The University of Texas Pan-American

Senior Design MECE 4360

September 2011- May 2012

The Wire Winding Machine

Elite 4

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I. Abstract

Delta Heat LLC, manufacturer of heating products for viscosity control and freeze protection, contacted the University of Texas Pan American during the summer of 2011 for design and prototyping of a wire winding machine. The company stated that the particular product they wish the machine to produce is resistive wire with a fiberglass core. The product is currently used within their flexible rubber heaters product line. This type of resistive wire is currently available in the market. However, purchasing must be made in bulk and shipping is also a major issue due to time constraints of the orders placed. Delta Heat LLC currently buys material in bulk sizes and is constantly left with a surplus of raw material. The wire winding machine desired was to produce resistive wire based on input and both decrease surplus and increase revenue.

This project was divided into two phases, a design phase and a prototyping phase. The design phase included problem formulation, conceptual design, and final design analysis methodology. Research was conducted to begin drafting an initial design of the wire winding machine. However, it was noted that the information about the machines was limited due to the fact that these machines are usually trade secrets. The team took a different approach and researched similar production methods and based on these methods developed a final design. The design phase was effectively completed on December 2012 and prototyping began in January 2012. The prototyping phase included prototyping, calibrating, and redesign of machine. It was agreed that two identical machines were to be constructed with one to be delivered to the company in May 2012. The second machine is to stay at The University of Texas-Pan American where further research will be conducted to improve both its production and quality control aspects as well as implement automation.

II. Introduction

Overview of Situation

This project deals with the design and prototype of a wire winding machine. It was divided into a design and prototype phase with each lasting approximately 15 weeks. A prototype capable of producing resistive wire with a fiberglass core was completed, calibrated and delivered to Delta Heat Llc on May 2012. A second prototype was also completed by May 2012 to be kept at the mechanical engineering department for further research and development.

Company Background

Delta Heat LLC is a located in Rio Hondo, Texas that currently produces heaters for freeze protection, condensation and viscosity control as well as other applications. Their line of product includes flexible rubber heaters and insulated fuel pipes. Current customers are from (but not limited to) markets in military, aerospace, medical, automotive, and vending equipment due to the multiple applications of each product line. [1,2,3]

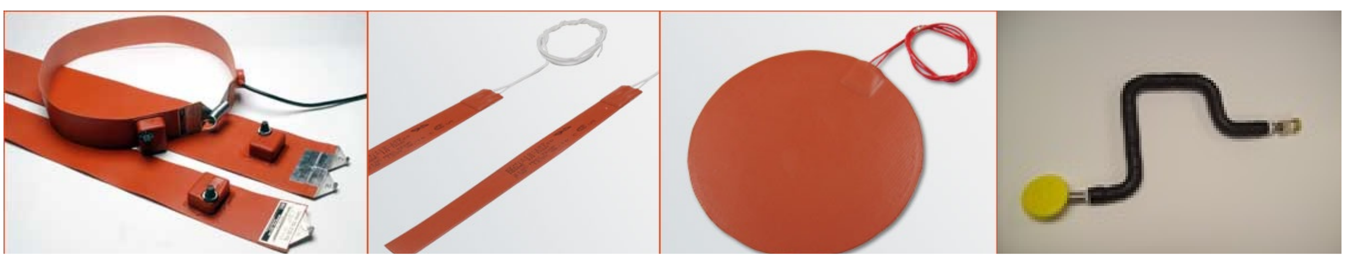


Figure 3: *Examples of some of the products that Delta Heat LLC produces using the Heating Resistance Wire: Drum Heaters, Pad Heaters, Fuel Heaters. Courtesy of www.electroflex.com, and www.deltaheatllc.com.*

Proposed Overall Design

The design of the wire-winding machine should be able to wind resistance wire around a fiber class core. It should be capable of using different type of wire materials and measure the resistance of the wire very accurate. The user must be able to control the motor velocities and sub sequentially control the amount of loops around the fiberglass core. The machine will use a real time resistance measurement device which the team is to design to ensure proper production. Finally all parts used in the prototype should be easily obtained from the market.

Figure 3: *In this figure we show the different material and spools the machine will handle to create the resistance wire.*

Constraints

The main constraint in this project is creating accurate resistance wires with a + or – 3 % resistance tolerance. Another is that when winding from to 2 to 3 wires we must make sure the wires stay parallel to each other as they wind. Constant spacing and maintain proper wire tension is important so that our machine can produce quality product. Our machine design must also be compatible with in-market parts. [1,2]

Needs

To meet our customers' requirements our machine needs to be able to create resistance wires for variable resistances. [1,2]

Figure 4: *Example of the Heating Resistance Wire. There are different materials used for each and have different resistances due to the loops of wire around the core. Also notice the double wire wind on the right*

Wants

Some of the wants that are going to be enforced in our machine will be a measuring system that will display the resistance for current wire being produced. Also, an alarm will be integrated to inform the user that parameters stay with the norms.[1]

Research was conducted to begin drafting an initial design of the wire winding machine. However, it was noted that the information about the machines was limited due to the fact that these machines are usually trade secrets. The team took a different approach and researched similar production methods and based on these methods developed a final design. The design phase was effectively completed on December 2012 and prototyping began in January 2012. The prototyping phase included prototyping, calibrating, and redesign of machine. It was agreed that two identical machines were to be constructed with one to be delivered to the company in May 2012. The second machine is to stay at The University of Texas-Pan American where further research will be conducted to improve both its production and quality control aspects as well as implement automation.

III. Problem Formulation

Methodology

Our senior design team has begun to research similar machines or processes that wind wire or perform other similar tasks. We began our design formulation by first getting to know our customer. The team met with the company at their plant and observed both their finished products as well as the wires that the machine is to produce. Wrapping wire around a fiberglass core adds flexibility, which is what the customer needs for his products. There are many factors that must be calculated as well as design constraints. We need to determine the necessary torque and wire tension for the winding process. This is because we need a good estimate of the horsepower needed in the motors in order to accurately design our machine with the right parts. The use of different types of materials will also have to be takes into consideration due to the fact that every material has a different type of resistivity. Implementation of these factors and constraints throughout the next few months will lead us to a final design. Parts will be ordered afterwards and prototyping as well as the final machine will be built by May 2012.

Another problem with each product requiring a specific resistance wire is that wire manufacturers sell only in preset amounts of resistive wire tentatively locking in profit for the Delta Heat LLC (until the remaining wire is used) as well as adding raw materials to the inventory for which storage also becomes a dilemma in the long run.

Implementation of the machine that our senior design group will design and construct will help the company overcome the current situation of excessive raw material and cost. It will give the company more freedom for development of new product lines and increase the company's profit. [1,2]

Figure 2:*In this picture shows the bulk the company wants to avoid.*

Proposed Timeline

Gantt Chart

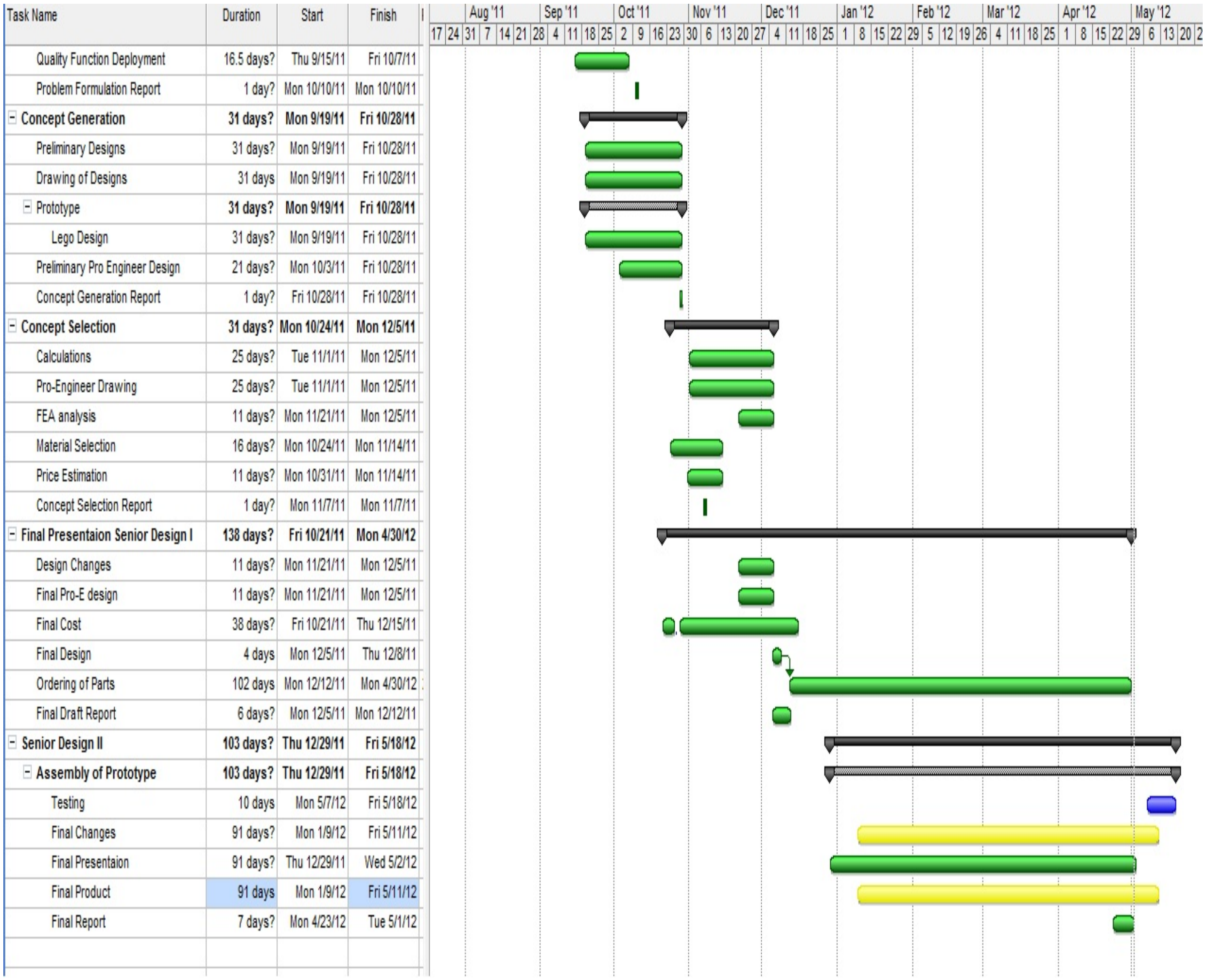
In the Gantt chart above, we show the proposed timeline as well as the steps it will take for the project to be successful. This Gantt chart however is preliminary and is subject to change.

We started with the Problem Formulation and the steps required to create our first presentation. We will be conducting some plant visits, research on existing products, scheduling, and as well as the QFD.

Following, we included the Concept Generation. Here the team will create ideas and compare them with their advantages and disadvantages. The drawings for these ideas will be included so we can analyze them, and a prototype of each will be made so we can observe their behavior.

Next we have Concept Selection. In this timeline we will show our selected design, and we will do some calculations, Pro-Engineer drawings, FEA analysis and some price estimation.

Finally for this semester we have the Final Presentation. By this time we will have a final design, a final cost, and will begin ordering the parts for the next semester so we can begin assembly of our machine design.



Task Name	Duration	Start	Finish
Quality Function Deployment	16.5 days?	Thu 9/15/11	Fri 10/7/11
Problem Formulation Report	1 day?	Mon 10/10/11	Mon 10/10/11
Concept Generation	**31 days?**	**Mon 9/19/11**	**Fri 10/28/11**
Preliminary Designs	31 days?	Mon 9/19/11	Fri 10/28/11
Drawing of Designs	31 days	Mon 9/19/11	Fri 10/28/11
Prototype	**31 days?**	**Mon 9/19/11**	**Fri 10/28/11**
Lego Design	31 days?	Mon 9/19/11	Fri 10/28/11
Preliminary Pro Engineer Design	21 days?	Mon 10/3/11	Fri 10/28/11
Concept Generation Report	1 day?	Fri 10/28/11	Fri 10/28/11
Concept Selection	**31 days?**	**Mon 10/24/11**	**Mon 12/5/11**
Calculations	25 days?	Tue 11/1/11	Mon 12/5/11
Pro-Engineer Drawing	25 days?	Tue 11/1/11	Mon 12/5/11
FEA analysis	11 days?	Mon 11/21/11	Mon 12/5/11
Material Selection	16 days?	Mon 10/24/11	Mon 11/14/11
Price Estimation	11 days?	Mon 10/31/11	Mon 11/14/11
Concept Selection Report	1 day?	Mon 11/7/11	Mon 11/7/11
Final Presentaion Senior Design I	**138 days?**	**Fri 10/21/11**	**Mon 4/30/12**
Design Changes	11 days?	Mon 11/21/11	Mon 12/5/11
Final Pro-E design	11 days?	Mon 11/21/11	Mon 12/5/11
Final Cost	38 days?	Fri 10/21/11	Thu 12/15/11
Final Design	4 days	Mon 12/5/11	Thu 12/8/11
Ordering of Parts	102 days	Mon 12/12/11	Mon 4/30/12
Final Draft Report	6 days?	Mon 12/5/11	Mon 12/12/11
Senior Design II	**103 days?**	**Thu 12/29/11**	**Fri 5/18/12**
Assembly of Prototype	**103 days?**	**Thu 12/29/11**	**Fri 5/18/12**
Testing	10 days	Mon 5/7/12	Fri 5/18/12
Final Changes	91 days?	Mon 1/9/12	Fri 5/11/12
Final Presentaion	91 days?	Thu 12/29/11	Wed 5/2/12
Final Product	91 days	Mon 1/9/12	Fri 5/11/12
Final Report	7 days?	Mon 4/23/12	Tue 5/1/12

Figure 3: This is the Gantt chart. This is the proposed timeline for our project.

Need Statement

Delta Heat LLC contacted the University of Texas Pan American for design and prototyping of a wire winding machine which will create different resistance wires based on the need of the company. The resistive wire used in the current and future line of products is currently limiting both the expansion and revenues of the company due to fact that each product line requires different resistance wire. For each product line, the company is required to order a different type of resistive wire with an average cost of $70 per pound. Flexible rubber heaters require having the wire wound around a fiberglass core which typically costs an extra 10% to 15%. Production of the flexible resistive wire by the wire winding machine will effectively save the company 10% to 15% per pound.

Problem Definition

Goals

Our goal in our senior design project is to design a wire-winding machine that will allow constant resistance wire production. The machine should be able to run smoothly at all time and highly precise. The machine should be easily operated by an external source such as a computer. It should be highly reliable and easy to maintain.

Objectives

Our wire-winding machine should be able to wind 1 to 3 resistance wires around a fiber class core. It should be capable of using different type of wire materials and measure the resistance of the wire very accurate. We must be able to control the motor velocities and control the amount of loops around the fiberglass core. The machine will use *LabView* to operate the machine and must have an alarm if a wire is broken during production. The machine's parts should be easily obtained from the market. [1,2,3,4,5]

Figure 3: *In this figure we show the different material and spools the machine will handle to create the resistance wire.*

Constraints

Some constraints in our senior design project is creating accurate resistance wires with a + or – 3 % resistance tolerance. When winding from to 2 to 3 wires we must make sure the wires stay parallel to each other as they wind. Constant spacing and maintain proper wire tension is important so that our machine can produce quality product. Our machine design must also be compatible with in-market parts. [1,2]

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To meet our customers' requirements our machine needs to be able to create resistance wires for variable resistances. [1,2]

Figure 4: *Example of the Heating Resistance Wire. There are different materials used for each and have different resistances due to the loops of wire around the core. Also notice the double wire wind on the right*

Wants

Some of the wants that are going to be enforced in our machine will be a measuring system that will display the resistance for current wire being produced. Also, an alarm will be integrated to inform the user that parameters stay with the norms.[1]

Competitive/Similar Products

Companies that manufacture these flexible heating cable, have kept their manufacturing machinery secret. There is no information on how these machines work and operate by the same reason. Some companies that have the capabilities to make these wires are Omega.com, Kanthal, and Jelliff.[3,4,5]

Figure 5: *Competition: These are other companies that manufacture the Heating resistance wire.*

QFD

In the Following Table, we show the Quality Function Deployment Chart. In this chart, we show the relationship between the Customer Requirements and the Functional Requirements of our product. For example: The Low Cost Replacement Parts has a very strong relationship with the number of motors since it must be cheap; Number of parts being the same reason and size. This also has a medium relationship with the weight since we must pick the cheapest and most available parts from the market for the product. And the ease of use is not relevant at all, since they are only for replacement. In our final design, the team has tried to comply these requirements.

Row #	Weight Chart	Relative Weight	Customer Importance	Maximum Relationship	Functional Requirements / Customer Requirements (Explicit and Implicit)	Two Motors	# of Parts	Size	Weight	Ease of Use
1		19%	10	9	Must Wind 1-3 Spools onto Fiberglass Core	●	▽	▽	▽	○
2		4%	2	3	Alarm	▽	○	▽	▽	○
3		13%	7	9	Speed Control for Resistance Wires	●	●	○	○	○
4		13%	7	3	Digital Device that reads Wire Resistance	▽	○	▽	▽	○
5		13%	7	9	Speed Control For Fiberglass core	●	○	○	○	○
6		10%	5	9	Low Cost Replacement Parts	●	●	●	○	▽
7		15%	8	9	Operability	○	▽	▽	▽	●
8		12%	6	9	Easy to Repair	○	●	○	○	▽

Figure 6: QFD Chart. This is the Quality Function Deployment chart that this project will base its design.

IV. Conceptual Design

Methodology

Our Senior Design group began generating concepts by asking our customer on the name of the company that they purchased their resistance wires from. Jelliff is the name of the company that Delta Heat LLC purchases their resistance wires from. Delta Heat LLC needs their resistance wires to be wound around a fiberglass core which adds an extra cost to the wires. Our customer also had to buy their resistance wires through bulk so this led to overstock of product at their manufacturing facility. This led our customer to approach us to design a wire winding machine so that they can produce their own resistance wire.

We began by researching companies that created these resistance wires. Omega.com, Jeliff, Springfield Wire, and Kanthal are some of these companies. After researching these companies, our senior design team could not find any information on the machines that create the wires. The companies would not post pictures or any other information on these machines. Our team found out that these machines are in-house trade secrets and companies do not release information on the wire winding machines. Due to this fact, our team began researching other similar products and similar methods for winding products.

One great example our senior design group found was the winding of rope. Rope is composed of flexible fibers which are than braided together.

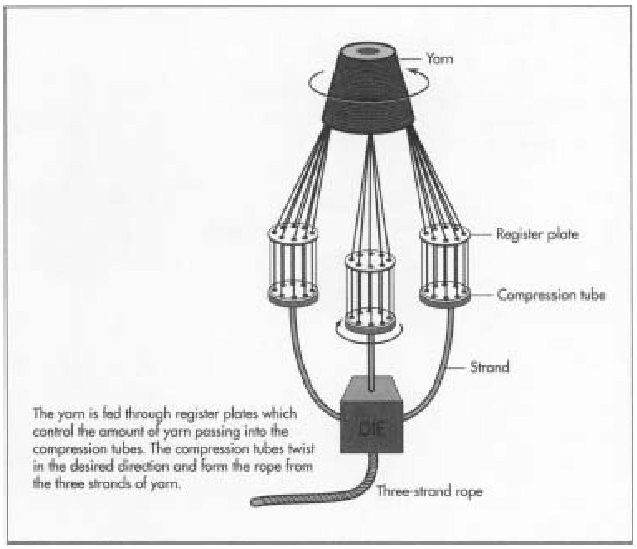


Figure 7: *This concept shows rope winding.*
http://www.madehow.com/Volume-2/Rope.html

The flexible wires are first formed into yarn and then twisted and braided into a rope. As can be seen in the figure above, the yarn is fed through these plates that are spinning and are than fed though a die where they are twisted and formed into a three-strand rope.

Another perfect example are guitar strings. Guitar strings are made up of a steel wire that is than coated with bronze or nickel. The reason for this is to create the perfect vibrations for the tone of music. As can be seen below in the two figures, the guitar strings are winded around using a hook and a spinning action.

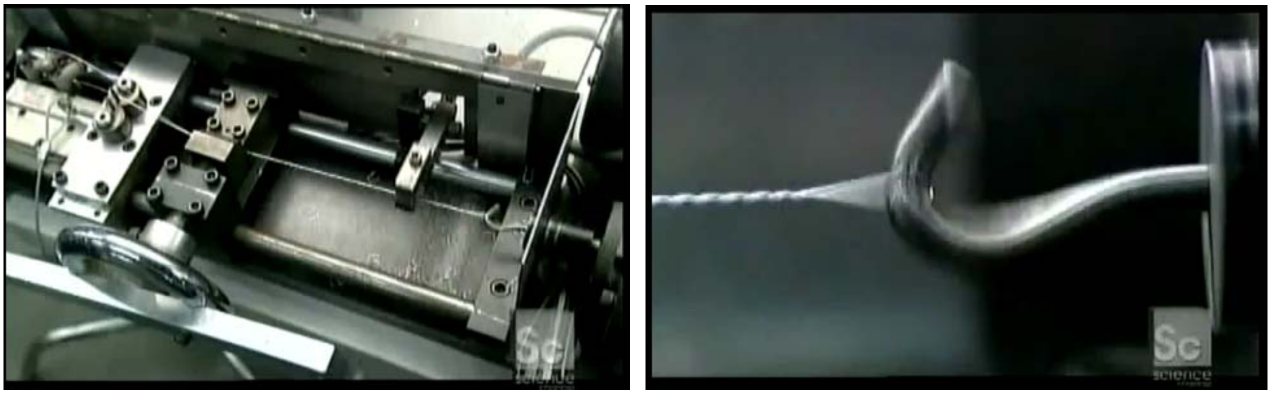


Figure 8: *In this figure we show another of the concepts we tool for our project. This concept is for guitar strings.* *www.*howitsmade.com/guitarstrings

With the help of these examples, we were able to generate ideas for our wire winding machine. We used the rope and guitar strings as examples for formulating and design the best possible wire winding machine possible.

System Concept

The problem formulation aspects of this project allowed the team to get an insight into what was needed and a clear view of this project's objectives. This in itself allowed for a general list of component requirements for the machine to be designed. The team then took this list and began drafting possible configurations for the machine which would satisfy all the requirements. This design, although preliminary, allowed for further analysis and development. Below is a list of some design criteria that the machine had to meet:

- Wind one to three spools onto a fiberglass core
- Measure Resistance of the wire produced
- Be able to manufacture different resistance wire based on input
- Have the final product wind onto a spool
- Must have a simple user interface
- Must be highly precise and easy to maintain

Careful observation of these requirements allowed the team to develop three possible designs. However, there is a wide range of configurations which meet this requirement. In order to optimize the design to meet the objectives at the minimum cost possible without sacrificing quality, it was necessary to look at a list of main components that a general configuration of the wire winding machine would require. Each component listed would not necessarily be used in the final design but rather provide an acceptable starting point for application of reverse engineering methodology. The general list of major components includes:

- Table
- Motors
- Drive Train components
- Resistance Monitoring Devices
- Housing
- Winding Component/s

The above listed was reverse engineered and the main functions for the wire winding machine was then derived by using a function decomposition methodology provided by Dr. Robert Freeman on his website: mece.utpa.edu/~rafree. While this list was later modified as the project progressed it was necessary to begin the process for component selection as well as a more accurate wire winding machine concept selection. The list is as follows:

- Product Development
- Power Input
- Power Transmission
- Quality Assurance
- Product Development
- Environmental Protection

The concept generation for the wire winding machine called for reverse engineering in order to derive the functional decomposition of this project. At this point, it was possible to move forward into the researching possible components for each of the main functions listed above. The team then began selecting potential components for each function by listing each and doing a brief advantage/disadvantage analysis in order to narrow the list of viable component options for the wire winding machine.

Product Development

Product development is a very vital function in the design of the Wire Winder Machine. For the sub function, the senior design group has determined that wire winding is a very important aspect for the development of our wires.

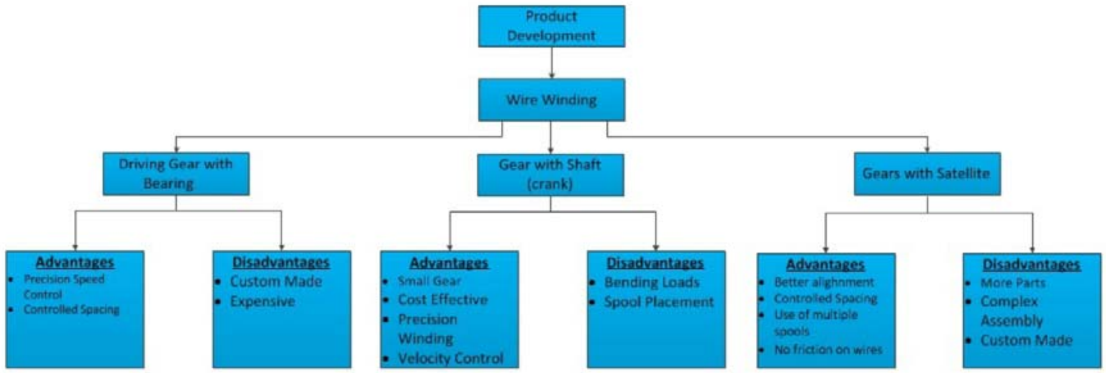


Figure 9: *Product Development Diagram*

The diagram above, outlines the advantages and disadvantages of our three methods for wire winding that could be used for developing our resistance wires. The details of the analysis that resulted in the diagram are explained below.

Initial Concept Design #1: Gear with Shaft

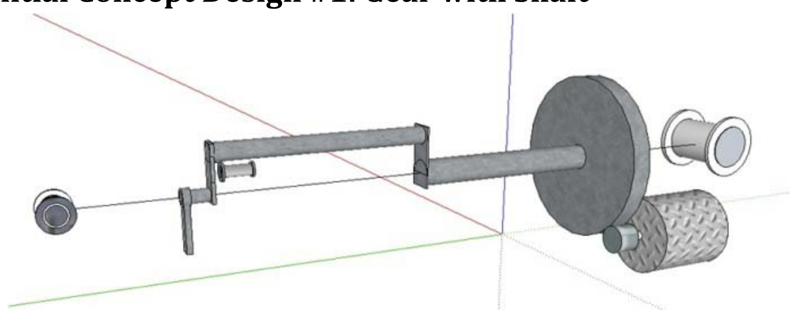


Figure 10: *Initial Concept Design #1: Gear with Shaft*

The way of this design works is the following: the Fiber glass Core in the back, passes the driven gear and the winder tube to a final spool where the Resistance wire is collected. The main Gear is driven by an AC motor in which the velocity can be controlled. Attached to the main gear is a frame made out of tubes. This frame has the wire spool on the top part of the frame. As the gear rotates, the external part of the frame rotates around the core, and this movement will make the wire to wind on to the fiber glass core.

Advantages/Disadvantages

Figure 10 depicts a system that can result in a positive reaction for our problem. This has a couple of advantages that make this system very efficient. This system has a capability of being very precise in winding spacing and placement while maintaining very cost effective. The main disadvantage for this design is that it may introduce bending loads to the shaft making it very difficult to control and might need maintenance. Having 3 wire spools wounded around the core in parallel, and in symmetry is almost impossible to achieve.

Initial Concept Design #2: Driving Gear with Bearing

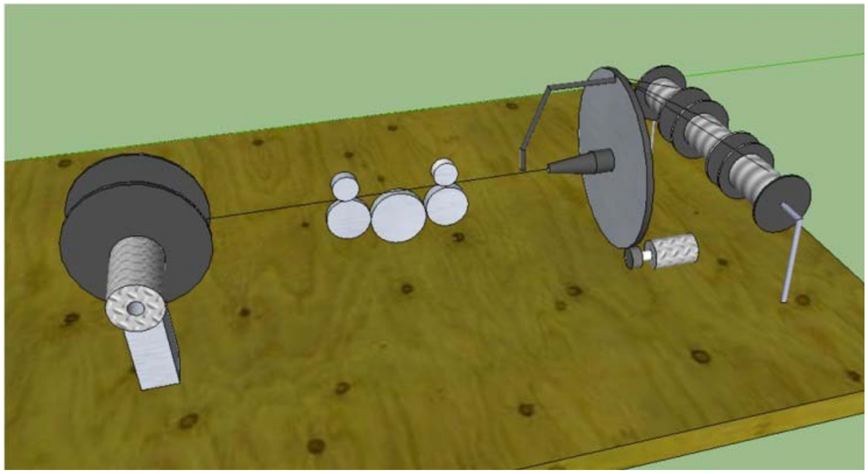


Figure 11: *Initial Concept Design #2: Gear with Bearing*

In this design, the core is attached to the back of the gear and the wires are further back of the main gear. As the gear rotates, the core is fed in the middle of the gear and is pulled by wire rollers. The main gear also has a tube attached to a bearing n which the wires pass through it. This tube helps for the wire to be driven or guide them to a certain angle to the core. Then as the main gear is in rotation, the wires are being winded in the fiberglass core. After the winding, the resistance wire is being fed to a spool so the customer can take it.

Advantages and Disadvantages

Using a driving gear with a bearing (Fig 55) will allow for precise control of the winding of the wires around the fiberglass core. This is a very important feature because the precision requirement set by Delta Heat Llc could be met. Gears are highly precise and the motor will be able to control it with ease. Using a bearing also has an advantage because by doing so, the distance between the wires to be wound can be manipulated without introducing twist to the wires.

The disadvantages of implementing this design for the wire winding process is that the gear size necessary was approximated to be close to 12". When looking at prices in the current market, the size requires the gear to be custom made and after several inquiries the average cost of the gear was $4000-$5000. This high cost really is a huge setback not only because of the budget, but also because if it gets damaged it could be hard to find a replacement since its custom made. The bearing to be used for this also brings up a concern due to the fact that it has to fit inside the driving gear, and the inside of the bearing must be custom made. This could significantly raise the cost of the initial design which just from the gear will be significantly high.

Initial Concept Design #3: Satellite

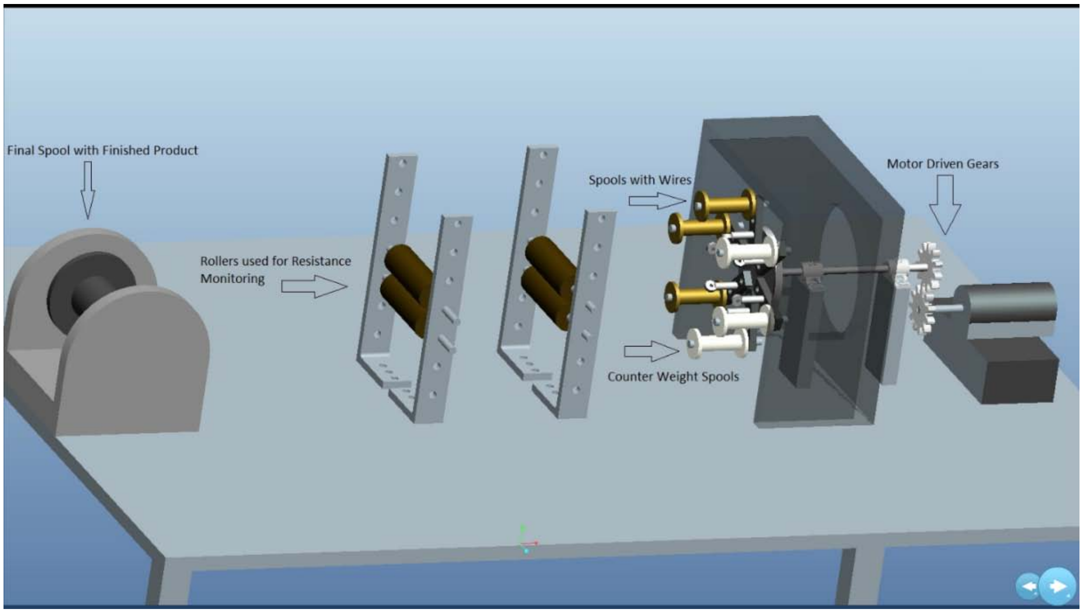


Figure 12: *Initial Concept Design #3. Gear and Satellite Spools.*

In this design, the fiberglass is placed behind the housing and motor, and it will pass through the. During this time, it will pass through a mounting plate with spools, in which they rotate around the core and the wire is being winded around it. After the winding the product will pass through 2 rollers, in which are coated with rhodium plating, to measure the resistance per foot. After that the product is being spooled in the final spool.

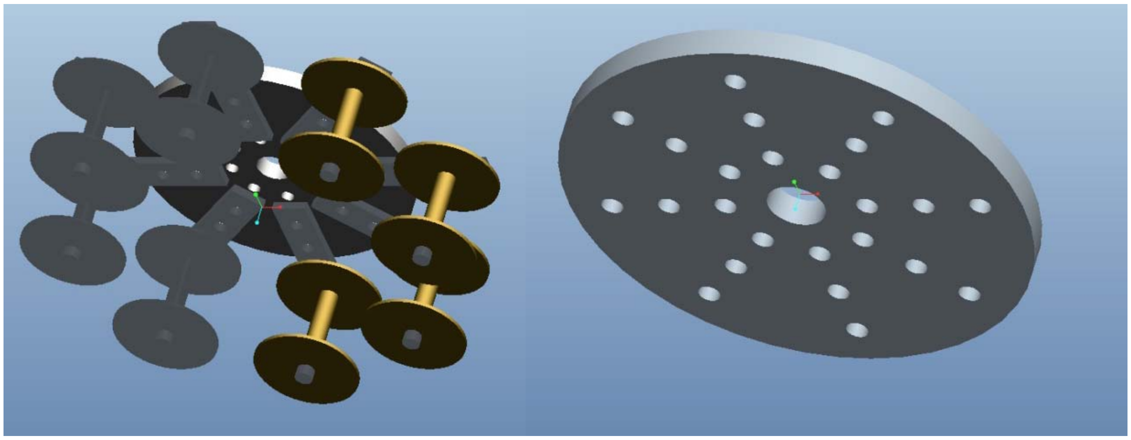


Figure 12a: Mounting Plate: Picture on the right is the mounting plate without the spools, and the one of the left is with spools.

The mounting plate is one of the most important parts of the machine. The mounting plate's purpose in the wire winder machine is to hold up to 4 spools of resistance wire. As it rotates, these wires will wind around the fiberglass core, creating then the flexible resistance wire. The material that will be used f is aluminum. This material was chosen because there will be constant addition and/or removal of spools and the tightening and loosening of the bolts may wear any other material. Also the aluminum is lighter than other metals, and this helps to reduce the angular momentum and torque required to stop and or start the machine.

The mounting plate will be connected to a driven gear with a tubular shaft (where the Fiberglass core will pass). The angular velocity the mounting plate and driven gear is 460 rpm. This speed was obtained from the drawing speed of the fiber glass core (7.5 in/min) and how many winds we require per inch (60 winds per inch max, 6 winds per inch min). This velocity will remain constant at all times.

The advantage of the mounting plate design is that the user will be able to have 2 different spool placements. Listed below are the advantages and disadvantages of each of them:

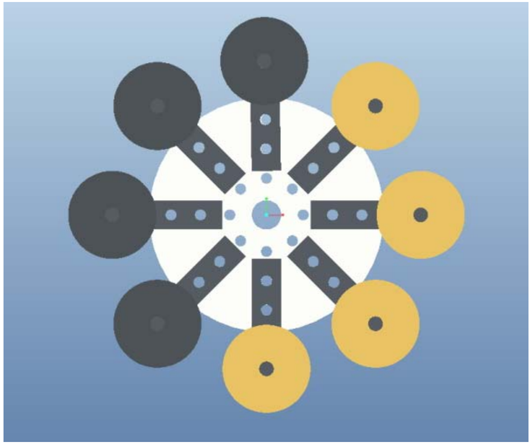


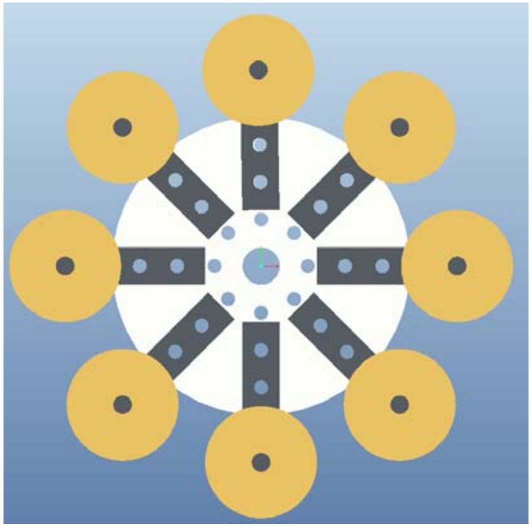
Figure 12b: Spools with Counter weight

Spools with counter weight:
Advantages

- Lines Easier to be parallel.

Disadvantages

- Maximum number of spools: 4
- May cause vibration



Opposite Spools
Advantages

- May place up to 8 spools
- May not cause vibration
- More uniform rotation

Disadvantages

- Too many wires can cause intertwinement or a “cable” effect.
- Harder to have parallel wire

Figure 12c: Opposite spools

With this design of flywheel we can play between the “Spools with counter weight” and the “Opposite Spools” to determine the best option to obtain a better winding.

Design Criteria Weighting Matrix: 0 - 1 Scale											
Wire Winding	**# Spools**	**Alignment**	**Quality**	**Control**	**Precision**	**Service**	**# Parts**	**Durability**	**Cost**	**Score= Row Sum**	**Weight**
# of Spools		1	0	1	0	1	1	1	1	6	0.166666667
Alginment	0		0	1	0	1	1	1	1	5	0.138888889
Quality	1	1		1	1	1	1	1	1	8	0.222222222
Control	0	0	0		0	1	1	1	1	4	0.111111111
Precision	1	1	0	1		1	1	1	1	7	0.194444444
Service	0	0	0	0	0		1	0	1	2	0.055555556
# Parts	0	0	0	0	0	0		0	1	1	0.027777778
Durability	0	0	0	0	0	1	1		1	3	0.083333333
Cost	0	0	0	0	0	0	0	0		0	0
Total Number of Comparisons = Sum Scores										36	1

The above matrix shows the design criteria weighing matrix for the wire winding mechanism. After several weeks of working on different designs we have come to the conclusion of the three different wire winding mechanisms. We were able to determine 9 different design criteria’s. We felt number of spools, alignment, quality, control, precision, service, number of parts, durability, and cost were the most important criteria’s to our wire winding mechanism. As can be seen on our matrix above, precision, number and spools, quality, and alignment had the highest weight. We than compared each of the designs which were gear design, satellite design, and crank design to each of the design criteria’s.

Design Variant Ranking with Respect to # of Spools					
# of Spools	Gear	Satellite	Crank	Score = Row Sum	Norm. Score
Gear		0	1	1	0.333333333
Satellite	1		1	2	0.666666667
Crank	0	0		0	0
				3	1

The above matrix shows our designs in respect to the number of spools. It can be seen from our matrix that the satellite design had the best score in respect to the number of spools. We have determined that we will be able to add more number of spools in our design if you use a satellite design to our machine. Our design must be able to wind 1-3 wires around a fiberglass core.

Design Variant Ranking with Respect to Alignment					
Alignment	Gear	Satellite	Crank	Score = Row Sum	Norm. Score
Gear		0	1	1	0.333333333
Satellite	1		1	2	0.666666667
Crank	0	0		0	0
				3	1

The above matrix shows our designs in respect to the alignment. It can be seen from our matrix that the satellite design had the best score in respect to the alignment. The crank had a score of 0 while the satellite had the highest score with 0.667. We have determined that the satellite design will have the best alignment in respect to wire winding.

Design Variant Ranking with Respect to Quality					
Quality	Gear	Satellite	Crank	Score = Row Sum	Norm. Score
Gear		0	0	0	0
Satellite	1		1	2	0.666666667
Crank	1	0		1	0.333333333
				3	1

The above matrix shows our designs in respect to quality. It can be seen from our matrix that the satellite design had the best score in respect to the alignment. The gear design got a 0 score due to the fact that the wires that go through the bearing in our design are going to wear and are going to affect the resistance of the wires due to the friction on the wires. The satellite design was our best candidate in respect to quality due to the fact that the wire will be wounded with little friction on the wires.

Design Variant Ranking with Respect to Control					
Control	Gear	Satellite	Crank	Score = Row Sum	Norm. Score
Gear		1	1	2	0.666666667
Satellite	0		1	1	0.333333333
Crank	0	0		0	0
				3	1

The above matrix shows our design in respect to control. It can be seen from our matrix that the gear design had the best score in respect to control. The gear design provides the best control due precise control of the gear. We felt that our crank design had the worst score in respect to control due to the weight of the spools on the crank not providing a good center of balance when the crank is spinning around the fiberglass core.

Design Variant Ranking with Respect to Precision					
Precision	Gear	Satelite	Crank	Score = Row Sum	Norm. Score
Gear		0	0	0	0
Satellite	1		1	2	0.666666667
Crank	1	0		1	0.333333333
				3	1

The above matrix shows our design in respect to precision. It can be seen from our matrix that the satellite design had the best score in respect to precision. The satellite design has the best precision die to the placements of the spools on the flywheel and the precision of the winding around the fiberglass core.

Design Variant Ranking with Respect to Service					
	Gear	Satellite	Crank	Score = Row Sum	Norm. Score
Gear		0	1	1	0.333333333
Satellite	1		1	2	0.666666667
Crank	0	0		0	0
				3	1

The above matrix shows our design in respect to service. It can be seen from the matrix that the satellite had the highest score in respect to service. The crank design would require a lot of service and it would take a while to change the spools. We feel that the satellite design will be the best design in respect to service due to the ease of changing of spools.

Design Variant Ranking with Respect to # Parts					
# of Parts	Gear	Satellite	Crank	Score = Row Sum	Norm. Score
Gear		1	1	2	0.666666667
Satellite	0		0	0	0
Crank	0	1		1	0.333333333
				3	1

The above matrix shows our design in respect to the number of parts. It can be seen from the matrix that the gear design will be the best of choice for our machine. Due to the fact that the gear design will have the least number of parts, it had the best score.

Design Variant Ranking with Respect to Durability					
Durability	Gear	Satellite	Crank	Score = Row Sum	Norm. Score
Gear		0	1	1	0.333333333
Satellite	1		1	2	0.666666667
Crank	0	0		0	0
				3	1

The above matrix shows our design in respect to the durability. Due to the design, the satellite gear had the best score in respect to the durability. Due to the bending loads in the crank and the life of the gears in the gear design, it was concluded that satellite would be the best design to be durable.

Design Variant Ranking with Respect to Cost					
Cost	Gear	Satellite	Crank	Score = Row Sum	Norm. Score
Gear		1	0	1	0.333333333
Satellite	0		0	0	0
Crank	1	1		2	0.666666667
				3	1

The above matrix shows our design in respect to the cost. Due the crank being very cost efficient, it had the highest score. The satellite design and the gear design had the highest cost.

Selection Matrix										
	# Spools	Alignment	Quality	Control	Precision	Service	# Parts	Durability	Cost	Score
Gear	0.33	0.33	0.00	0.67	0.00	0.33	0.67	0.33	0.33	
	0.06	0.05	0.00	0.07	0.00	0.02	0.02	0.03	0.00	0.24
Satellite	0.67	0.67	0.67	0.33	0.67	0.67	0.00	0.67	0.00	
	0.11	0.09	0.15	0.04	0.13	0.04	0.00	0.06	0.00	0.61
Crank	0.00	0.00	0.33	0.00	0.33	0.00	0.33	0.00	0.67	
	0.00	0.00	0.07	0.00	0.06	0.00	0.01	0.00	0.00	0.15
										1
Decision										

The above matrix shows the selection matrix where we find out from our previous matrices which design for the wire winding mechanism is best. After comparing all of our design criteria's to our different wire wind mechanisms it can be seen that satellite design had the highest score which means that respect to our criteria it would be our best choice for our machine. It beat out the other wire winding methods by many points. We believe that the satellite design will provide everything we need for our wire winding machine.

Power Input

For power input the team have a couple of options to choose from. There is a great availability form AC to DC motors, but there are advantages and disadvantages to each product.

DC Motors

For the option of DC motors the advantages are that we have a great selection to choose form and can handle very fast RPMs, this can be very thanks to the speed control using a gearbox. Even though we have these advantages the disadvantages are vital due to the precision requirements of our machine. The disadvantages include extensive maintenance due to brush life deterioration, but the most critical disadvantage is that the relationship between torque and RPM are inversely related.

Figure 13: *DC Motor. www.instructables.com*

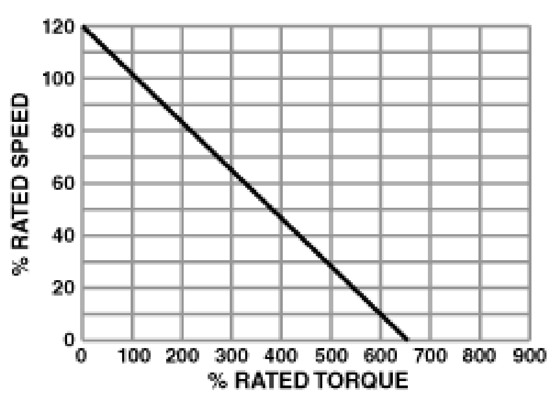


Figure 14: *DC Motor speed vs. torque relationship. www. Globalspec.com*

AC Motors

AC Motors are very reliable and very accurate if used appropriately. Some advantages that AC motors have are that they are very costly effective and needs minimum amount of maintenance due to a change of parts within the motor. Last, but very important, is that AC motors maintain their torque all thru their RPM range. Some disadvantages are that AC motor velocities are a bit more complex when compared to DC motors, but overcoming this obstacle can be a matter of buying a precise and accurate Variable Frequency Drive.

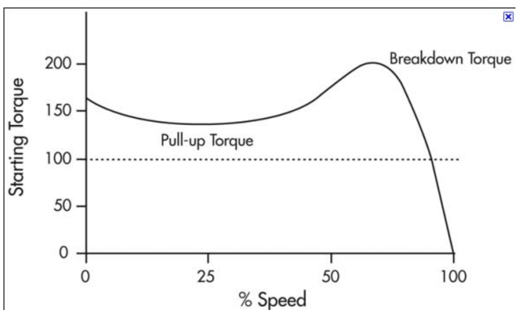


Figure 16: *Torque vs. %Speed for AC motor. www.globalspec.com*

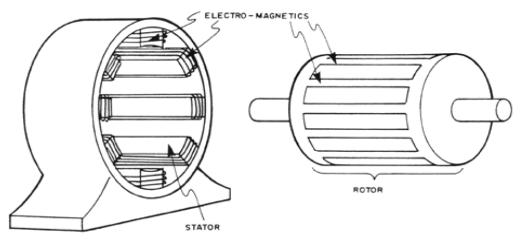


Figure 15: ***A****C Motor. www.globalspec.com*

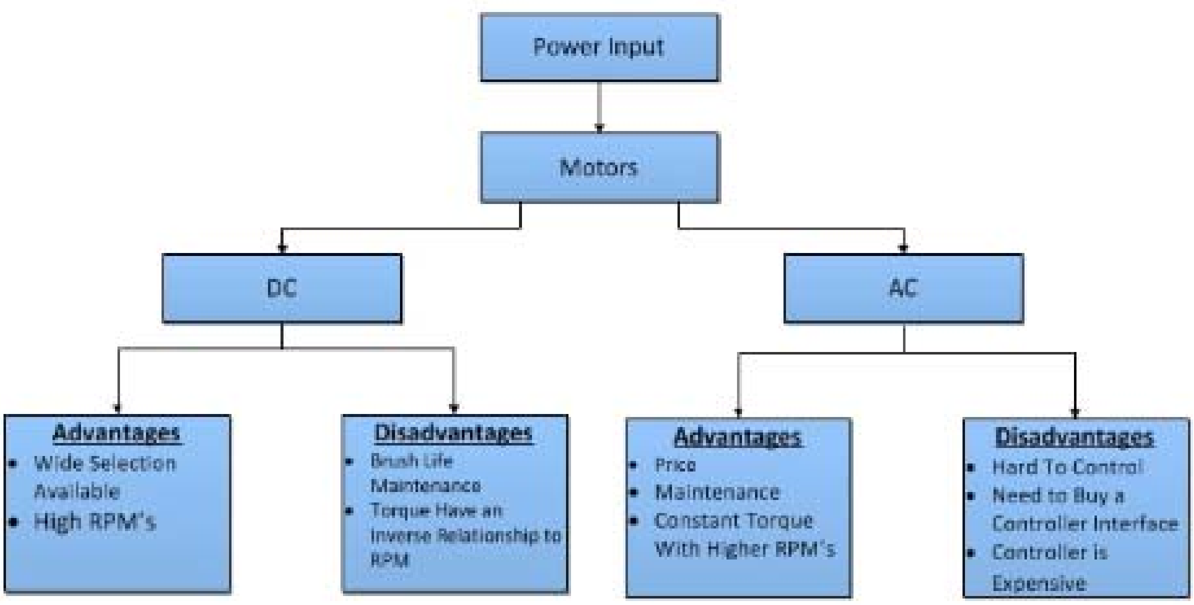


Figure 17: *Power Input Diagram*

Power input is the major factor to control velocities and precision. The customer requirements were to have an AC motor for the input of power. There are three different types of motors. Because of the application two of these options are discarded. Servo motors are used to control angular position in a clockwise and counter clockwise motion using a PWM. The objective is to control speed while maintaining constant torque. Servo motors will not satisfy the objective requirements. Stepper motors are mainly to control direction and position of the driven. This motor is an excellent prospect for the application, the only deficiency is its torque curve and rpm relationship; which are inversely proportional. The best candidates are inverter motors. This type of motors will keep constant torque for all its RPM range. Also, the inverter motor has a variety of controllers that are compatible to control its speed, while maintaining precision.

Power Transmission

This section will deal with the transmission of power to the wire winding machine. There are many options but the most simple and accurate options are belts, chains, and gears. These different options can be helpful and efficient on delivering the needed torque, speed, or accelerations to the system.

Figure 18: *Belts. www.meyle.de*

Belts:

For belts the advantages are that they absorb vibrations due to the materials that they are made of. This also makes them very economical. However, after long periods of operation, the belts lose efficiency. Also, a rise in the temperature affects its life.

Chains are a very effective in delivering power. Thanks to the usage of links, sizes of chains are very easy to find, making them price proficient. The problem with chains is that vibrations that are inducted to the system may accelerate and decelerate the shaft being driven; this is a crucial negative effect that we want to avoid. [10,11]

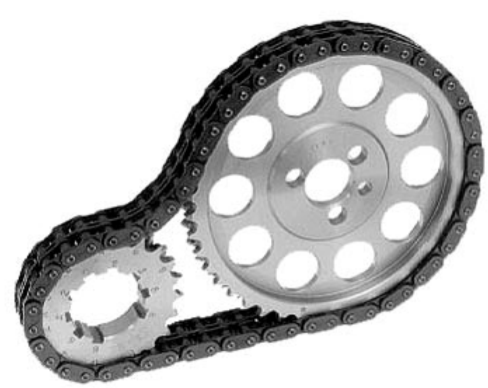


Figure 19: *Chain and Sprocket. www.profromance.com*

Gears:

Gears are an excellent way of transmitting power. There are many types of gears, but the useful types for the wire winder machine are spur gears. Spur gears have a great contact area that does not allow any slip, this allows for constant speeds to be easily achieved. The negative effects that gears contribute to the solution are the amount of inertia a gear contain. Mass of a gear is a huge factor that can result on the impact of motor selections and casing selection, this could lead directly to a negative impact to the budget.[14]

Figure 20: *Helical and Spur Gears. http://www.emerson-ept.com/*

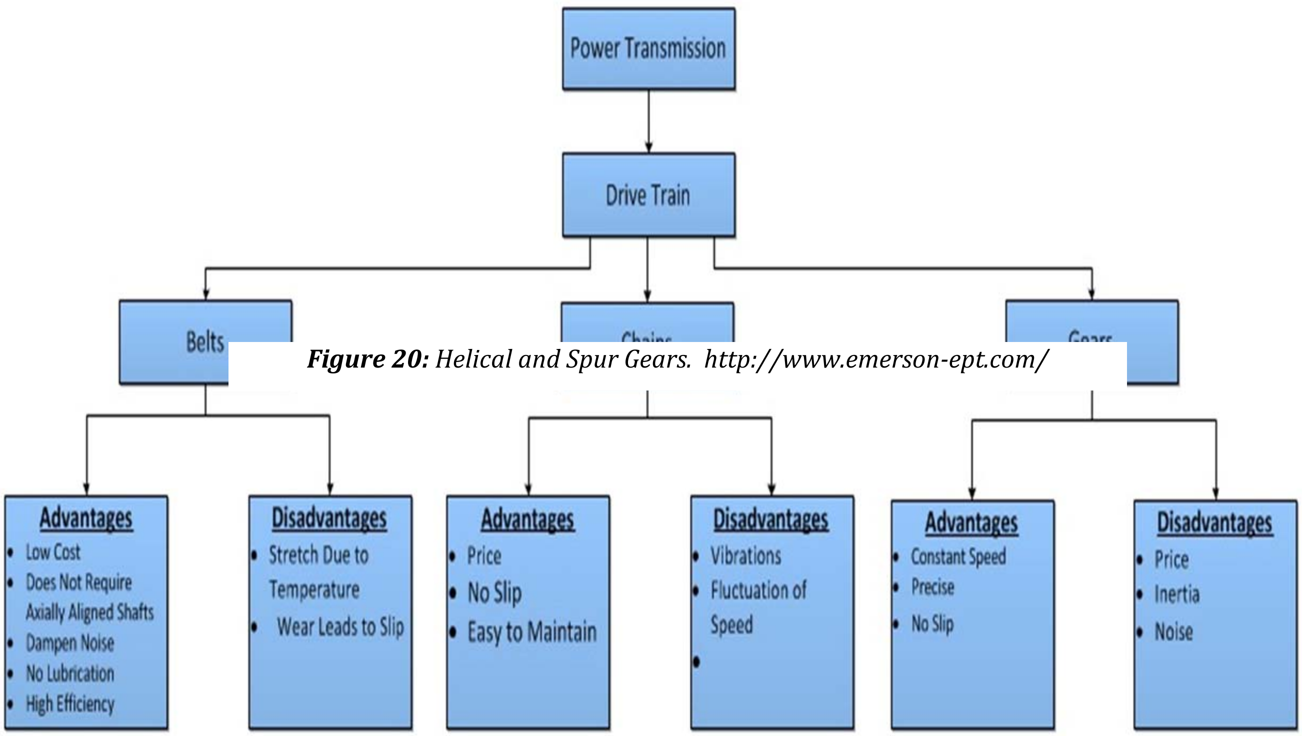


Figure 21: *Power Transmission Diagram*

The first objective for this project is to be precise and efficient. Cost is not a major factor due to an extensive budget. So the outcome for this weighting matrix was that maintenance and precision being equally important. This design criterion was based on cost, maintenance, and precision.

Design Criteria Weighting Matrix: 0 - 1 Scale					
	Cost	Maintenance	Precision	Score = Row Sum	Weight
Cost		0	0	0	0
Maintenance	1		0	1	0.5
Precision	0	1		1	0.5
				2	1

For the first matrix analyzing gears, chains, and belts are very important. As far as cost goes, chains is the best cost effective mechanism we can utilize, second being belts, and third gears.

Design Variant Ranking with respect to Cost					
Cost	Gears	Chains	Belts	Score = Row Sum	Norm. Score
Gears		0	0	0	0.00
Chains	1		1	2	0.67
Belts	1	0		1	0.33
				3	1.00

Now comparing the same components to maintenance. This yields that gears are really good at being maintenance efficient. Chains tend to wear the sprockets and lubrications is very critical. Belts come in 2nd , the reasoning is that belts are good until they start wearing, but do not need any lubrication.

Design Variant Ranking with respect to Maintenance: 0 - 1 Scale					
DC4 Maintenance	Gears	Chains	Belts	Score = Row Sum	Norm. Score
Gears		1	1	2	0.67
Chains	0		0	0	0.00
Belts	0	1		1	0.33
				3	1.00

This matrix shows components versus precision. Precision playing a big factor in this design criteria as shown before. For over all that can be seen that gears are the most precise component in this list. Chains fluctuate speed due to the chain vibrations; this is a big disadvantage affecting directly the precision of our machine. Belts were a good option but wear is very critical and impacts speeds directly.

Design Variant Ranking with respect to DC5 (Precision): 0 - 1 Scale					
DC5 Precision	Gears	Chains	Belts	Score = Row Sum	Norm. Score
Gears		1	1	2	0.67
Chains	0		0	0	0.00
Belts	0	1		1	0.33
				3	1.00

In conclusion, gears are suitable for the machine application. The matrix shows the winning component with a .67

Selection Matrix				
	Cost	Maintance	Precision	Score
Gears	0	0.67	0.67	
	0	0.335	0.335	0.67
Chains	0.67	0	0	
	0	0	0	0
Belts	0.33	0.33	0.33	
	0	0.165	0.165	0.33
Decision				**High Score Wins**

Quality Assurance

Delta Heat Llc, requested that the wire winding machine be highly precise when producing resistance wire. The tolerance allowed for the final product is a resistance within +/- 3% of the resistance input by the user. This requirement is due to the fact that the heating products that will be manufactured using the wire produced by the machine are very precisely manufactured and have a resistance tolerance of +/-5%.

In order to ensure the production of highly accurate resistance wire, the team will implement a real time resistance measurement system as one of the major components of the wire winding machine. The resistance monitoring will require a device must have output capabilities in order to set off an alarm system which will alert the user of resistive readings outside the set tolerance. For this purpose, two easily acquirable devices can be used: oscilloscopes and multi-meters. The use of an oscilloscope as a resistive measurement component was analyzed first and use of a multi-meter subsequently.

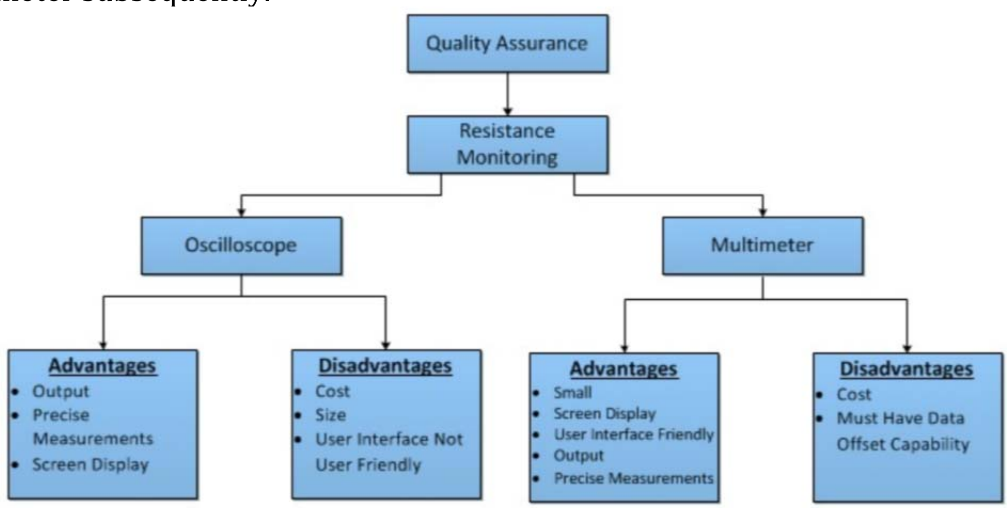


Figure 22: *Quality Assurance Tree Diagram*

The above tree diagram outlines the advantages and disadvantages of both multi-meters and oscilloscopes when being considered as resistance monitoring components. The details of the analysis that resulted in the diagram are listed below.

Using an Oscilloscope for Resistance Monitoring

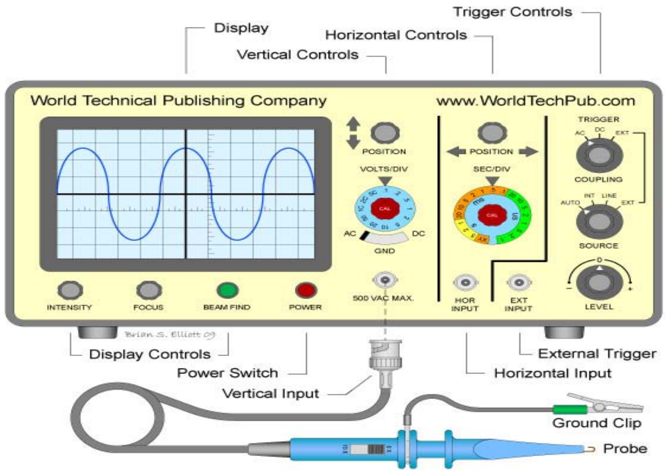


Figure 23: *Front view of an Oscilloscope.*www.worldtechpub.com

Oscilloscopes can be used for a wide range of applications. This includes observations of electrical signals, wave shape, rise time, period and pulse width. Oscilloscopes can also accurately measure voltage, current and resistance. The only application to be analyzed, however, will be resistance measurement for implementation as a resistance monitoring component in the wire winding machine.

A brief overview of the functions of the oscilloscope demonstrates that it can address one main function of the wire winding machine which is quality assurance by resistance monitoring. However, in order to for it to be considered as a potential component the advantages and disadvantages of its use had to be analyzed and weighed.

Advantages and Disadvantages

Oscilloscopes have high precision readings when taking measurements. The resolution and accuracy of the oscilloscope will determine its precision. The table below demonstrates the different resolutions available and the high precision associated with each resolution.

Oscilloscope resolution	Number of steps	Smallest change that can be detected	Ideal dynamic range
6 bits	64	1.6% (16,000 ppm)	36 dB
8 bits	256	0.39% (4,000 ppm)	48 dB
12 bits	4,096	0.024% (244 ppm)	72 dB
16 bits	65,536	0.0015% (15 ppm)	96 dB

Figure 24: *Types of Oscilloscopes and Resolution.http://www.picotech.com/applications/resolution.*

For the purpose of this project, it is also necessary to note that oscilloscopes have an output capability which is a necessary function. Oscilloscopes also encompass lcd displays which display all the measurement readings it is generating.

The setbacks of using oscilloscopes are cost, size, and UI. The 8 bit oscilloscope resolution is the most common resolution for oscilloscopes and it is highly precise. The average cost of an 8 bit oscilloscope ranges from roughly $400 to $1200 depending on brand, sampling rate, and bandwidth as well as other factors. The size of an oscilloscope is also to be considered a disadvantage because while highly precise, oscilloscopes are typically 2'x2'x1'. This is considerably large considering that the wire winding machine with all the components is to be 6' in length. However, user interface is the most important setback because Delta Heat Llc has requested a simple user interface for the machine which will require little or no training. This becomes an issue because oscilloscopes are very complex equipment which requires extensive training for the user before they can be used.

Using a Multi-meter for Resistance Monitoring

Figure 25: *Multi-meter.http://www.fluke.com/fluke/uken/bench-*

A multi-meter has various measurement functions including voltage, current and resistance. While a multi-meter does not include have the same functionality of an oscilloscope, it meets the sub-functional requirement of resistance monitoring and therefore should be considered.

Advantages and Disadvantages

Multi-meters have a simple user interface which requires very little to no training. This is a big advantage which meets the simple user interface requirement for the wire winding machine requested by Delta Heat Llc. Highly precise measurements can also be observed and acquired from multi-meters. Multi-meters precisely measure data with an accuracy offset of +/-0.5%. They allow the user to monitor the measurements visually on the hardware itself on an LCD and through an output to a computer. The output capability is a big advantage because this will allow for easier data monitoring by the alarm system.

The drawback of a multi-meter is that in order to get precise resistive measurement readings it must have data offset capabilities. As with any other product, more features will lead to higher cost.

After considering the advantages and disadvantages for both oscilloscopes and multimeters, it was necessary to further analyze both resistance monitoring components in order to select the best option for our design. Selection matrices were used for this purpose beginning with outlining the main design criteria for the function and comparing each criterion against the others. This was necessary in order to determine how much weight each design criteria held. The results are displayed in the table below

.

Design Criteria Weighting Matrix: 0 - 1 Scale							
	Cost	Size	Easy User Interface	Output Capacity	Precision	Score = row Sum	Weight
Cost		1	0	0	0	1	0.1
Size	0		0	0	0	0	0
Easy User Interface	1	1		1	0	3	0.3
Output Capacity	1	1	0		0	2	0.2
Precision	1	1	1	1		4	0.4
Total number of comparisons = Sum of the Scores						10	1

The next step in this process is to start with the first design criteria and based on just this one criteria, the oscilloscope and multimeter were compared in order to obtain the normative score which is to be used in the selection matrix (the last matrix in this set) to select the best component for the design. It is important that the next matrices [size, easy user interface, output capacity and precision] follow this same logic.

Design Variant Ranking with respect to DC1(Cost): 0 - 1 Scale				
Cost	Oscilloscope	Multimeter	Score = Row Sum	Norm. Score
Oscilloscope		0	0	0.00
Multimeter	1		1	1
Col. Sum			1	1.00

Design Variant Ranking with respect to Size: 0 - 1 Scale				
Size	Oscilloscope	Multimeter	Score = Row Sum	Norm. Score
Oscilloscope		0	0	0
Multimeter	1		1	1
			1	1

Design Variant Ranking with respect to Easy user interface: 0 - 1 Scale				
Easy User Interface	Oscilloscope	Multimeter	Score = Row Sum	Norm. Score
Oscilloscope		0	0	0
Multimeter	1		1	1
			1	1

Design Variant Ranking with respect to Output capacity: 0 - 1 Scale				
Output Capacity	Oscilloscope	Multimeter	Score = Row Sum	Norm. Score
Oscilloscope		0	0	0
Multimeter	1		1	1
			1	1

Design Variant Ranking with respect to Precision: 0 - 1 Scale				
Precision	Oscilloscope	Multimeter	Score = Row Sum	Norm. Score
Oscilloscope		1	1	1
Multimeter	0		0	0
			1	1

Using the normalized scores from the matrices above, and multiplying each by the weight of the design criteria (from first matrix) the final score was drawn and the best component for the machine was determined to be the multimeter. The results are displayed in the table below.

Selection Matrix						
	Cost	Size	Easy User Interface	Output Capacity	Precision	Score
Oscilloscope	0	0	0	0	1	
	0	0	0	0	0.4	0.4
Multimeter	1	1	1	1	0	
	0.1	0	0.3	0.2	0	0.6
						1
Decision	**High Score Wins**					

Components Support

Components support was implemented in order to ensure that our machine has a stable base where all the components will place atop. Our team has decided to use a wood table

Figure 27: *Wooden Table*

Environmental Protection

Environmental protection was implemented in order to ensure that the machine runs without any strain from its environment and that it does not become a danger hazard to anybody around it. The team decided to build or buy a housing unit for the wire winding machine. Three distinct materials were considered for the housing unit. This includes aluminum, wood and steel. The general properties of each material were observed and a tree diagram was derived.

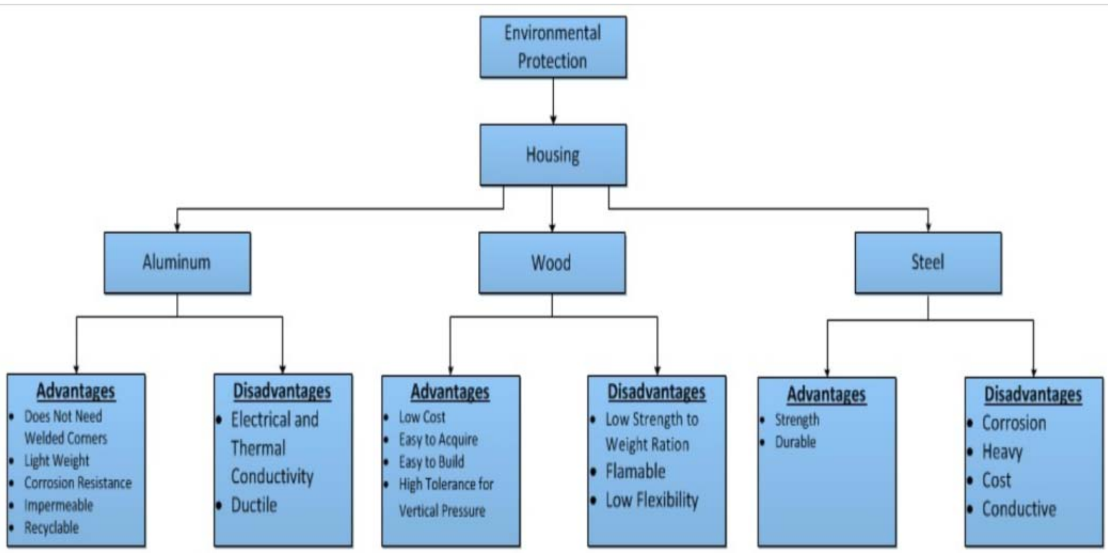


Figure 28: *Environmental Protection Tree Diagram*

The above tree diagram outlines the advantages and disadvantages of aluminum, wood and steel to be considered for use in the machine housing components. The details of the analysis that resulted in the diagram are listed below.

Using Aluminum as Primary Housing Component Material

Aluminum is one of the most common used metals for a wide range of applications. Depending on the strength, tensile and other property requirements, aluminum is alloyed or forged. Typical applications for this material include outer shells for mechanical and electrical devices ranging from cars, to computers and even foil sheets. Since aluminum is widely used for outer shells in equipment, it was considered a valid component material for the wire winding machine housing. [15,16]

Advantages and Disadvantages

Aluminum is light weight and does not require welded corners due to the fact that although strong, it also has ductile properties. It is corrosion resistant and will not wear when exposed to environmental factors such as water, dew, and dirt. Aluminum is also an impermeable material which is a property necessary to avoid outside factors influencing the wire winding machine operations.

Some disadvantages to the employment of aluminum for the machine housing is that since aluminum is a metal, it tends to have thermal and electrical conductivity which is something that the team wants to avoid as this will become a hazard to the operator. As previously mentioned, ductility can be thought of as a double edged sword while it may be good for building, it might also lead to deformations in the machine housing. [15,16]

Using Wood as Primary Housing Component Material

Wood serves many purposes in today's market and industry including its use in construction, furniture making, paper, and for fuel to cook and keep warm during cold days. The material was considered a potential component material because it can be used to build the housing for the machine which is part of the environmental protection function.[18]

Advantages and Disadvantages

Wood is easy to acquire at any hardware store and with a good procedure, it is a good material from which the housing component can be made. It is also low cost which stands out due to the fact that the total cost of the machine is to be minimized. However, the main characteristic that makes it a valid candidate is that it has high tolerance for vertical pressures. This material property will ensure that no deformation occurs to the housing component and therefore ensure the wire winding machine operates efficiently.

The disadvantages of this material are that it has a low strength to weight ratio meaning that it could possibly be heavy. It has no flexibility which might not be an issue for this application but was considered nonetheless. Finally, the main concern to draw out of using wood for the component housing is that it is flammable and will not protect the machine in case of a fire breakout. [18]

Using Steel as Primary Housing Component Material

Steel is one, if not the most common material used in everyday applications. It is an alloy of iron and carbon with carbon content being only about 0.2%. Steel production is everywhere in the 21st century and the applications for its use are limitless. For this reason, Steel was considered for an analysis to determine if it met the design criteria to be used for the housing component. [16,17]

Advantages and Disadvantages

Typical properties of steel indicate that it has a high strength. This is important to note as component strength is something of great importance when considering environmental protection. Steel is also very durable.

The disadvantages of using steel is that corrosion can occur based on influence from external factors such as water. It also tends to be heavy and its cost is constantly rising due to its many applications which results in high demand. One last thing to note is that like aluminum, it is both electrical and thermal conductive. If used for the housing, careful planning must occur in order to ensure that these last two properties do not present a hazard to the operator or anyone around the machine. [16,17]

Design Criteria Weighting Matrix(Housing): 0 - 1 Scale							
	Cost Efficient	Easy to Construct	Safety	Size	No Interference	Score = row Sum	Weight
Cost Efficient		0	0	1	0	1	0.1
Easy to Construct	1		0	1	0	2	0.2
Safety	1	1		1	1	4	0.4
Size	0	0	0		0	0	0
No Interference	1	1	0	1		3	0.3
Total number of comparisons = Sum of the Scores						10	1

The above matrix shows the design criteria weighing matrix for the environmental protection which would be our housing. We were able to determine 5 different design criteria's. We felt that cost efficiency, ease of construction, safety, size, and no interference with the equipment were the most important criteria's to our housing of our machine. As can be seen on our matrix above, safety and no interference with our equipment had the highest weight for our housing. We than compared each of the different materials for our housing and compared it to our criteria.

Design Variant Ranking with respect to Cost Efficient: 0 - 1 Scale					
Cost Efficient	Aluminum	Wood	Steel	Score = Row Sum	Norm. Score
Aluminum		0	1	1	0.33
Wood	1		1	2	0.67
Steel	0	0		0	0.00
				3	1.00

The above matrix shows our design materials for the housing in respect to the cost. Due to the ease of getting wood at local hardware store and the low cost of wood, this led to wood having the highest score.

Design Variant Ranking with respect to Easy to Construct: 0 - 1 Scale					
Easy to Construct	Aluminum	Wood	Steel	Score = Row Sum	Norm. Score
Aluminum		0	0	0	0.00
Wood	1		1	2	0.67
Steel	1	0		1	0.33
Col. Sum	2	0	1	3	1.00

The above matrix shows our design materials for the housing in respect to the ease of construction. Due to the ease of construction of wood, it had the highest score in our matrix.

Design Variant Ranking with respect to Safety: 0 - 1 Scale					
Safety	Aluminum	Wood	Steel	Score = Row Sum	Norm. Score
Aluminum		1	0	1	0.33
Wood	0		0	0	0.00
Steel	1	1		2	0.67
Col. Sum	1	2	0	3	1.00

The above matrix shows our design materials for the housing in respect to safety. Due to steel having a higher strength it had the highest score in our matrix.

Design Variant Ranking with respect to Size: 0 - 1 Scale					
Size	Aluminum	Wood	Steel	Score = Row Sum	Norm. Score
Aluminum		1	0	1	0.33
Wood	0		0	0	0.00
Steel	1	1		2	0.67
Col. Sum	1	2	0	3	1.00

The above matrix shows our design materials for the housing in respect to size. All these were equally weighed but steel had the highest score due to availability of welding our housing and creating the size that we want.

Design Variant Ranking with respect to DC5 (No Interference): 0 - 1 Scale					
No Interference	Aluminum	Wood	Steel	Score = Row Sum	Norm. Score
Aluminum		1	0	1	0.33
Wood	0		0	0	0.00
Plexiglass	1	1		2	0.67
Col. Sum	1	2	0	3	1.00

The above matrix shows our design materials for the housing in respect to no interference with our machine. Steel ended up having the highest score in our matrix above.

Selection Matrix						
	Cost Efficient	Easy to Construct	Safety	Size	No Intereference	Score
Aluminum	0.33	0	0.33	0.33	0.33	
	0.033	0	0.132	0	0.099	0.264
Wood	0.67	0.67	0	0	0	
	0.067	0.134	0	0	0	0.201
Steel	0	0.33	0.67	0.67	0.67	
	0	0.066	0.268	0	0.201	0.535
Decision						High Score Wins

The above matrix shows the selection matrix where we find out from our previous matrices which design for the housing would be best. After completing all of our design criteria's to our different housing options, it was determined that steel was the winner. We believe steel will be a great candidate for our housing due to the good strength.

V. Final Design Analysis

The Conceptual Design section of this project was imperative in order to analyze all the possible solutions to building a highly precise machine. It led the team to a final list of possible components to use. The final design was first depicted in Pro Engineer and then Solidworks. Afterwards a detailed analysis with calculations for each component was done in order to ensure that the parts ordered exceed their applicable loads, torque, etc.

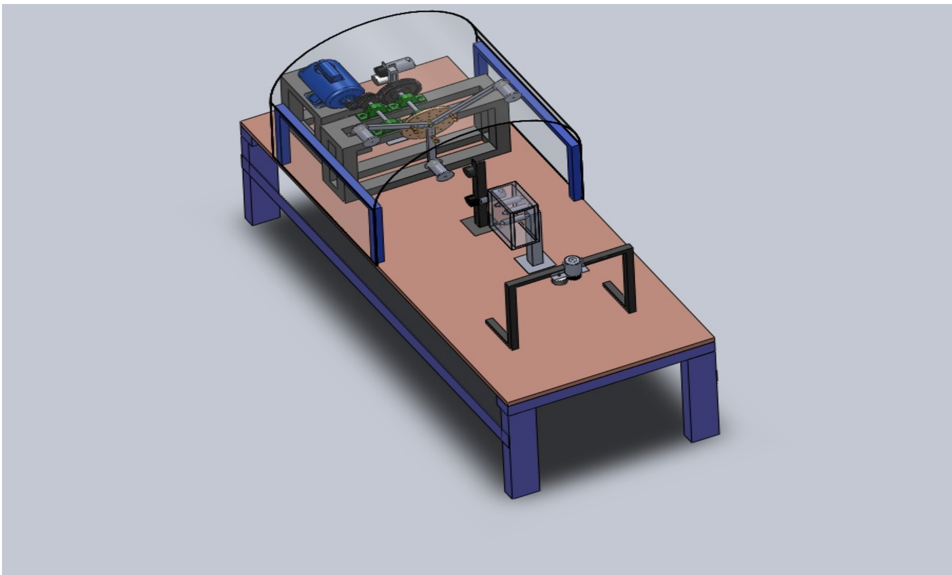


Fig. 29 Final Design model in Solidworks

Given parameters

In any engineering problem, we have our given parameters or initial boundary conditions. In this case, the customer, Delta Heat LLC gave us some parameters to start from, but also we had to create some of them from our observation of the final product.

The Parameters are the following;

1. Production Velocity: 6 in/min=.1in/sec
2. All the Resistances of the Alloys
3. Areas of the Minimum and Maximum gauges (40 and 22)
4. Maximum and Minimum number of turns per inch: 60 and 4 turns per inch.

Initial Equations

Taking into consideration the given parameters, we have to search for formulas to obtain other information or values.

1. *Number of Winds for given resistance per foot.*

$$R = \frac{\rho L}{A} \ldots \ldots L = \frac{RA}{\rho}$$

$$L = \sqrt{(N\pi D)^2 + (PN)^2}$$

$$\frac{RA}{\rho} = \sqrt{(N\pi D)^2 + (PN)^2}$$

$$N = \sqrt{\frac{\left(\frac{RA}{\rho}\right)^2}{(\pi D)^2 + P^2}}$$

Where A is the cross sectional are of the wire in in^2, R is the Resistance in Ohms, ρ is the Resistivity of the wire, L is the length of the wire in inches, D is the Diameter of the Coil, P is the pitch in inches, and N is the Number of turns.
With this formula we can find out the number of Turns per foot that a wire must take around the Core in order to obtain the wanted resistance per foot. This formula is important for the controllers as well to predict the resistance of a coil.

2. *Velocity of the Motor Depending of the frequency*

$$V = RPM = \frac{120f}{P}$$

Where V is the Velocity of the mounting plate in RPM, f is the frequency in Hertz and P is the number of Poles of the motor.
This formula is also important in the controller in order to vary the resistance we vary the RPM of the mounting plate.

3. *Number of Winds depending on the linear velocity*

$$V = 0.1\frac{in}{sec}$$

So:

$$60\ turnsin\ 10\ seconds$$

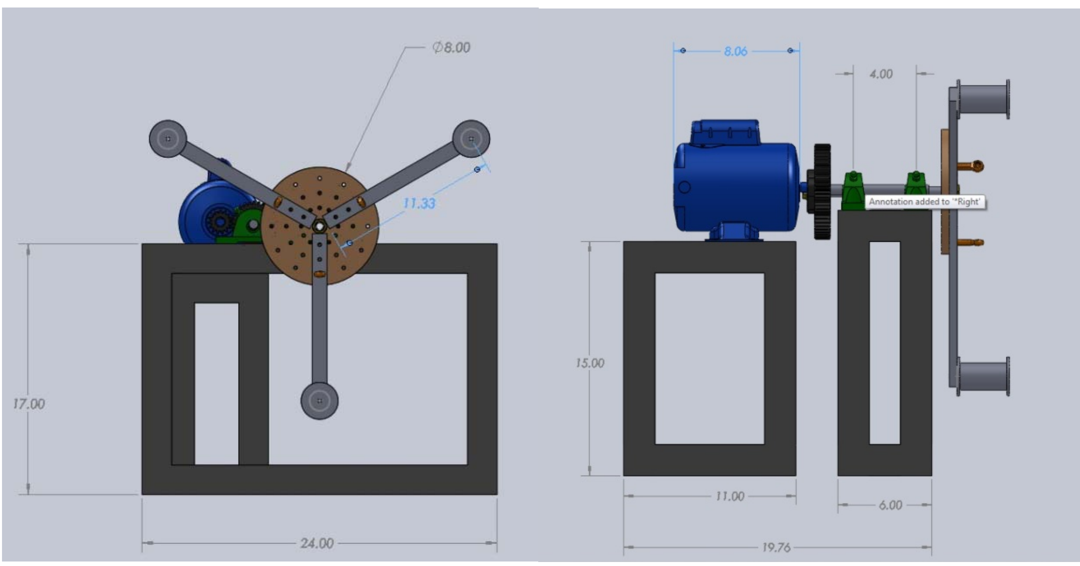
$$\frac{60turns}{10\ seconds} = 6\frac{turns}{second} \times \frac{60sec}{1min} = 360\ RPM$$

This formula was to obtain the maximum velocity, for the 60 turns per inch. That is the maximum resistance.

Pulling Mechanism

The resistive wire production rate is dependent on pulling speed equally associated with the pulling mechanism. The pulling mechanism will always stay at constant angular velocity; this will enable flexibility when producing wire. Making the pulling mechanism independent allows for easier control with respect to the amount of winds being produced. The correlation between number of winding and faceplate angular velocity will determine running speeds at which product can be looped around. The initial mechanism failed due to excess required torque, due to this we had to modify our design. Assigning multiple driving points will decrease the amount of torque required by the pulling motor, and deliver minimal stresses to the product. The use of a quality control system is active during production this delivers friction, which directly impacts the amount of toque required by the pulling mechanism. This quality control mechanism is composed of 3 idlers which 1 ft of material wraps around in s-shape forcing material to make contacts with idlers enabling resistance measurements to be taken. This is very crucial step towards delivering a expected product and meeting customer expectation. For the modified pulling mechanism, 3 rubber rollers are used to sandwich the final product and eliminate slippage. The addition of idlers close to the faceplate will contribute to drive the fiberglass straightly to the center of the shaft, prevent hanging of the string. This is a crucial parte because if tension is not kept properly the string will hang and touch the shaft and rotate with it, delivering an unwanted product. These idlers also get wrapped in and S-shaped form, which allows constant tension. The same mechanism will be in effect in back of the motor, and this will deliver the fiberglass core to the system while maintaining constant tension. The main problem we saw due to experimentation is tension, in order to deliver a good quality product the tension of the fiberglass has to be constant while maintaining speed production speed.

Winding Mechanism



Power Transmission

Gears

The gear transmission is the mechanism used to transmit rotational energy from the motor to the Wire Winding Mechanism. This Transmission comprises of three gears: a pinion, an idler gear and a driven main gear, and there is a speed reduction ratio of 4:1.

Gear	Outside Diameter (in)	Pitch Diameter (in)	Bore (in)	No. of Teeth	Pitch	Material
Pinion	1.37	1.47	0.59	15	10.2	AISI 1045
Idler	3.14	2.95	0.59	30		
Driven	6.1	5.9	1	60		

Table 1: Transmission Properties Characteristics

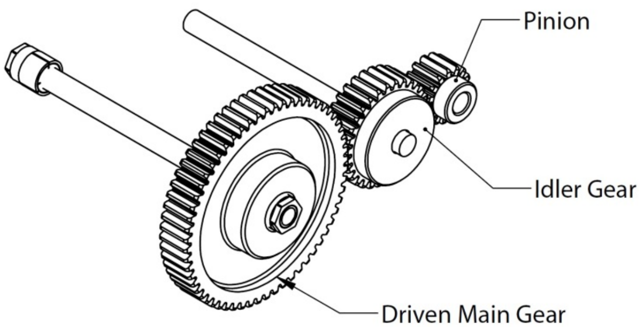


Figure1: Gear Transmission

1. *FEA Analysis*

The team included FEA analysis using the boundary conditions of the Lewis Equation to find the gears' maximum Bending stresses.

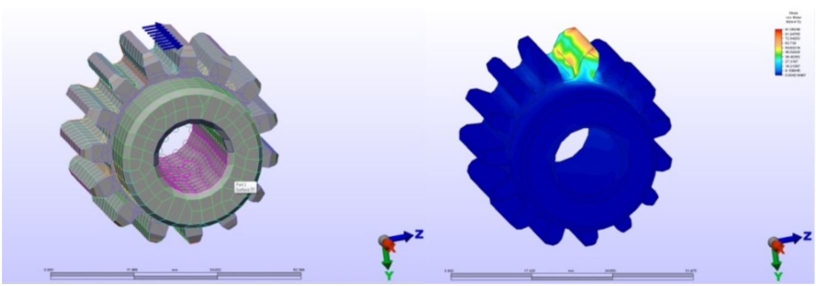


Figure 3: FEA analysis of the Pinion

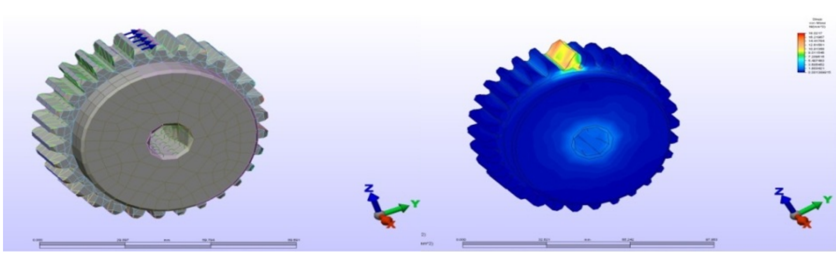


Figure 2: FEA analysis of the Idler gear

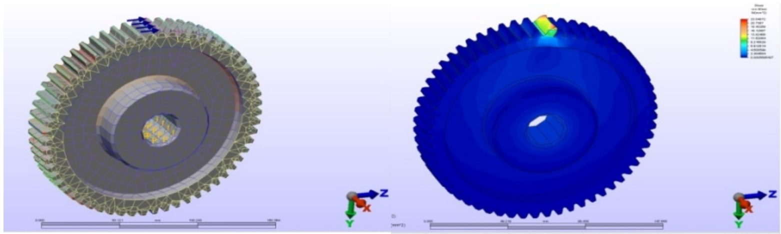


Figure 3: FEA analysis of the Driven Gear

Some of the assumptions for the FEA Model analysis are:

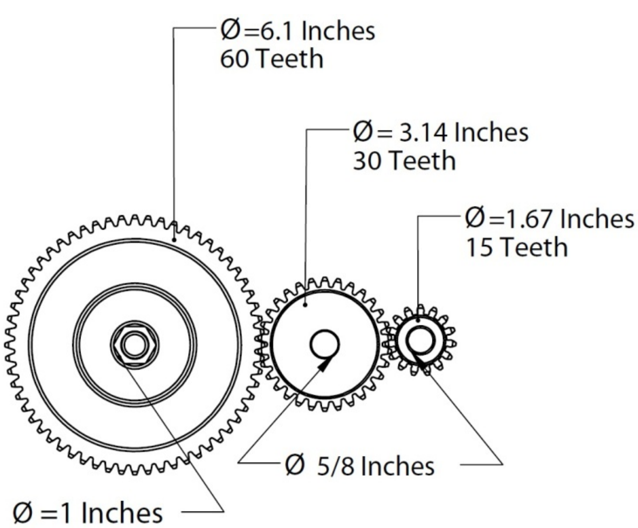
1.-The gear’s bore are pinned.
2.-There is an acted force on the tip of the teeth.

These assumptions are important in order to set the boundary conditions on the model.

Gear	No. of Elements	Von Misses Stresses (ksi)	Maximum Principal Stresses (ksi)
Pinion	8337	13.205	12.183
Idler	13134	2.614	2.496
Driven	15910	3.33	1.75

Table 2: FEA Results

2. *Lewis Equation and Bending endurance strength*



Gear Specifications	
Precision Grade	JIS Grade N8 and JIS grade 4
Gear Teeth	Standard Full Depth
Pressure Angle	20 degrees
Material Specifications	
Material	AISI 1045
Hardness	HB165-194
Yield Strength	73.2 ksi
Tensile Strength	111.6 ksi

Lewis Eq $\sigma = \frac{F_t P}{bJ} K_v K_o K_m$

Pinion: $\sigma = \frac{21\ lbf \cdot 10.2}{1\ in \cdot .21} \times 1.3 \times 1.25 \times 1.6 = 2652\ psi$

Idler: $\sigma = \frac{21\ lbf \cdot 10.2}{1\ in \cdot .27} \times 1.3 \times 1.25 \times 1.6 = 2062\ psi$

Driven: $\sigma = \frac{21\ lbf \cdot 10.2}{1\ in \cdot .29} \times 1.3 \times 1.25 \times 1.6 =$

$\sigma = Bending\ Stress$
$Ft = Force\ Acted\ on\ Gear$
$P = Pitch$
$b = Thickness$
$J = Geometry\ Factor$
$K_V = Velocity\ Factor$
$K_o = Overload\ Factor$
$K_m = Mounting\ Factor$

Table 2: Gear Properties

$$S_n = S'_n C_L C_G C_S k_r k_t k_{ms}$$

$$S_n = \frac{111}{2}(1)(1)(.75)(.9)(1)(1.4)$$

S_n=52.44 ksi

$S_n \gg$1920 psi=σ

$S_n = Fatigue\ Stength$
$S'_n = Endurance\ limit$
$C_L = Load\ Factor$
$C_G = Gradient\ Factor$
$C_S = Surface\ Factor$
$k_r = Reliability\ Factor$
$k_t = Temperature\ Factor$
$k_{ms} = Mean\ Stress\ Factor$

As we can see from the Lewis Equation, the bending stresses came out lower than our Yield Strength. Also, since the Fatigue Strength (Sn) is 52.44 ksi, and the Bending Stress is only 1848 psi acted on the gears, the gears are usable for infinite life.

Keyless Bushings

Since the Wire Winder Machine has a tubular shaft to pass the fiberglass core through, it automatically discards the possibility to install a key bore. The team researched for a way or method to attach the gears and mounting plate in place and came out with the Keyless Bushings. The following illustration explains the mechanism behind the Bushings.

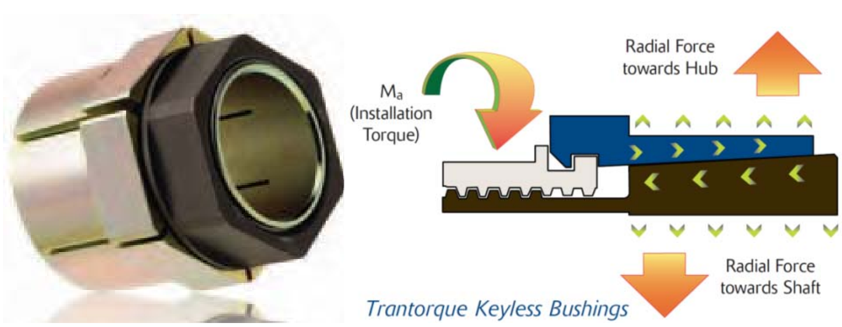


Figure 4: Trantorque Keyless Bushing. www.fennerdrives.com

Winding Velocity Control

Figure 5: Yaskawa G7 VFD

With the purpose to control the resistance of the wire produced, the wire winding machine needs to accurately vary the number of windings around the fiberglass core. An three phase, ½ H.P. AC motor will be used for this function. However, to be able to vary its velocity and therefore the number of windings, there need to be a control system for the motor.

A Yaskawa G7 series Variable Frequency Drive (VFD) will be used to control the frequency. The frequency is linearly proportional to the rpm of the motor so by implementing a variable frequency drive as a control mechanism for the winding, the team will ensure highly precise winds around the fiberglass core. The main requirements for the VFD are that it can control a three phase motor and that it has a port to receive input from the resistance measurement alarm system. The VFD selected has all these requirements.

Calibration

During the design phase, the team calculated the torque, power, and possible behavior of the machine, however a great deal of information was missing and many assumptions were taken in order to proceed with the design, this could be from factors of safety, speculation and possible behavior. Therefore a calibration analysis is needed in order for it to perform as desired. This analysis is dependent in the number of variable components and options.

The next table shows a list of factors that affect the proper winding of the wire around the core:

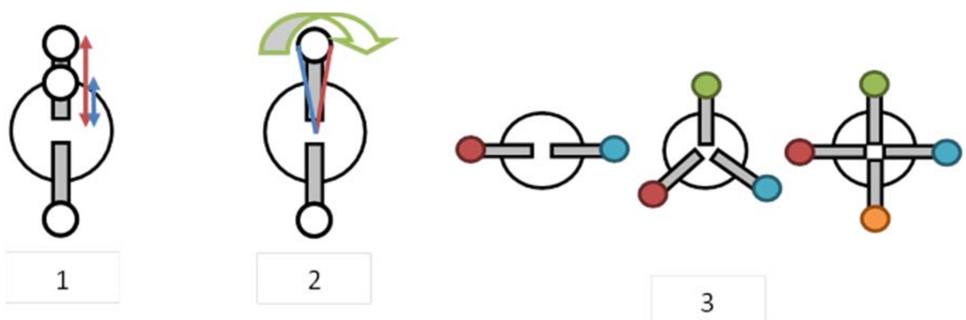
Image	Factor	Variation	Result
1	**Distance of Alloy Spools to Fiber glass Core**	From 12’’ to 3”	Tension of wire varies according to distance.
	Compression on Alloy spools	Tightness Variation	Tension of wire vary according to tightness
2	**Direction of wire on Alloy Spools**	Right or Left	Direction of wire unwrapping affect the proper alignment between wires. Also affects the winding around the core
	Power on sequence • **Winding Mechanism** • **Pulling Mechanism**	Time=0 1. ON, ON 2. ON, OFF	Variation of alignment of wires.

		3. OFF, ON	
	Pre-Union of wires before operation (two or more)	Direction of initial winding by hand	Wire winds around the core, or core slips through the wires
	Material and thickness of Alloys		Possible variation of all of the above and may behave differently with different number of spools.
3	**Number of Spools**		Possible variation of all of the above and may behave differently with different number of spools.

Resistance Measurement (Quality Control)

The component selected for resistance measurement was the multimeter. While there are many different types of multimeters, it was possible to narrow down our selection based the customer objectives. The best selection was then narrowed down to panel mount resistance meters which incorporate an alarm system into their design.

For this project, the Laurels Resistance Meter will be used. It is highly accurate with a +/- 0.01% tolerance. It also has high read rates at up to 50-60 conversions per second of analog to digital signal. This will allow for accurate real time



resistance measurements. Finally, with the contact relay built in, it can measure resistances to be within a given tolerance and if the resistance read is outside the specified, it will open or close the relay and send an alarm to the VFD which will then stop production.
Below is a QA example from laurels.com

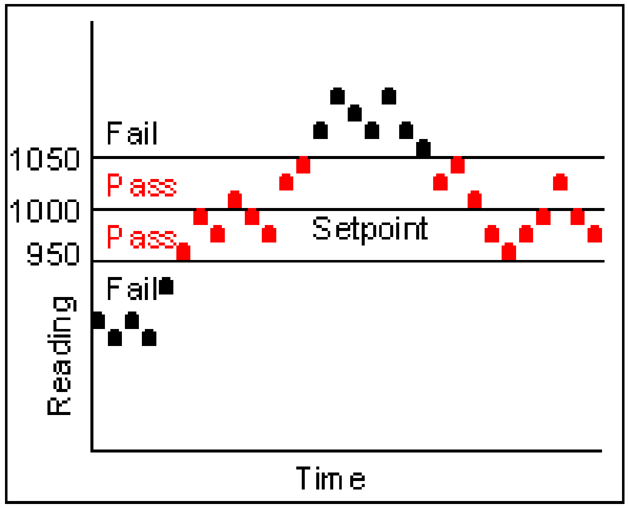


Fig 31. QA Application with Relay Option in Passband Mode
<http://www.laurels.com/ohms.htm>

Rollers used for Resistance Measurement

In order to measure the resistance of the finished product, the machine will use a set of rollers as a location for resistance measurement. The resistance will be measured in ohms/ft and a foot of wire will wrap around the rollers. An important thing to note is that the crevices and sides of the roller must be aligned. The rollers will be made out of aluminum. The aluminum will suffice for the application of the excitation voltage to measure resistance. A sketch of the setup can be seen in figure 32.

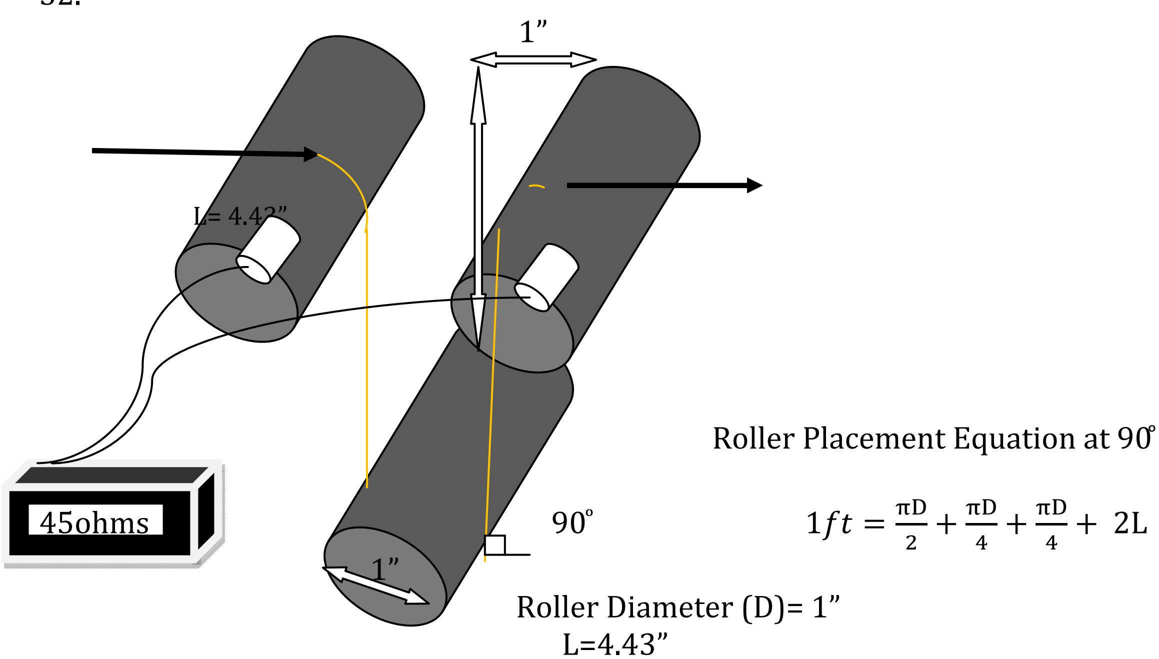


Figure 32. Resistance Measurement Setup

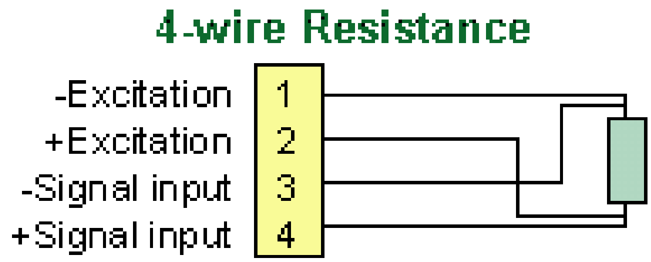


Figure 32. 4-Wire Resistance
Laurels.com

As seen above, the laurels resistance meter will be used in the 4-wire resistance configuration around the roller. Two wires will be connected at opposite ends (the probes locations in fig 32) to apply an excitation voltage and the other two will be used for signal readings. By the resistance will be measured internally by the ohmmeter by measuring the difference between the applied voltage and the voltage read.

Test Plan

Once the prototype was completed, we began testing of the machine. Below is the list of tests that were done on the machine to make sure it was working properly. As can be seen below, from the tests that we have conducted, most have worked properly. The pulling mechanism still has to be tweaked. We noticed that the roller had to be higher to properly pull the final product. This is something that we will continue to work on and perfect to make the machine work properly. Also, the resistance measurement still needs to be tested while running.

Testing	Pass/Fail/Recommendation
Proper Gear Alignment with Clean Turning	Pass
Motor and VFD Properly Functioning	Pass
Pulling Motor and Final Spool Placement Motor Functioning	Pass
Wire Winding Around Fiberglass (2 wires) running	Pass
Wire Winding Around Fiberglass (1 wire) running	Pass

Pulling Motor Function (running)	Pass
Resistance Measurement	Working/ Relay Setup still remains to be configured

Overall Design Summary

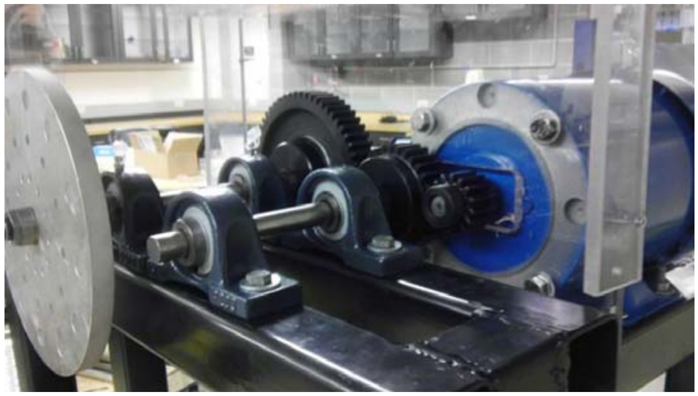
The final prototype has been constructed and all the pieces that have been discussed in this report have been working. Overall we were very pleased with the final prototype. After some initial testing, the overall objective was completed by being able to wind wires around a fiberglass core. As they were being wound around the fiberglass core, the wires were staying parallel to each other which is what we wanted in our resistance wires. The machine met our expectations and we will continue to perfect it.

Conclusion and Recommendations

Our recommendation is to continue to work on the tension of the wires of the fiberglass core and the wires to ensure quality products are being manufactured. This will include more work on the feeding of the fiberglass core and the perfecting of the motors used in the pulling mechanism.

VI. Component Assembly

GEAR/BEARINGS ASSEMBLY

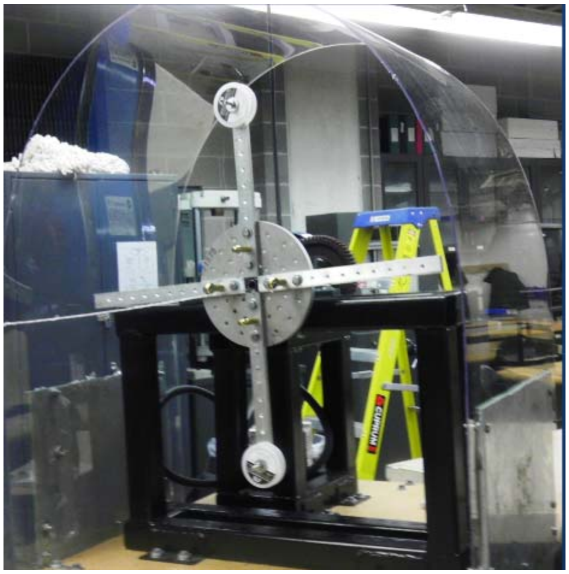


As previously discussed the power transmission consists of a 4:1 gear ratio. The pillow blocks that lead to the mounting plate were centered and driving gear was placed on the opposite end of the mounting plate. The gears were aligned with each other and sub sequentially with the mounting plate (as seen above) using 5/8" pillow mount bearings and hardened steel shafts.

Component	**Specifications**	**Quantity**
Driving Gear	- 6.1" outer diameter with 5/8" inner diameter	1
Idler Gear	– 3.14 outer diameter with 5/8" inner diameter	1
Pillow Block Bearing	- 5/8" inner diameter with 5/16" holes for mounting	4
Bolts	- 5/16" x 3" Galvanized Steel	4
Nuts	5/16" galvanized steel	4
Washers	5/16" galvanized steel	4
Shaft	5/8" diameter with 1ft length hardened steel	4

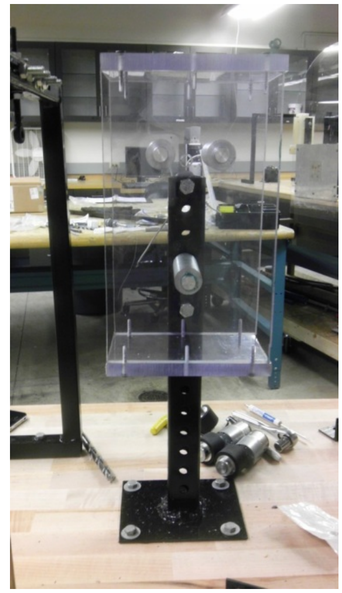
Prototyping Challenges

WINDING MECHANISM



Component	Specifications	Quantity
Mounting Plate	8” Aluminum with 4- ½” holes placed at 90˚	1
Arms	10” length by ¼” width Aluminum with 1/2” holes 1” apart	4
Wire Guides	¼” diameter by 2.5” length	4
Helical Springs	Steel Compression Spring Zinc-Pltd Wire, 1.00" L,.970" OD,.080" Wire	4
Keyless Bushing	Trantorque Mini. Shaft Diam. .6250 In. Length 1.1250 in	1
Bolts	½” diameter bolts with 5” length	4
Washers	½” galvanized steel	4
Nuts	½” galvanized steel	4
Motor	1/2 hp Elektrimax Motor, 1800 RPM, three phase - 38CF-3-.50-18	1

RESISTANCE MEASUREMENT



The resistance measurement assembly utilized three aluminum rollers with a 1"in diameter and 3" in length. These were machined to also have an extra ½" diameter by ¾" length on both ends to be able to place them inside the Plexi glass enclosure.

Component	Specifications	Quantity
Roller	1" Diameter Rollers 3" length with two ½"x 3/4" ends and .283" inner diameter	3
Unistrut Leg	2ft high with ½" holes for mounting	4
Panel Meter	Laurels ohm meter	1
Rotary Connectors with wires	Mercotac 105A- 0.283" diameter	2
Bolts	½" diameter bolts with 5" length	2
Washers	½" galvanized steel	2
Nuts	½" galvanized steel	2
Enclosure	10" x 6" front and back ½" thick Plexiglas ; 6"x4" top and bottom ½" thick Plexiglas	1

Prototyping Challenges

PULLING MECHANISM

Component	Specifications	Quantity
Motor	Jameco	3
Unistrut Leg	2ft high with ½” holes for mounting	4
Panel Meter	Laurels ohm meter	1
Rotary Connectors with wires	Mercotac- 0.283” diameter	2
Bolts	½” diameter bolts with 5” length	2
Washers	½” galvanized steel	2
Nuts	½” galvanized steel	2
Enclosure	10” x 6” front and back ½” thick Plexiglas ; 6”x4” top and bottom ½” thick Plexiglas	1

DATA COLLECTION

VI. Summary

As per requested by Delta Heat Llc, the machine was designed and prototyped to produce the desired resistive wire with a fiberglass core. The prototype was developed by reverse engineering and development of function decomposition procedures. The team researched different types of subcomponents (e.g. gears, belts, chains) and different types of materials (e.g. aluminum, steel, wood) for the three initial conceptual designs. Accordingly, depending on their advantages, disadvantages, and operation, proper selection of components fulfilled. Selection matrices were used during the component selection to select the proper component based on application. The outcomes were observed and the winning component for each function was then purchased and used during the prototyping of the wire winding machine.

A final design was drafted and each individual component was researched and calculations for each component were carried out in order to ensure that the finalized selection of materials was the adequate and exceeded the necessary torque, applicable loads, etc. The team has now completed all the parts of the design prototyping phase of the project. The machine has been tested and calibrated and the team has demonstrated the machines ability to produce the wire desired. Finally, with the built in real time resistance measurement device, not only will the user measure the resistance of the product but ensure that the quality of the material is sustained.

VII. Future Work

The project was successfully completed in May 2012. However, Delta Heat Llc. requested that further research and development be conducted on the second prototype which is to stay at The University of Texas-Pan American to improve both its production and quality control aspects as well as implement automation.

VIII. Acknowledgements

This project was undertaken by the senior design team consisting of Joaquin Vaca, Adrian Delgado, Oscar Cantu, and Juan Mendiola. Dr. Isaac Choutapalli and Dr. Young Gil Park provided invaluable technical expertise as the technical advisors assigned to the group. Special thanks to Dr, Kamal Sarkar for the remarkable guidance and advising on this project.

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VII. Appendix

Tables

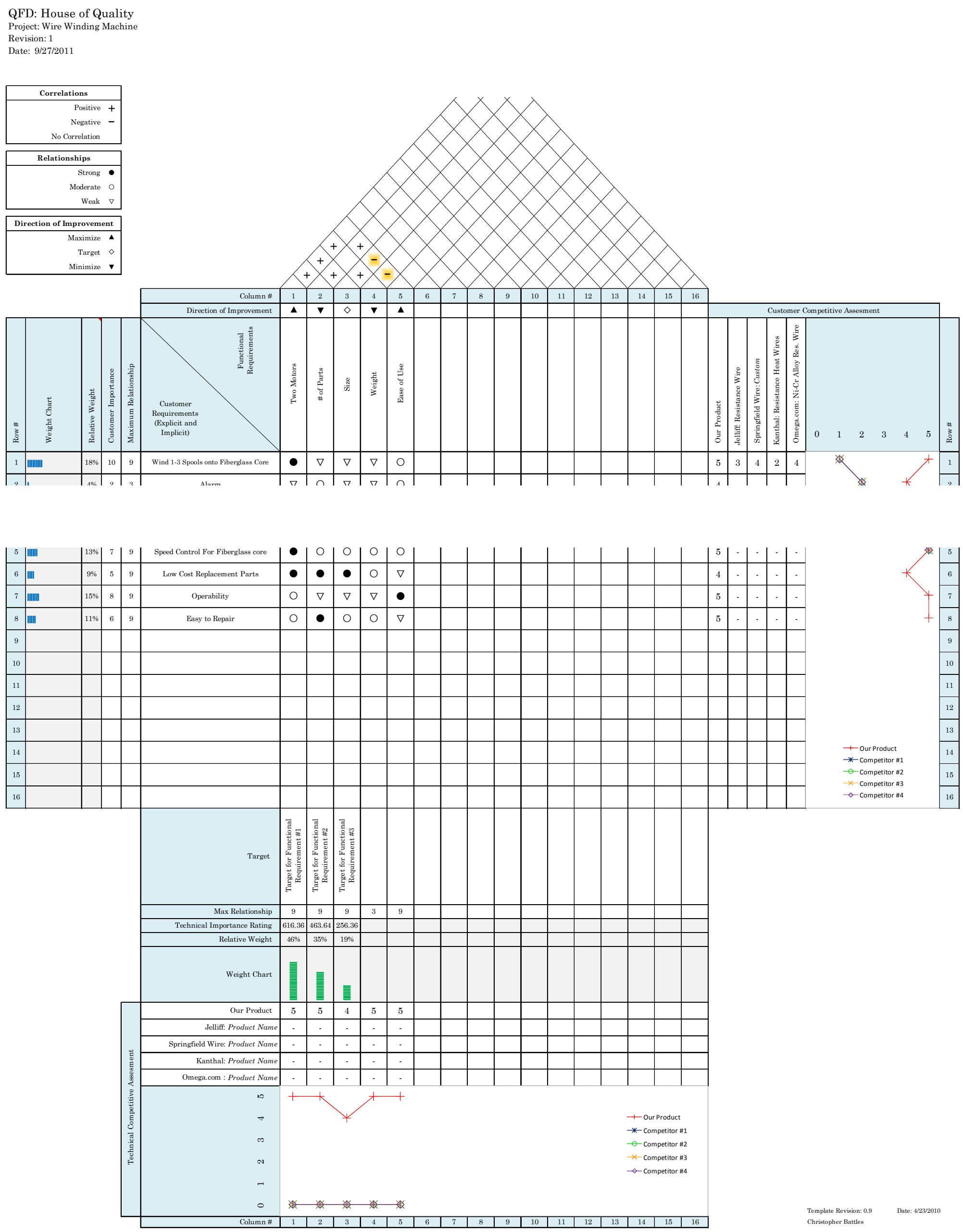

Figure 7: Quality Function Deployment Chart

Name	Catalog	Quantity	Provider	Price per
Motor Gear 12 VDC, 246 MA	155013	3	Jameco Electronics	$23.95
Slotted Machine Screw M3 size, 6mm length. (100 per box)	91290A113	1	McMaster-Carr	$6.21
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
18-8 Cup Point Set Screw, 10-32 X 1/4" for Neoprene Idler and Drive Roller	60885K67	2	McMaster-Carr	$1.11
Steel Shaft 1/2" Diameter, 30" Length	6061K79	1	McMaster-Carr	$15.57
Oil-Resistant Neoprene Idler and Drive Rollers Bookmarked Drive Roller, 1-1/2" Dia X 1" W, 1/2" Bore ID	60885K51	3	McMaster-Carr	$22.68
Plug-in Voltage Transformer , 2000 MA, 120 VAC Input, 12VDC Output	70235K23	1	McMaster-Carr	$19.35
Rocker Switch Standard, SPST, Off-on, 15 Amps	7395K11	3	McMaster-Carr	$4.62
1/2 hp Elektrimax Motor, 1800 RPM, three phase - 38CF-3-.50-18	38CF-3-.50-18	1	Valley Armature & Elec	$138.00
G7 Series Yaskawa Drive, 3/4 HP 230 V 3 Phase Input (CIMR-G7U20P41	G7U20P41	1	Valley Armature & Elec	$936.00
10 Turn 5 K OHM speed pot - 1E4258	1E4258	1	Valley Armature & Elec	$22.50
Aluminum Custom Mounting Plate		1	Amaida	$74.00
Keyless Bushing, Trantorque Mini. Shaft Diam. .6250 In. Length 1.1250 in	13J122	3	Grainger	$41.90
SS Steel Spur Gear Module 2.5 15 Teet	SS2.5-15	1	Quality Transmission Component	$16.86
SS Steel Spur Gear Module 2.5 30 Teet	SS2.5-30	1	Quality Transmission Component	$44.22
SS Steel Spur Gear Module 2.5 60 Teet	SS2.5-60	1	Quality Transmission Component	$103.04
Cast Iron Mounted STL Ball Bearing Base Mount, Set Screw Lock, for 5/8" Shaft Diameter	6667K12	4	McMaster-Carr	$27.65
Steel Compression Spring Zinc-Pltd Music Wire, 1.00" L,.970" OD,.080" Wire (6 Pck)	1986K3	1	McMaster-Carr	$8.91
Carbon Steel Welded and Drawn Tubing High-Pressure, 5/8" OD, .527" ID, .049" Wall, 6'L	89975K32	1	McMaster-Carr	$18.60
Steel Drive Shaft 5/8" OD, 24" Length	1346K25	1	McMaster-Carr	$17.66
Self-Lube Bronze Race Ball Joint Rod End 1/4"-28 RH Female Shank, 1/4" Ball ID, 11/16" L Thrd	6072K155	4	McMaster-Carr	$5.42
Fully Threaded C1035 Steel Rod End 1/4"-28 Thread Size, 1/4" Hole ID, 3-1/2" Length	3798K51	4	McMaster-Carr	$7.87
Bookmarked18-8 Stainless Steel Fully Threaded Stud 1/4"-28 Thread, 2" Length	95412A573	4	McMaster-Carr	$5.26
Corrosion-Resistant Washdown Enclosure Switch Two Button, Flush, Green/Red	7546K27	1	McMaster-Carr	$40.18
3-1/8" Dia, " Emergency Stop" Legend Plate for 22 mm Panel Cutout Emergency Stop Switch	6741K55	1	McMaster-Carr	$7.74
22 mm Panel Cutout Emergency Stop Switch Pull to Reset, 1-1/4" Button Dia, 2 NC Contact	6741K42	1	McMaster-Carr	$38.25
Laurel Ohmmeter for Resistance in Ohms L20305R3	L20305R3	1	The Meter Shop	$390.00
One conductor Rotary Connection. Model 105	Model 105	2	Mercotac	$29.10
One contact receptacle 5921-S	5921-S	2	Mercotac	$3.11
Industrial Workbench, Type Maple Top, Top Width 72 Inches, Top Depth 30 Inches	7D194	1	Grainger	$365.63
Low-Carbon Steel Square Tube 2" X 2", .120" Wall Thickness, 6' Length	6527K33	4	McMaster-Carr	$47.10
Low-Carbon Steel 90 Degree Angle 3/16" Thick, 1-1/2" Leg Length, 6' Length	9017K59	5	McMaster-Carr	$23.94
Low-Carbon Steel Square Tube 1" X 1", .083" Wall Thickness, 6' Length	6527K22	4	McMaster-Carr	$21.72
Scratch-Resistant Clear Cast Acrylic Sheet 1/8" Thick, 48" X 96"	8560K264	1	McMaster-Carr	$172.94
Scratch-Resistant Clear Cast Acrylic Sheet 1/2" Thick, 12" X 24"	8560K266	5	McMaster-Carr	$51.05
Miscellaneous (Bolts, Washers and Nuts)			Lowes	$100.00
				Total