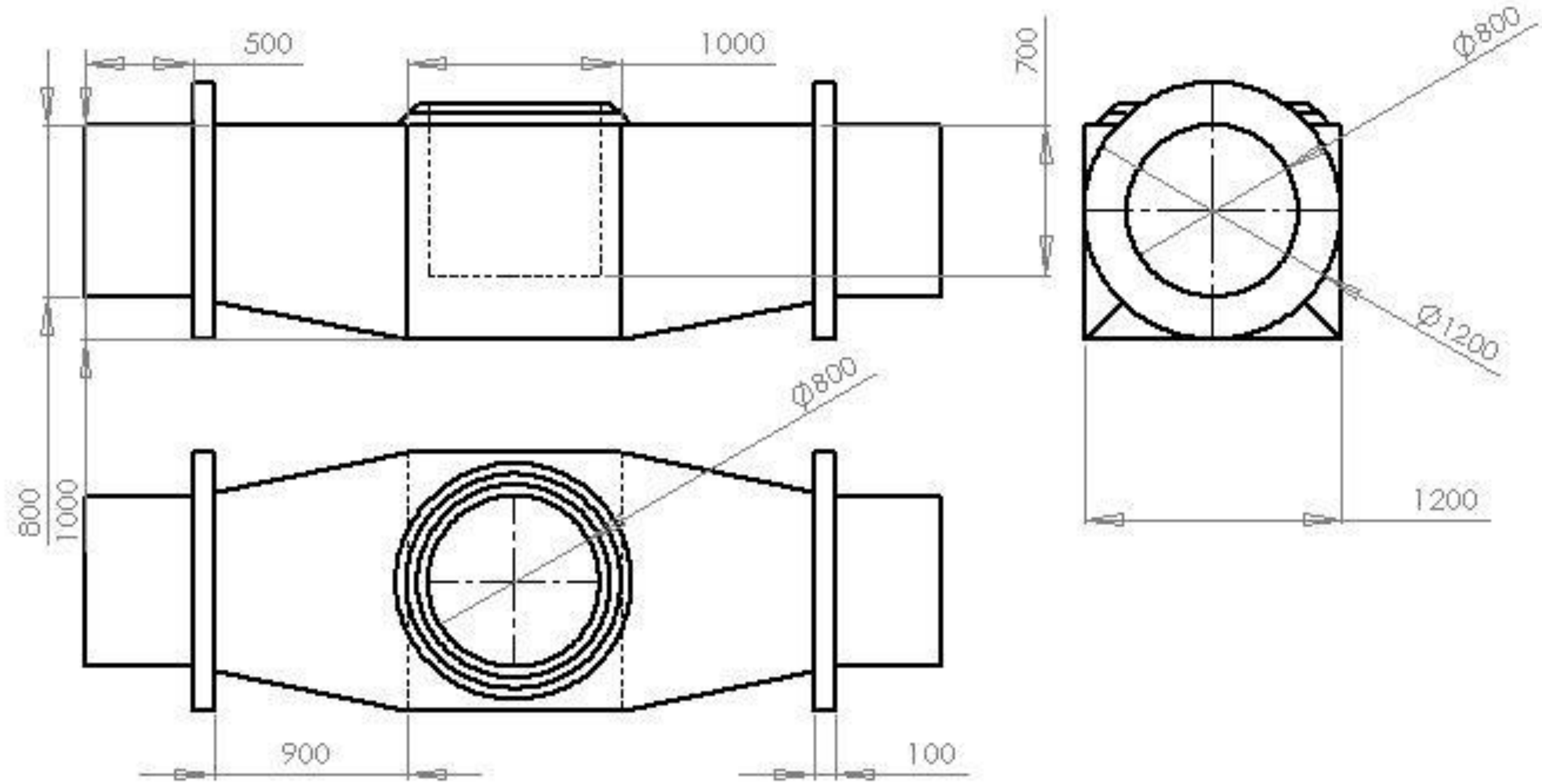

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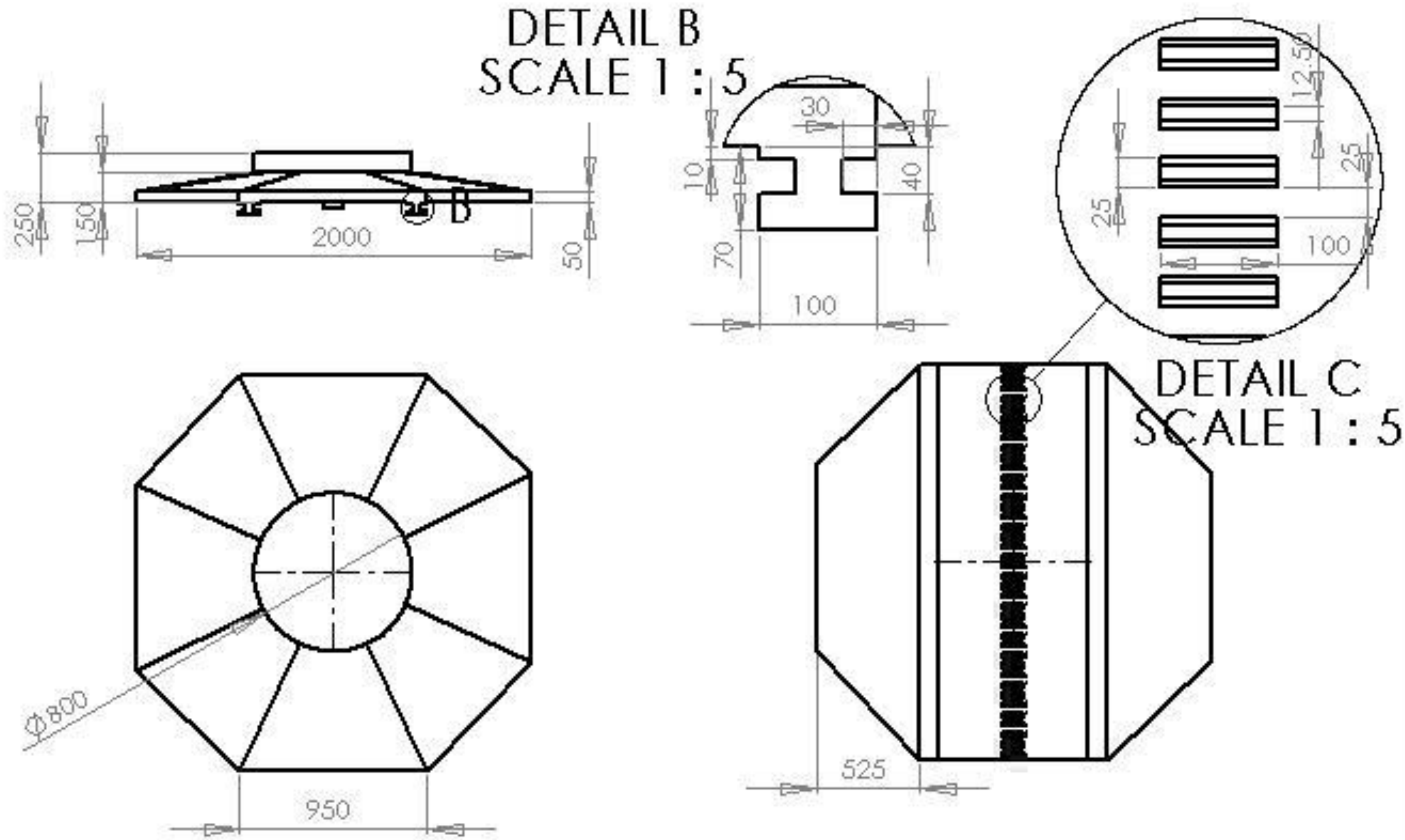

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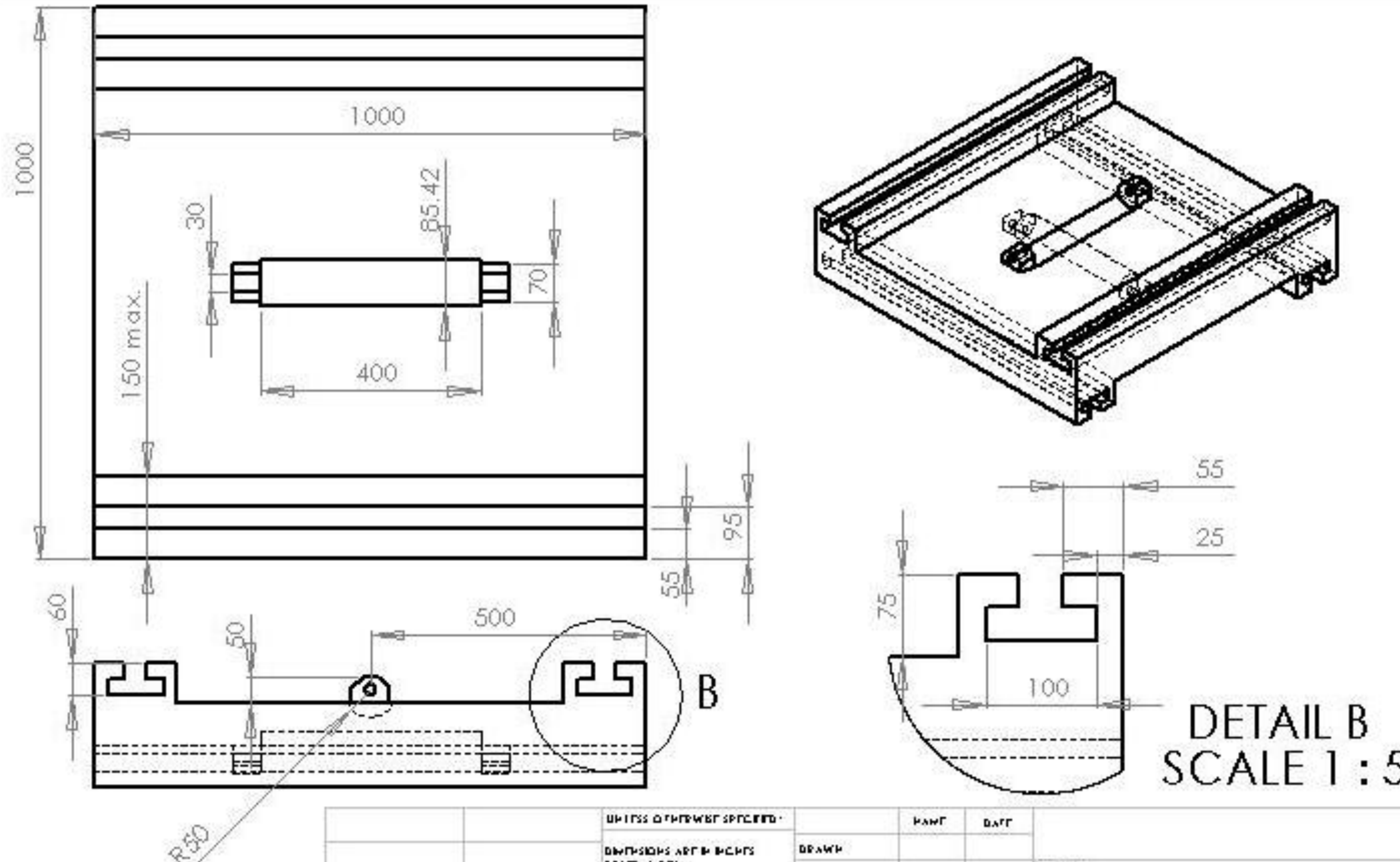

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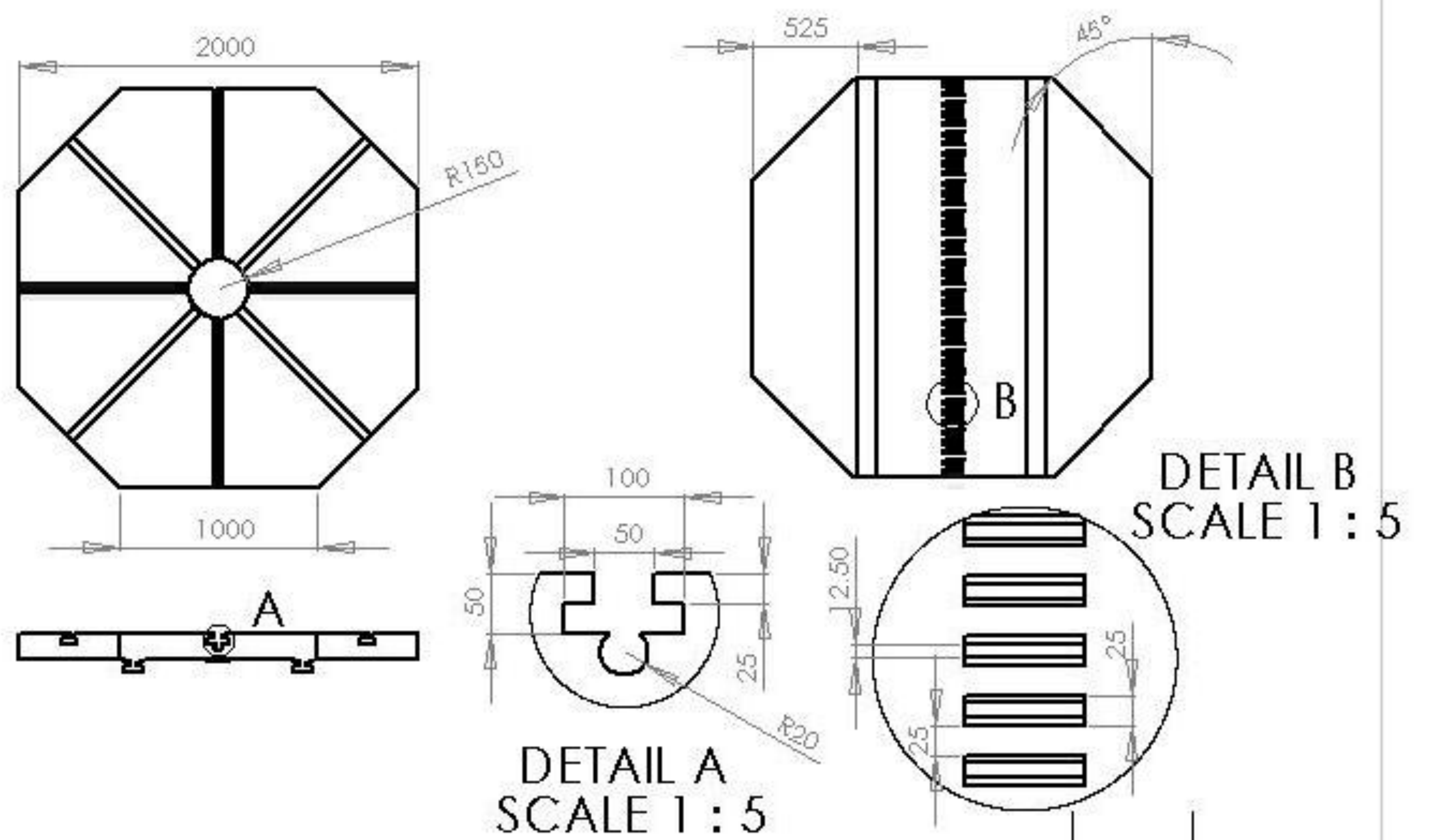

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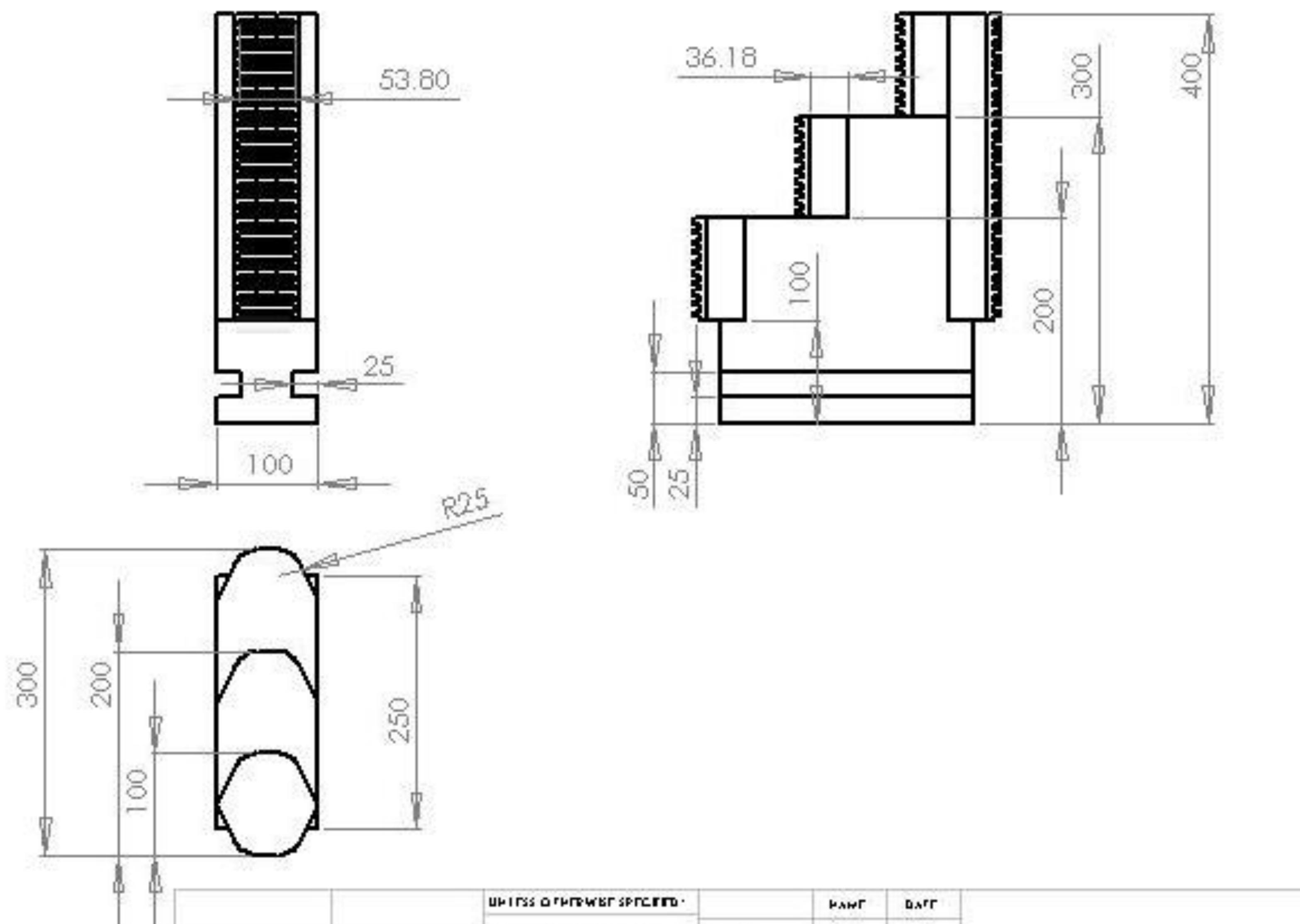

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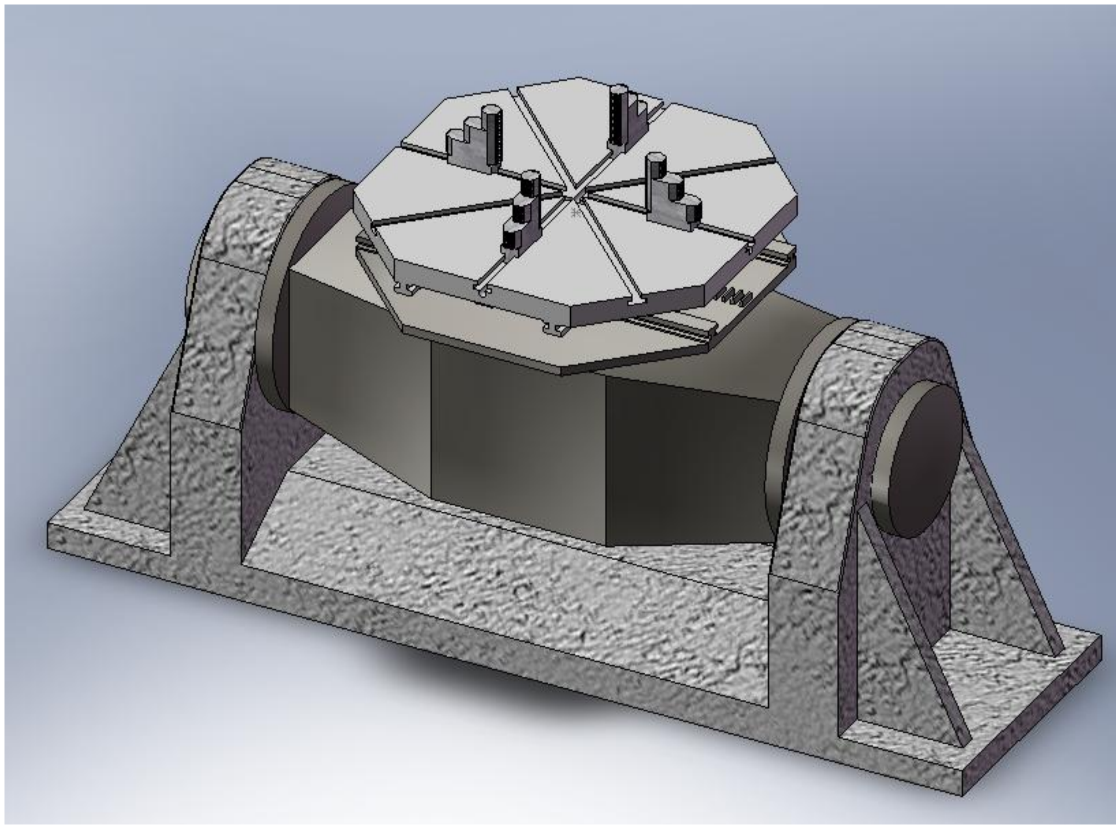
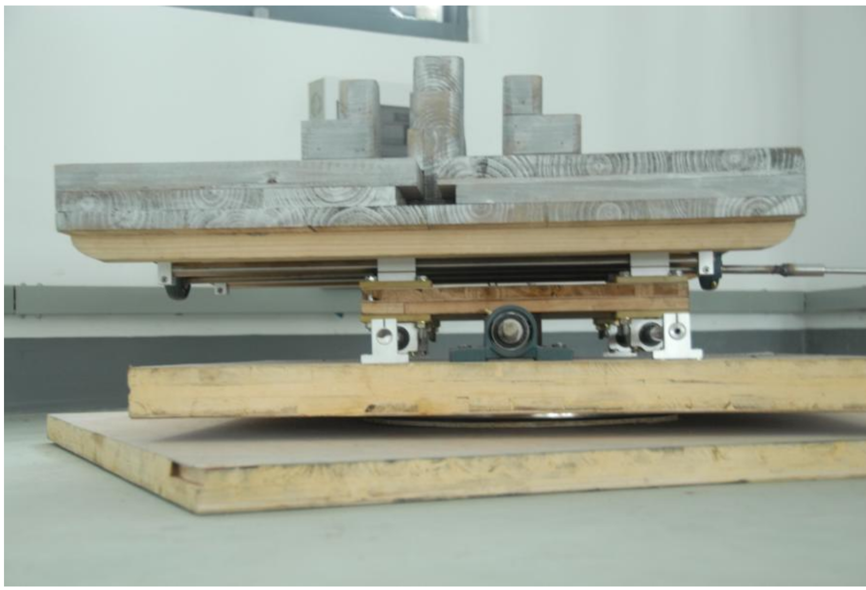
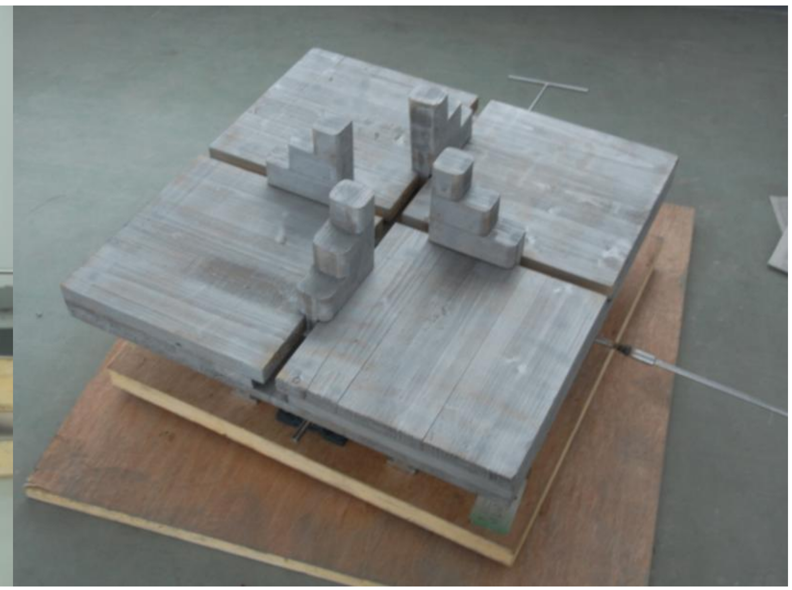
Appendix B – 3D Machine View

Pictured below is a three dimensional model view of the finalized design. This CAD model was modeled using SolidWORKS software package. All individual machine parts were created separately and can be seen in the machine part drawings in Appendix A.



Appendix C – Prototype Pictures

One of our main goals in the project was to create a prototype which would give us accurate information as to our design idea. The actual machine dimensions and materials would be too time consuming, large, and expensive for the scope of our project so an accurate prototype was constructed of the upper portion of the final design. Images of the actual constructed prototype are pictured in this section.

Appendix D – Gantt Chart

Throughout the entire length of the project the group followed a design schedule to ensure all important parts of the design and production process would not be missed. Below is a Gantt chart which serves as a visual representation of how time was spent completing each individual task.