Dry Lube Applicator for Wire Mill Production

Final Design submitted to the
Department of Mechanical and Materials Engineering
College of Engineering and Applied Science
University of Cincinnati

in partial fulfillment of the
requirements for the degree of

Bachelor of Science

in Mechanical Engineering Technology

by

Sam Knueven

October 2023

Thesis Advisor: Dr. Calhoun

Table of Contents

Problem Statement

This project focuses on the manufacturing of large diameter hardfacing wire and the recurring issue of inconsistent lube application. Customers can face issues when feeding the welding wire through their machines which could be caused by an uneven distribution of lube on the wire.

The aim of this project is to reduce this issue, benefiting both customers as well as the operators manufacturing the wire in a reliable and consistent way.

Background of the Problem

The process of manufacturing metal cored welding wire can vary depending on what kind of wire is being made and its size specifications. For smaller diameter wire, the manufacturing process can be very tedious, requiring several steps to get to the correct final diameter.

An issue with large diameter hard facing wire is there's no opportunity to add lube to the wire in a secondary process. If the wire doesn't have enough lube it can cause tip wear as shown in fig 1.

This project will be able to positively affect 67% of the total amount of wire that Welding Alloys USA produces.

Figure 1, Left worn tip, right unused tip. Both are 3.2mm tips, both show the exit side of the tip

Applicable Standards

Through researching industry standards there are two specific OSHA standards that this project will need to adhere to. The first being Standard Number 1910.212 which is referencing machine guarding. (1) If this project has moving parts they will need to adequately protect the operator from rotating parts, pinch points and ingoing nip points. The second being Standard Number 1926.55 which is referencing Gasses, vapors, fumes, dusts, and mists. (2) The lube that is being used is called Moly Disulfide which comes in the form of a powder. The fixture will need to adequately contain the powder such that operators are not subject to its inhalation.

State of the Art

There are three different products out of the market that could potentially solve these issues. A current piece of technology that is state-of-the-art in this situation is called a Motorized

Die Box (3). A Motorized Die Box is a machine that holds dies and allows for the welding wire to pass through to be reduced in size and at the same time have lubrication applied. This works by having an internal reservoir that is filled with soap while rotating fins constantly agitate the material allowing for an even distribution.

There are a few pros and cons to using a Die Box. A pro of using a Die Box is that the soap is evenly distributed throughout the wire. A cons is that a die is needed to operate so the wire has to be reduced in size. Another con is that these machines are usually pretty bulky and run by big electric motors mounted to them. This isn't a great solution when spatial constraints are a problem like in this project.

A second example of state-of-the-art technology is a Model DE-AG-CUP 20 Ounce Agitator (4). This model is made by Decorative Engineering and Supply and is an attachment that fits on HVLP Spray Guns. This product is used for spraying on dry lube onto your parts that require it. A pro of this product is that since it's a spray applicator, operators can be sure all of the wire or parts are getting a good dose of dry lube. The cons of this are that the product is hand held so it's not conducive to automation like the solution will need to be. It's also powered by a compressor which isn't ideal and would need some kind of feedback system for excess lube to get recycled through the system.

A third example of state-of-the-art technology is a Soap Box. These boxes are filled with the soap or dry lube and the wire is then run through the mixture coating it with the material. This is also the current solution used by Welding Alloys. These types of Soap Boxes are very common within the wire making industry. A pro of using Soap Boxes is that they are very easy to maintain. A cons is that the powder, when not agitated, can carve out a “tunnel” and not be applied evenly. Another con is that the powder is being applied passively, allowing for a low dispersion rate along the wire.

End User

The end user of this product would be Welding Alloys USA and all its operators. Currently there are three locations in the United States in Kentucky, Pennsylvania, and Alabama. All three of these locations create the wire that this project will be affecting. To get more specific this project will affect the operators the most after its implementation. With the completion of his project the Mill operators should have an easier time making this wire consistently.

Summary of Research

While the welding wire is being produced by the mill there are circumstances that require the addition of dry lube or “soap”. This application can happen several different ways but none that meet the needs and standards of Welding Alloys currently. A Die Box (3) would be the best current option but they are far too big for the application and would require electricity to run. The Model DE-AG-CUP isn't suited for manufacturing purposes and the regular soap box is the current solution that isn't working as well as it's needed to. The end user, the operator, needs a device that actively applies lube to the wire removing the need for them to babysit the regular Soap Box. They also need something that is small enough to fit between the mill heads that is modular. When this type of wire isn't being produced the device will have to be easily removable to allow for different wire production. This is where the current gap in technology is for this specific application and what this project strives to achieve.

Quality Function Deployment

Based upon the following survey completed on 9/27/2022 at Welding Alloys USA engineering characteristics and product objectives were produced for this project. Responses were collected from mill operators on both first and second shift and the results were recorded and analyzed. Below, a copy of the questions and answer options for the survey can be found.

Survey Sample

Hi, my name is Sam Knueven and I'm a coop student working on my senior capstone which is redesigning the current moly box used for the production of large diameter wire. Listed are some customer features that **could be seen in the redesign of this fixture.** Please take a moment and fill out the survey ranking each customer feature from a low priority (1) to a high priority (5).

- Ease of Use ( )
- Safety ( )
- Light Weight ( )
- Machine Integration ( )
- Tool less Installation ( )
- Adjustability ( )
- Lube Application Consistency ( )
- How much would you be willing to pay for this product? $1000, $5000, $10,000, $20,000

How satisfied are you with the **Current** Moly Box system and performance?

1 being not satisfied and 5 being very satisfied

- Ease of Use ( )
- Safety ( )
- Light Weight ( )
- Machine Integration ( )
- Tool less Installation ( )
- Adjustability ( )
- Lube Application Consistency ( )

Customer Features

Ease of Use

Safety

Light Weight

Machine Integration

Tool less Installation

Adjustability

Lube Application Consistency

Engineering Characteristics

Mounting Hardware

Frame Design

Fixture Design Shape

Cause of Locomotion

Material Selection

Ergonomics

Wire Diameter Adaptation

Powder Refill Mechanism

House of Quality

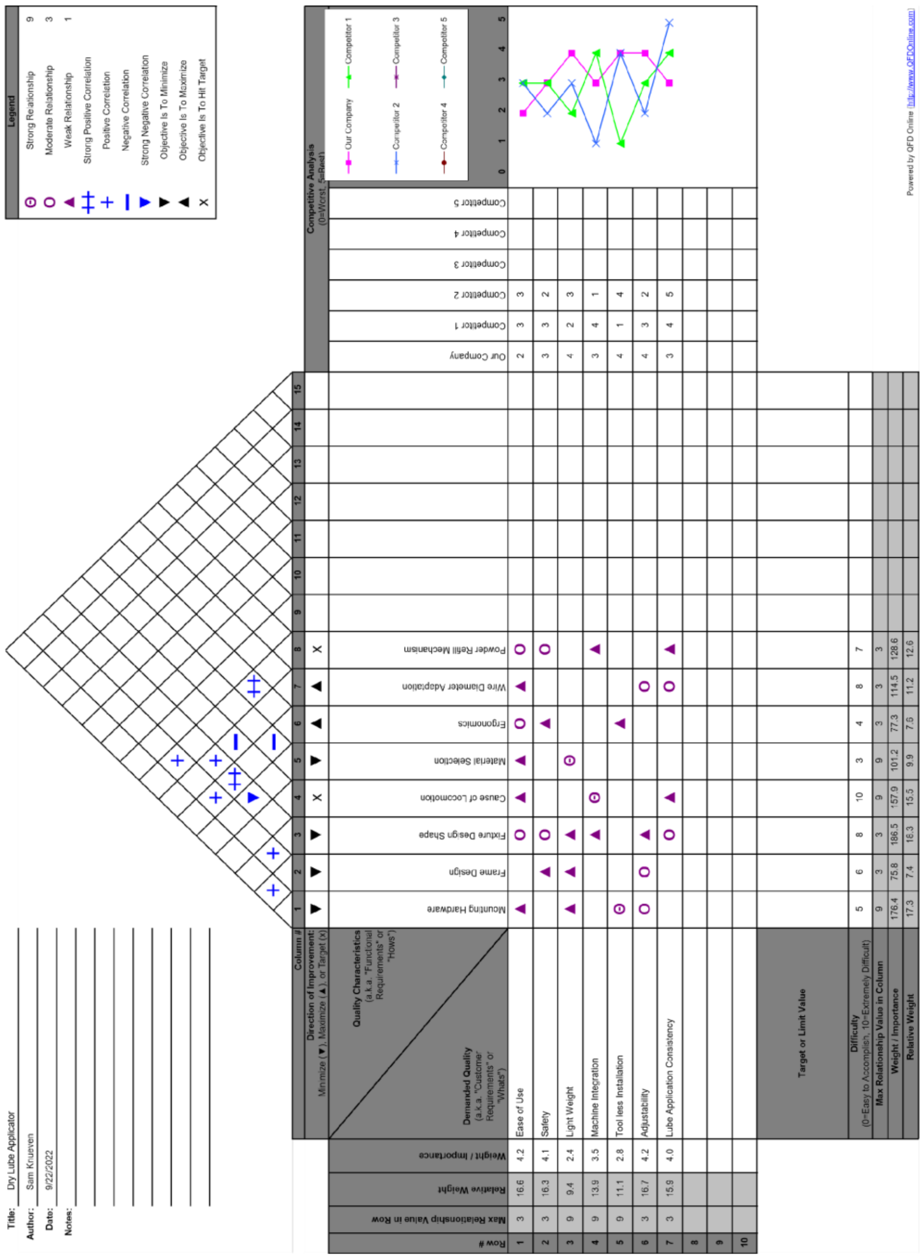


Figure 2, House of Quality

Product Objectives

After the survey responses were received, the answers were weighted. The responses can be found below, with the weighted percentage of how important each.

Ease of Use (16.6%)

This machine will need to be easy to install and remove as some wires don't require its use. The wire itself also needs to be easily thread through the system so as to not add more down time during changeovers. This could be done via the application mechanism or part of the fixtures body making the threading easier through something like a funnel.

Safety (16.3%)

The lube applicator will need to be sealed in such a way that the lube is not becoming airborne and breathed in by the operators. It also needs to have properly placed guards such as to not allow operators to pinch points during its use.

Light Weight (9.4%)

The fixture being lightweight could be accomplished primarily through material selection but also through the shape and design of the body.

Machine Integration (13.9%)

The level of machine integration will depend upon the cause of locomotion for this project. If it's something like an electric motor that could be tied into the existing PLC. However, if the machines use the passive movement of the wire to run then machine integration will not be an option.

Tool less Installation (11.1%)

A thumb screw or screws could be used to attach this fixture to the machine. Or this could be simply slotted in place by a pinned mechanism.

Adjustability (16.7%)

The fixture will have to be easily adjustable to the height and width of the wire in-between the mill heads. It also needs to be able to fit securely within the spatial constraints of the mills.

Lube Application Consistency (15.9%)

The fixture needs to apply the lube in an even and uniform way around the entire diameter of the wire as well as across the length of the production.

Concept Drawings

After survey responses were received and analyzed, three different concept drawings for dry lube soap boxes were created, taking into account the product objectives most important to Welding Alloys operators.

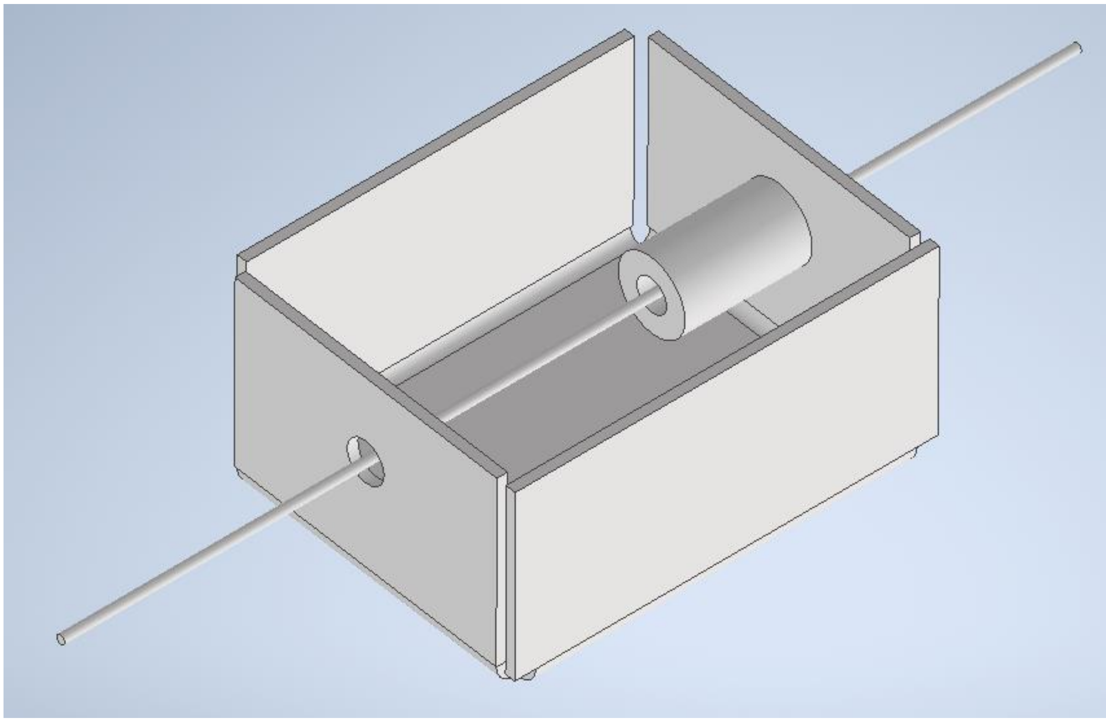


Figure 3, Concept 1

Concept 1

This concept consists of using a pressure die as the main element of lube application. How this works is the die has a small opening a little bit larger than the wire itself. There's a chamber in front of the die that traps the lube that is then forced onto the wire as it travels through the box pressing it between the die and wire. It is definitely the simplest solution requiring only a few custom dies but would require change over time and is passive which could allow for uneven distribution of lube.

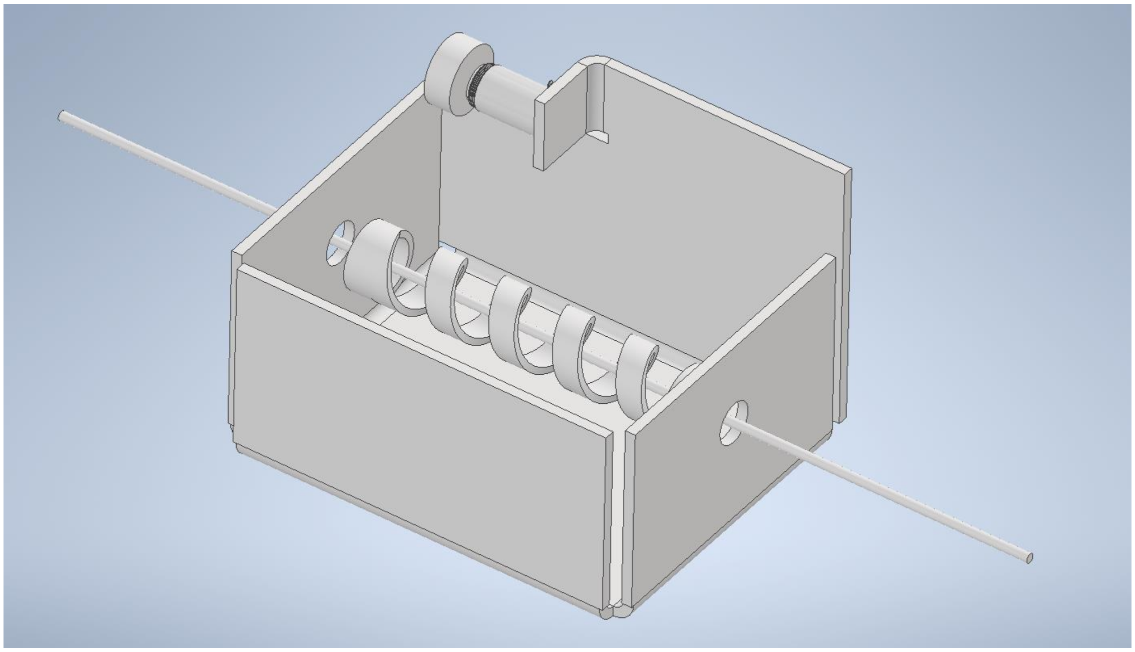


Figure 4, Concept 2

Concept 2

This concept consists of a spiral brush running the length of the box that will be applying lube to the wire. It could be powered by a variety of things but in this example, an electric motor is used. This is a good active example since it has outside power the operator will never have to worry about if it's still rotating or not. But adding an electrical component adds complexity but also the opportunity for machine integration.

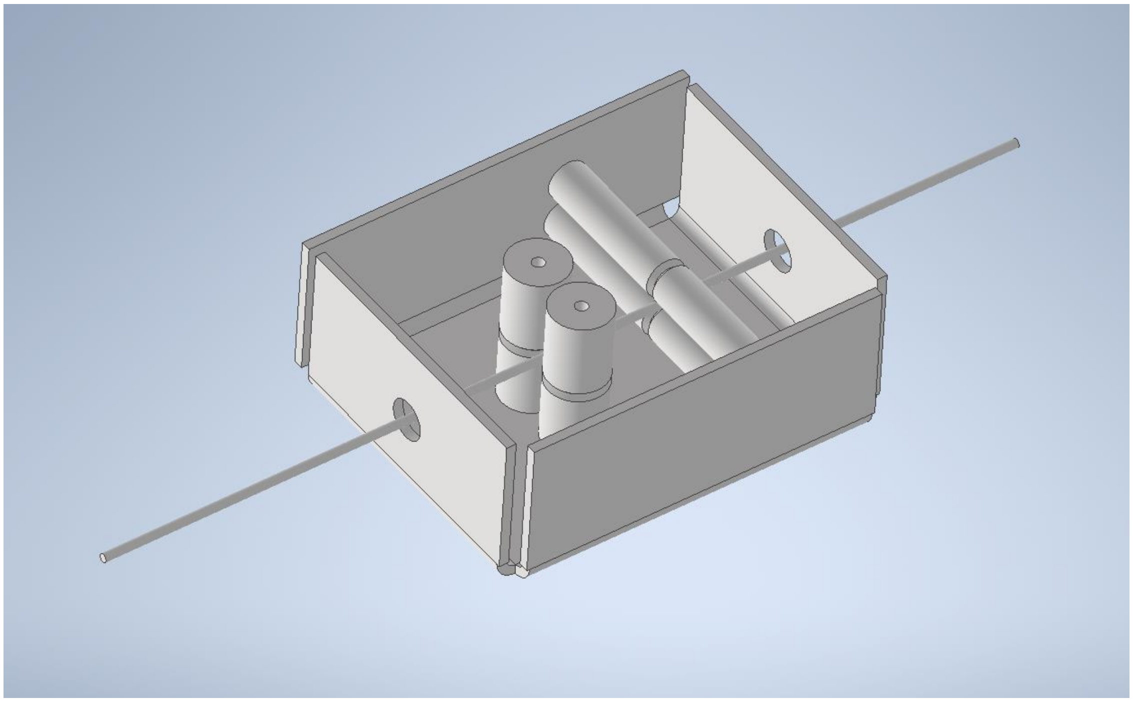


Figure 5, Concept 3

Concept 3

This concept consists of two sets of rollers that will act as transfer mechanisms for locomotion from the wire. From this inherent movement the rollers could be connected to an agitator device that will keep the lube flowing as a wire passes through the box. The rollers would also help with the application of the lube pressing into the wire between the rolls. This might require some adjustment from wire to wire. The rollers would also need some spring mechanism to keep the tension on the wire.

Project Management

Project Budget Limit

After having a meeting with the Welding Alloys Project Manager and a Production Engineer, a budget range of $5,000 to $7,000 was set for this project.

Key Milestones

Dates	Project Objectives
10/11/2022	Senior Design II
10/14/2022	Concept Decision Finalized
11/4/2022	Prototyping
11/28/2022	Presentation I
1/3/2023	Testing/ Final Design
1/9/2023	Senior Design III
1/10/2023	Manufacturing
3/31/2023	Final Testing
4/14/2023	Tech Expo

Project goals

The main goal of this project is to create an applicator device that distributes an even amount of lubrication across the wire as it moves through the mill. A subsequent goal is to calculate the amount of moly disulfide that should be consumed by the wire so the hopper is of adequate size for a full day's production. Another goal is to develop a way to validate the design and to quantitatively determine how much lube is getting on the wire.

Rate of Consumption

The first thing that needed to be done was to determine the amount of lube that was going on the wire. In order to calculate the rate of consumption, first the amount of lube being applied to the wire needed to be determined. Until starting this project, this number had never been investigated by welding alloys. Several ideas on how to get a working approximation were brainstormed. The first was to measure out a set amount of powder and put that in the current system and measure how much wire it took to consume all the powder. However, this wouldn't be a good approximation since the current soap box does not apply the wire evenly, and since the wire is higher than the bottom of the box the wire would never naturally consume all the moly disulfide.

Another way this number could be derived is by taking test samples of wire and trying to get a weight before and after the moly disulfide was applied. However, since the powder is so fine (about the coarseness of powdered sugar), the weight actually getting on a 12in piece of wire has to be very small. To try and negate this issue, the most accurate scale in the Welding Alloys plant can be used, which happens to be in the Quality Control lab. This scale is able to go down to the thousandths of a gram, so if anything can detect that powder change it should be this scale.

In order to run this rest, wire samples that matched the size and properties of the wires that the fixture would be producing were acquired from Mill 3. These samples were then cut down in a sample jig that cuts the wire to 12in every time. Ten wires were used as a sample size and then laid out on the QC table. From there the wires were labeled and the weight of all of the samples was taken while also noting their diameter and length for future calculations. Next, the samples of wire were run through piles of moly disulfide and wiped off to ensure no clumps of the powder were still stuck on the wire. From there, they were put back on the scale and their weights were recorded again.

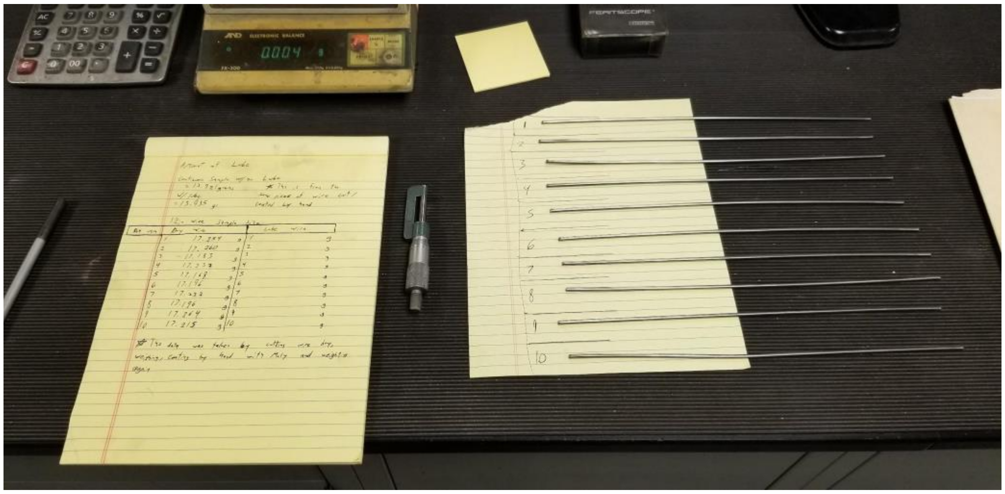


Figure 6, Weighing Wire

Once all before and after weights were recorded, all the data was put into an excel spreadsheet where the difference in grams was calculated in order to find the amount of powder put on the wire. For an average 12in length of wire, 0.008 grams of moly disulfide was on the wire. Taking the diameter and lengths of the wire, the surface area of the wire samples was calculated and determined a unit, which is Grams/M^2, which will show how much powder is on the surface of the wire. The average of the 10 samples came out to be 2.3 Grams/M^2.

Utilizing the average of 2.3 Grams/M^2, a calculator was created in Excel that finds the amount of powder per wire produced, in turn determining the consumption rate per length of wire. Next, grams of moly disulfide were converted to a volume in centimeters^3. Finally, these tools are able to be used to determine the volume of the hopper for the fixture; this came out to 136 cm^3.

	Diameter (mm)	Dry Wire (grams)	Moly Wire (grams)	Diff Grams		Surface Area Calculation (M^2)	Grams/M^2	
1	3.37	17.254	17.261	0.007		0.00323	2.169	
2	3.36	17.26	17.267	0.007		0.00322	2.176	
3	3.38	17.183	17.189	0.006		0.00324	1.854	
4	3.37	17.232	17.24	0.008		0.00323	2.479	
5	3.38	17.168	17.176	0.008		0.00324	2.472	
6	3.41	17.196	17.204	0.008		0.00327	2.450	
7	3.38	17.222	17.231	0.009		0.00324	2.781	
8	3.36	17.196	17.202	0.006		0.00322	1.865	
9	3.38	17.264	17.272	0.008		0.00324	2.472	
10	3.35	17.215	17.225	0.010		0.00321	3.117	
				Avg.		Avg.	Avg.	
Length (M)	0.3048			0.008		0.00323	2.383	Grams/M^2
Bobbin Consumption Calculation								
Diameter of Wire (mm)		3.2						
Length of Wire (M)		28724.3						
Total Area (M^2)		288.768						
Grams to Be Consumed		688.261						
Converstion to Volume (cent^3)		136.000						

Figure 7. Consumption Calculation

The powder box was ultimately made slightly bigger than 136cm^3, coming out to a total volume of 160 cm^3. This should allow for some buffer if 136cm^3 turns out to be an underestimation.

Coefficient of Friction

Before building prototypes of the powder box fixture, a definitive way to compare the amount of powder on the wire needs to be developed. Simply measuring the weight of the wire before and after applying powder cannot be done because that would require cutting and measuring lengths of wire half way through the mill which would interfere with the wire manufacturing process.

There are a few different ways that these wires could be compared. One option is to do a simple visual inspection, but that is very subjective, therefore not a good quantitative method. Expanding on the idea of a visual inspection a camera could be used to detect the color change on the wire to determine which wires have more powder. This would be more accurate than a subjective inspection but the powder color contrast on the wire isn't very good, so that might cause issues with the camera system. This would also only look at one side of the wire so it wouldn't give a very good overall picture of how much lube is on the wire. A way to get around this might be to use different colored wire to increase contrast but then the powder might apply to the wire differently than the moly disulfide would. The amount of powder on the wire is more of a symptom of what is being looked for, which is the friction of the wire to go down. Because of this the coefficient of friction would need to be measured and see how that differs through different wire setups. After some experimentation with kinetic equations a ramp could be used to measure the angle at which the static coefficient of friction broke and could then be back calculated to an estimated coefficient of friction for the given sample assuming a constant velocity. To test this a piece of angled steel was placed against a table's edge and used as a lever to test this theory. Once that was proven a more robust and repeatable version of this test fixture was necessary. This consisted of a piece of angle steel that has been sanded and polished to create a uniform surface. After that a hinge was added for the bottom of the ramp and welded it to a thick piece of metal that was used as a base. A lever arm was added that connects to the end of the ramp to help assist in a constant increase in angle as well as a plate to place the electronic protractor.

Figure 8. Test Coefficient Fixture

Having taken some preliminary measurements using this device and comparing the coefficient of friction of non-coated wires to coated wires, that data was not very accurate. The standard deviation for the data sets was around 2.5 which isn't accurate. A standard deviation that would be acceptable would be below 0.2. Therefore, a better method of measuring this variable needed to be found.

Welding Alloys in France was currently working on a project that allowed for the measurement of the coefficient of friction for wire. Not seeking to reinvent the wheel, Welding Alloys France was contacted and their team sent over documentation about the project. Their fixture was created by building a ramp off of two plates that the wires were connected to.These two plates are then placed face down on one another so the only contact that is being measured is the wire touching the wire allowing it to isolate that variable. With this in mind, a similar operation was created for this project, except for the power moving the ramp is hand driven and there's a motor increasing the ramps angle at a constant speed also alleviating some inconsistencies from sample to sample. Once the top plate breaks away and slides down the ramp a sensor at the bottom stops the motor and allows you to take the angle measurement for that wire. In summary, a fixture that will allow for the calculation of the wires coefficient of friction was created.

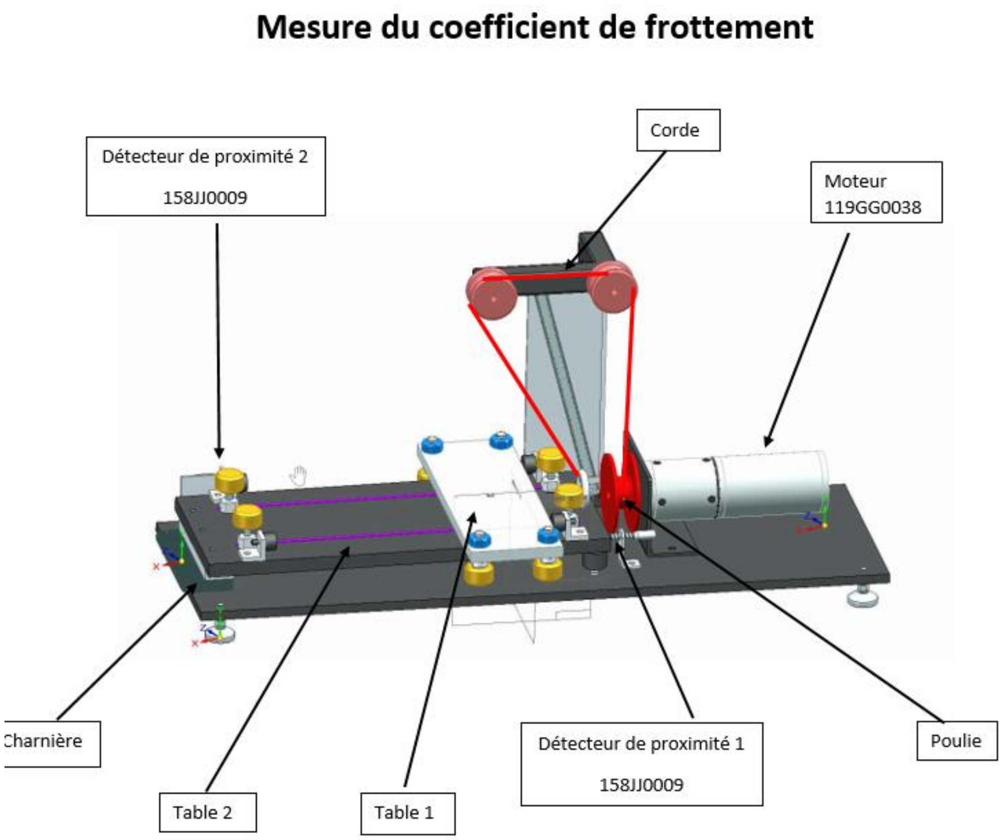


Figure 9. French Coefficient of Friction Fixture

Final Design

The final design ended up being a combination of the best qualities of each of the three concept drawings found on pages 10-12. Moving forward with this bearing press design over the other two for a few specific reasons. The biggest issue with the current system is that there's nothing causing the powder to be mated with the wire as it goes down the mill allowing for parts of the wire to go unfinished. Using a mixer type shaft to constantly agitate the powder would solve the patchy issue but it's not clear that this would ensure a good application of lube onto the wire. A better solution would be to apply some kind of force to the wire to apply the lube pressing it into the wire. Another solution that was tested would fulfill this by using ball bearings to apply pressure. This would come from the gravitational force pressing down on the balls. It would help but it doesn't have a consistent compression force on the wire. Both of these previous examples would also be difficult to apply to a small space like this project requires.

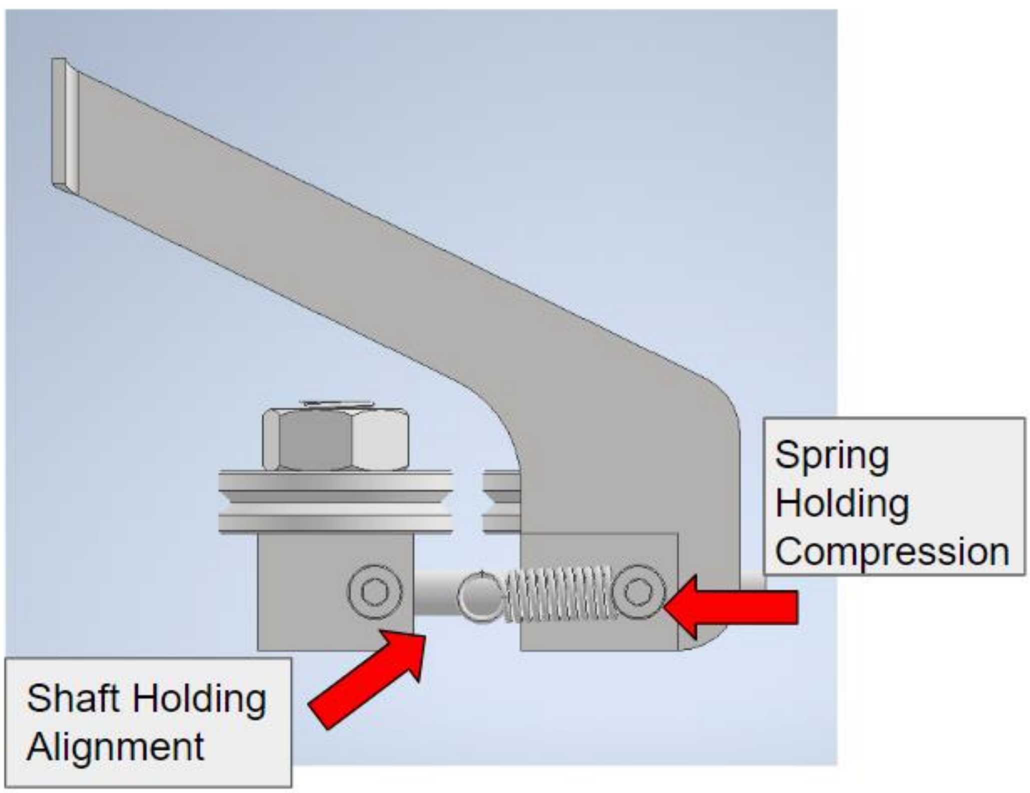


Figure 10. Internal Mechanism

How this final design will come together is pretty straightforward. Start with the bearing that has a notch precut for the wire. This will be mounted on a bolt going into the base of this fixture. Off of that base there will be two linear shafts that keep the two bodies aligned so the wire will accurately locate every time. Keeping these two bearings in compression there will be a spring mounted on the sides of the base. On the far side there will be a thumb tab which makes it easy for the operators to open the fixture and feed the wire through. This bearing compression device will be mounted in the powder box alighting with its input and output holes for the wire.

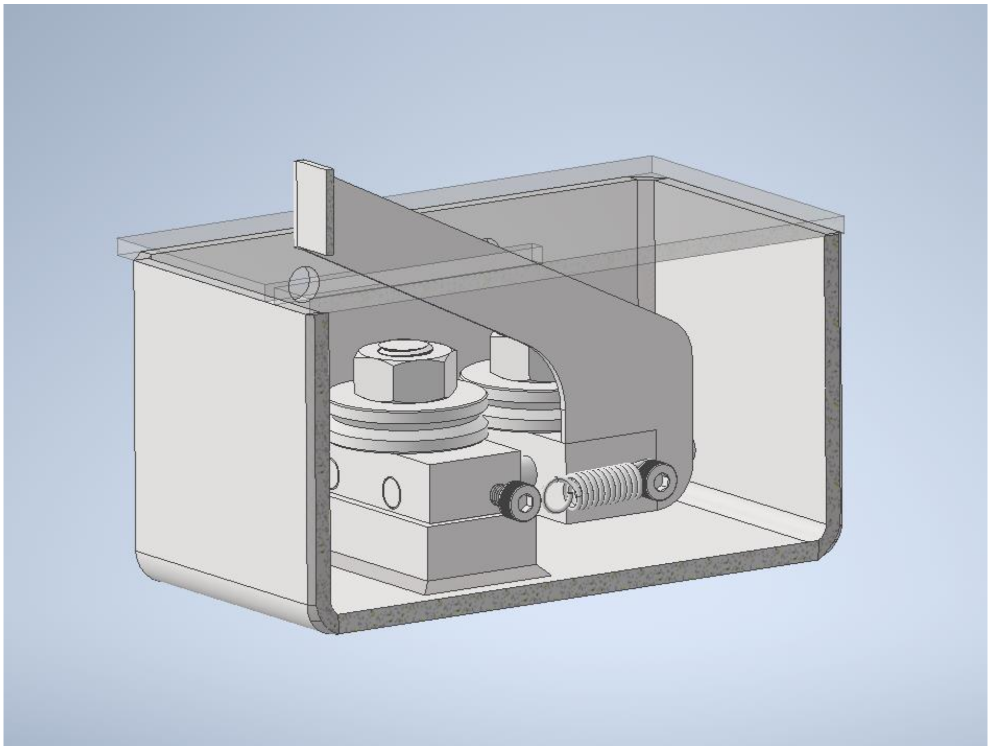


Figure 11. Final Design Cutaway

This allows for the complete saturation of the wire within the powder. The bearings will add that compression force on the wire allowing for some aid in the application of the wire. This fixture will be mounted to the turk head on both the T1 and T3 mill head models that are used in various Welding Alloys plants across the United States. Shown below are the models verifying the clearance of the fixture on both of these models. In the case of the T3 head there's about a 6 in gap between the heads but for T1 there's only a 3 in gap.

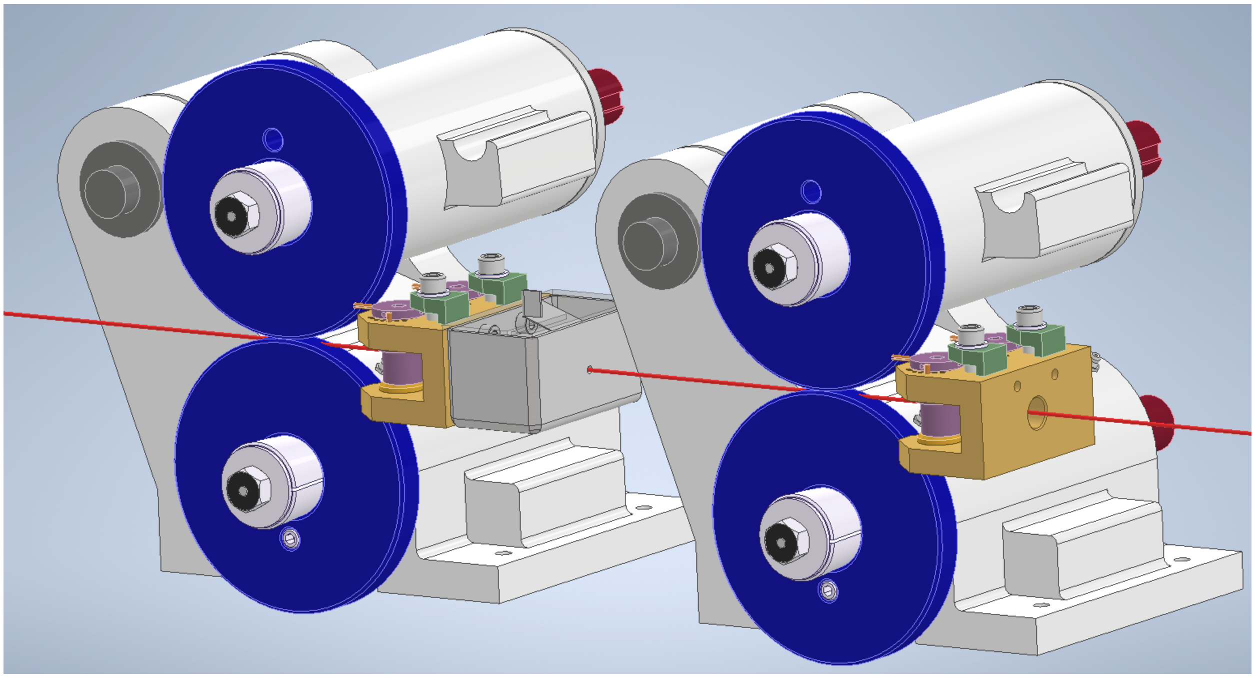


Figure 12. Clearance Check T1

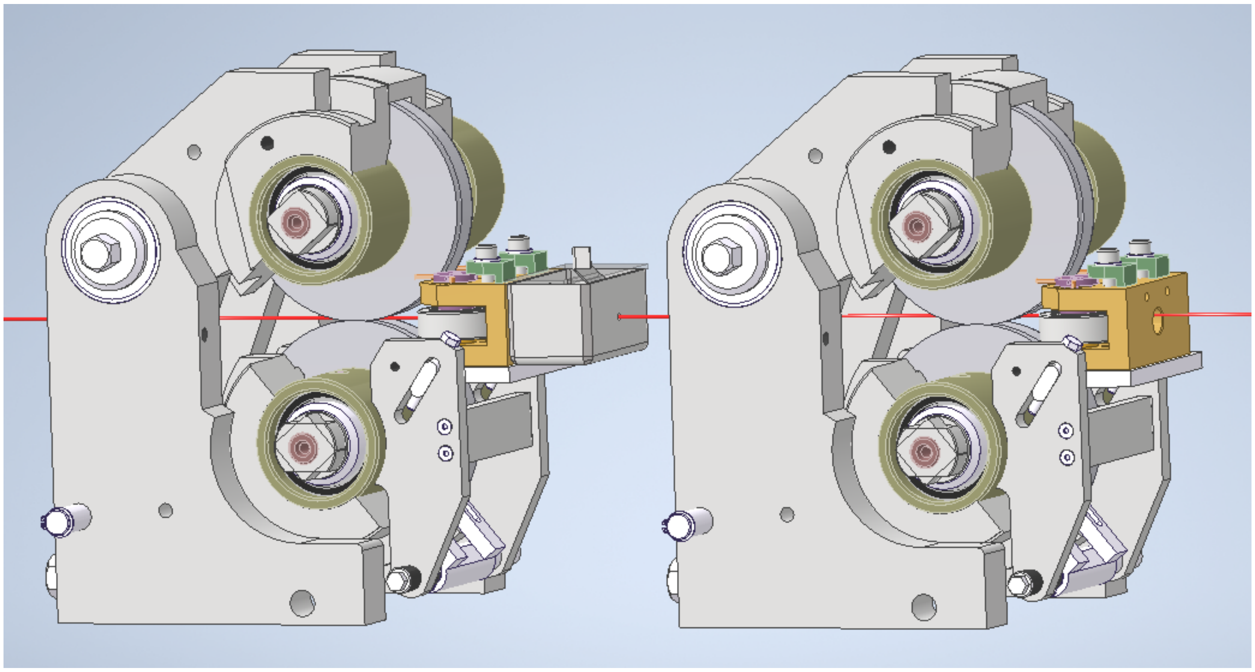


Figure 13. Clearance Check T3

Cost Breakdown

Using a lot of tools and machinery in house will go a long way to reduce the overall cost of this design. The rest of the parts can easily be purchased by most hardware stores but for ease of access McMaster Carr will be used for a lot of the purchased parts. In the proposal paper for this project a budget of $5000 to $7000 dollars was set for the entirety of this project. The estimated cost for the final design prototype comes well underneath that upper threshold.

Cost Breakdown: Final Design		
Part	Manufacturing	Price
Cut Bearings	Custom Bulk Order	$200
Bolts/Nuts	McMaster	$20
Sheet Metal Formed Parts	In-house Plasma Cutter	$10
Spring	McMaster	$8
Machined Base	In-house Milling	$10
Plexiglass	McMaster	$20
Alignment Shafts	McMaster	$28
	Total Estimated Cost	$296

Prototype

To begin the phase of prototyping some parts would need to be machined as well as cut out on a plasma table. Using the CAD model from the final design technical drawings were made that allowed the manufacturing of these pieces. These consist of two machined blocks holding the bolts to mount the cut bearings and the alignment rods. Two M10 bolts cut to specific lengths and two 6M shafts to keep the alignment. The first piece made was done by plasma cutting the bodies as well as levers to actuate the mechanism. The flat bodies were then bent in a vise into rectangular boxes and the corners welded shut to be watertight. Using the end mill, chunks of steel were cut down to their respective dimensions of 40mm by 20mm by 15mm and 40mm by 20mm by 21.10mm.

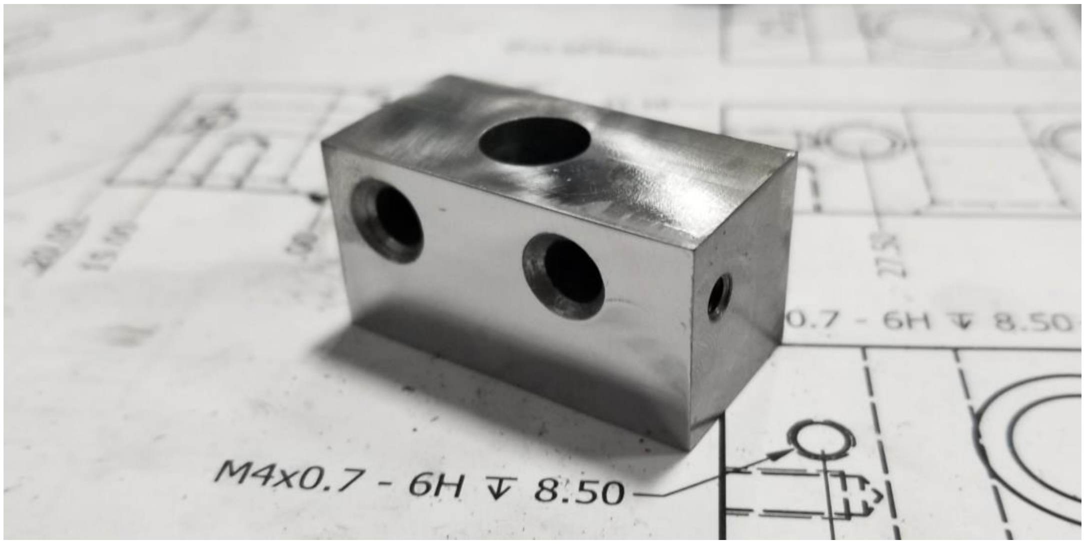


Figure 14. Bearing Press Body

From there, the center 10.5mm hole was drilled out to make room for the retention bolt that would be welded in later. The two 6mm holes for the alignment rods were drilled out in the same way. The last holes that needed to be drilled were pilot holes for tapping M4X0.7 threads to hold the spring as well as mount the base block into the fixture. Once these bodies were finished two bolts were welding into the bodies to allow the bearing to be bolted down. A washer was placed between the block and the bearing to allow the bearing to spin freely. The M6 alignment rods were then welded into their mounting holes on the larger block allowing the smaller block to slide freely on the other side. Once these pieces were assembled a spring was placed between them to keep compression between the two bearings. With the box welded shut the two pieces could be bolted together to finish this prototype.

Figure 15. Bearing Press Assembly

The other prototype that was made was far simpler to build as it only consisted of a mesh screen being placed into one of the powder boxes. Then this mesh was welded into place and ball bearings placed in the cavity that it created.

Testing Fix 1-A, Fix 2-A

To keep costs low and to kill two birds with one stone a meeting with research and development was set to find a way to use scrap material to create the wire for the fixture testing. Looking through inventory it was decided to use a mixture of HCP-O and HC20 adding up to 1,511 lbs of powder and 1,773 lbs of 0.600X0.012 strip. This will allow us to make enough wire to get a good idea of how the fixture will act over time as well as leaving enough raw material open for future potential tests. The wire was run for all three scenarios, the first being with no lube, just raw wire, the second for fixture one and the third for fixture two. Once each scenario had its own drum full of 500 lbs of wire they were tested on the friction test machine.

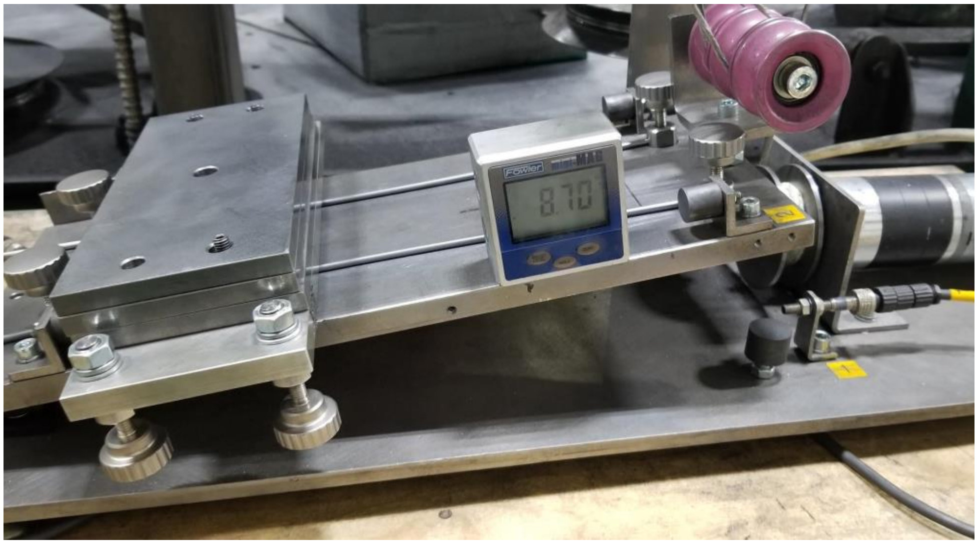
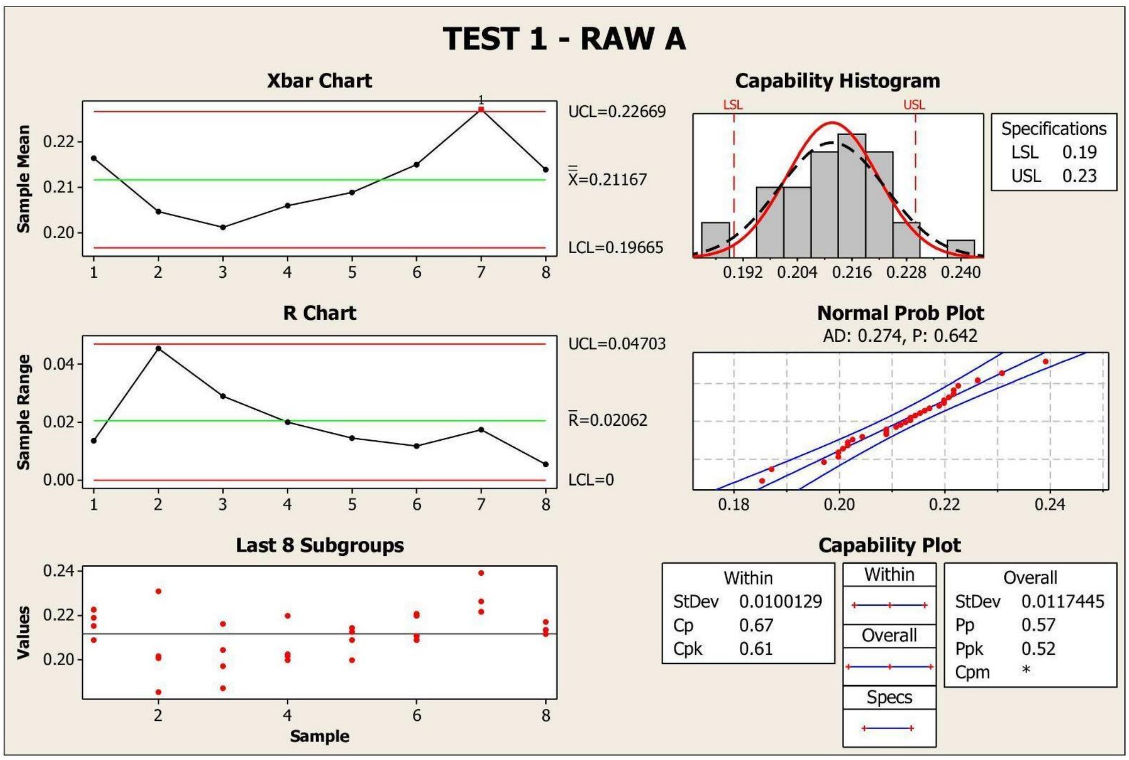


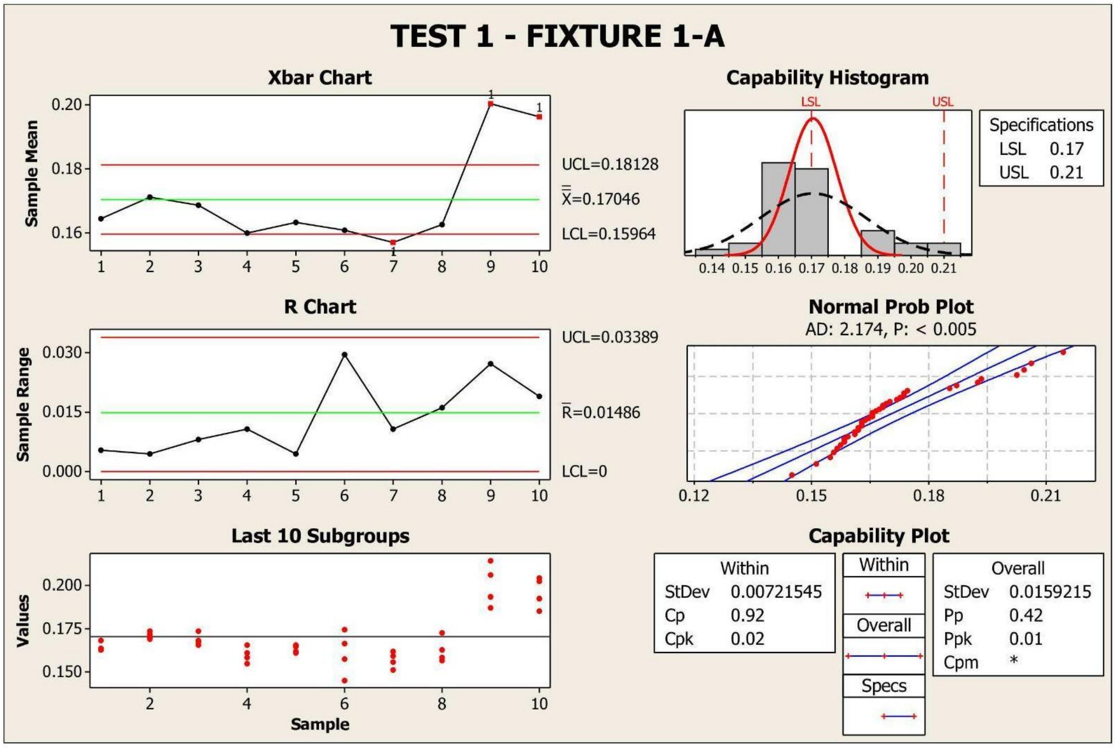
Figure 16. Coefficient of Friction Tester

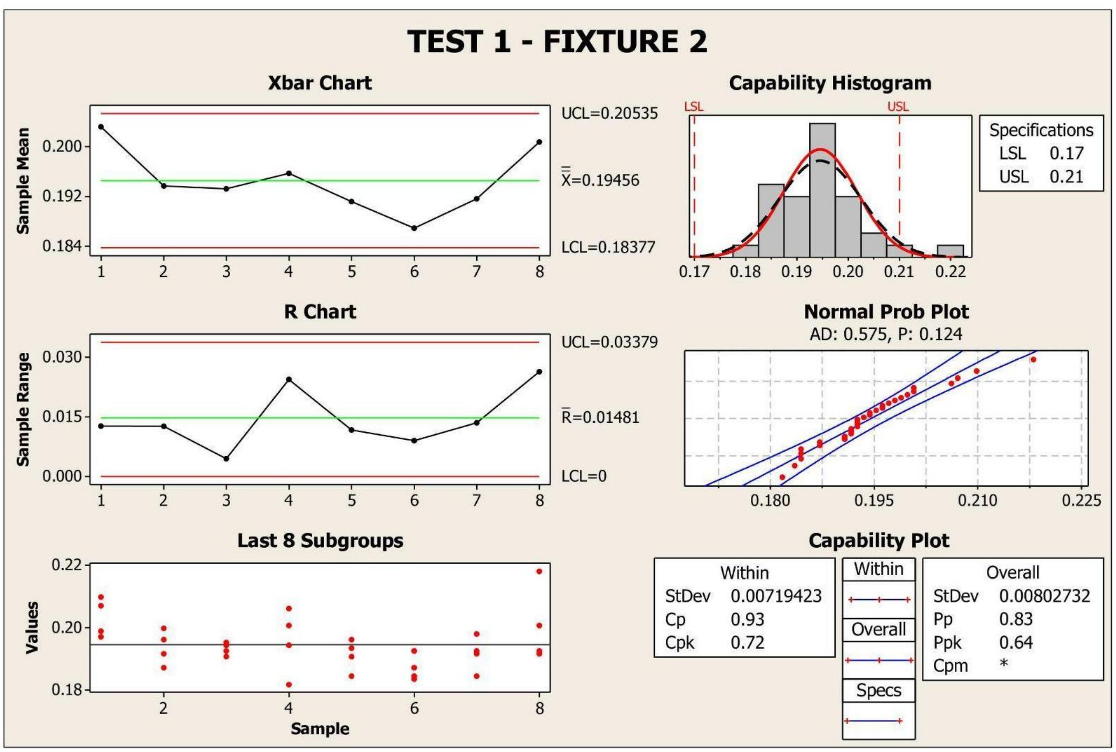
This friction tester was developed by our conglomerate partners in France and was borrowed to run these tests. To run a test on this fixture first four pieces of wire must be carefully cut from the drum of wire. Taking care not to touch the center of the wire where the two pieces will meet and lay on top of each other in the fixture, feed the piece of wire through one end of the wire holder and then cut the other end to allow it to feed through its respective holder. Repeat this process for all four pieces of wire and tighten down each end so the wire cant move. Then place the top carriage on the ramp of the fixture centered so the sides will not pinch when the carriage slides down. Make sure the control box is set to the UP position and press start. The ramp will increase its angle at a constant rate and the wire carriage will at some point slide down the ramp and trigger the stop sensor halting the ramp's motor. From there simply zero out a digital angle finder and record the angle at which the ramp is stopped. Switch the control box to the DOWN position and press start again to lower the ramp to its starting place. Repeat this process for all thirty two samples required for all three drums.

Analysis

The data analysis was then done by plugging all 96 data points into an excel spreadsheet. The degrees were converted into radians and the tangent was then taken. This gives the estimated coefficient of friction for all the samples taken. From there Minitab was used to get a more comprehensive understanding of this data as shown below.







Fixture 1-A was the obvious winner with a mean coefficient of friction of 0.170 compared to 0.211 for the raw wire and 0.194 for fixture 2 showing that the bearing press was the best at applying lube to the wire. However, while this fixture was in use there were some issues with its operation. First being while running on the mill, the powder at points looked to be stagnant over top of the bearings which could indicate that the powder is caving and not feeding properly to the bearing press and wire. Second the way the moly box was dimensioned there were large portions on the side of the bearing press that had lube with no way to get to the wire as they were located under the bearings. To test the first issue more wire from Fix 1-As drum was tested for its coefficient of friction. This wire had a different color and different finish to the first 32 samples. Raw wire has a gray tone with a shiny finish and lubed wire has a blue tone with a dull finish. Eight more coefficients of friction tests were done on this wire and the found values were more like raw wire than lubed wire. This is a very big issue since this project's goal is to not only put lube on the wire but do it consistently. Since this fixtures application is inconsistent a redesign and retest is required to ensure that all the project's goals are being met.

Redesign/ Retest

To design Fixture 1-B it needed more usable molly in the hopper, to use gravity as much as possible to help keep the powder feeding and keep the powder agitated on top of the bearing press. To satisfy these new requirements a new box was designed with a smaller width to just fit the bearing press that then got wider near the top to help the powder flow down to the bearing press. This angle was found by measuring the side angles of our hoppers that we use for the mill powder feeding. To help the goal of keeping the powder on top of the bearing press moving, another idea was to add something to the top of the bearings themselves like a thin rod or mixing whisk. This idea had some downfalls though, first being the bearings themselves are very small and there isn't enough space to weld anything onto them. Aside from welding there was no other way to mount something like that to the bearing. Also adding spinning rods to the inside of the box would add a pinch point to the fixture itself causing it to be more of a hazard to operators. The second idea was to add some kind of linear actuator to manually stir the powder to keep it flowing while the fixture was in use but this would add a lot of mechanical complexity to the device as well as cost. The solution that was finally settled on to keep the powder moving on top of the bearing press was a vibrating lid agitator. The vibrator mounts to the top of a lid that has two prongs going down into the solution of powder stopping 5mm on top of the bearing press. This should translate the vibration directly to the area of the powder that needs to keep flowing.

Since the moly box was being redesigned the bearing press itself would be redesigned as well since it had some issues during its operation. The rods that the two bodies were sliding between didn't have a tight enough tolerance for smooth movement when the wire was being threaded through the fixture. Sometimes this would cause the smaller body to pinch against the rod stopping its movement. To fix this issue the method of actuation was changed from linear to a pivoting motion. This simplifies the points of contact as well as how the two pieces are joined. The welded bolt threads were replaced by M10 threaded holes where shoulder bolts would now hold down the bearings themselves. The M4 bolt holes for mounting the spring stayed the same except for two additional holes so the spring tension could be increased. The previous spring tension came out to be about 10lbs. Using these new bolt location distances and the springs compression rate a range of 9.72lbs, 10.62lbs, and 11.16lbs was calculated so the operators could have some adjustment if they needed.

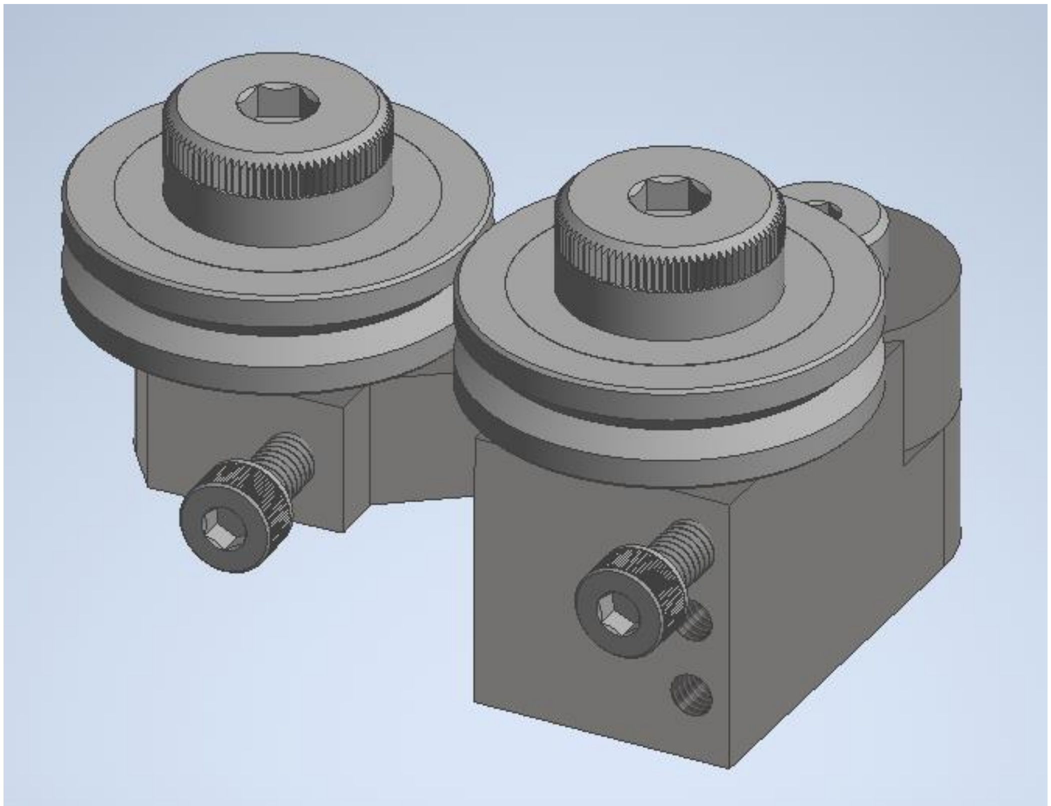


Figure 17. Bearing Press REV2

This new Fixture 1-B was designed and built in a few days similarly to the first round of fixtures. The body of Fix 1-B was cut on the plasma cutter and then bent and welded together. Since the new bearing press design was too complicated to be machined in house it was sent out to be made by a machine shop; but for the purposes of this secondary test the bearing press was simply reused in this new apparatus. This wouldn’t affect the process since the issue with feedability is due to the powder caving and not the bearing press malfunctioning.

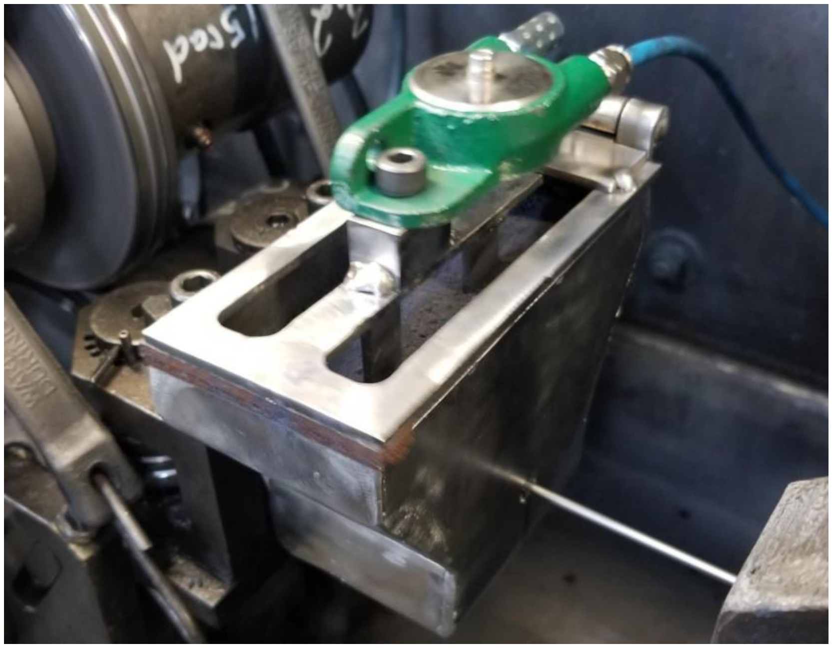
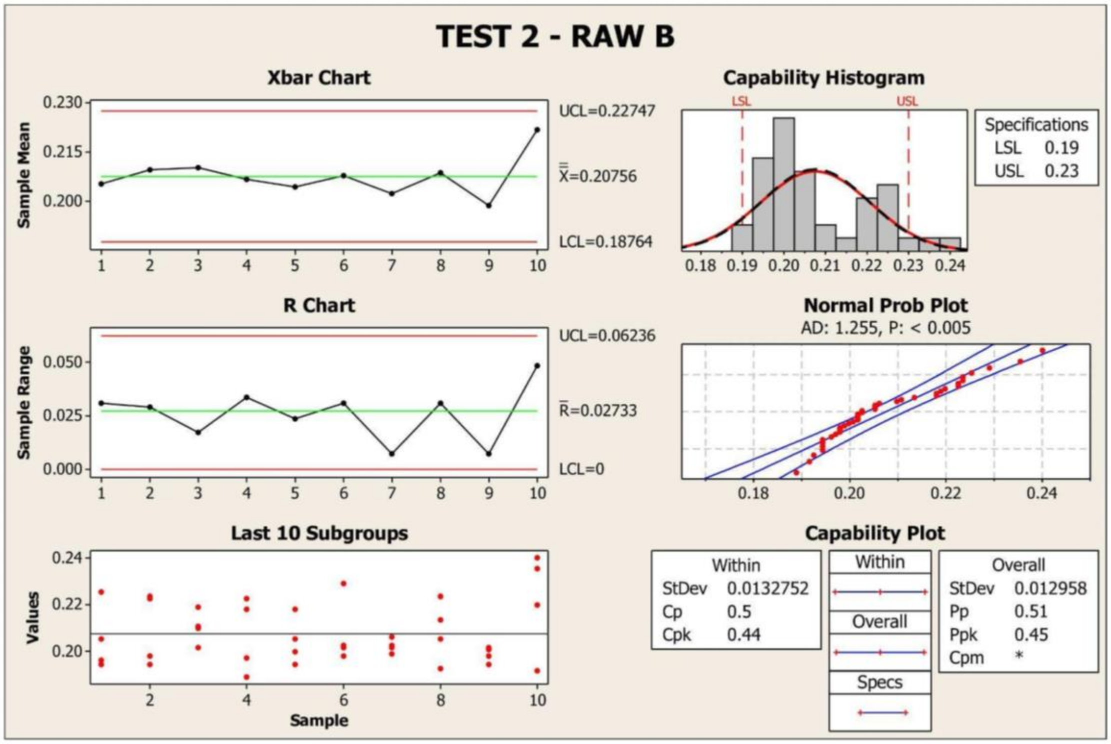


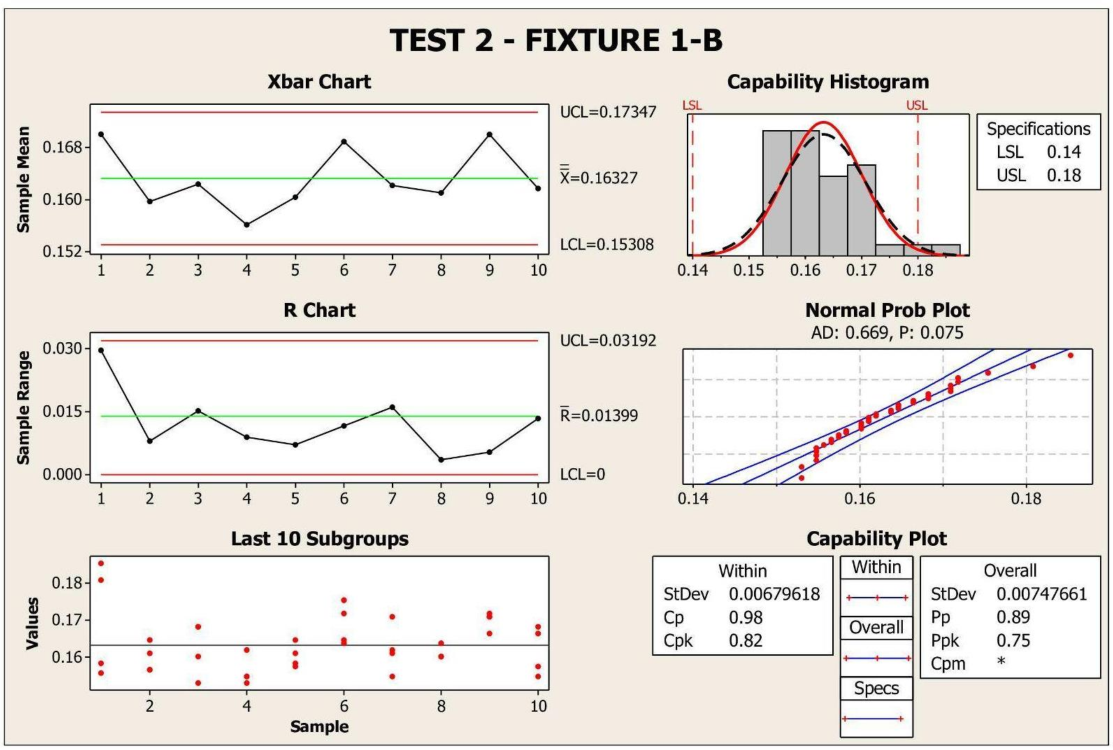
Figure 18. Fixture 1-B

For this final test the data points needed to be spread over the entire run, not just a small portion of the wire. A new method was put in place to collect the wire samples. Two samples would be run from pieces of wire next to each other in the drum. Then a portion of the wire would be removed from the drum to create distance to the next sample. The wire removed was a handful or about 20 to 25 coils of wire between the samples. For testing this new fixture we used actual wire that would be used in production to get an even more accurate simulation of what wire a customer might be purchasing. Like the first test a drum of raw wire was taken followed by the fixture being mounted and another drum run. This wire was then tested as previously described to get a spread of data points across the entire drums being about 100 lbs of wire each.

Final Analysis

Once this data was collected this time being 40 samples each they were analyzed the same way as the first set of tests. First calculating the coefficient of friction then graphing for easier comparisons as shown below.


TEST 2 - RAW B
Xbar Chart
Capability Histogram
UCL=0.22747
X̿=0.20756
LCL=0.18764
Sample Mean
LSL
USL
Specifications
LSL 0.19
USL 0.23
R Chart
Normal Prob Plot
AD: 1.255, P: < 0.005
UCL=0.06236
R̄=0.02733
LCL=0
Sample Range
Last 10 Subgroups
Capability Plot
Values
Sample
Within
StDev 0.0132752
Cp 0.5
Cpk 0.44
Within
Overall
Specs
Overall
StDev 0.012958
Pp 0.51
Ppk 0.45
Cpm *


TEST 2 - FIXTURE 1-B
Xbar Chart
Capability Histogram
UCL=0.17347
X̿=0.16327
LCL=0.15308
Sample Mean
LSL
USL
Specifications
LSL 0.14
USL 0.18
R Chart
Normal Prob Plot
AD: 0.669, P: 0.075
UCL=0.03192
R̄=0.01399
LCL=0
Sample Range
Last 10 Subgroups
Capability Plot
Values
Sample
Within
StDev 0.00679618
Cp 0.98
Cpk 0.82
Within
Overall
Specs
Overall
StDev 0.00747661
Pp 0.89
Ppk 0.75
Cpm *

The results of this consistency test for Fixture 1-B came out very similar to the original test for Fixture 1-A. Fix 1-B came out with a mean coefficient of 0.16327 compared to Fix 1-A with a mean coefficient of 0.17046. This shows that the application of the lube onto the wire was not only more than the other fixtures but also stayed consistent over time.

Conclusion

The original goal of this project was to create a fixture that would fit in between the mill heads and apply moly disulfide evenly to the welding wire as it moved through the mill in an even and consistent manner. Using design and engineering methods based upon the results from the QFD different engineering characteristics were used to fulfill the project's goals, then they were prototyped and tested using two different designs to compare to raw wire. Seeing issues with Fix 1-A, it was redesigned and retested as Fix 1-B with the hopes of solving the consistency problems. With the addition of a newly designed moly box and a vibrational lid, the fixture was able to apply the most moly disulfide in the most consistent manner.

The final fixture is also able to fit within the T1 mill heads which had the smallest spatial constraints at width of 3 in, length of 8 in and a height of 2.5 in. This box's volume is 574 cm^3 which can hold enough powder for 3000 lbs of wire.

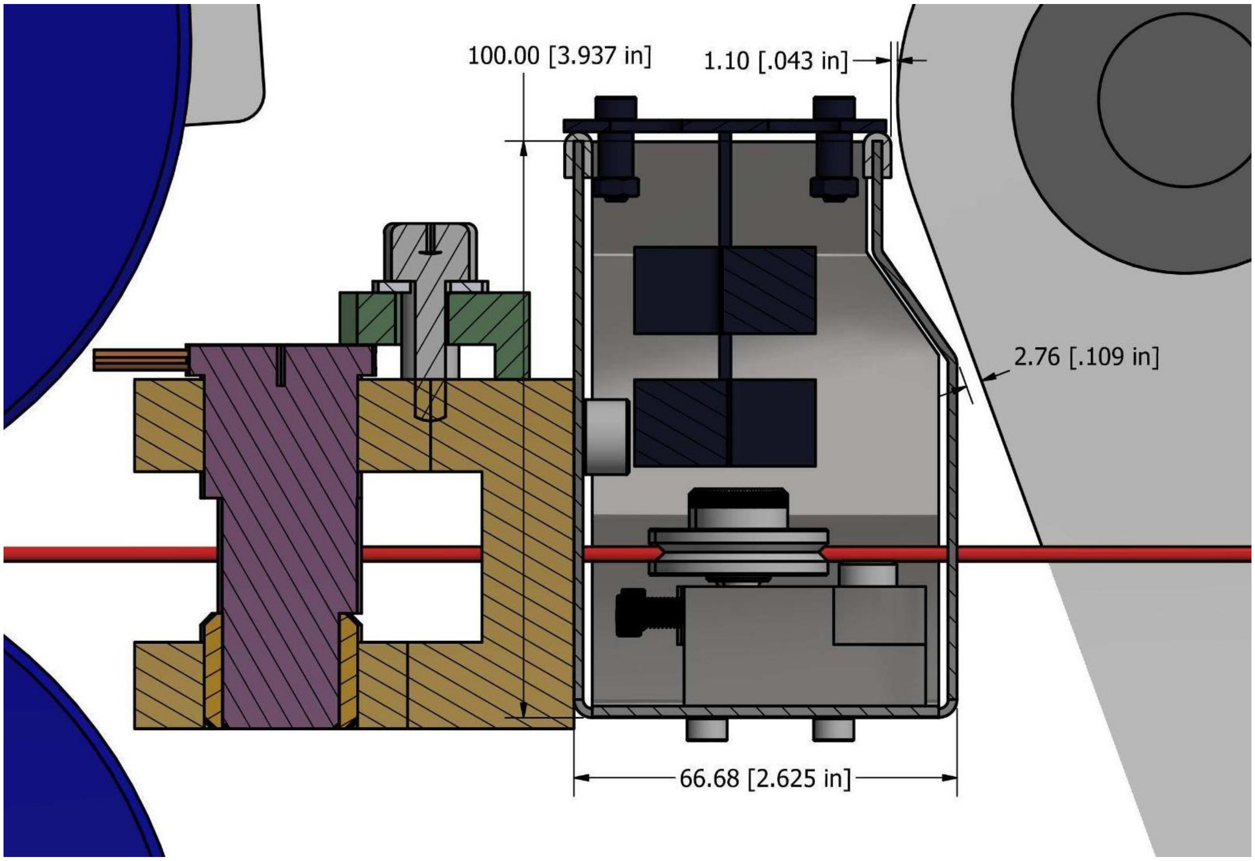


Figure 19. Fixture 1-B between T1 Mill Heads

The final cost breakdown is displayed below showing all three iterations of the prototypes tested as well as the final design that will be used in production. The total cost of this project came out to be $2879 under the proposed $5000 dollar budget.

	Prototypes			
	Part	Quantity	Procurement	Price
Fix 1-A	Fixture Body (1/8in)	1	Plasma Cutter (from scrap)	N/A
	M10 Shoulder Bolt	2	Inhouse	N/A
	M10 Nut	2	Inhouse	N/A
	M8 Washer	2	Inhouse	N/A
	Bearing Base/ Bearing Base Long	1	McMaster	$33
	Spring	1	McMaster	$11.45
	M4 Bolt	2	Inhouse	N/A
	6mm guide rod	1	McMaster	$3.32
	10.5mm	1	McMaster	$19.50
	3.3mm	1	McMaster	$3.55

Total price Fix 1-A =	**$70.82**

Fix 2-A	Steel Wire Cloth	1	McMaster	$4.36
	Wear Resistnat 52100 Steel Balls	1	McMaster	$14.99
	Fixture Body (1/8in)	1	Plasma Cutter (from scrap)	N/A

Total price Fix 2-A =	**$19.35**

Fix 1-B	Fixture Body Redesign (1/8in)	1	Plasma Cutter (from scrap)	N/A
	Bearing Press	1	Fix 1-A	N/A
	Vibration Lid With Prongs	1	Plasma Cutter (from scrap)	N/A
	Hinge	1	McMaster	$10
	Vibrator	1	McMaster	$250

Total price Fix 1-B =	**$260.00**

	Final Design			
	Part	**Quantity**	**Procurement**	**Price**
Fix 1-B	Molly Box Rev 2	2	Modern Sheet Metal	$331
	Hinge Arm	2	Ace Machine	$590
	Hinge Base	2	Ace Machine	$850

Total price Final Design =	**$1,771**

Total price for Senior Capstone	**$2,121.17**

To summarize, in this senior capstone project a new fixture was researched, designed, prototyped, tested and analyzed using various methods to solve the project's goal of inconsistent and low quantities of lube getting on large diameter hardfacing wire during its manufacturing. These problems were solved using engineering and design methods while staying on schedule and under budget.

References

1. **United States Department of Labor.** www.OSHA.gov. *General requirements for all machines. .* [Online] [Cited: 27 9, 2022.] https://www.osha.gov/laws-regs/regulations/standardnumber/1910/1910.212.

2. **United States Department of Labor .** www.OSHA.gov. *Gases, vapors, fumes, dusts and mists. .* [Online] [Cited: 27 9, 2022.] https://www.osha.gov/laws-regs/regulations/standardnumber/1926/1926.55.

3. **Assomac Wire Machinery People Group.** Motorized Soap Applicator Die Box. *https://www.assomacmachines.com/.* [Online] IndiaMART InterMESH Limited. [Cited: 9 9, 2022.] https://www.assomacmachines.com/motorized-soap-applicator-die-box.html.

4. **Decorative Engineering and Supply, Inc. .** Dry Lube Applicators. *decorativeengineering.com.* [Online] [Cited: 9 9, 2022.] http://www.decorativeengineering.com/dry-lube-applicators.html.