DESIGN AND IMPLEMENTATION OF A FIXTURE FOR ROBOTIC WELDING

A Senior Project submitted to

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of the Requirements for the Degree of

Bachelor of Science in Manufacturing Engineering

by

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Abstract

The Cal Poly IME department recently purchased a robotic welder. The faculty would like to see this robot incorporated into the welding class. The robot was capable of moving, but was not able to perform a weld prior to this project. This problem is addressed by creating a demonstration part for the welding class. The objectives that need to be complete for this to be possible is designing a part, designing a fixture, analyzing the cost of robotic welding, and implement welding the part in the class. The part is designed with specific requirements in mind. The fixture is designed using an approach from “A Review on Design of Fixtures.”

The results of this project are a completed part and fixture. There were several issues that occurred when fabricating the fixture. This resulted in a fixture that was incapable of producing parts that met the requirements. The robotic welding process is shown to be impractical for this application from an economic standpoint. The robotic welder is now fully operational and with little effort can be used in the welding class.

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1. Introduction

Welding has been a large part of the materials joining industry for the production of various consumer products. The robotic welding industry has become more important in these processes as it allows rapid production and higher quality parts to be produced while reducing labor costs and operator exposure to hazardous bio-products of the welding process. In order be able to use robotic welding for production, a fixture must be designed that will locate, hold, and support the part while it is being welded. The design of the fixture will have a drastic impact on the quality of part that is produced from the process.

The welding class is set up to teach students how this process is done in manufacturing as well as limitations that this process has. This class does not currently have a robotic welding process in any portion of the class. The IME department has recently purchased a robotic welder, but it is currently not capable of being used for various reasons. The faculty in the department would like to see this robot incorporated in the welding class so that students are able to see how it works and what is possible to be achieved with this machine.

The objectives of this project are:

- Design a useful part that can be robotically welded
- Design a fixture to allow the automatic welding of the part
- Analyze the cost of the robotic welding process compared to other methods

- Develop a demonstration for the robotic welding class

The first step to accomplishing these objectives is to research robotic welding. The research will be focused on the robotic welder that has been purchased by Cal Poly's IME department, the Fanuc ARC Mate 50ic. The research includes the type of welding the machine does, defects and how to avoid them, fixtures for welding, programming the robot, and the reasons for automating welding. This research will be used for the design of the part and final fixture.

The next step after research is designing the part and fixture. The part is designed with machine capabilities and part weldability in mind. The part will need a fixture so that robotic welding is possible. The fixture is designed using basic fixture design principles as well as weld specific guidelines. Determining the success of the fixture requires running a program and evaluating the quality of the parts produced.

Testing the fixture first requires setting up a program for the robot to run. This is done using a teach pendant from Fanuc. The part is then welded and can be inspected. The inspection of the part is a visual check of the weld and measuring key dimensional requirements of the final part. This may lead to a re-design of the fixture in order to meet requirements.

The completion of these main objectives will allow the robotic welder to be used in the materials joining class and give the student a real world look at how robotic welding works. It will also provide a cost analysis of robotic welding compared to manual welding to determine whether robotic welding is a realistic solution to production problems.

The remainder of this report will cover the research that was done, the design of the part and fixture, the methodology for fabrication and testing of the fixture, and the results of the project.

2. Literature Review

This section of the report summarizes the research that was done for this project. The topics that were researched in depth are; gas metal arc welding, common welding defects, fixture design for welding, types of weld joints, programming a robotic welder, and the motivation for purchasing a robotic welder. These topics were researched because they can dramatically impact the final outcome of this project and to help the reader understand the process.

2.1 Gas Metal Arc Welding

One of the most suitable methods for robotic welding is gas metal arc welding (GMAW). GMAW is a highly economic process because it has higher deposition rates compared to other methods and does not require frequent stops to change electrodes. GMAW is also suited for almost any metallic material in almost any welding position and does not require as much post process cleaning as other methods (Pires, Loureiro, & Bölmsjo, 2006). This makes GMAW ideal for robotic welding applications.

The current robotic welder at California Polytechnic University uses the GMAW process. This welding process can use a variety of methods to weld the material together. The method of transfer that will be focused on in this project is short-circuiting transfer. The reason for this is that this type of weld is best suited for thin parts and can be used in every weld position. This method also reduces distortion in the part due to lower heat input in the joint. This method of welding works by creating a short circuit that heats up the electrode and welding surface and a droplet of the electrode gets pinched off (seen in figure 1) and travels to the weld location (Armao, et al. 2014). Both the filler metal from the electrode and the base material are melted and then solidify together to form a structurally sound joint.

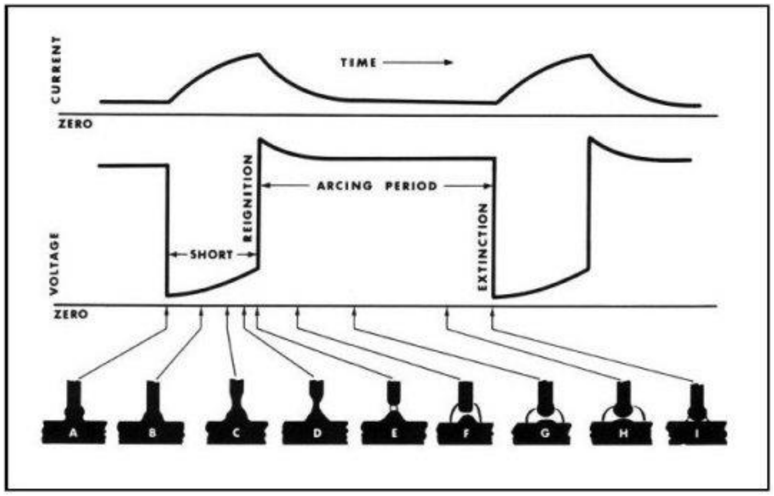

Figure 1 : Short circuit transfer process with respect to voltage and current.

(Handbook – Metal Transfer Variation)

There are nine basic internal parameters that can be adjusted to achieve the optimal weld result. These variables are peak current, base current, rise time, falling time, wire feed speed, arc voltage, waveform response time, pulse mode, and pulse frequency. These variables must be carefully controlled during the weld or a variety of errors may occur. Each of the current and voltage modifiers are used to control the arc which affect how the weld penetrates and how the weld bead will form. The wire feed speed will need to be constant in order to maintain a uniform bead across the weld surface ("Automated MIG Welding of Aluminum.", 2004). Each of these variables needs to be tested and carefully controlled to minimize defects in the produced parts. All of these parameters are controlled manually for the welder at Cal Poly. This means that each parameter must be tested and altered with until part quality is satisfactory for the application. There are basic guidelines available at Lincoln electric.

2.2 Welding Defects

One of the biggest challenges to welding parts is trying to avoid defects. Many of these defects can be controlled with the welding parameters and can prevent the problems from occurring. Some of the most common types of welding defects created during metal inert gas (MIG) welding are porosity, lack of fusion, and burn through. There are several reasons why a weld may have porosity. These include; Contamination by the atmosphere and other materials such as oil, dirt, rust, and paint, changes in the physical qualities of the filler wire due to excessive current, entrapment of the gas evolved during weld metal solidification, loss of shielding gas because of too fast travel shielding gas flow rate too low and not providing full protection or drawing air into the arc area, wrong type of shielding gas being used, defects in the gas system (Grill). The reason for lack of fusion or burn through is often current or travel speed settings. Carefully controlled welding parameters will ensure the highest level of quality in the parts and reduce the overall cost of making each part.

2.3 Fixtures

Robotic welders do not have the ability to search for and find the exact location they are meant to be welding. A robotic welding program will execute the same actions during each cycle of the operation. Because of this, a fixture is needed to locate the part that is being welded. The part of the fixture that locates the part is generally a fixed point that restrains the part in each degree of freedom. The fixture is also used to hold the part while the process is running. This is generally done through clamps that allow the easy removal of the part, while ensuring enough clamping force to prevent the part from moving while the operation is happening. Another aspect of the fixture is to maintain the geometry of the part and fixture while thermal stresses are acting on it (Vural, Muzafferoglu, and Tapici, 2007). This means that the material selected for the welding fixture needs to have a higher melting temperature than the part especially if the fixture is close to where to material joining process is happening. This also makes the selection of the art material a critical aspect. A part with a lower melting temperature will help to reduce the cost of the fixture, but the part requirements still must be satisfied.

Flexible fixtures are becoming more common in modern manufacturing practices. Rather than having a dedicated fixture for a part, a robotic gripper is used to hold the part during the welding process. These systems are highly complex and require several cameras to allow the location of the part before it is grabbed, and to position the part at the correct location to allow the welding process to be completed. The gripper provides the same basic function of the dedicated fixture, but could be used to process a variety of parts without requiring a new fixture to be designed and manufactured for each unique part (Demers and Bernier, 2013). The cross communication between the robotic welder and robotic gripper must be precise because the gripper allows the part to be moved while the operation is happening. This motion allows for complex parts to be operated on because of the dynamic rather than a static fixture.

2.4 Weld Joints

There are several common types of welding joints (figure 2) that require a different level of skill to create. The weld that is used changes depending on the task that is required. Butt joints are used where high strength is required. They are reliable and can withstand stress better than any other type of weld joint. This is the most basic type of joint and can easily be accomplished with most materials. Thin sheet metal is more difficult to join in this way because there is little contact with the different materials. For sheet metal a transverse fillet weld is used. This weld type requires significant clamping to ensure that sufficient contact is made between the mating surfaces. Corner joints are similar consist of sheets or plates mating at an angle to one another. With thinner materials this weld type requires sufficient tooling to ensure a satisfactory weld. It is not recommended for thin materials because this weld type can cause distortion and warping in the part. Edge welds are used where the edges of two sheets or plates are adjacent and are in approximately parallel planes at the point of welding. This type of weld is limited to low stress applications because the weld does not penetrate completely through the joint thickness (Weld Joints and Weld Types.).

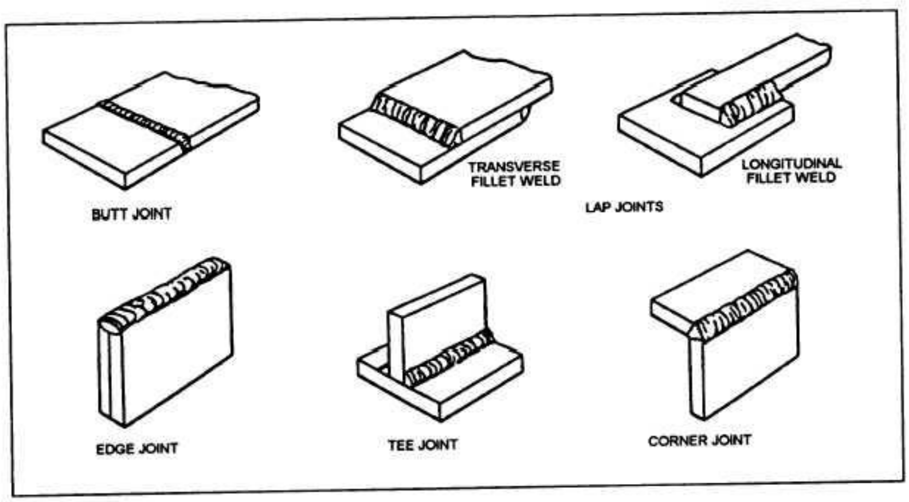

Figure 2 : Types of welded joints ("Engineering Training and Reference Manuals.")**.**

2.5 Programming for Robotic Welding

There are several methods of programming available for achieving a welding program. The method that I will be using for this project is using a teach pendant (figure 3). This pendant operates by selecting a coordinate system (joint, world, tool, or user) and moving the robot to each desired position. Each position that is desired for the robot to move to in the program is set by pressing a button to save that point. The positions must be set precisely to avoid collisions with the work-piece and fixture. The speed for each move is set manually using knowledge about the type of weld and material that is being welded. Each brand of robot has slightly different functions that can be learned and applied easily ("Simplified Welding Robot Programming.").

Figure 3: Fanuc Teach Pendant

Another method for programming a robotic welder is offline programming. This method uses a software package to create the program for the robot to use. In order for this style of programming to be used, the robot's workspace must be modeled in software so that collisions do not occur when the program is being run on the shop floor. When programming how the robot will move, the position of the robot before and after the move must be input to the program in order to avoid singularity errors (Ivan et al. 2015). (A singularity error occurs when there are an infinite number of possible paths the robot can take to get to the same point. Generally this means that one or more axes are perfectly aligned and the program cannot determine which axis to move). This method of programming will give the same results as using the teach pendant, but can be done offline to save valuable operation time.

2.6 Why robotic welding?

"Robot-based automation increases the efficiency of welding processes and enables your organization to manufacture more parts in less time, while minimizing scrap, increasing quality and improving the working environment" ("Robotic Solutions for Welding Applications."). It is for these reasons that many companies have decided to move away from manual welding toward a robotic substitute.

The biggest motivation for companies moving toward robotic welding as opposed to manual methods is cost. The cost of producing a weld is broken down into the material requirements as well as labor costs. Approximately 70% of the cost of a weld is attributed to labor and a robotic welder can reduce the labor by 75% (Summers and Stevens, 2008). This effectively means that by implementing a robotic welding cell a company can save nearly half of the cost of producing each weld. The biggest factor that influences the cost is the speed. This can be different from company to company, but robotic welding nearly always saves time. AB Allt i Plåt, a company that makes mining equipment, is able to produce cabs in three hours opposed to manual welding taking an entire shift (Farnsworth, 2008). Another case study from Stross reports that the cycle time was reduces to 54 minutes, three times faster than a human welder can complete the task. This is a dramatic reduction in the cost per unit and can quickly add up to the initial cost of the robotic welder.

Another advantage of adopting robotic welding systems is that every welded product will be completely consistent with each other. You can use software to program your equipment and procedures according to the specifications of your project. The result will be that every product will have the characteristics that you need (Wilson, 2016). The ability of a robotic welder to consistently repeat the same weld is one of the biggest advantages of robotic welding. There is very little variation in the weld from part to part and the parameters are much more closely controlled when compared to manual welding. This allows each part to have excellent quality and reduces rework and scrap production.

Mid-Continent Engineering Inc. decided to invest in robotic welders for three reasons; Speed, uniform welds, and shortage in qualified labor. The ability to find skilled labor to weld is becoming increasingly more difficult. The training required for a manual welder can be several years, while the ability to operate a robotic welder can be learned in just a few days (Cleveland, 1997). This is becoming a larger reason for companies to switch to robotic welders. It is becoming the key driver for making the switch to robotic welding and programming the welders is becoming easier constantly (Lorincz 2015).

The final area that robotic welding has helped to improve is the health of employees. Welding is a process that produces toxic fumes and with continued exposure can lead to some serious health problems. The effects of various metals can cause a variety of problems, most of which do not cause permanent damage ("Welder's Guide to the Hazards of Welding Gases and Fumes." 2009). This can still affect the performance of the welder and cause delays in production. It also affects the moral of the workplace and decrease long term productivity of the company. Robotic welding can eliminate many of these problems and allow a more constant workflow without risking employee health.

3. Design

3.1 Part Design

The first design for this project was the part that would be manufactured during the demonstration. There were several issues that were addressed with the design. The first issue was creating a part with components that were easily attainable. The components that were used were all available to be purchased with no additional machining required before they could be welded together. The second issue that shaped the final part was how useful it would be in a business application. I decided to look to construction where manual welding is common to assemble parts. The final issue that influenced the design of the part was the part's suitability for robotic welding in the cell that was previously set up. This primarily kept the part size from being too large due to the limited workspace, and kept the part from being too small because of the robot capabilities.

The part that was decided to be used for this project was a simple flange attached to a pipe (See Appendix A). This part is used for high pressure water or gas systems in a building. Most of the pipe and flanges used in construction are larger, but this part is still applicable in many smaller systems. The reason that this size was used for this project is because of the lower cost associated with obtaining the components. The size was also ideal because it is neither too large for the workspace, nor too small for the welder.

3.2 Fixture Design

The fixture design began after the part was finalized. The approach that was taken to design the fixture was based on "A Review on Design of Fixtures" (Pachbai and Laukik, 2014). This basic approach is outlined below.

3.2.1 Define requirements

The fixture must hold the flange and pipe in order to locate critical dimensions while it is being welded. It must also hold the part tightly in order to minimize warping from the welding process. The fixture must allow for the robot to reach the weld location with the tip of the welder. The material needs to resist the heat generated from the weld. Finally the part needs to be able to be easily inserted prior to the weld, and easily removed after the weld is complete.

3.2.2 Gather and analyze information

3.2.2.1 Machine Specifications

The robot that is being used is capable of rotating on six axes. Joint 1 can rotate 360°, Joint 2 can rotate 200°, Joint 3 can rotate 388°, Joint 4 can rotate 380°, Joint 5 can rotate 240°, and Joint 6 can rotate 720° (joints shown in figure 4). This allows for nearly any position to be achieved within an open workspace. The workspace that was set up is approximately 3 feet long by 6 feet wide and 5 feet tall. This means there are some restrictions on which positions can be reached by the robot. The interference area can be seen in Appendix B.

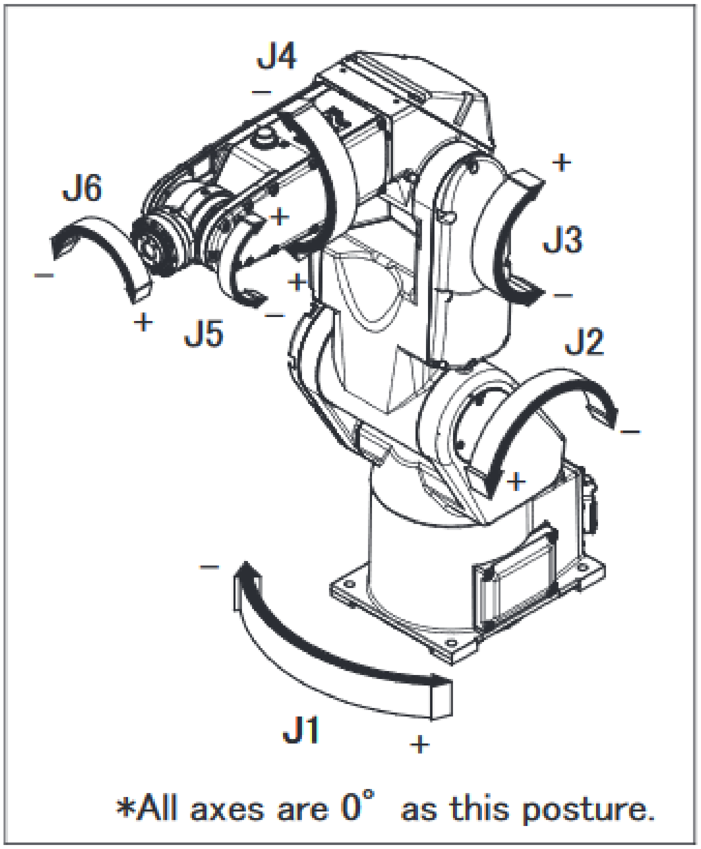

Figure 4: Robot Joints

3.2.2.2 Part Specifications

The parts that were used for this project are a flange and ½ inch pipe (Appendix C and D). The fixture was designed with these dimensions in mind. The key requirements for this part were perpendicularity and parallelism because of the assembly it will later be attached to. The tolerance associated with this part is used because of the current methods for checking these features. The manual method for checking these tolerances in the field is using a bubble level

(Pipe Fitter's Handbook, 2012). These are typically accurate up to .1 degrees and that rating over 20 inches is .03 inches. This part is made out of low carbon steel in order to withstand the high pressure it is subjected to.

3.2.3 Develop Several Options

3.2.3.1 Flange Locator Part

The part used for locating the flange (see Appendix E) was the same for each of the following designs. The flange is located in the flat surface of the part to get the weld height correct. This part locates the center of the flange by using pins that are inserted into the holes on the flange. The final feature of this part of the fixture is a hole cut in the center to allow the flange to sit flat against the flat surface. This was designed assuming geometric dimensioning and tolerance were the tolerances given by the flange manufacturer. This is a simple method for location because it is fixed and does not require the fixture to move to locate these features.

3.2.3.2Fixture A

Fixture A (see figure 5) is a horizontal fixture that has enough clearance from the base plate to allow the robotic arm to complete the weld. The locator part attaches to the fixture using steel rods and a nut on either side of fixture. The locator part is able to be moved by unscrewing or screwing in the threaded rod. This also holds the part tightly while it is being welded. Both flanges are attached at the same time to reduce set-up time and increase the productivity of the welding process. This sacrifices the variability in the length of the part in order to maximize productivity.

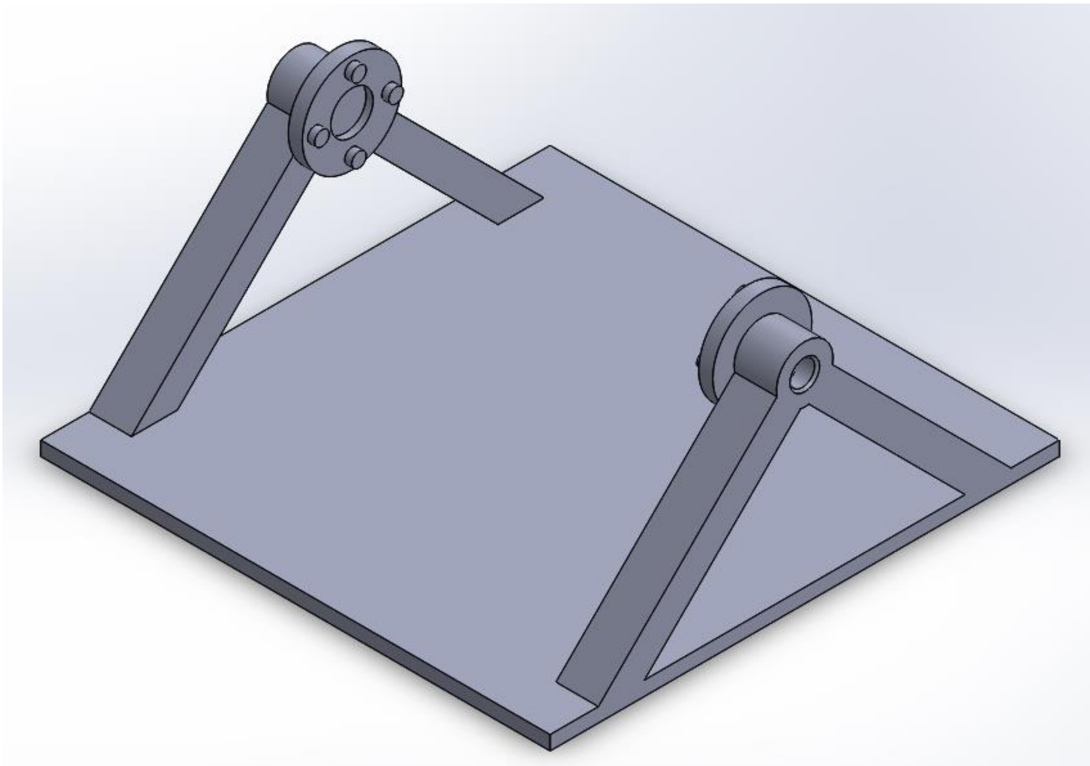

Figure 5: Fixture A

3.2.3.3Fixture B

Fixture B (see figure 6) is made using square steel tubing as the base. One side of the locator part is fixed to the steel tubing while the locator part on the other side is attached to a threaded rod and is screwed into the steel tubing. This fixture stands vertically so that it is more accessible to the welder and is easier to insert the welded part components. The square tubing allows for the fixture to be built bigger because of the material strength. The square tubing is also less difficult to assemble because of the reduced warpage when welding the fixture together.

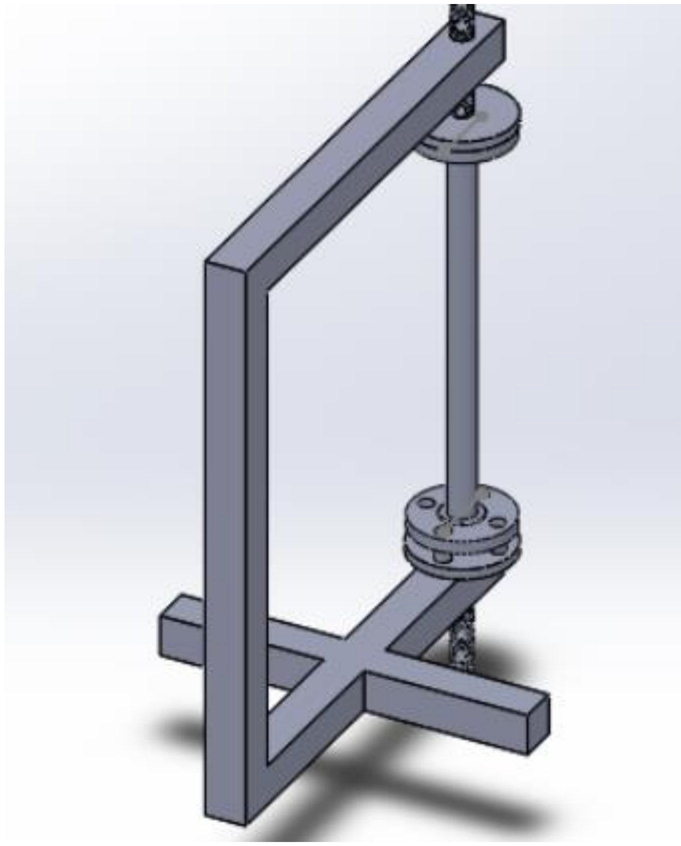

Figure 6: Fixture B

3.2.3.4 Fixture C

Fixture C (see figure 7) is made using steel bar stock attached to a plate. A single locator part is welded directly to the plate. The pipe is centered using a V block to locate the center. The pipe is held using a bungee cord that is simple for an operator to attach and will provide enough support to hold the pipe while it is welded. The main advantage of this design is that the length of the pipe can vary significantly. Another advantage is that the welder has plenty of clearance because the size and shape of the fixture is created based on the robot capabilities rather than part requirements. This fixture is less efficient because it has to be set up twice in order to finish the welded part.

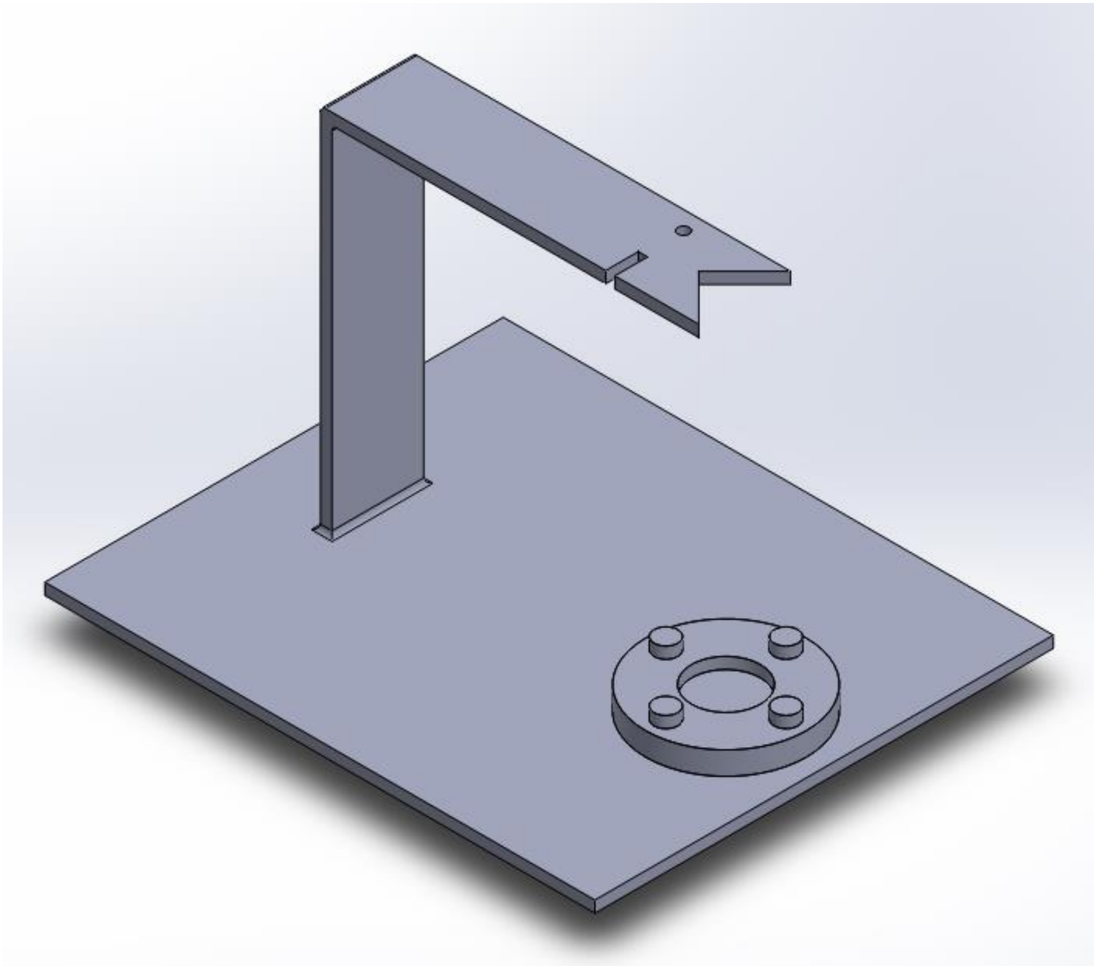

Figure 7: Fixture C

3.2.4 Selecting the best option

The fixture that was chosen for this project is fixture C. This is mostly due to the versatility in the length of the pipe. Most pipe and flange systems are cut to length in construction. This fixture is able to accommodate this so that the length does not have to be set at one size. Another reason why this fixture was chosen is because of the machine capabilities. This fixture allows the machine to move more freely in the workspace without worrying about collision between the robot and the fixture. This fixture is significantly easier to work with when compared to the other fixture designs. This design fulfills all of the requirements for this fixture and is the best choice.

4. Methodology

4.1 Fixture Fabrication

4.1.1 Locator Part

The locator part is the nearest piece of the fixture to the welded spot. This means that it will be subject to high temperatures and needs to be able to withstand them. The material that is used for this part is a low carbon steel. This part was made from 3.5 inch round bar stock that was processed on a cnc mill. The mill was used to cut the face of the part, pocket the center, and drill the holes. The pins that would be put into the holes were cut using a lathe. A lathe was used to ensure that the pin was at the correct diameter for the holes. The pins were then pressed into the holes resulting in a finished part.

4.1.2 Fixture Body

The remaining part of the fixture is also made from low carbon steel. This material was chosen so that the fixture would be able to resist wear from the operation. The base plate and two supporting beams were cut from steel sheet using a shear. The V was also sheared into the top beam using the press. The notch was cut using a vertical band saw. These parts were then welded together by the welding professor. The locator part was position so that when a part was inserted it would be vertical. This part was then welded to the base plate of the fixture.

4.2 Programming

In order to being testing my fixture design a program had to be written for the robot to weld the part. This was done using the teach pendant. The teach pendant works by allowing the operator to control each of the six axes on the robot to move to the necessary weld points. Several points were chosen along the weld seam of the flange and pipe that formed an arc around the pipe. This program was written so that the robot would follow the same path each time the run button was pressed. As long as the fixture was placed in the correct location the program would run and make a satisfactory arc around the part. The program that was used to weld this part is seen in figure 8.

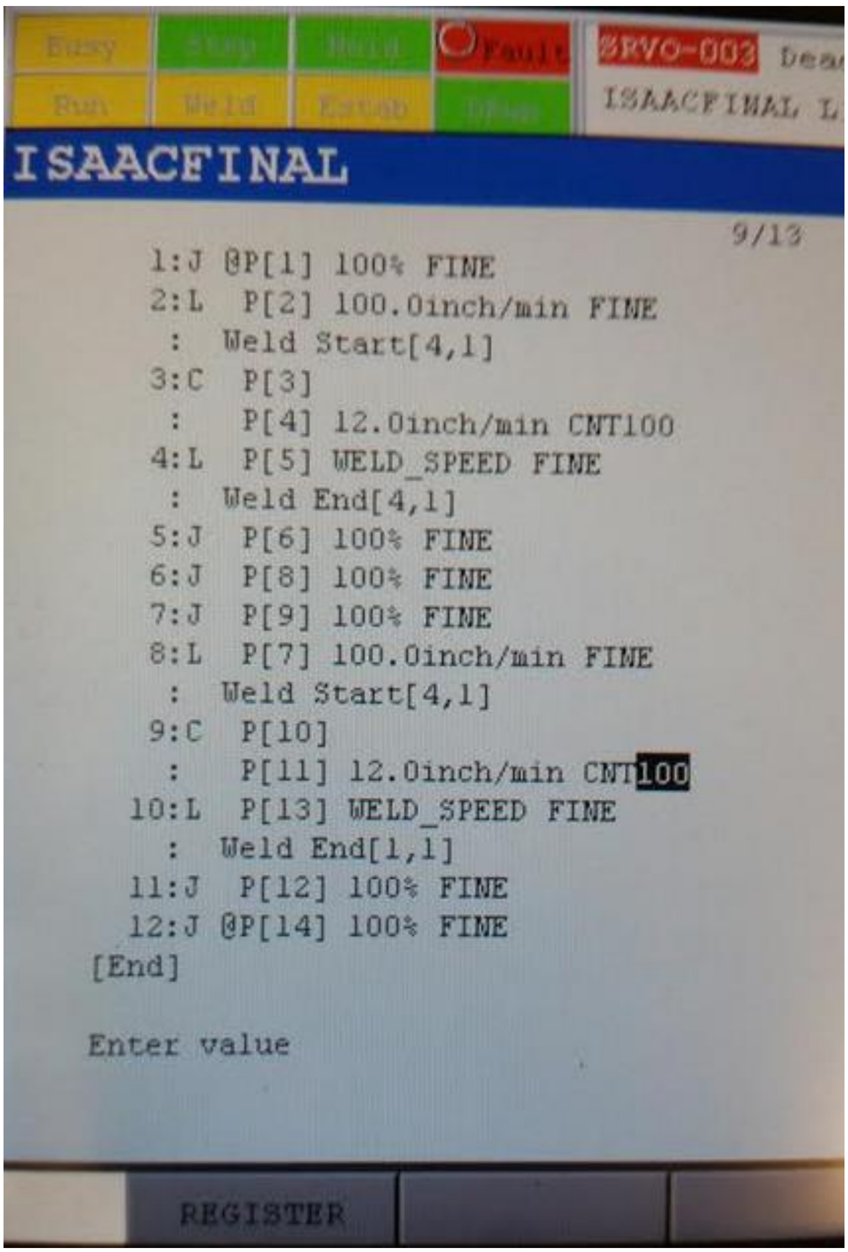

Figure 8: Welding Program

After the basic motion of the welder was set up the weld parameters needed to be input to create a high quality weld. The initial weld parameters of wire feed speed and voltage were set up using the Millerwelds mobile application for initial settings. The weld travel speed was calculated using the desired weld volume and calculating travel speed based on wire feed speed. The initial wire feed speed was 300 inches per minute, voltage was 21, and travel speed was 6 feet per minute. These parameters were tested using steel stock of similar thickness and orientation. The fillet weld was repeated and parameters were adjusted until the weld was satisfactory. The wire feed and voltage were satisfactory, but the travel speed was adjusted to 12 feet per minute. These settings were input into the weld program and the fixture was ready to be tested.

4.3 Weld Quality

The quality of the weld is determined by visual inspection. It would be ideal to test the weld by placing it in a system to see if can withstand a desired pressure, but that was unable to be accomplished in this project. It is difficult to tell if the quality of the welding process due to small number of parts that were able to be created. This limitation is mostly due to the cost of the flanges. More substantial testing would be required before this was implemented in a large manufacturing capacity.

The quality of the part as a whole is determined by whether it meets the specifications for the part (Appendix A). The specification that has to do with the welding process is the parallelism of the flanges to each other and the perpendicularity of the pipe to each flange. This is important because if the perpendicularity or parallelism of the part is too far off, the part will not function when it is connected in a system. These geometric requirements can be tested using a flat table and a dial indicator or various other methods.

5. Results

5.1 Defects

After creating a small number of parts hardly any defects were present in the weld. The only defect that was present was due to an error by the operator. This defect was improper fusion of the part and flange because the welding gas was not turned on before the program was started. This mistake was caught early in the weld and the part was able to be reworked. This is an issue that could come up again if the gas runs out during a weld or is not properly set up before the welding begins. The weld is remarkably consistent because all of the parameters are so tightly controlled and this process is capable of producing high quality welds.

A separate issue is that the part did not meet the perpendicularity and parallelism requirements. The reason for this is a poorly aligned fixture as well as the warpage that was not fully accounted for. This issue requires a rework of the fixture to ensure that the parts are aligned properly. This is a simple rework that requires re-welding the locator part to the plate. The problem occurred when the locator warped while it was being welded to the base plate. This can be solved either attaching the locator part mechanically or bending the plate before each side of the locator is welded on.

5.2 Economic Analysis

The result of the economic analysis of this process compared to manual welding is shown in figure 9. This analysis was created using 3250 parts per year at $50 each with a 3.5% interest rate. This shows that if these numbers are used, the robot will pay for itself after nine years of production. This payoff period rapidly changes if the number of parts is increased. The payoff period is also highly dependent on the labor rate. The labor rate was determined using payscale.com and is a national average for welders. The number that was given was adjusted by 1.5 times to account for other expenses like workers compensation, social security, ect. The time it took to complete each task was measured when I was setting up the part in the welder and the welder performed the weld on the part. The cost to produce each part is shown in Appendix F and Appendix G. These costs include factors of setup time, welding time and material usage. The robotic welder is more cost effective in each of these areas, but requires a large initial investment making it a less attractive option in the short term.

Yearly Parts ->	3250
Selling Price ->	$50.00
Interest Rate ->	3.50%

Year	0	1	2	3	4	5	6	7	8	9	10
Profit Robotic	(35,117.71)	(23,810.94)	(12,108.43)	3.67	12,539.68	25,514.46	38,943.36	52,842.27	67,227.64	82,116.50	97,526.47
Profit Manual	(606.71)	7,334.10	15,552.83	24,059.22	32,863.33	41,975.59	51,406.77	61,168.05	71,270.97	81,727.50	92,550.00
Difference Robotic Vs Manual	(34,511.00)	(31,145.03)	(27,661.26)	(24,055.55)	(20,323.65	(16,461.12	(12,463.41)	(8,325.78)	(4,043.33)	389.00	4,976.47

Figure 9: Economic Analysis Summary

5.3 Other Implications

There are reasons why a company shouldn't use this process other than economic reasons. One reason is the impact on current employees. This is an issue that is common when automating a process. Robotic welding is more efficient and would require fewer employees than a manual process. This means that welders could potentially lose their jobs and would negatively impact them and their families. Another reason why a company may not want to implement this system is because it would require the training of an employee on how to use this system. This is not as much of an issue because the training would only take a few days before the operator would be proficient.

There are also some positive impacts that implementing this automation would have. Robotic welding is less hazardous for employees because they do not have to breathe the toxic fumes that are produced during welding. The operator is able to stand clear of the fumes which will have a positive impact on their physical health. Another benefit automation has is a reduction in material usage. This means that fewer natural resources are needed to produce each part. The reason for this reduction in material is that the robot performs the weld more consistently than a manual welder. This means less welding gas and wire is lost because the weld is closer to ideal every time. These factors should be considered when deciding whether or not to implement a robotic system.

5.4 Implementation

The implementation of this project in a manufacturing environment would be simple to complete. The biggest obstacle would be training an operator for the robot. This is a relatively simple robotic system to operate and finding someone capable of learning it should not be difficult. The implementation also requires more extensive testing of this fixture. It is not possible to determine actual quality of the parts produced with such a limited sample size. Another issue that should be considered before implementing this system is the small market for this specific size of pipe. Assuming this process is capable of producing high quality parts this fixture could easily be modified to accommodate other pipe sizes that are more commonly used. This would increase the number of parts that could be produced and sold to decrease the idle time the welder would likely face.

6. Conclusions

This project has provided a solution to the existing problem. The approach to this project involved designing a part, fixture, and process for welding the part. The part was designed keeping in mind the requirements that it should be useful, the components should be easily attainable, and automatic welding was a valid method for the part to be assembled. The fixture was designed using the approach outlined in "A Review of Fixtures" as well as the basic principles of fixture design.

Results of the project:

- Designed a useful part that can be robotically welded
- Designed a fixture to allow the automatic welding of the part
- Analyzed the cost of the robotic welding process compared to other methods
- Developed a demonstration for the robotic welding class

The parts that were produced in this project failed to meet the specifications. This is due to warpage in the fixture while it was being assembled. This can be solved by re-welding the locator part to the base of the fixture with less heat in order to avoid warpage. A press fit pin in both parts could also be considered if the fixture still warps. Refabricating the fixture and further testing of the fixture should be completed before manufacturing this part on a larger scale. The economic analysis shows that this is not a practical solution for small scale manufacturing as it would take nine years and 3200 parts per year to pay for itself over manual welding. The economic analysis included several assumptions that would have to be looked at again for a company making this implementation.

The next step for the class is to create a “hands on” demonstration so that students in the welding class could use the robot themselves. This would benefit them more than just seeing how the robot works. This can be done easily now that the robot is fully set up and running smoothly. Some exercises have already been created but need to be refined before this is an option in the classroom.

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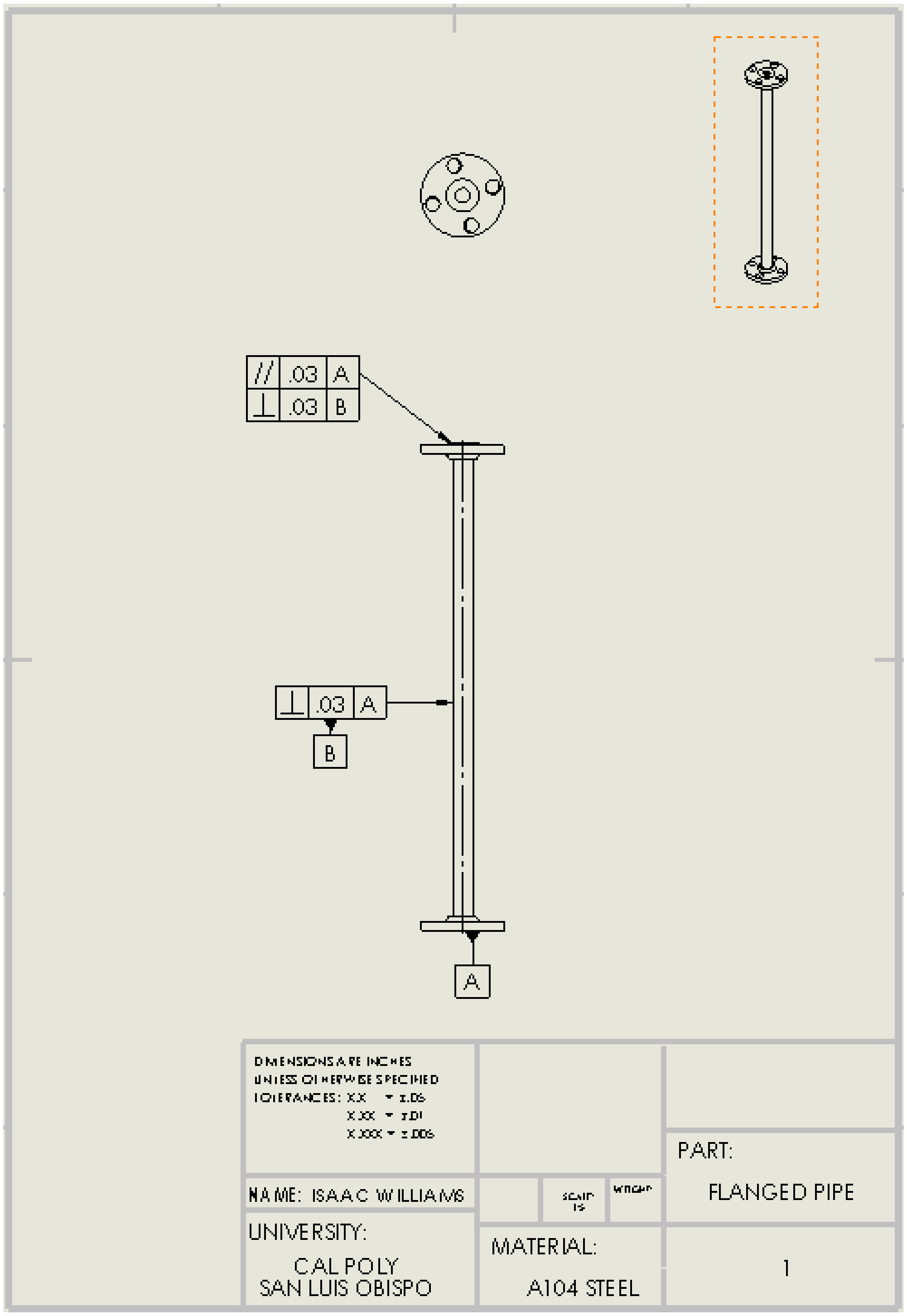
Appendix A



// .03 A
⊥ .03 B
⊥ .03 A
B
A
DIMENSIONS ARE INCHES
UNLESS OTHERWISE SPECIFIED
TOLERANCES:
NAME: ISAAC WILLIAMS
UNIVERSITY:
CAL POLY
SAN LUIS OBISPO
MATERIAL:
A104 STEEL
PART:
FLANGED PIPE
1

Appendix B

3.BASIC SPECIFICATIONS B-82584EN/07

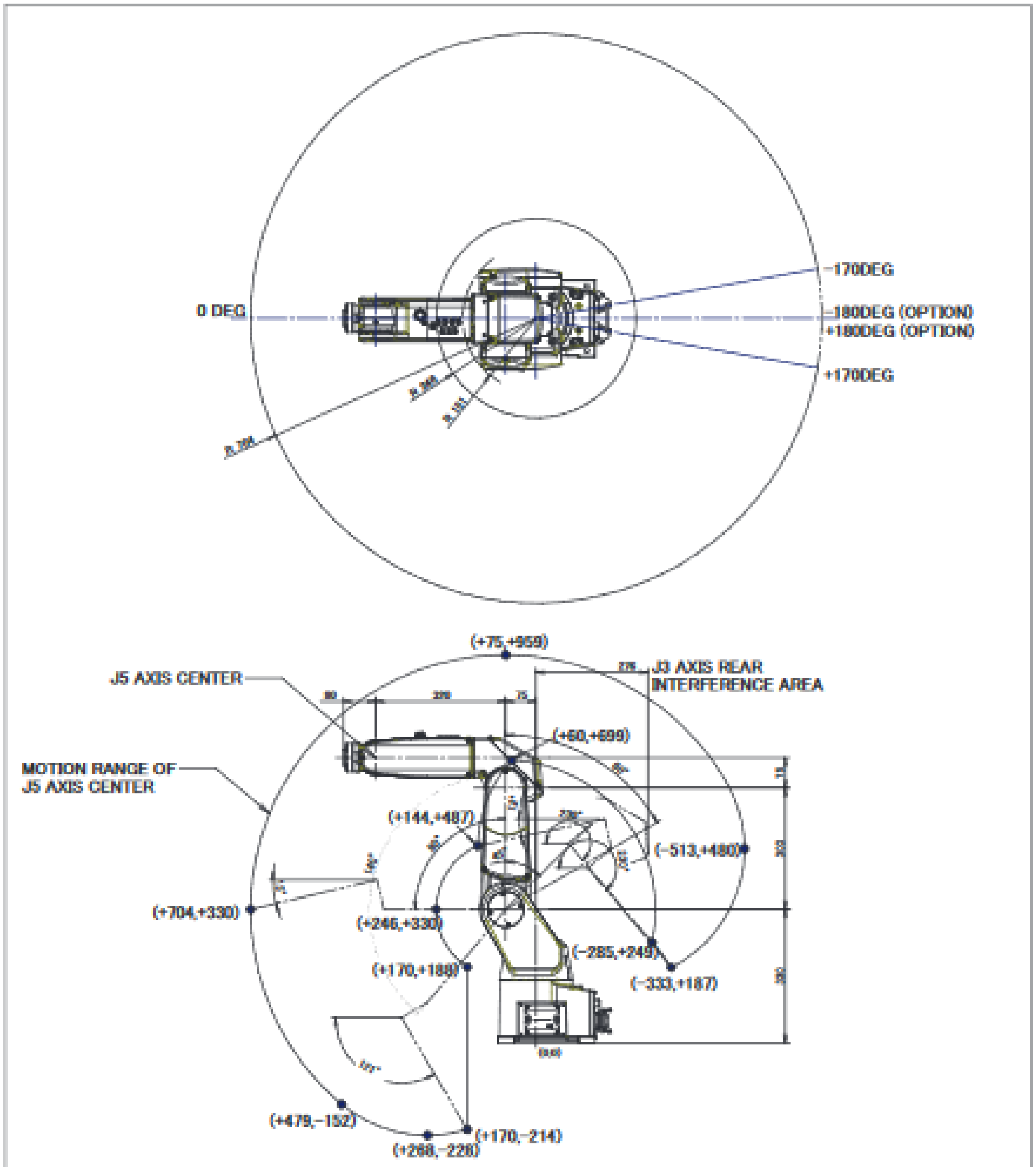
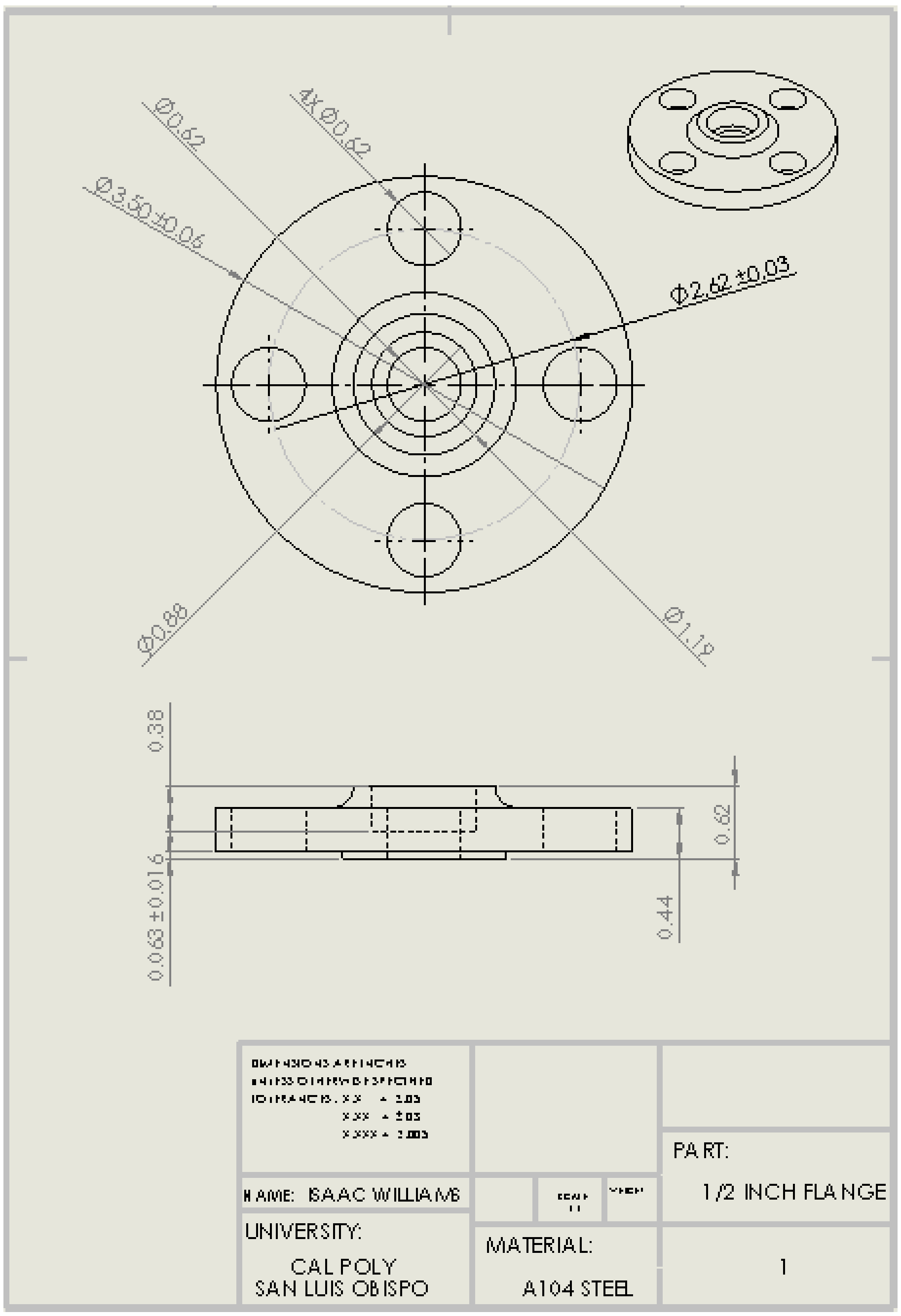


Fig. 3.3 (a) Interference area(LR Mate 200*i*C,LR Mate 200*i*C/5C,5WP,5H, ARC Mate 50*i*C)

Appendix C



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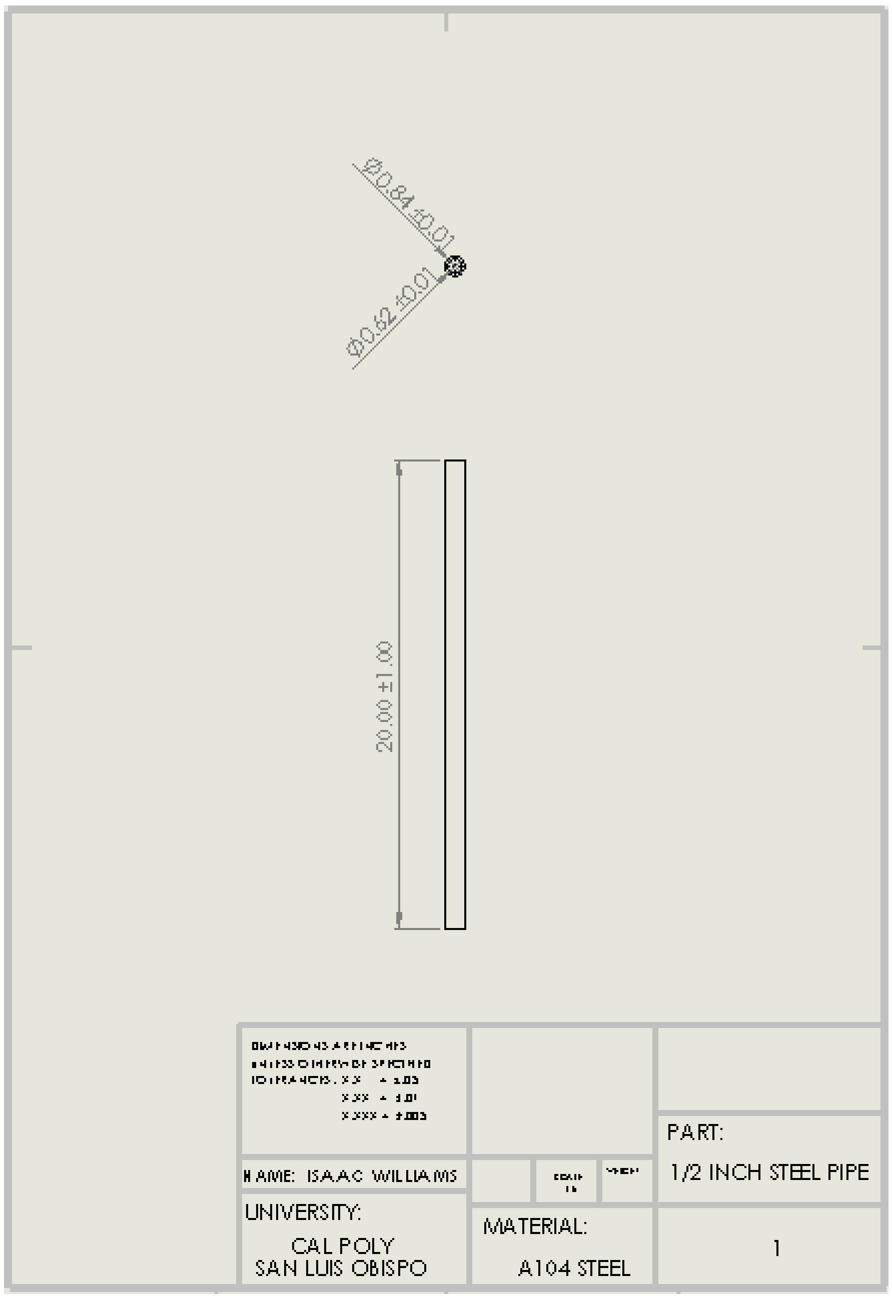
Φ2.62 ±0.03
Ø0.88
Ø1.19
0.38
0.62
0.063±0.016
0.44
NAME: ISAAC WILLIAMS
UNIVERSITY:
CAL POLY
SAN LUIS OBISPO
MATERIAL:
A104 STEEL
PART:
1/2 INCH FLANGE
1

Appendix D



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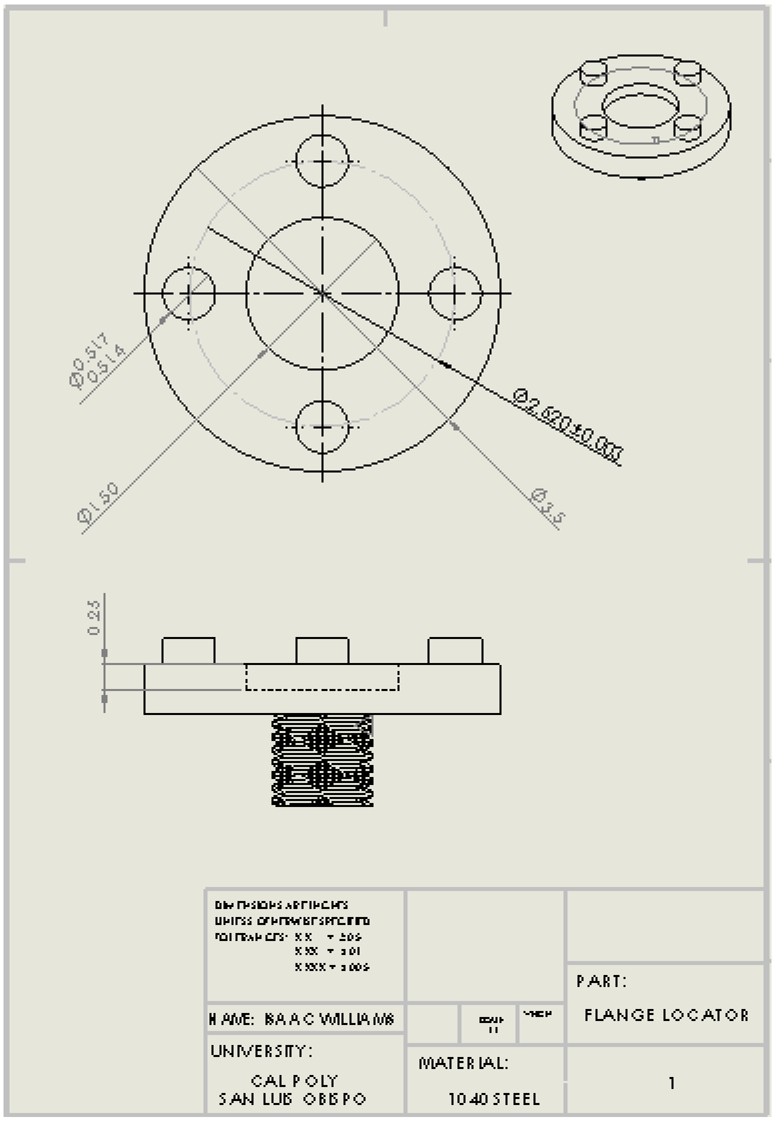
Ø0.62 ±0.01
20.00 ±1.00
NAME: ISAAC WILLIAMS
UNIVERSITY:
CAL POLY
SAN LUIS OBISPO
MATERIAL:
A104 STEEL
PART:
1/2 INCH STEEL PIPE
1

Appendix E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NAME: ISAAC WILLIAMS
UNIVERSITY:
CAL POLY
SAN LUIS OBISPO
MATERIAL:
1040 STEEL
PART:
FLANGE LOCATOR
1

Appendix F

Robotic Welding			
Variable Costs	Quantity	Cost Per Unit	Total Cost per Part
Part Flatting (minutes)	2.00	0.58	1.17
Setup (minutes)	3.00	0.58	1.75
Welding Time (minutes)	0.75	0.58	0.44
Inspection Time (minutes)	2.00	0.58	1.17
Idle Time	5.00	0.58	2.92
Electrode (feet)	18.75	0.01	0.25
Shielding Gas (Cubic Feet)	0.31	0.16	0.05
Pipe (feet)	1.67	2.47	4.12
Flange (each)	2.00	16.54	33.08
Quality	0.005	44.93	0.22
Total Variable Cost per Part			**45.16**
One Time Costs			
Robot			35,000.00
Fixture parts			23.96
Fixture Time			93.75
Total One Time Cost			**35,117.71**
Fixed Annual Costs			
Small Storage Unit			600
Maintainence			1000
Total Annual Costs			**1600**

Appendix G

Manual Welding			
Variable Costs	Quantity	Cost Per Unit	Total Cost per Part
Part Flatting (minutes)	2.00	0.58	1.17
Setup (minutes)	3.00	0.58	1.75
Welding Time (minutes)	2.50	0.58	1.46
Inspection Time (minutes)	2.00	0.58	1.17
Idle Time	5.00	0.58	2.92
Electrode (feet)	62.50	0.01	0.84
Shielding Gas (Cubic Feet)	1.04	0.16	0.16
Pipe (feet)	1.67	2.47	4.12
Flange (each)	2.00	16.54	33.08
Quality cost	0.01	46.65	**0.47**
Total Variable Cost per Part			**47.12**
One Time Costs			
Welder			489.00
Fixture parts			23.96
Fixture Time			93.75
Total One TIme Costs			**606.71**
Fixed Annual Costs			
Small Storage Unit			600
Maintainence			100
Total Annual Costs			**700**