2015 Fall Honors Capstone Projects

Honors College

12-1-2015

# DESIGN FOR A VARIABLE PIPE CUTTING JIG

Truitt Ammons

Recommended Citation
Ammons, Truitt, "DESIGN FOR A VARIABLE PIPE CUTTING JIG" (2015). *2015 Fall Honors Capstone Projects*. 6.
https://mavmatrix.uta.edu/honors_fall2015/6

# DESIGN FOR A VARIABLE PIPE CUTTING JIG

by

TRUITT AMMONS

Presented to the Faculty of the Honors College of
The University of Texas at Arlington in Partial Fulfillment
of the Requirements
for the Degree of

HONORS BACHELOR OF SCIENCE IN MECHANICAL ENGINEERING

THE UNIVERSITY OF TEXAS AT ARLINGTON

December 2015

# ACKNOWLEDGMENTS

I would like to recognize and thank Parker-Hannifin Stratoflex for their support of the University of Texas at Arlington and, specifically, my engineering team. Without them, my team and I would not have been able to work on this project. Matthew Honkus from Parker-Hannifin was an invaluable resource. He was continually willing to meet with my team, allow us to use their resources and help us with any other questions or issues that we had.

I would also like to give recognition and thanks to my faculty advisor, Dr. Woods, who met with my team weekly for two semesters. In those weekly meetings, he provided guidance, counsel, and seasoned advice as to what direction to take this project. Without his experience and willingness to help, my team and I would not have been as nearly as successful at completing this project.

Lastly, I would like to give thanks to the members of my engineering team: Josh Henley, Will Buck and Nick Ricciardelli. None of us could have completed this project alone. It took hard work and cooperation to finish this design in the amount of time that we did. I’m honored to have worked with the team that I had.

November 2, 2015

# ABSTRACT

## DESIGN FOR A VARIABLE
## PIPE CUTTING JIG

Truitt Ammons, B.S. Mechanical Engineering

The University of Texas at Arlington, 2015

Faculty Mentor: Robert Woods

Parker-Hannifin is an aerospace company located in Fort Worth, Texas. A large part of their business entails creating custom metal pipes that are used for aerospace applications. These pipes are all bent and cut at different specifications. Currently, the method being used to cut these pipes takes a lot of storage space, it is lengthy, it uses unsafe methodology and it adds up to be costly.

My team and I were commissioned by Parker-Hannifin to design a system that will alleviate these problems. The solution that this team has proposed will save the company storage space, lower the time it takes to cut the pipes at the correct specifications, save the company money and improve the safety of the employees.

## TABLE OF CONTENTS

ACKNOWLEDGMENTS .......... iii

ABSTRACT .......... iv

LIST OF ILLUSTRATIONS .......... vii

LIST OF TABLES .......... x

Chapter

1. INTRODUCTION .......... 1
    - 1.1 Background of the Project .......... 1
    - 1.2 Considerations for the Design .......... 2
        - 1.2.1 Storage Issues .......... 2
        - 1.2.2 Time Consumption .......... 3
        - 1.2.3 Safety Concerns .......... 3
        - 1.2.4 Large Expenditures .......... 4
        - 1.2.5 Simplicity .......... 5
        - 1.2.6 Level of Precision .......... 5
    - 1.3 The Approach that was Taken .......... 6
2. TECHNICAL APPROACH .......... 8
    - 2.1 Description of Design .......... 8
3. DATA ANALYSIS .......... 12
    - 3.1 Results .......... 12
    - 3.2 Limitations .......... 13

3.3 Budget .......... 14

4. CONCLUSION .......... 16

Appendix

A. PIPE GEOMETRY .......... 18

B. LINEAR RAIL SYSTEM .......... 20

C. ENCODERS .......... 22

C.1 Linear Encoders .......... 23

C.2 Angular Encoders .......... 24

D. MULTI-CUTTER SAW .......... 27

E. ADDITIONAL DATA ANALYSIS .......... 30

F. PARTS AND ASSEMBLY .......... 39

G. DETAILED DRAWING .......... 48

H. BILL OF MATERIALS .......... 50

REFERENCES .......... 54

BIOGRAPHICAL INFORMATION .......... 55

# LIST OF ILLUSTRATIONS

| Figure | | Page |
|---|---|---|
| 1.1 | Current jig being used | 1 |
| 1.2 | Picture of a band saw | 4 |
| 2.1 | A modified jig | 8 |
| 2.2 | Digital readout for the cut length | 10 |
| 3.1 | Original number of jigs against reduced number | 13 |
| A.1 | Diagram of the four main parameters | 19 |
| B.1 | Different sizes of Monorail AMS 3B | 21 |
| C.1 | View of the placement of the linear rail and encoder | 23 |
| C.2 | Rotary encoder being used to measure the angle | 25 |
| C.3 | Rotary encoder incorporated into design | 26 |
| D.1 | DW872 DeWalt Multi-Cutter Saw | 28 |
| E.1 | Bend angle frequency for .25” pipe diameter and .375” bend radius | 31 |
| E.2 | Cut length frequency for .25” pipe diameter and .375” bend radius | 31 |
| E.3 | Bend angle frequency for .25” pipe diameter and .5” bend radius | 32 |
| E.4 | Cut length frequency for .25” pipe diameter and .5” bend radius | 32 |
| E.5 | Bend angle frequency for .5” pipe diameter and .5” bend radius | 33 |
| E.6 | Cut length frequency for .5” pipe diameter and .5” bend radius | 33 |
| E.7 | Bend angle frequency for .5” pipe diameter and 1.0” bend radius | 33 |
| E.8 | Cut length frequency for .5” pipe diameter and 1.0” bend radius | 34 |

E.9 Bend angle frequency for .625” pipe diameter and 625” bend radius .......... 34
E.10 Cut length frequency for .625” pipe diameter and .625” bend radius .......... 34
E.11 Bend angle frequency for .625” pipe diameter and 1.25” bend radius .......... 35
E.12 Cut length frequency for .625” pipe diameter and 1.25” bend radius .......... 35
E.13 Bend angle frequency for .75” pipe diameter and 1.5” bend radius ............ 35
E.14 Cut length frequency for .75” pipe diameter and 1.5” bend radius ............. 36
E.15 Bend angle frequency for 1.0” pipe diameter and .969” bend radius ........... 36
E.16 Cut length frequency for 1.0” pipe diameter and .969” bend radius ........... 36
E.17 Bend angle frequency for 1.0” pipe diameter and 1.5” bend radius ............ 37
E.18 Cut length frequency for 1.0” pipe diameter and 1.5” bend radius ............. 37
E.19 Bend angle frequency for 1.0” pipe diameter and 2.0” bend radius ............ 37
E.20 Cut length frequency for 1.0” pipe diameter and 2.0” bend radius ............. 38
E.21 Number of original jigs vs. new jigs ........................................................ 38
F.1 Full assembly jig ........................................................................................ 40
F.2 Linear rail slide assembly .......................................................................... 40
F.3 Linear rail ................................................................................................... 41
F.4 Linear rail slide cover ................................................................................. 41
F.5 Linear slider pillow block .......................................................................... 41
F.6 Linear encoder ............................................................................................ 42
F.7 Linear rail ................................................................................................... 42
F.8 Rotating pin with bearing and shaft ........................................................... 42
F.9 Rotating shaft ............................................................................................. 43
F.10 Bolt ............................................................................................................ 43

F.11 Bearing ........................................ 43
F.12 Locknut ........................................ 43
F.13 Fixed straight block ........................................ 43
F.14 Fixed angle block ........................................ 43
F.15 Rotating angular block ........................................ 44
F.16 Sliding base ........................................ 44
F.17 Sliding base and rotating angular block ........................................ 45
F.18 Sliding base, rotating angular block, hook clamp, fixed angular block ......... 45
F.19 Straight fixed block ........................................ 46
F.20 Cutting table ........................................ 46
F.21 Cutting table and linear rail assembly ........................................ 47
F.22 Cutting table, sliding base and linear rail assembly ........................................ 47
G.1 Detailed drawing of modified jig ........................................ 49
H.1 Copy of estimate from Schneeberger ........................................ 53

# LIST OF TABLES

Table Page

D.1 Specifications for DW872 ........ 29

H.1 Bill of Materials ........ 51

H.2 Copy of estimate from Newall ........ 52

# CHAPTER 1

# INTRODUCTION

## 1.1 Background of the Project

Every pipe that Parker-Hannifin has to cut is custom ordered. That means that each pipe has to be cut and bent to different measurements. There are four parameters on these pipes that can change for each order whose outcome must be accounted for: cut length, pipe diameter, bend radius and bend angle. Furthermore, a pipe can have multiple bends at multiple angles. To better understand more about these parameters, see Appendix A. With the current system, a “jig” must be used to cut the pipes (Figure 1.1). A jig acts as a template for cutting the pipes. Once the pipe is bent at the specified radius and angle, it is laid inside the jig, the jig is pushed through a band saw and the band saw cuts the pipes through the slits in the jig.

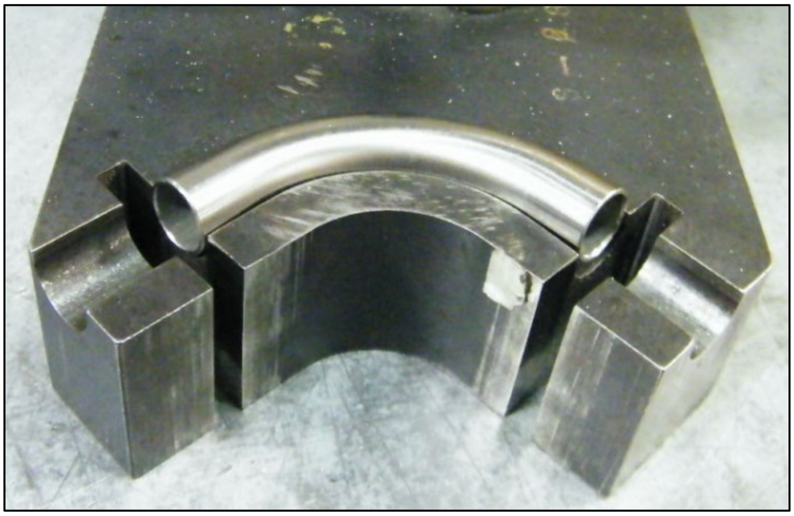


Figure 1.1: Current jig being used

Whenever a custom pipe needs to be made, if there isn't already a jig that fits the specifications, a new jig must be created to match the exact parameters of the pipe (cut length, pipe diameter, bend radius, bend angle). A standard jig is about 8"x8"x4" (sizes vary). Some jigs are manufactured by a machine shop and some are printed by a 3D printer. Consequently, the material the jigs are made out of can range from steel to plastic. Some are heavy, some are light. Some have finer finishes and some don't. In order to accommodate the many custom orders that Parker receives for piping, they estimate that they have constructed a total of approximately 2500 jigs.

Parker has used this system of cutting pipes for many years. During this time, several complications have arisen with the process. My team was commissioned to address these issues and present a solution for them. The six biggest problems were addressed in order to find a solution.

## 1.2 Considerations for the Design

### *1.2.1. Storage Issues*

Because Parker was producing so many jigs, storing them became an issue. They eventually designated a storage room to keep their 2000+ jigs. There was not a great system of organizing them, so the room became disorganized and it became difficult to find a jig when it was needed. On top of that, jigs would go missing or be misplaced. If a jig could not be found, then it would have to be manufactured all over again. Parker needed a system that would cut down on the amount of storage space that was required and help them find a jig when it was needed.

### *1.2.2. Time Consumption*

One of the biggest issues that Parker faced with the current system of cutting pipes was time inefficiency. Each jig that Parker makes is either machined or printed with a 3D printer. Both processes take time. If they decide to have the jig machined, the project must be sent to a machine shop and can take up to a week to have completed and returned. Their 3D printer, although much quicker, can still take several hours to finish printing the jig. In addition to the time it takes to manufacture the jig, it also takes time to modify the design to accommodate the new parameters. Depending on how the jig is manufactured, it may even require some assembly.

Once the jig is made, it is stored in the designated storage room. Because they have over 2,000 of these jigs in storage, it takes some time to sort through them and find the correct one. Parker says that it will take an employee an average of 15 minutes to find (or not find) the correct jig that they need for the job. Overall, this process can take much more time than they would like. Therefore, one of the biggest considerations in creating a design was to find a way to shorten the process.

### *1.2.3. Safety Concerns*

Safety is always a big concern in the engineering industry. Companies are always looking to increase the safety of their employees and customers. Safety was one of the issues that Parker wanted us to consider in this design.

As stated before, their pipes are placed in the jig and are slid into a band saw (Figure 1.2), a tall, vertical blade that quickly vibrates up and down in order to cut. Band saws are very useful and have many applications. However, they wobble to the side a little and they do not have any sort of a guard to protect fingers. Since these jigs have to be slid into the band saw, the technician's fingers can get very close to the blade. In addition to the safety factor, band saws are not very precise with their cuts and, although there have not been any injuries, Parker asked that we research alternatives to the band saw and find a saw that was safer and more precise.

Figure 1.2: Picture of a band saw [1]

### *1.2.4. Large Expenditures*

A natural consequence of having to construct more jigs is larger expenditures. Throughout this process, the engineer is being paid to design the jig, the technician is being paid to find the jig, and the process of building the jig (whether in a machine shop or 3D printer) takes money as well. Parker estimates that each jig takes approximately $600 to build. This is for construction only. It does not include the cost of the time of the employees, storage space, and other miscellaneous items. This means that, with over 2,000 jigs, Parker has spent at least $1.2 million on jigs. This is a major expense that can be reduced in the future by implementing a more effective system of cutting pipes.

### *1.2.5. Simplicity*

The engineers may be who design and build the jigs, but they are not the ones that have to find the jigs and cut the pipes. This is done by technicians. Technicians are not typically involved with the complexities behind the design, so the system to be implemented must be something that anyone can easily figure out and pick up on; it has to be easy to use. Although it is desired to improve the design in several other areas, the changes must be implemented in a way that is simple and easy to understand.

### *1.2.6. Level of Precision*

The cut lengths of the pipes are desired to be within +- .015” of the correct length, and the bend angle of the pipes are desired to be within 30 seconds of the correct angle (see Appendix A for an explanation of angle measurement).

Currently, the cut lengths of the pipes are not meeting the criteria for the precision. This is partly due to the fact that that the slit through which the band saw goes is so wide that the cut can be anywhere inside that range. It is also partly because the band saw is so wobbly that it is difficult to get a consistent cut out of it. Parker would like a more accurate method of measuring the lengths of the cuts.

The bend angle of the pipes are believed to be meeting the criteria that is specified. However, the pipes are bent before they are taken to the jig. So, after they are bent, there is no method of checking the bend angle of the pipe other than to see if it fits correctly in the jig. Although this seems to be an effective way of checking, Parker would like a more reliable way of checking the bend angle of their pipes.

## 1.3 The Approach that was Taken

There were many different directions that this project could have taken. Several different options were discussed. The most advanced option would have been a completely automated process that entailed 3D scanners, robotic arms, laser cutting, and other advanced equipment. This was quickly ruled out due to the expense that it would have entailed.

The simplest and most effective system would have been some type of modular board that would have adjusted for all of the changing parameters in the different pipes. If a design was created for that, it would have eliminated the need for different fixtures and it could have consolidated the 2,000+ jigs to just one. However, no plausible design for this was ever created.

Instead of designing an entirely new system that Parker would have to implement, it was decided that the best approach would be to improve the system that they currently had. The team decided to improve the current design to accommodate multiple parameters and eliminate the largest number of jigs possible.

Throughout the course of this project, the responsibilities were divided amongst the team members. My personal responsibilities mostly entailed doing the research that we needed to carry out the design. None of the team members had any previous experience with the mechanisms used in this project. It was my responsibility to research those devices, learn how they work, make sure they meet the required specifications and help incorporate them into the design. I was also responsible for getting most of the quotes for these items and forming a bill of materials. Further personal research included looking into different options for saws and construction materials.

Brainstorming and creative ideas were a collaborative effort. Joshua Henley was our group leader. He was responsible for delegating tasks, piecing together each part of the project and making sure the project stayed on track. Will Buck was responsible for the completion of the design model in both SolidWorks and CATIA, the two computer aided design programs that were used for this project. Nicholas Ricciardelli was mainly in charge of analyzing the data that was given to us by Parker Stratoflex. He organized the data and used it to make assumptions and estimates. Each team member played an active role in the process. As needed, we would help each other with their assigned duties. Miscellaneous tasks often needed to be carried out and were divided fairly to each member.

For the purposes of this thesis, I included some of the research that I previously conducted for the group project, but much of it was either rewritten or modified. However, all of the research presented in this paper is my own personal research. I also reevaluated the design and the data analysis that were previously carried out by team members. I found it necessary to make some slight changes to the two. The discussion and details presented in each section are my own. Designs and graphs, although some have been slightly changed, are mostly in their original form as created by team members.

# CHAPTER 2

# TECHNICAL APPROACH

## 2.1 Description of Approach

Because changing all four parameters of the pipes could not be accounted for in a single design, the team decided to account for only two of the four. The two that seemed the most plausible were the cut length and the bend angle. The goal was to modify the jigs to have a set diameter and bend radius while being able to adjust to any given length and angle.

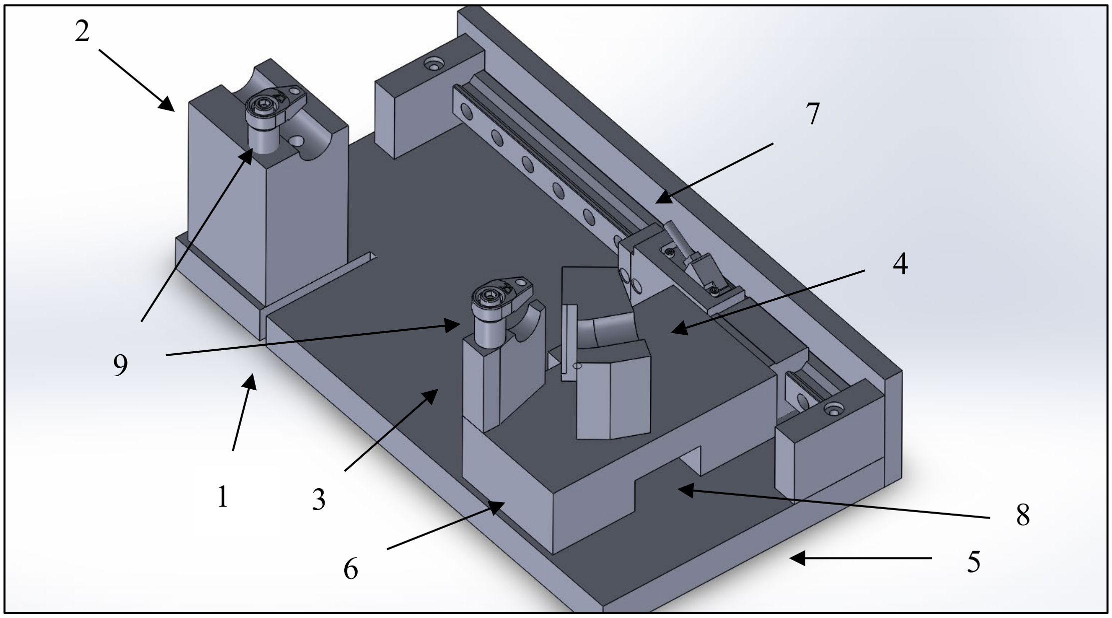


Figure 2.1: A modified jig

The final design (Figure 2.1) includes many modifications to the original design from Parker (Figure 1.1). The pipe to be cut is laid down on the blocks at points 2, 3, and

4. Once the pipe is placed inside the jig, it is secured with the two hook clamps shown at 9. This design was built around the implementation of some type of chop saw with a circular blade instead of the band saws already being used (see Appendix D for details and specifications of the recommended saw). The slit at point 1 was created to allow the saw to move down vertically to cut the pipe and pass through the slit without damaging the jig.

In order to adjust for different cut lengths, the sliding block (point 6) is mounted on a linear rail system (point 7). See Appendix B for details on the linear rail systems. This allows for movement along the rail, which will change the cut length of the pipe. Once the block is set at the correct cut length, it will be secured using a setting screw. Because the saw cannot cut pipes too close to blocks 2 and 3, a minimum cut length was set at .125 inches. It was decided that any cut length smaller than that could not be created with the modified jig design. A length of .125 inches was decided on because very few cut lengths were smaller than that. None of the pipes that Parker makes have a cut length greater than 8 inches. For this reason, the modified jigs can cut a maximum cut length of 8 inches.

The cut length is measured digitally by a linear encoder placed inside the linear rail system (point 7). For more information on linear encoders, see Appendix C. As the sliding block is moved manually, the cut length is read on a digital readout shown in Figure 2.2. The accuracy and precision of the selected linear encoder meets all the requirements given by Parker. So that only one linear rail and encoder would have to be implemented, the modified jig was designed to cut only one side of the pipe. After the first side is cut, the pipe can be flipped to cut the second side.

Figure 2.2: Digital readout for the cut length [4]

A fixed angle block (3) and a rotating angle block (4) are both attached to the sliding block (6). Two angle blocks are implemented in order to provide adequate support for the pipe while it is being cut. Each angle block has a 15-degree angle. Because of this, when they are flush against each other, the smallest bend angle that can be cut is 30 degrees. This means that the modified jigs will not work for pipes with bend angles smaller than 30 degrees. However, the rotating block will move up to a 180-degree angle, which is the maximum bend angle that needs to be cut for the pipes.

Because Parker requested a digital reading of the bend angle of the pipes, an angular encoder was incorporated into the design. See Appendix C for details on angular encoders. As seen at point 8, a groove was created underneath the sliding block. This groove was designed in order to externally attach the angular encoder to the shaft that the rotating angle block is mounted on. This encoder will measure the bend angle of the pipes and send it to a secondary digital readout (Figure 2.2). Because the pipe will be bent before it is placed into the jig, the angle of the jig will first be adjusted to the correct angle. Once it reads the correct angle, the block will be set using a setting screw. The pipe will then be placed in the jig. If it fits, then the bend angle of the pipe matches the measured angle of the jig. This will confirm that they have bent the pipe at the correct angle.

The rotating angle block is attached to a shaft inside the sliding block via a double-threaded screw and nylon lock nut. The shaft goes through a bearing within the sliding block and goes through the bottom of the block where it attaches to the angular encoder.

The base (point 5) is designed so it can be permanently attached to the base of the chop saw. The rest of the jig is designed so that it can be removed from the base and changed with different parts that will accommodate different pipe diameters and bend radii. Once Parker decides on what saw they would like to incorporate, the base will be modified to be able to be bolted to the base of the saw.

Figure 2.1 was modeled using a one-inch pipe diameter and a two-inch bend radius. These parameters were used because a large number of the pipes being cut had this diameter and bend radius. Multiple modified jigs will still have to be constructed, so the design was created so that Parker could easily modify the parameters of it and use interchangeable parts. For a more detailed list of parts and diagrams, see Appendix F.

# CHAPTER 3

# DATA ANALYSIS

The team was given a spreadsheet with specifications for around 1300 pipes that Parker manufactures or has previously manufactured for clients. This spreadsheet included the specifications that were necessary for this project: cut length, pipe diameter, bend angle and bend radius. Parker has over 2000 jigs, which means they have manufactured over 2000 pipes with different specifications. This meant that the spreadsheet didn't contain all of the data necessary to perform a proper data analysis. However, the assumptions were made that the spreadsheet only contained data for pipes that were either recently manufactured or for pipes that were ordered the most. Because of that, the data was analyzed as if it represented the entirety of the pipes that Parker manufactures. This analysis was used to design the jig to work for as many pipes as possible.

## 3.1 Results

Each modified jig is designed with a fixed bend radius and a fixed pipe diameter. It will then adjust for any given bend angle and cut length (besides the exceptions discussed in 3.2). The data was then classified by the different combinations of pipe diameters and bend radii. The number of jigs that Parker currently has for each combination diameter and radius was totaled.

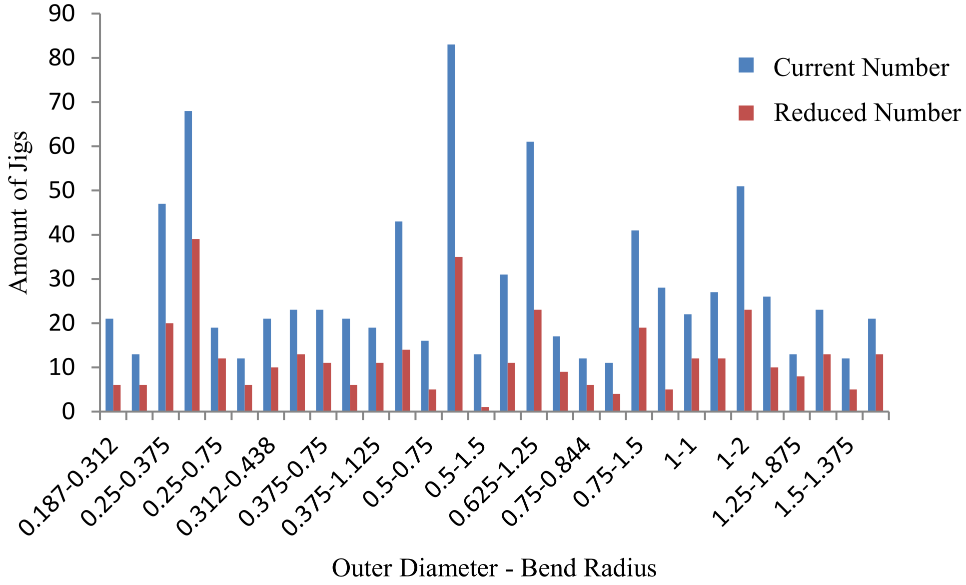


Figure 3.1: Original number of jigs against reduced number

Based on the analysis that was conducted, it was determined that the new design for the jig would eliminate about 57% of the old jigs. Instead of about 2000 jigs, Parker will only need 860. Although this is still a large number, it will make a huge difference to the company. The company will spend less over a longer period of time.

## 3.2 Limitations

The modified jig was designed with respect to the data analysis. The purpose of the new design was to eliminate as many of the original jigs as possible. However, there were limitations to the new design. By examining the data, these limitations were minimized as much as possible.

Some of the custom pipes that are made have multiple bends. The modified jig only accommodates pipes with single bends. For these pipes, Parker previously manufactured the bends into the jig. However, there are very few pipes that are ordered which have more than one bend. For this reason, Parker can continue to use the original jigs when it is necessary cut a pipe with multiple bends. Not all of the old jigs will have to be replaced. The more complex and customized ones will still be necessary.

The modified jigs can only cut pipes with cut lengths greater than or equal to .125”. This is because the saw cannot cut while it is flush against the fixed-angle block. This would cause too much friction between the surfaces. Again, there are very few pipes that are ordered with cut lengths below .125”. The original jigs that were made for cut lengths smaller than this can be kept and used just in case one of these pipes are ordered.

There is also a limitation to what bend angles the modified jig can accommodate. The two angular blocks are both 15°. They must be this thick in order to be stable enough and to support the pipe. The blocks are adjusted to their smallest angle when they are flush against each other. For this reason, the modified jig cannot cut pipes with angles smaller than 30°. This minimum angle was chosen because, as with the other limitations of the modified jig, there are a small number of pipes that have bend angles smaller than this and, as with the other limitations, the jigs which were constructed for those specific angles can be kept. The modified jig also cannot cut pipes with bend angles larger than 180°. However, pipes with bend angles this large are not ordered from Parker because an angle that big is redundant in aerospace applications.

## 3.3 Budget

Parker requested that each individual jig not exceed $3000. Although this budget is more than the $600 cost of the current jigs, fewer jigs will have to be manufactured over a long period of time. This budget does not include one-time purchases such as the saws and linear rails. It also does not include the cost of manufacturing and the time of the employees; the two will be minimal in comparison. Appendix H show the bill of materials proposed for one jig. A total cost of $623.23 is being proposed per jig. This price falls well within the given budget. Because Parker will have to produce fewer jigs, they will end up saving money over time.

Parker has six stations where the technicians cut the pipes. To initially set up the six stations with the new equipment, it will cost approximately $2210 each. This cost will not have to be repeated. There will be one saw at each stations and the saw will not be moved. It will be the same with the linear rail system and the digital displays. Only six saws will need to be purchased. Appendix D gives the details and specifications of the recommended saw. The proposed design is built around the assumption that the recommended saw will be implemented. However, the design can easily be modified if the company decides to use a different saw. Parker said that the expenditure of the saws would and the one-time costs will not count in the budget.

# CHAPTER 4

# CONCLUSION

By modifying the system that Parker Stratoflex currently uses to cut pipes, this team was able to meet all the criteria of the company and maintain a reasonable level of simplicity. The new design will decrease the storage space that is required and allow the company to maintain a higher level of organization.

Changing the type of saw used and the method of cutting the pipe will improve the safety of the employees as well. Sliding the jig into the band saw presents a safety risk because a finger could easily get caught in the saw. With the new saw and design, the jig will not have to be slid into the saw.

Since Parker has been using this system of cutting pipes, they have spent over a million dollars producing them. If they continue using the same system, they will continually have to produce more jigs and replace lost or broken jigs. The costs will just continue to add up. If they implement the system recommended by this team, they will save over half of their future costs. They will also save the costs of the time they lose and the employees they have to pay.

This system will save not only on costs, but also on time. Employees will save time finding the jigs they need and having to design new ones. They will not have wait on the manufacturing of the jig, and the technicians will not have not change jigs as often.

The cut lengths of the pipes will have a much higher level of precision. The precision of a band saws is not very reliable. The new system, along with the new saw, will improve the precision of the cuts. The cut lengths and the bend angles will now be able to be read with the digital displays to ensure that they are the right measurements.

# APPENDIX A

# PIPE GEOMETRY

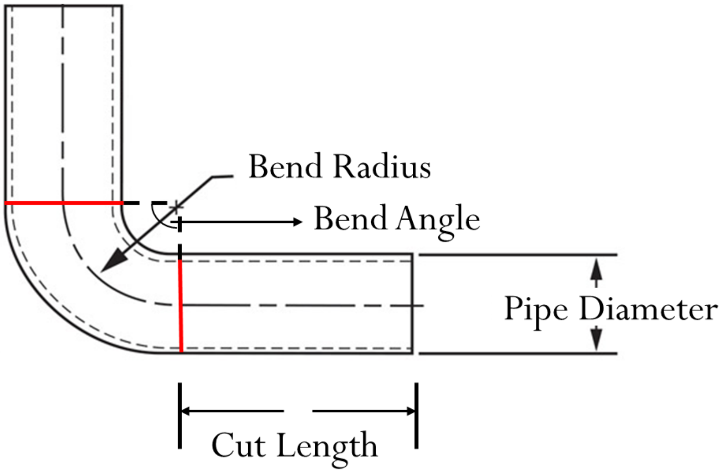


Figure A.1: Diagram of the four main parameters

Before the jig is used to cut the pipe, it is bent with a specified bend radius. This radius is the distance from the centerline of the pipe to the center of the circle that the pipe was bent around (see Figure A.1).

Pipe diameter is the distance from wall to wall on the outside of the pipe. This is also known as the outer diameter (Figure A.1).

The cut length of the pipe is the specified length in which the band saw needs to cut the pipe. This distance is measured from the end of the bend where the straight part of the pipe begins. This is also where the outside of the pipe becomes tangent to the bend (Figure A.1).

Bend angle of the pipe is completely independent from the bend radius because you can continue to increase the bend angle without changing the bend radius. It is the angle of the bend measured from the center of the bend.

# APPENDIX B

# LINEAR RAIL SYSTEM

A linear rail essentially consists of a block that slides along some sort of rail that creates a near frictionless contact allowing the block to slide easily and effortlessly. These rails are typically designed to be very sturdy and support loads. In this design, it was necessary to find a linear rail that would support the applied moment of the pipe and sliding block without rotating or bending.

Once the pipe is placed in the jig, the sliding block will be moved along the rail until the digital readout reads the desired cut length. The position will then be secured by tightening a setting screw that will prevent the block from moving any more.

The linear rail that was found actually incorporated a linear encoder as well. See Appendix C for details on linear encoders. The model is a Schneeberger Monorail AMS 3B (Figure B.1).

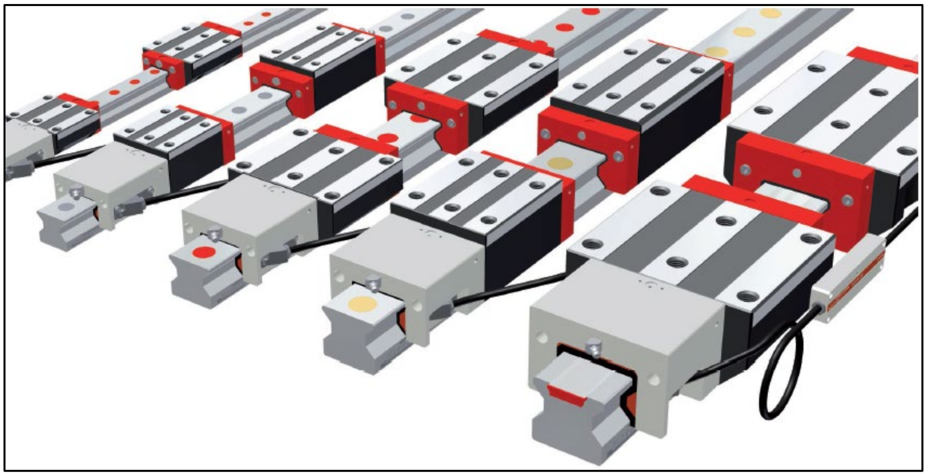


Figure B.1: Different sizes of Monorail AMS 3B [2]

# APPENDIX C

# ENCODERS

## C.1 Linear Encoders

There are many different types of encoders that can be used in various applications. The type that was found to be the best for this design was a magnetic encoder. The modified jig will experience vibrations while cutting the pipes. It is also a possibility that debris will result from the cut metal. Magnetic encoders are suitable for these kinds of conditions, which is why they will be suitable for this project. If the debris from the metal is ferrous, it will not affect the magnetic field within the encoder. Specifically, a Monorail AMS 3B (Figure B.1) sold by Schneeberger will be used in this design. This product is a linear rail that has a linear encoder incorporated into it. This will be more convenient for the design because a linear rail will be used in it as well.

There are two components of a linear encoder: the scale and the sensor. The sensor is built to recognize any movement along the scale. It detects this movement by sensing a change in the magnetic field. This is translated into an electrical signal that is read by some sort of readout [2]. The scale and sensor are built into the jig and they will be placed on the back of the saw table as shown in Figure C.1.

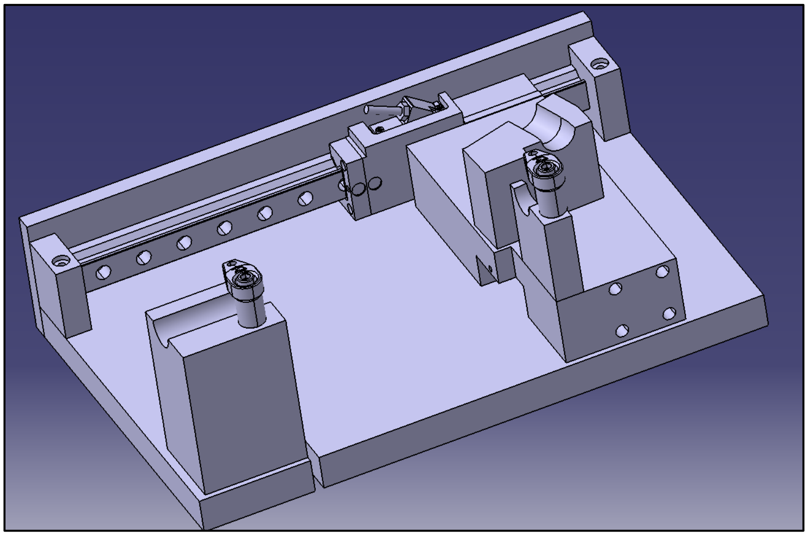


Figure C.1: View of the placement of the linear rail and encoder

There are two types of linear encoders: absolute and incremental. Absolute encoders will give the exact position at any time and point. Incremental encoders, such as the one being used in this design, give the measurement from a certain frame of reference. For example, an absolute encoder can be powered off and on and still give its position. An incremental encoder cannot. The encoders used for this modified jig design will be powered on and off as they are stored. However, the incremental encoder can be easily calibrated each time it is activated [3]. It only needs to be zeroed from the starting position. The longer the scale is, the more accuracy the encoder will lose. The scale for this application will be 15 inches and will be used to measure the length to cut the pipes at. This encoder has an accuracy of +-5 microns per meter, which translates to .0002 inches. The client, Parker Stratoflex, currently requires an accuracy of +-.015" for the cuts of their pipes, so this linear encoder will fulfill the requirement.

The linear encoder will be run from the rail to a digital readout. The digital readout will take the signal and convert it to a signal that can be read. For this project, an SA100 display will be purchased from the company, Newall (see Figure 2.2). This display has the option to read the signal in millimeters or inches. It can also operate as incremental or absolute. The resolution of the display can go as high as .001" which means it will display up to the one thousandth of an inch.

### C.2 Angular Encoders

In addition to the linear encoder being used for this design, a rotary encoder will be used as well. Once the pipes are bent at a certain bend angle, they will be placed inside the jig to be cut. It is necessary to measure the angle of the bend after it is bent to ensure that it was bent at the correct angle and to be able to adjust the cut block to the correct place.

Figure C.2: Rotary encoder being used to measure the angle [5]

The angular encoder that will be used for this project is a miniature size encoder from Nemicon as shown in Figure C.2. This specific encoder is being used because the body of it is 7mm. Since the modified jig design consists of moving and interchangeable parts, it is really important to have a rotary encoder that is small and will be able to fit into the design. The rotary encoder must also be able to move along with the cut block because of where it is located. Figure C.3 shows the placement of the encoder.

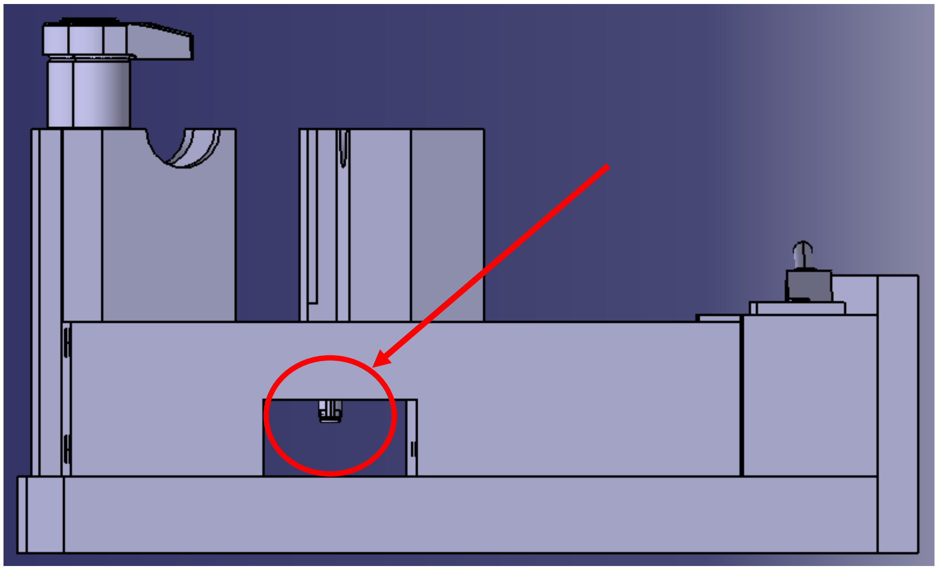


Figure C.3: Rotary encoder incorporated into design.

The rotary encoder works a little differently than the linear encoder. This specific one does not use magnetism to measure its displacement; it uses a mechanical system that then sends an electrical signal to the display. The digital readout that will be used for the rotary encoder will be separate than the one being used for the linear encoder. Both are SA100 models from Newall, but the rotary readout will display an angle while the linear readout will display a distance. The signal measured from this encoder will be incremental which means the device will have to be zeroed after every time it is reconnected.

The resolution for this encoder can go up to 400 PPR. This means that it can send up to 400 pulses per revolution, which means that it will be able to give an angular measurement to the nearest degree. Parker's pipes are cut to the second of a degree, but since the angular encoder is just measuring the angle as a sanity check, a resolution of 400 PPR will be fine [5].

# APPENDIX D

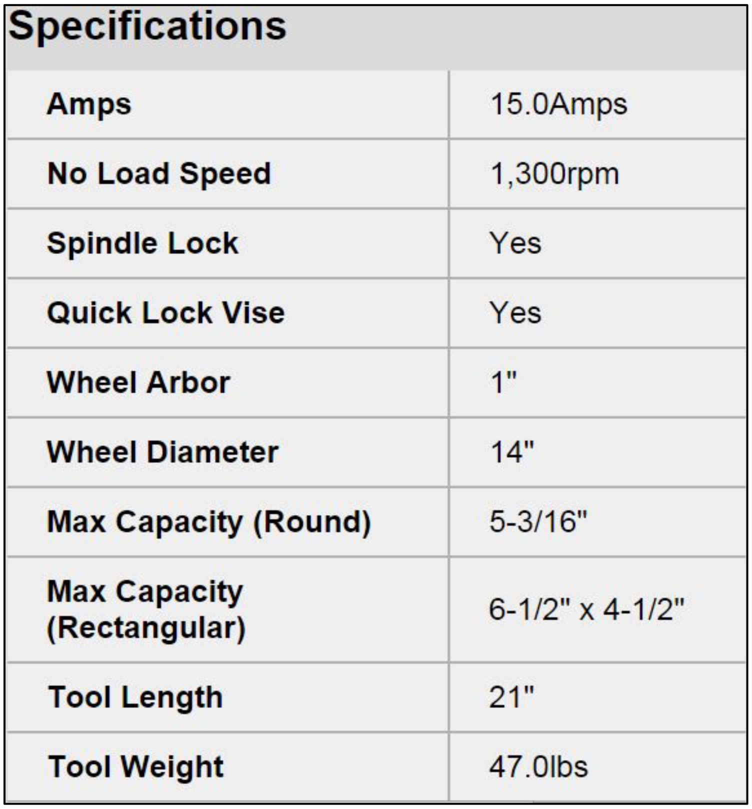
# MULTI-CUTTER SAW

The saw being recommended for implementation is a DW872 Dewalt Multi-Cutter Saw. There are four different materials that Parker uses for the pipes: inconel, stainless steel, titanium, and aluminum. Each material has different properties. Aluminum typically cannot be cut the same way as other metals. If an abrasive saw is being used to cut aluminum, the aluminum will cling to the saw and fill in its gaps, which will cause overheating and lead to the blade breaking. Non-abrasive saws are typically weaker than abrasive saws, so if they are being used to cut the other materials, they can break.

The Multi-Cutter Saw is being reccomended because it can cut ferrous and non-ferrous materials. It also has carbide-tipped blades, which will give it enough strength to cut all of the pipes. It will also provide speed, durability, and cut precision. The blade must be big enough to cut all the way through the pipe but still clear the base through the slit. The 14" will be sufficient for this requirement. Figure D.1 shows a picture of the DW872. The base will be reconifugred in order to make it compatible with the modified jig. Figure D.2 shows the manufacturer specifications for the saw [6].

Figure D.1: DW872 DeWalt Multi-Cutter Saw [6]

Table D.1: Specifications for DW872 [6]



| Specifications | |
|---|---|
| **Amps** | 15.0Amps |
| **No Load Speed** | 1,300rpm |
| **Spindle Lock** | Yes |
| **Quick Lock Vise** | Yes |
| **Wheel Arbor** | 1" |
| **Wheel Diameter** | 14" |
| **Max Capacity (Round)** | 5-3/16" |
| **Max Capacity (Rectangular)** | 6-1/2" x 4-1/2" |
| **Tool Length** | 21" |
| **Tool Weight** | 47.0lbs |

# APPENDIX E

# ADDITIONAL DATA ANALYSIS

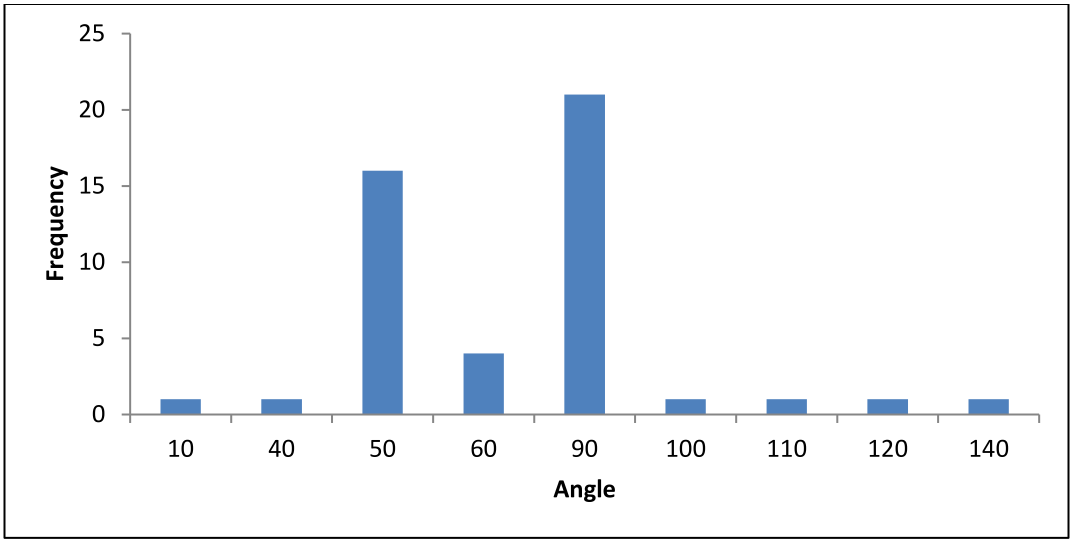


Figure E.1: Bend angle frequency for 0.25" pipe diameter and 0.375" bend radius

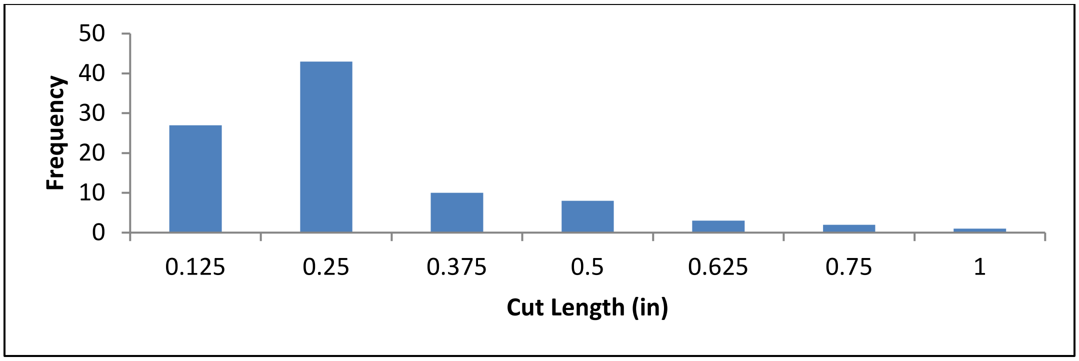


Figure E.2: Cut length frequency for 0.25" pipe diameter and 0.375" bend radius

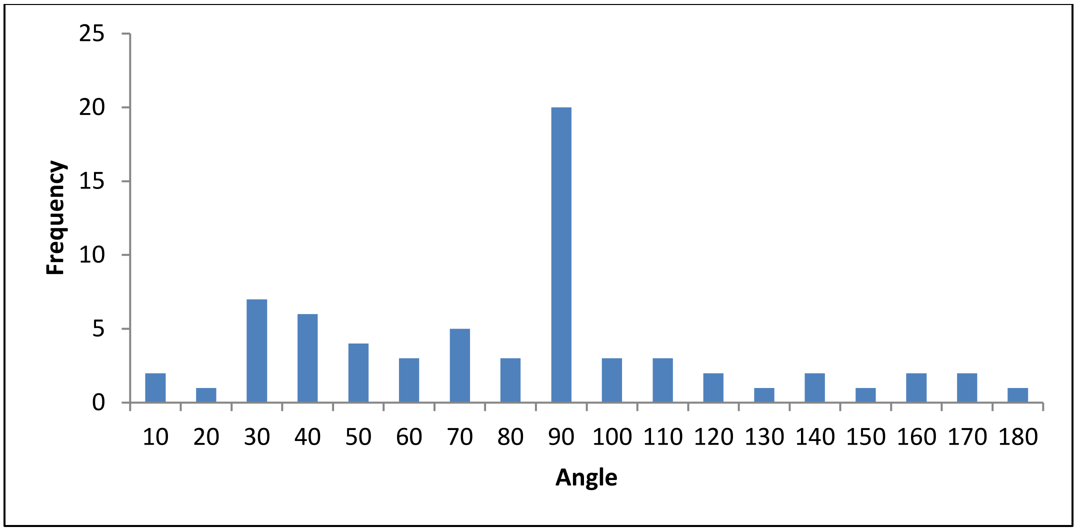


Figure E.3: Bend angle frequency for 0.25" pipe diameter and 0.5" bend radius

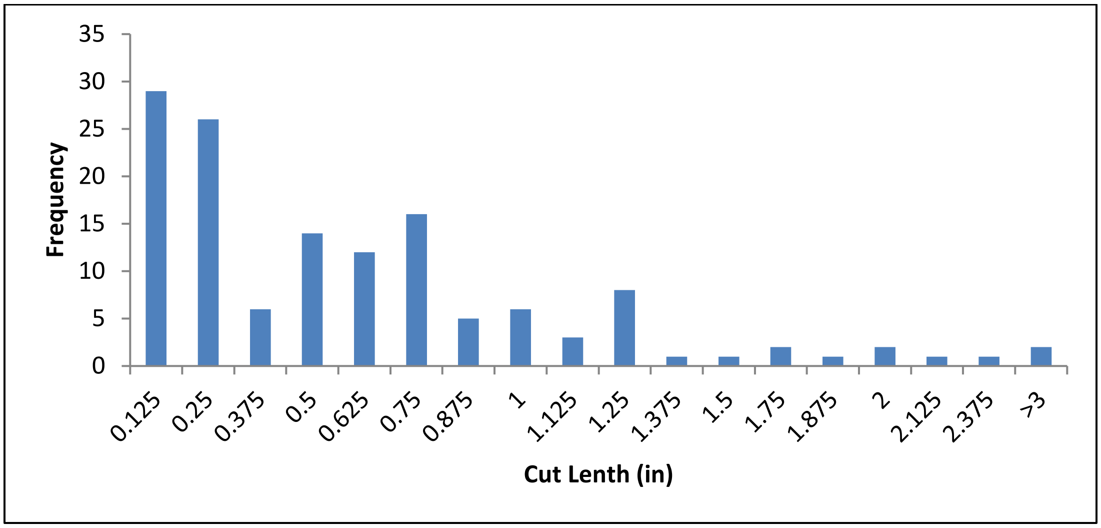


Figure E.4: Cut length frequency for 0.25" pipe diameter and 0.5" bend radius

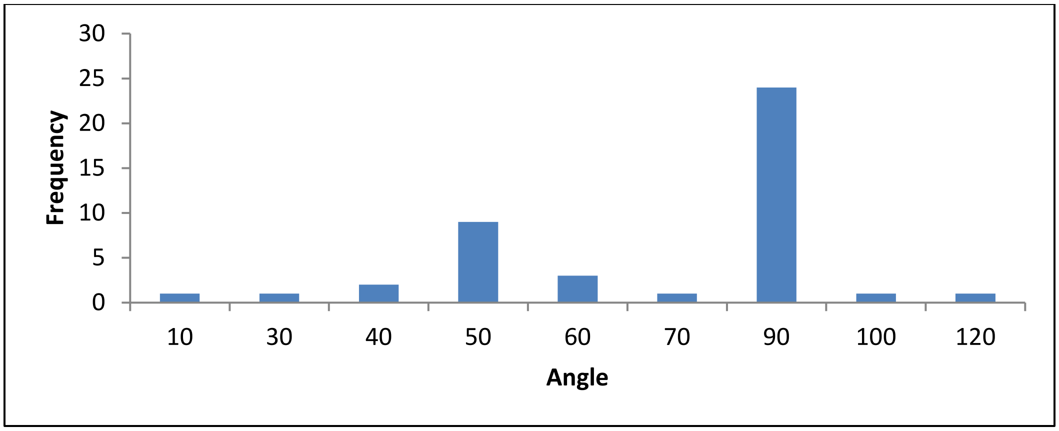


Figure E.5: Bend angle frequency for 0.5" pipe diameter and 0.5" bend radius

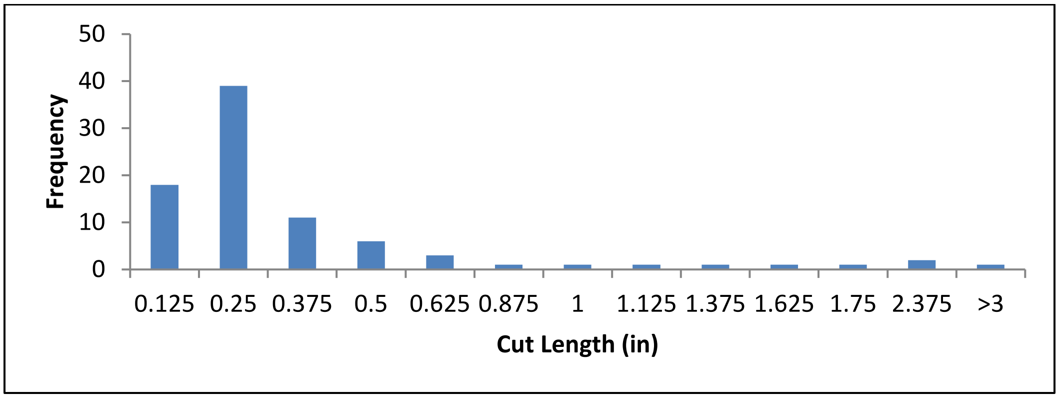


Figure E.6: Cut length frequency for 0.5" pipe diameter and 0.5" bend radius

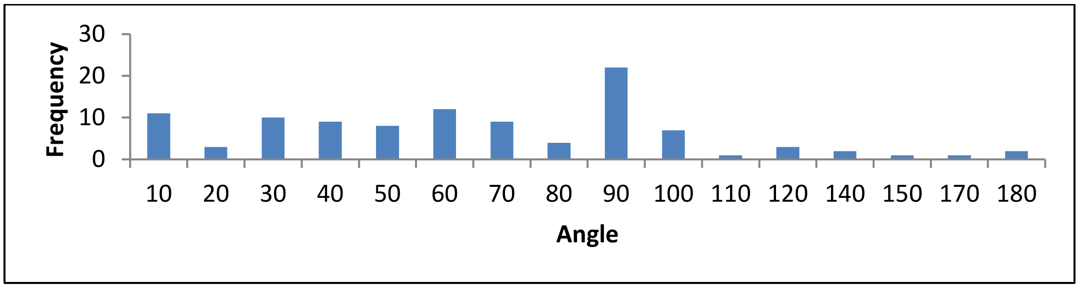


Figure E.7: Bend angle frequency for 0.5" pipe diameter and 1.0" bend radius

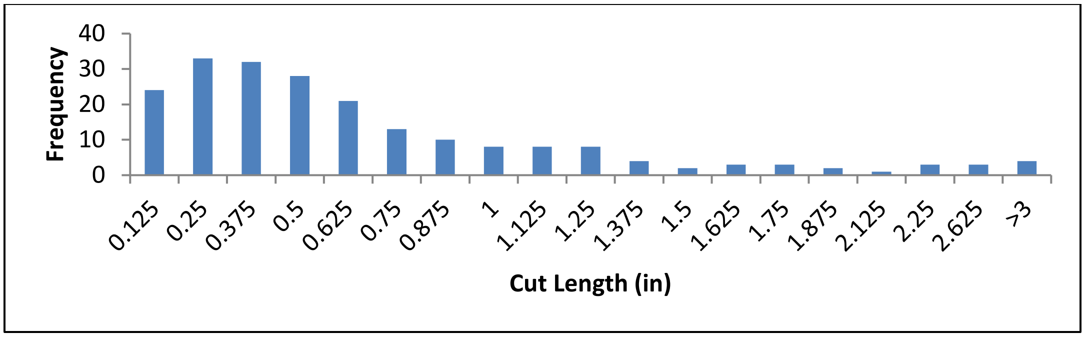


Figure E.8: Cut length frequency for 0.5" pipe diameter and 1.0" bend radius

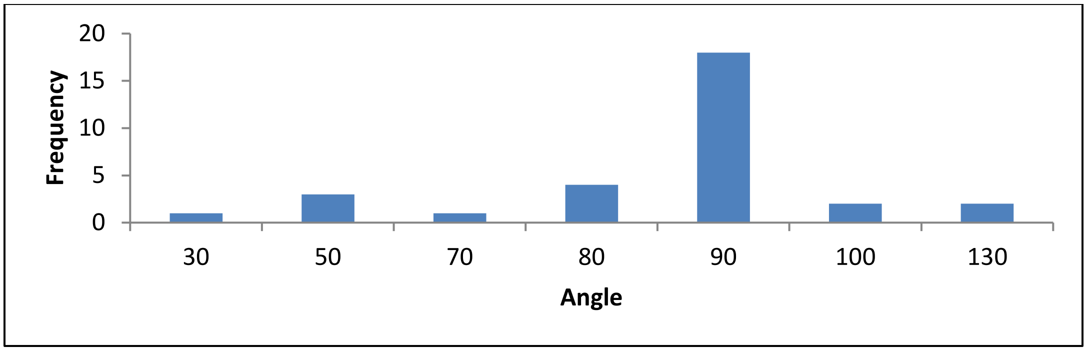


Figure E.9: Bend angle frequency for 0.625" pipe diameter and 0.625" bend radius

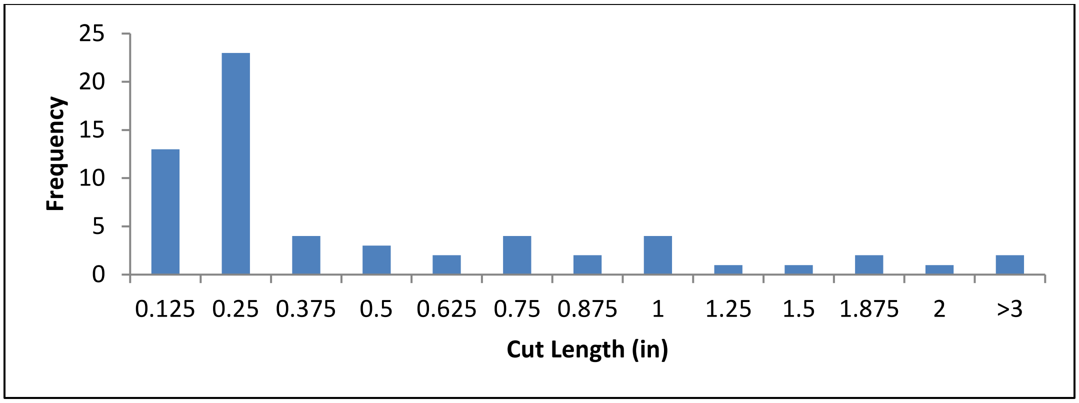


Figure E.10: Cut length frequency for 0.625" pipe diameter and 0.625" bend radius

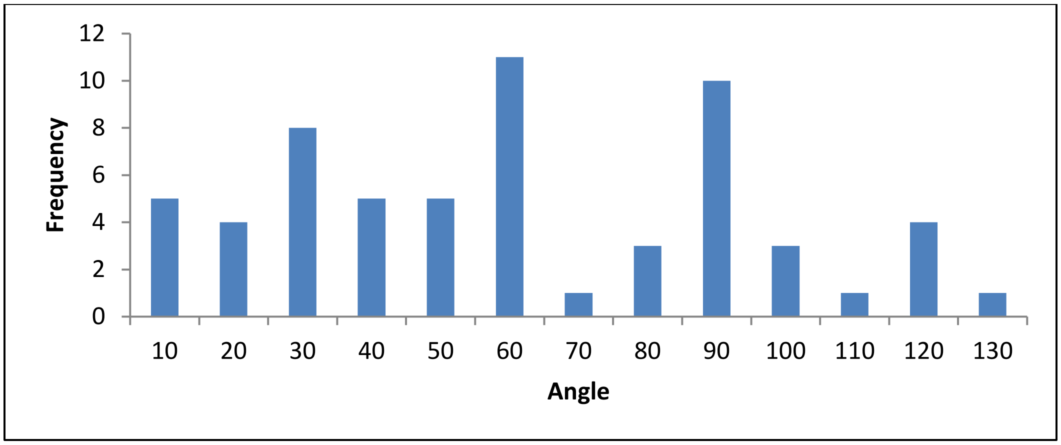


Figure E.11: Bend angle frequency for 0.625" pipe diameter and 1.25" bend radius

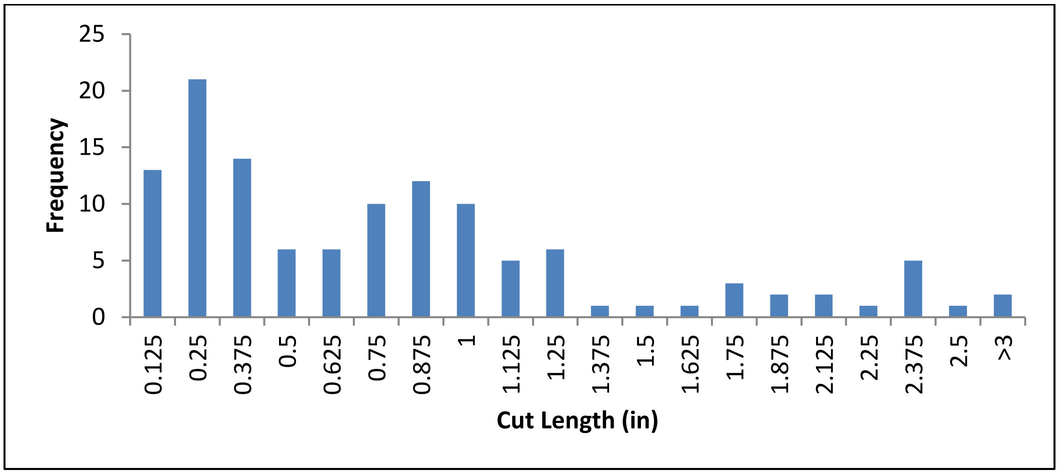


Figure E.12: Cut length frequency for 0.625" pipe diameter and 1.25" bend radius

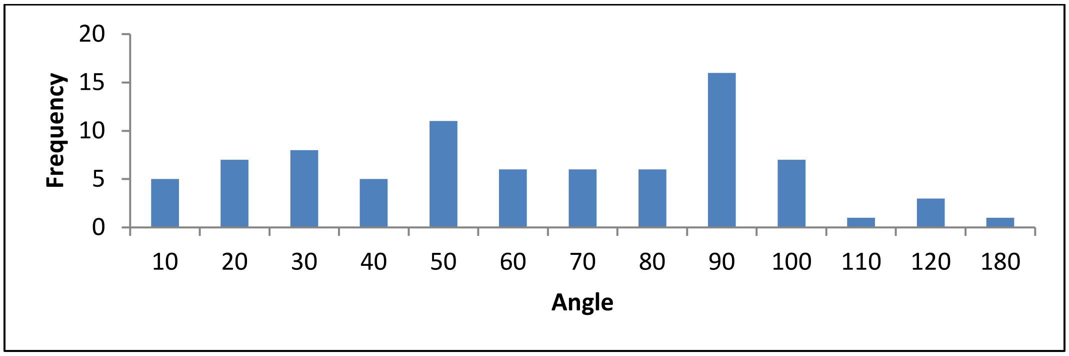


Figure E.13: Bend angle frequency for 0.75" pipe diameter and 1.5" bend radius

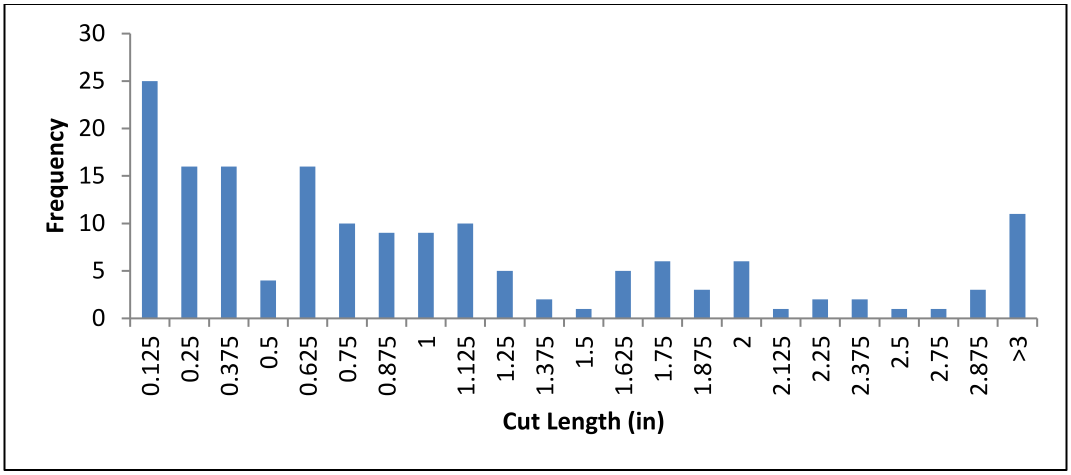


Figure E.14: Cut length frequency for 0.75" pipe diameter and 1.5" bend radius

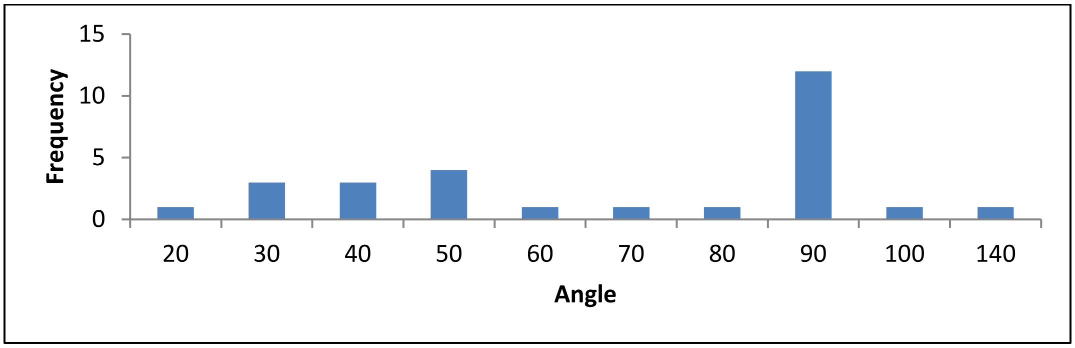


Figure E.15: Bend angle frequency for 1.0" pipe diameter and 0.969" bend radius

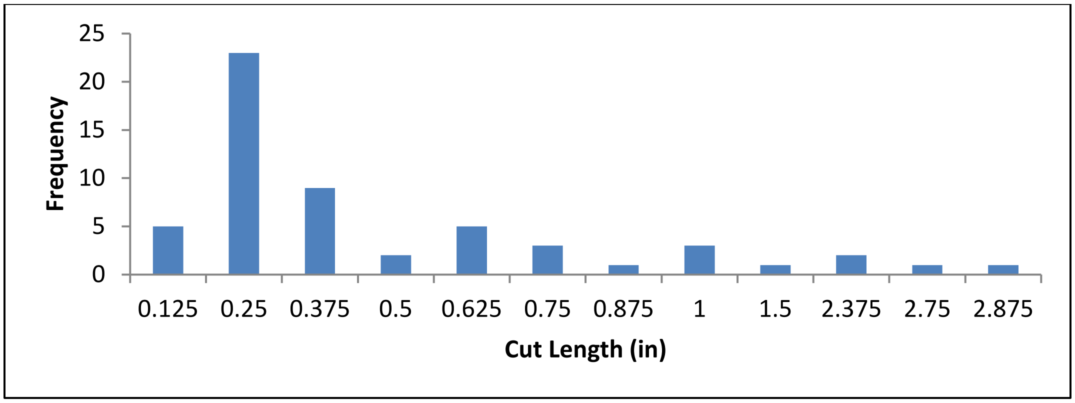


Figure E.16: Cut length frequency for 1.0" pipe diameter and 0.969" bend radius

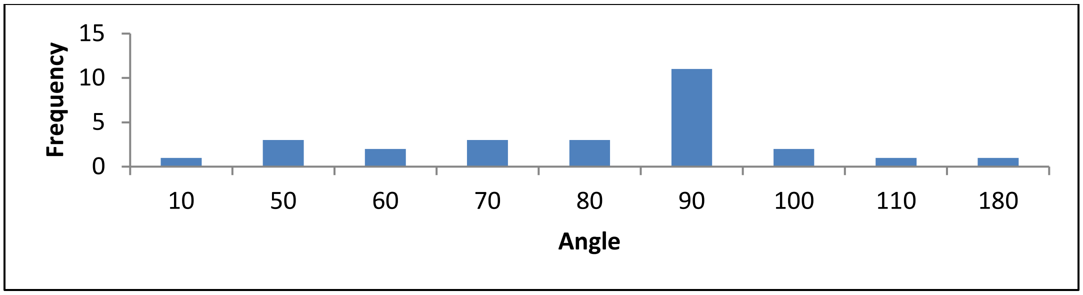


Figure E.17: Bend angle frequency for 1.0" pipe diameter and 1.5" bend radius

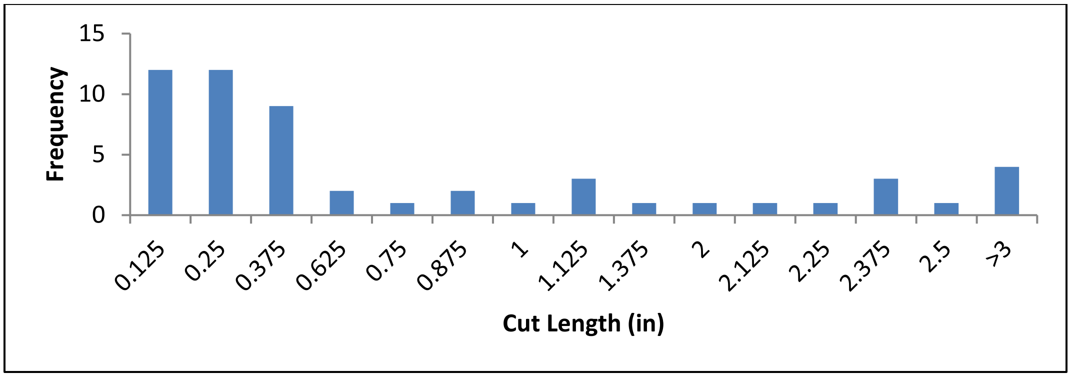


Figure E.18: Cut length frequency for 1.0" pipe diameter and 1.5" bend radius

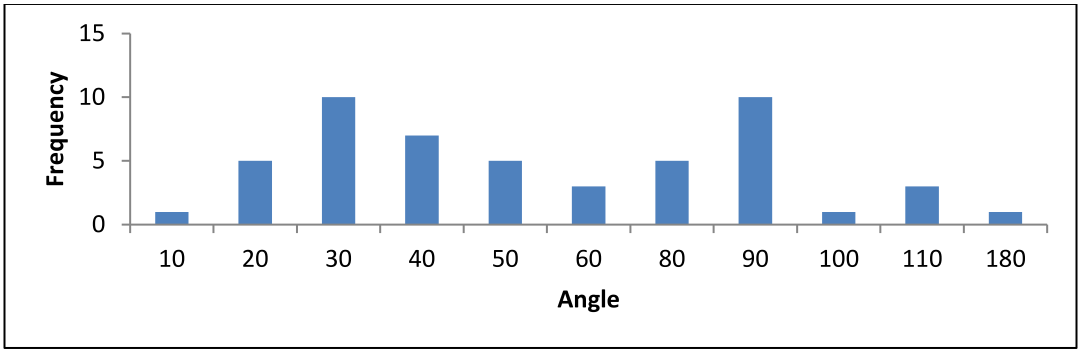


Figure E.19: Bend angle frequency for 1.0" pipe diameter and 2.0" bend radius

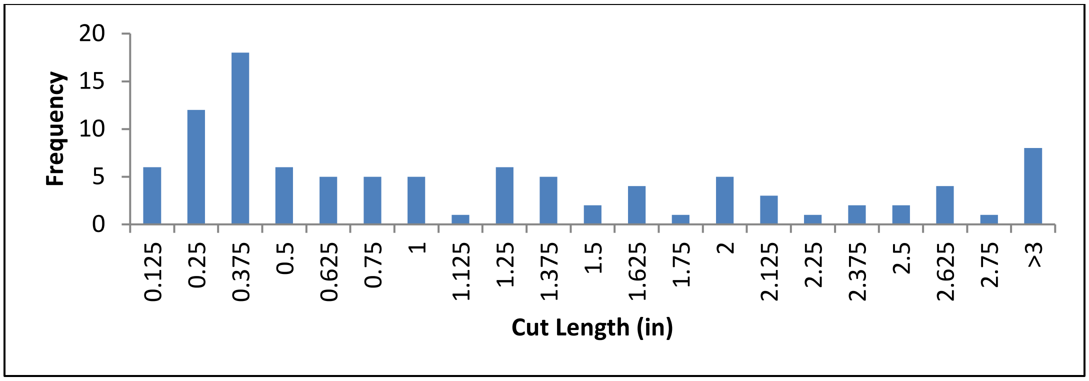


Figure E.20: Cut length frequency for 1.0" pipe diameter and 2.0" bend radius

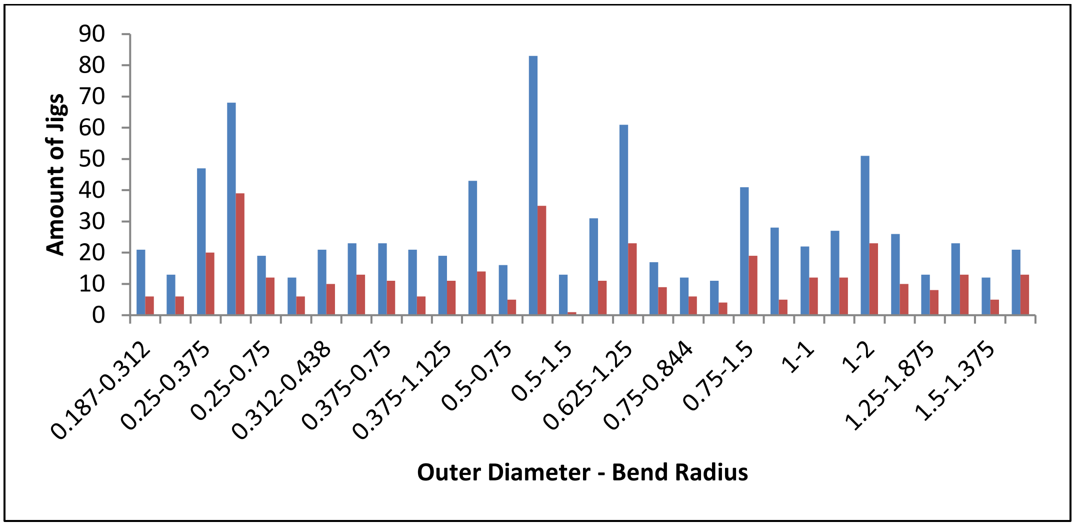


Figure E.21: Number of original jigs vs. new jigs

# APPENDIX F

# PARTS AND ASSEMBLY

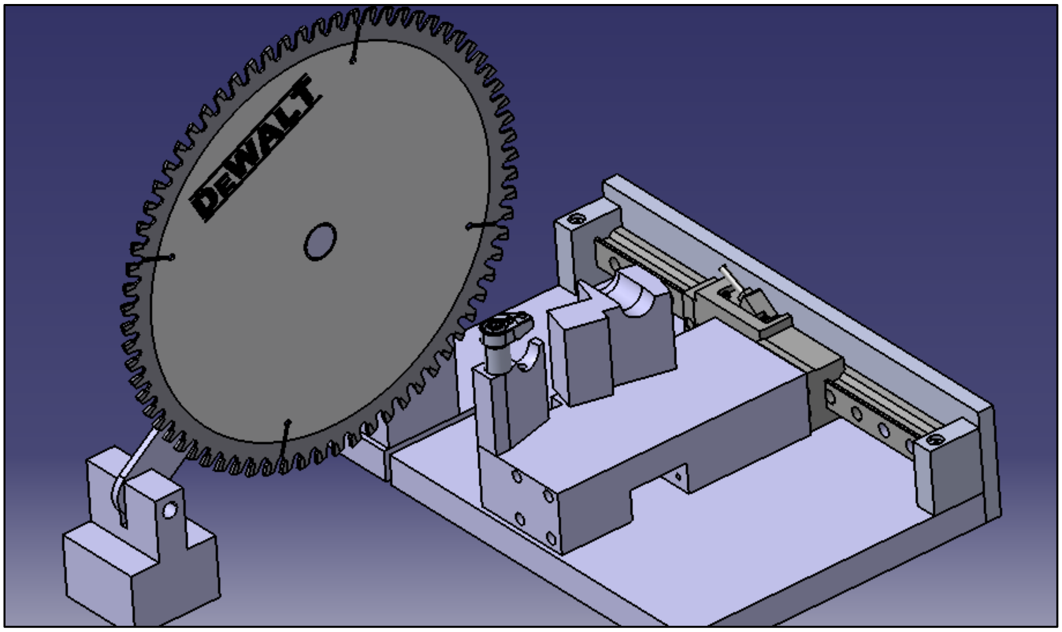


Figure F.1: Fully assembled jig

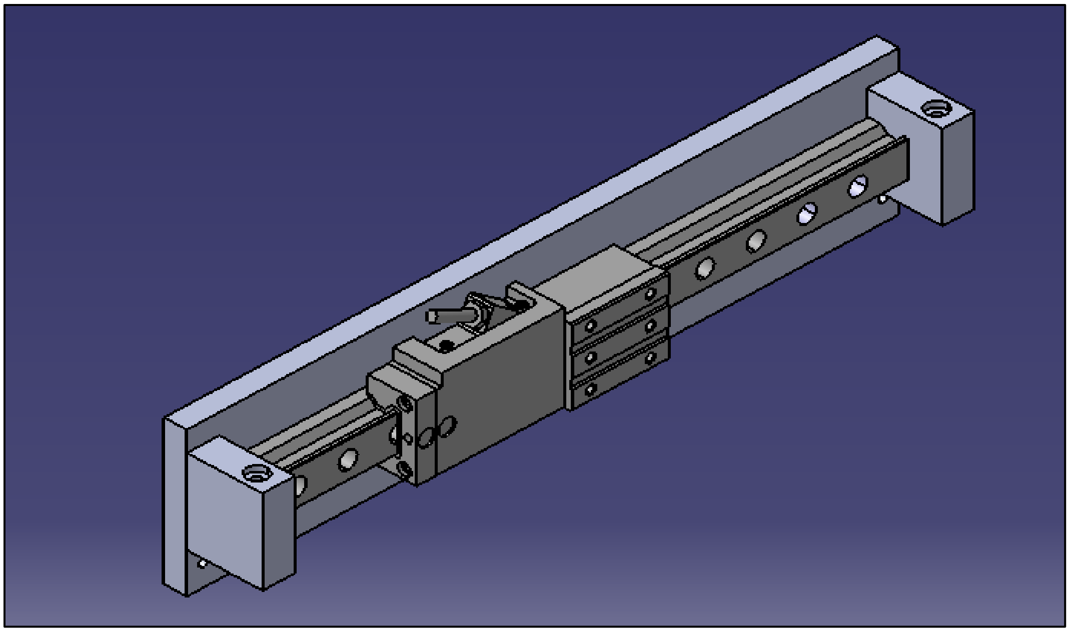


Figure F.2: Linear rail slide assembly [2]

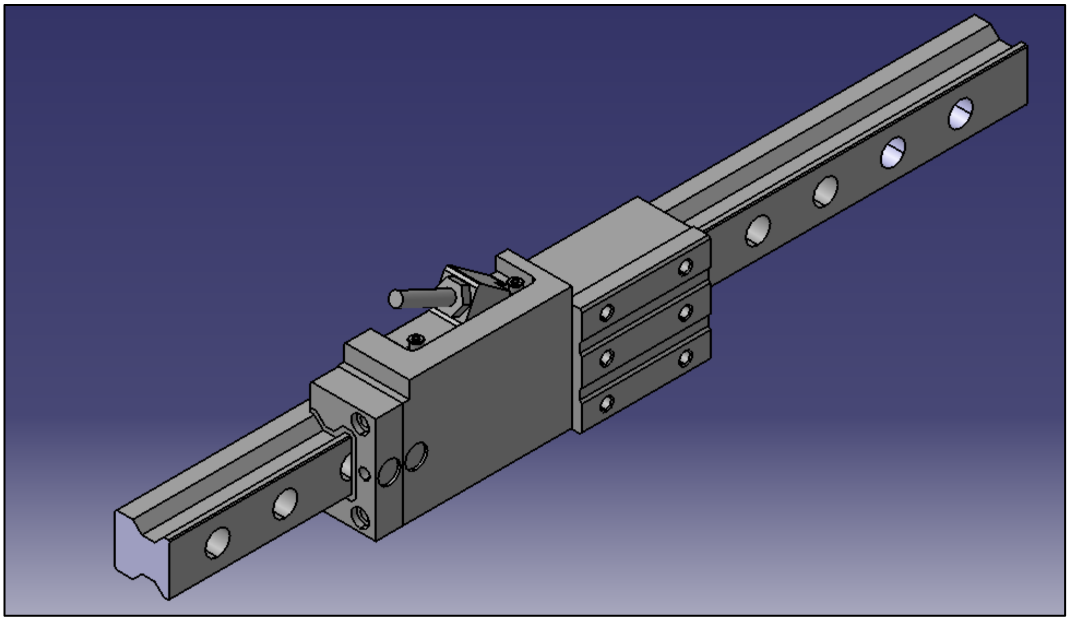


Figure F.3: Linear Rail [2]

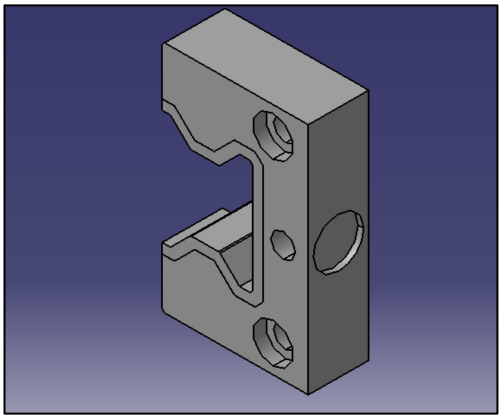


Figure F.4: Linear rail slide cover [2]

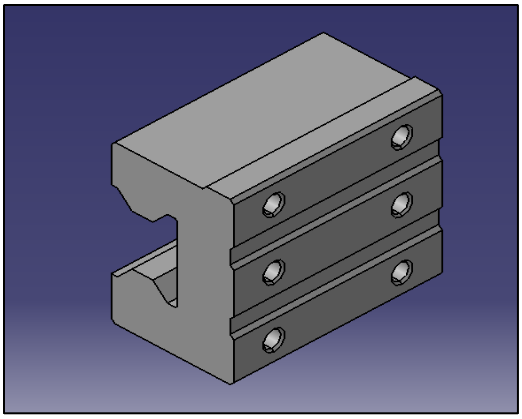


Figure F.5: Linear slider pillow block [2]

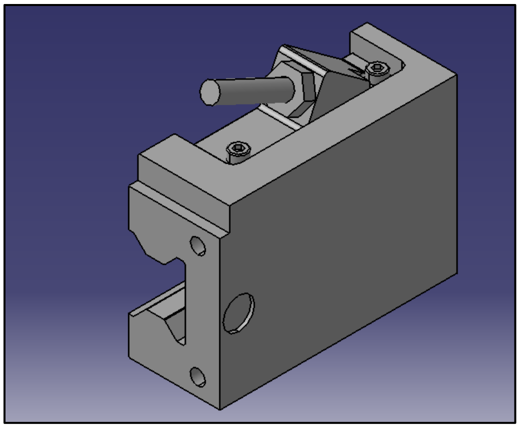


Figure F.6: Linear encoder [2]

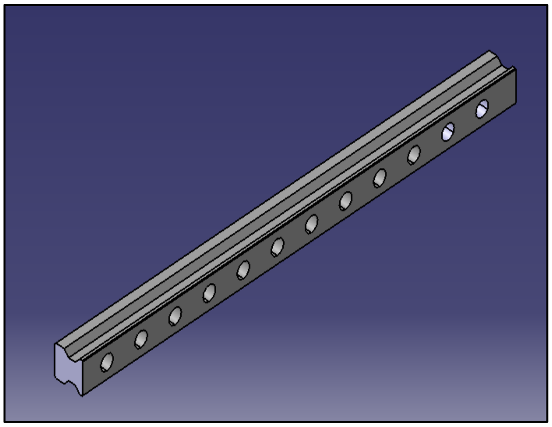


Figure F.7: Linear rail [2]

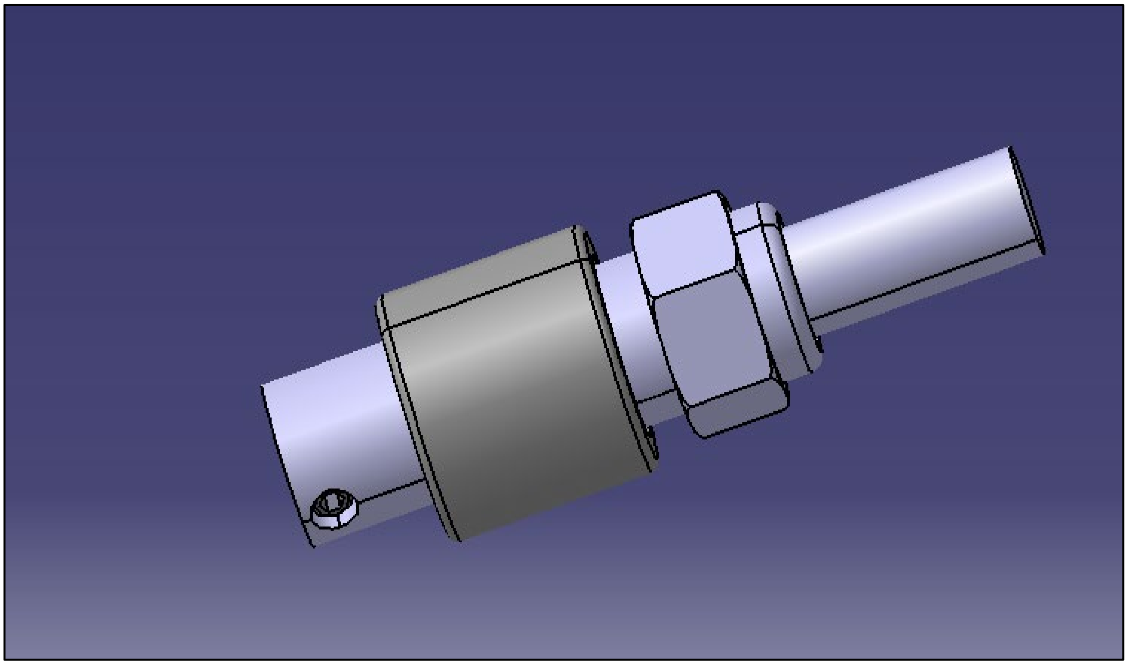


Figure F.8: Rotating pin with bearing and shaft

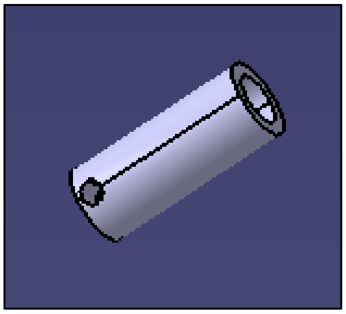


Figure F.9: Rotating shaft

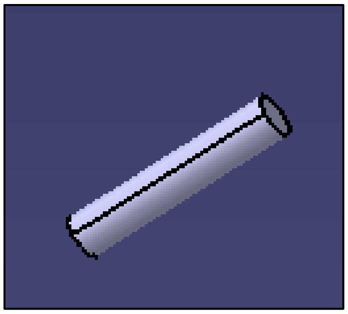


Figure F.10: Bolt

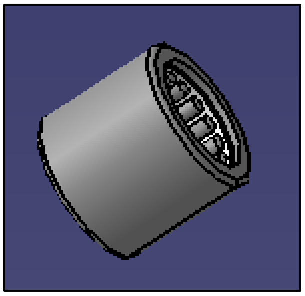


Figure F.11: Bearing

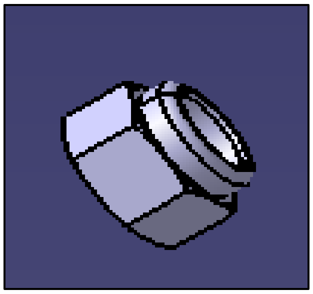


Figure F.12: Locknut

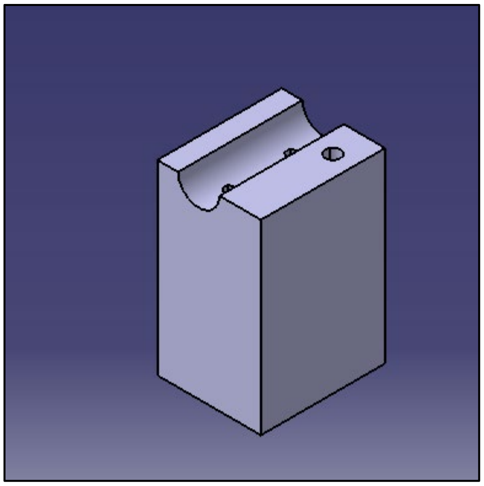


Figure F.13: Fixed straight block

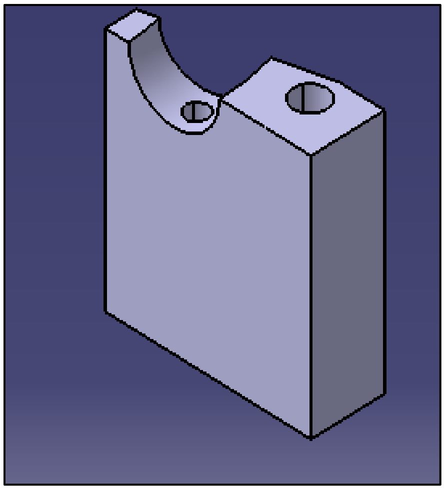


Figure F.14: Fixed angle block

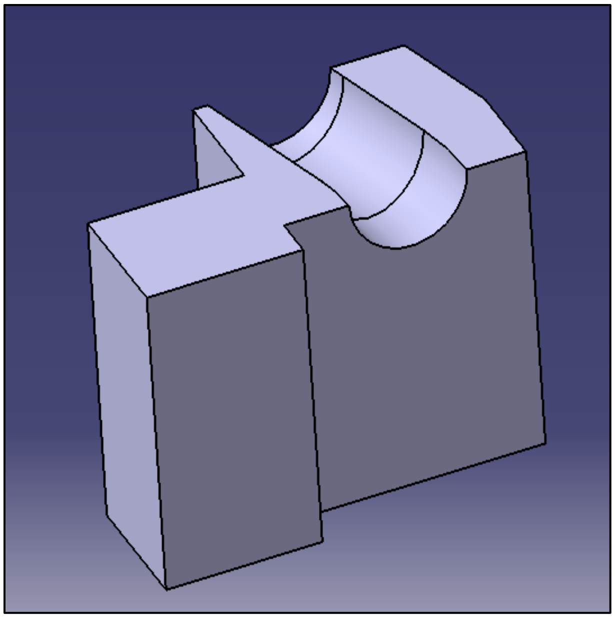


Figure F.15: Rotating angular block

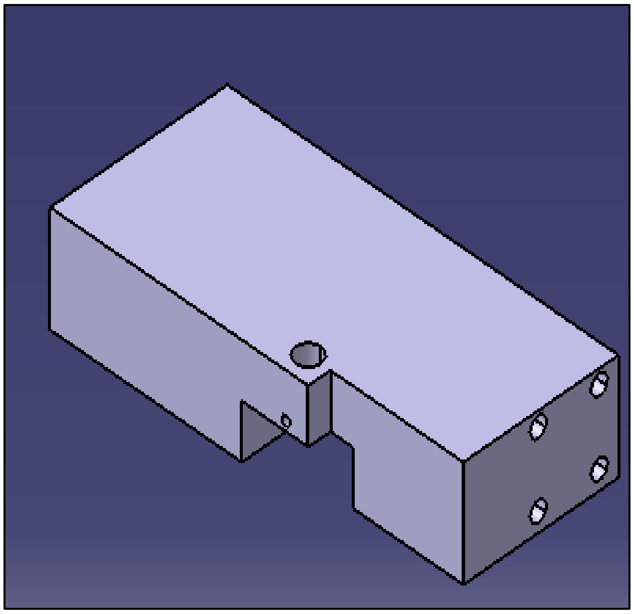


Figure F.16: Sliding base

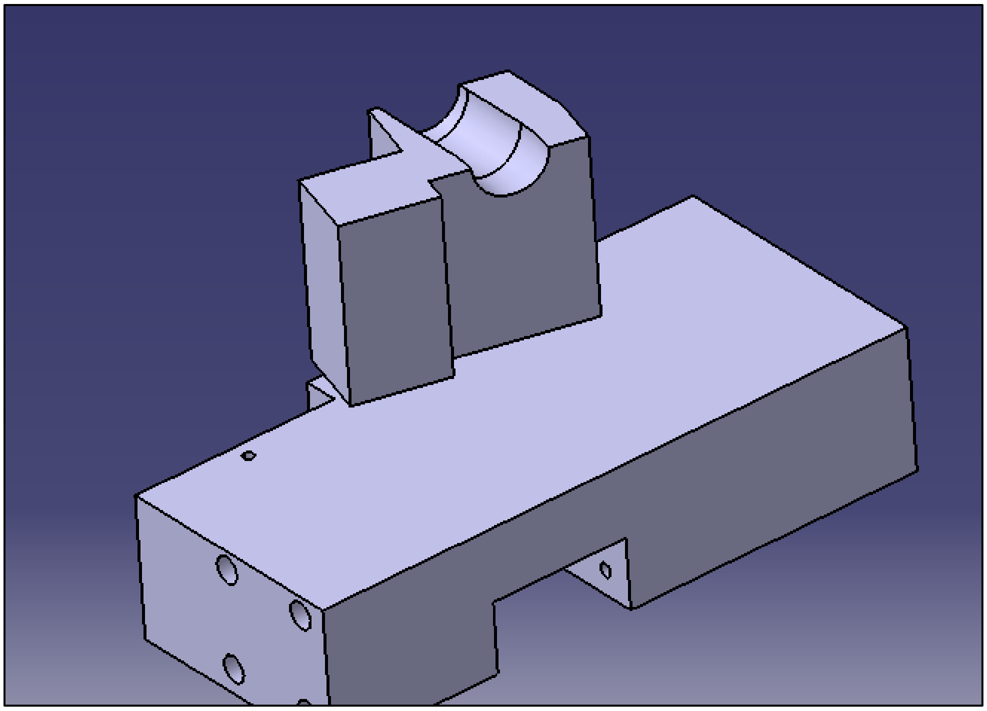


Figure F.17: Sliding base and rotating angular block

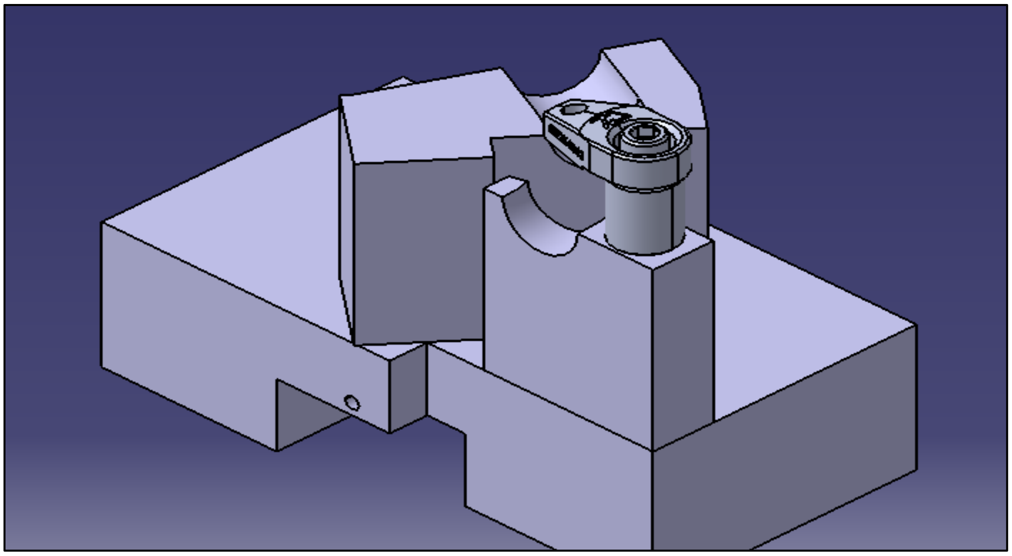


Figure F.18: Sliding base, rotating angular block, hook clamp, fixed angular block

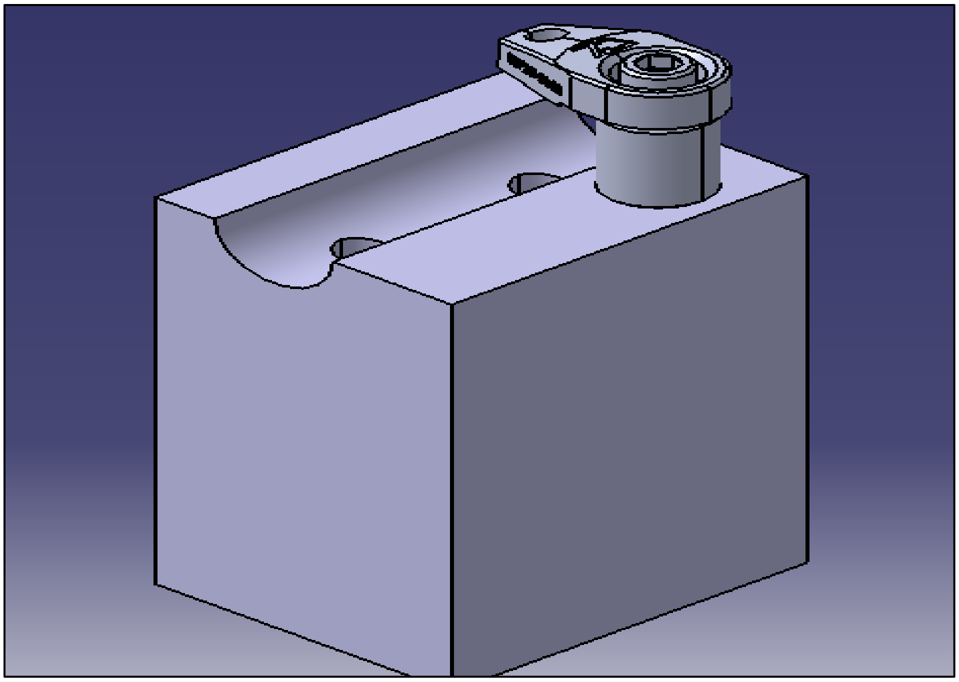


Figure F.19: Straight fixed block and hook clamp

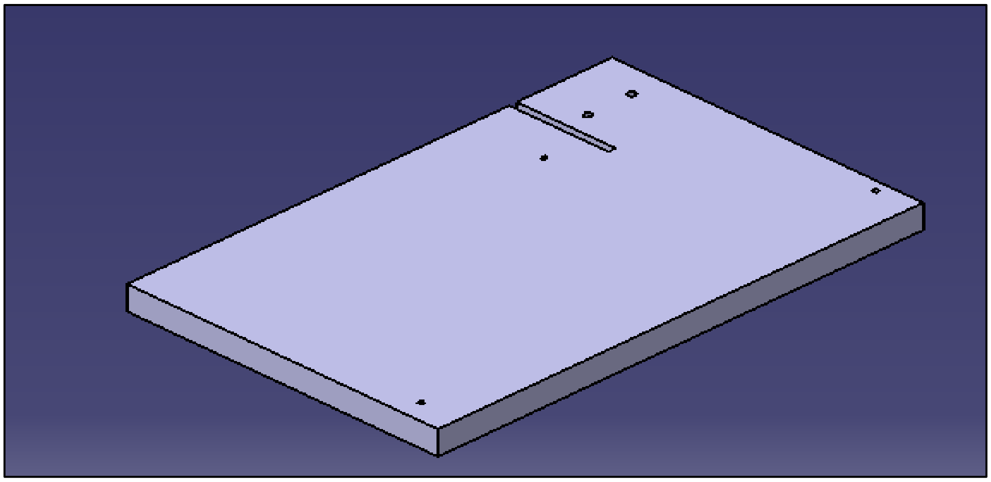


Figure F.20: Cutting table

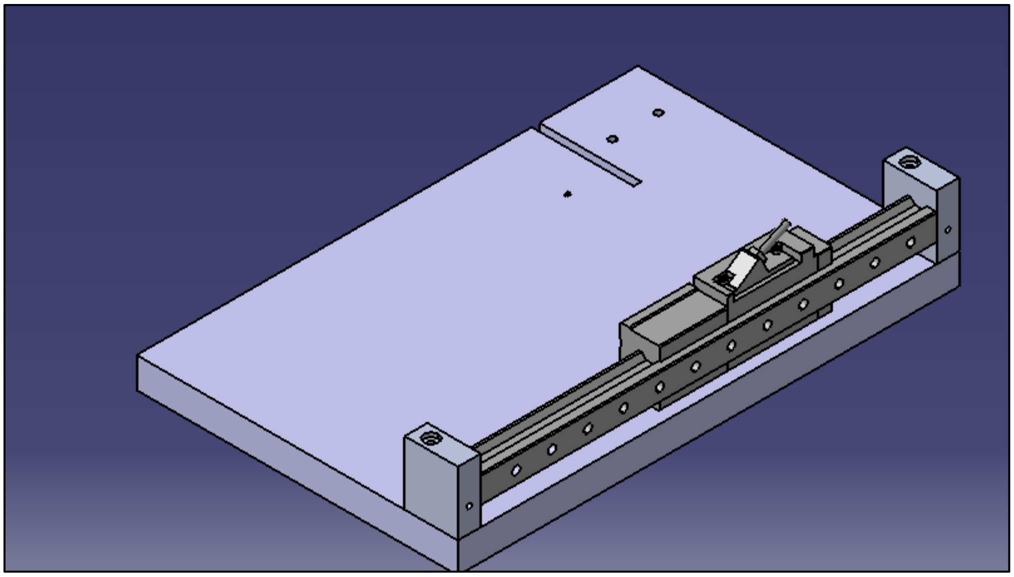


Figure F.21: Cutting table and linear rail assembly (rail from [2])

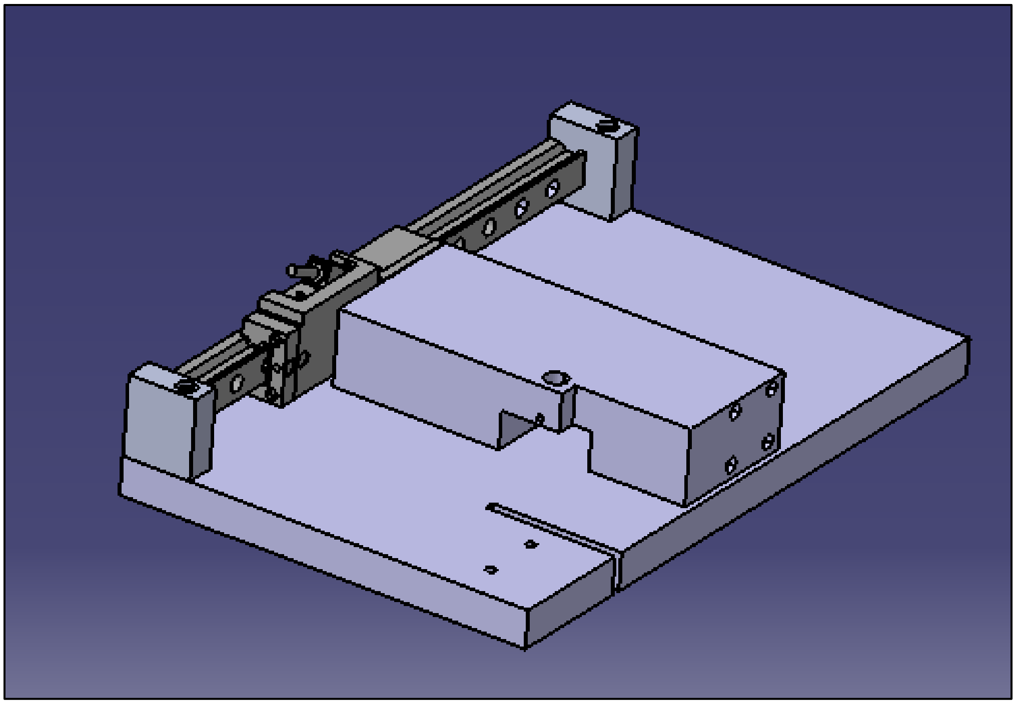


Figure F.22: Cutting table, sliding base, and linear rail assembly (rail from [2])

# APPENDIX G

# DETAILED DRAWING

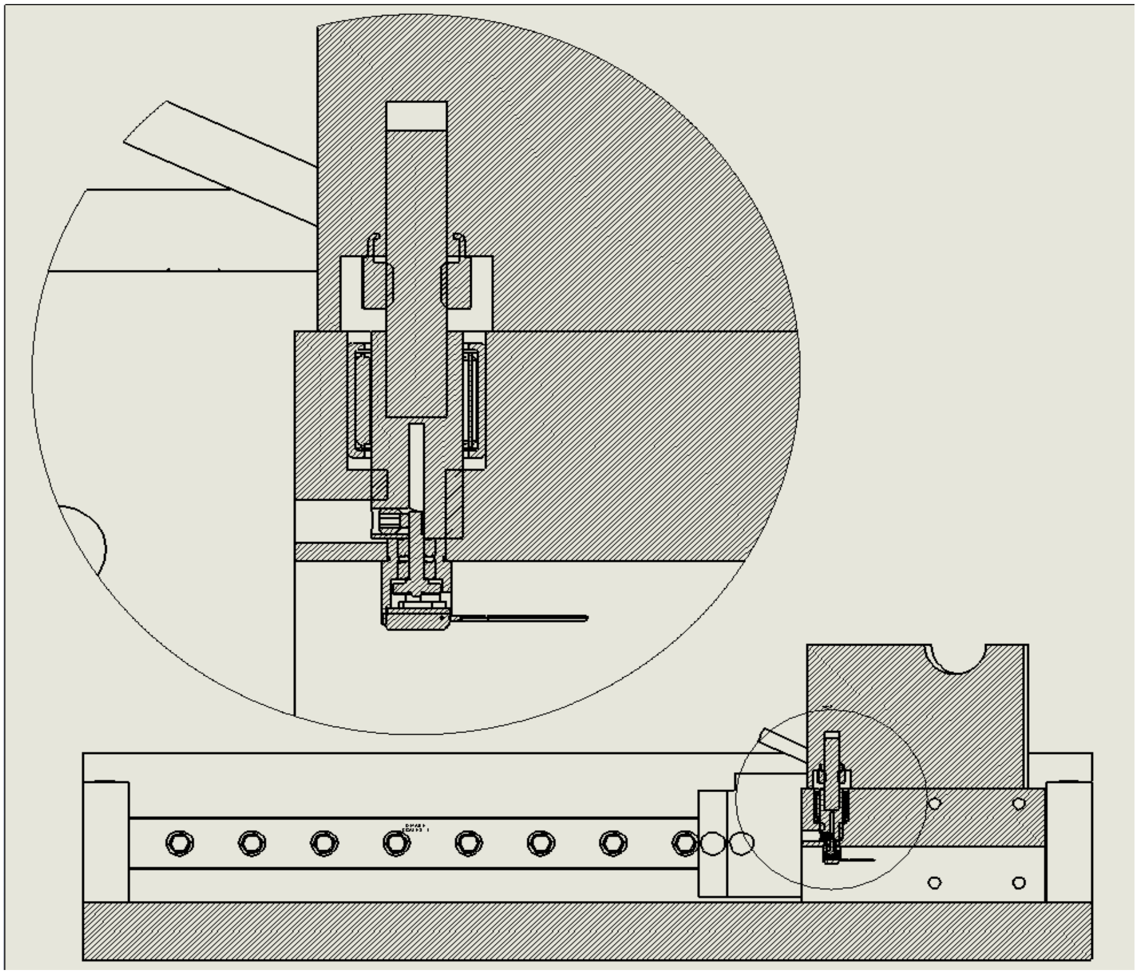


Figure G.1: Detailed drawing of modified jig (rail from [2])

# APPENDIX H

# BILL OF MATERIALS

## Table H.1: Bill of Materials

| Description | Vendor | Part Number | Qty | Unit Price Ea. $ |
|---|---|---|---|---|
| SA100-R Single Axis Rotary Display | Newall | DSA11000-R | 1 | 394 |
| SA100 Single Axis Linear Display | Newall | DSA11000 | 1 | 394 |
| Power Supply for SA100 Displays | Newall | 293-80080 | 2 | 107 |
| Mounting Bracket for two SA100 Displays | Newall | DSAKIT2 | 1 | 63 |
| Horizontal Mounting Arm for Display | Newall | 600-84115 | 1 | 123 |
| 10 Foot Cable<br>Connects Rotary Encoder to SA100-R<br>Newall will attach 9D connector (below) | Newall | ELDM180030FL1 | 1 | 146 |
| 9-PIN D CONNECTOR (MALE) WITH SHELL | Newall | 510-2000 | 1 | 8 |
| 7S Angular Encoder | Nemicon | 7S-400-2MC-50-OOE | 1 | 99 |
| Lock Nut | Fastenal | 1170860 | 1 | 0.35 |
| Package of 25 Double Threaded Bolts | Grainger | 4REC3 | 1 | 19.13 |
| Set Screw | Fastenal | 154097 | 1 | 2.25 |
| Linear Encoder and Rail Package<br>1 x AMSA 3B S 25-N-G0-KC-R11-0327-13.5-13.5-CN-TR50<br>1 x AMSA 3B W 25-F-P3-G0-V1-R1-CN-S10-LN-TMU<br>1 x container/s a 25 pcs MRK 25 | Schneeberger | "TBA" | 1 | $987 |
| Needle Roller Bearing | AST Bearings | SCE68 | 1 |  |
| Hook Clamp | Carr Lane | CL-MF25-5013 | 2 | 64.5 |
| 14-Inch Multi-Cutter Saw | DeWALT | DW872 | 1 | 435 |

|  |  |
|---|---|
| TOTAL PRICE | $2842.23 |

Table H.2: Copy of estimate from Newall

| Qty | Part # | Description | Unit Price Ea |
|---|---|---|---|
| 1 | SHG-TT VCMA 00800 | 8” Travel SHG-TT Incremental Linear Encoder with<br>• Scale Tube<br>• Bracket Kit for Mounting Scale Tube (# 600-80120)<br>• Reader Head: SHG-TT<br>• Cable: 3.5 Meter Armored<br>• Connector: 9-Pin D Male<br>• Output Signal: TTL Differential Quadrature (A quad B)<br>• Reference Marker (Index): Periodic<br>• Accuracy: +-10 µm per m<br>• Resolution: 1 µm | 572.00 |
| 1 | UBK01 | (Optional) Universal Bracket Kit<br>• For Mounting Reader Heads<br>• 1 Kit Mounts 2 Reader Heads | 119.00 |
| 1 | DSA11000-R | SA100-R Single Axis Rotary Display | 394.00 |
| 1 | DSA11000 | SA100 Single Axis Linear Display | 394.00 |
| 2 | 293-80080 | Power Supply for SA100 Display | 107.00 |
| 1 | DSAKIT2 | Mounting Bracket for two SA100 Displays | 63.00 |
| 1 | 600-84115 | Horizontal Mounting Arm for Display | 123.00 |
| 1 | RPEPV000A | RPE-PV Rotary Encoder | 725.00 |
| 1 | ELDM180030FL1 | 10 Foot Cable<br>• Connects RPE-PV to SA100-R<br>• Newall will attach 9D connector (below) | 146.00 |
| 1 | 510-2000 | 9-PIN D CONNECTOR (MALE) WITH SHELL | 8.00 |

Lance Cobb
3704 Eagle Isle Cir
Kissimmee, FL 34746
USA

Phone 407-433-1854
Office 781-271-0140
Fax 781-932-4127
E-mail orders.us@schneeberger.com
Internet www.schneeberger.com

SCHNEEBERGER
LINEAR TECHNOLOGY

**To:** **Will Buck**
**Company:** **?**
**Phone** **972-741-8664**
Date: Wednesday, August 05, 2015
From: Lance Cobb/SE Regional Sales Mgr
Direct phone: 407-433-1854
E-Mail: lance.cobb@schneeberger.com
**Re:** **RFQ**

**QUOTATION**

**WB-20-150805-00**

SBE reference: LC01455020

Schneeberger is pleased to provide you with the following quotation for your consideration:

| Part Number | Product Type | Description | Qty | Unit Price | Lead Time (ARO) |
|---|---|---|---|---|---|
| TBA | | 1 x AMSA 3B S 25-N-G0-KC-R11-0327-13.5-13.5-CN-TR50<br>1 x AMSA 3B W 25-F-P3-G0-V1-R1-CN-S10-LN-TMU<br>1 x container/s a 25 pcs MRK 25 | 1 | $987 | 9 Weeks |

Figure H.1: Copy of estimate from Schneeberger

# REFERENCES

[1] Thomson Linear Motion, n.d., from www.thomsonlinear.com

[2] Schneeberger, “Monorail and AMS,” Product Catalog 2015, from https://www.schneeberger.com/fileadmin/documents/downloadcenter/01_product_catalogues_company_brochures/01_Linear-_and_profiled_guideways/01_MONORAIL_and_AMS/Monorail_EN_low.pdf

[3] Giovanna Monari, 2013, “Understanding Resolution in Optical and Magnetic Encoders.” from http://electronicdesign.com/components/understanding-resolution-optical-and-magnetic-encoders

[4] Newall Measurement Systems LTD, “SA100 &SA100-R Digital Readout Display.” from http://www.newall.com/upload/content/file/sa100_english.pdf

[5] Nemicon, “Ultra Miniature Size Encoder 7S Series.” from http://nemicon.com/pdf/7S.pdf

[6] DeWalt, “DW872 Multi-Cutter Saw.” from http://www.dewalt.com/tools/metalworking-multi-cutter-saws-dw872.aspx

[7] Fastenal, “DW7745 14" 90T Thin Gauge Metal Cutting Blade.” from https://www.fastenal.com/products/details/0235658

# BIOGRAPHICAL INFORMATION

Truitt Ammons began his academic career at the University of Texas at Arlington in the fall of 2012. Truitt will be receiving his Honors Bachelor of Science in Mechanical Engineering with a minor in Mathematics.

Throughout his academic career, he was involved in several organizations on campus. After taking a “food fight” themed honors English course with Dr. Johnson, Truitt, along with other Honors students, was inspired to start an organization on campus dedicated to confronting arguable issues in food culture and food politics. Thus, The Food Fight at UTA was born.

After graduation, Truitt will go to work for his church, as technical director and an administrator, where he will continue to work and serve.