The Electric Reel for Soccer Fields

by

Stephen Taylor

Senior Project

ELECTRICAL ENGINEERING DEPARTMENT

California Polytechnic State University

San Luis Obispo

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Abstract

Painting a soccer field consumes too much time. The process of reeling the string after laying out string along the field needs to improve. As a result, my project addresses improvements in how the workers retrieve the string through the production of an electric reel. This electric reel allows the worker to have control of the speed, direction, and on/off state of the device. Direction control allows the user ability to reel and unwind the string. Variable speed allows the user to control how fast the reel unwinds and reels the string. The device gathers string in an orderly manner and detects when there is unwanted tension. Unwanted tension can come about when there is some form of interruption in the reeling process. The electric reel prevents the string from snapping when harmful tension occurs by detecting unwanted tension. In a basic view, the reel is a tool to address the needs of someone producing a soccer field.

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Chapter 1: Introduction

Producing a soccer field can take quite a bit of time. The process of just painting a soccer field can take three to four hours depending on the size of the field. Workers wrap string around stakes in the ground and lay the string along the field to prepare for the painters who paint the soccer field. An adult soccer field has a perimeter of 400 yards. Figure 1 displays the dimensions for U10/12 fields. Children under the age of ten play on a U10 field and children under the age of 12 play on a U12 field. Most soccer field productions occur before the elementary schools begin session in the fall. Workers have different functions and create many soccer fields in a short period before the soccer season begins. For this reason, an efficient way for workers to reel in the string proves useful. The workers collect the string after the painters paint the field. Collecting the string by hand can take 15 minutes. This demonstrates a very inefficient use of time considering that someone goes through this process every time the workers paint a soccer field.

This project proposes an investment opportunity to improve soccer field production in Clovis, Ca for a soccer organization CJSL (Clovis Junior Soccer League). The investment creates a reel that collects the string on a soccer field after painting. My research contains information about the function, parts, and assembly that the reel requires. Economic results display benefits from the production of the electric reel. Appendix A outlines improvements with jobs, money flow, and economic production. Appendix B uses cost analysis to support the idea of investing in a reel. I argue that a reel can boost soccer field production and save the soccer club money.

I have experienced reeling string as a worker who paints soccer fields. During the summer, I work for CJSL in the Clovis, California. This project relates to me personally because I could see how an electric reel could help the soccer organization. The soccer club could save more money if some minor changes in field productions could develop. This project could develop a more efficient way and lower the cost in producing a soccer field. In effect, field costs may go down, which make soccer cheaper for players. The electric reel allows workers to have an easier job and lowers soccer field productions costs for the club at the same time.

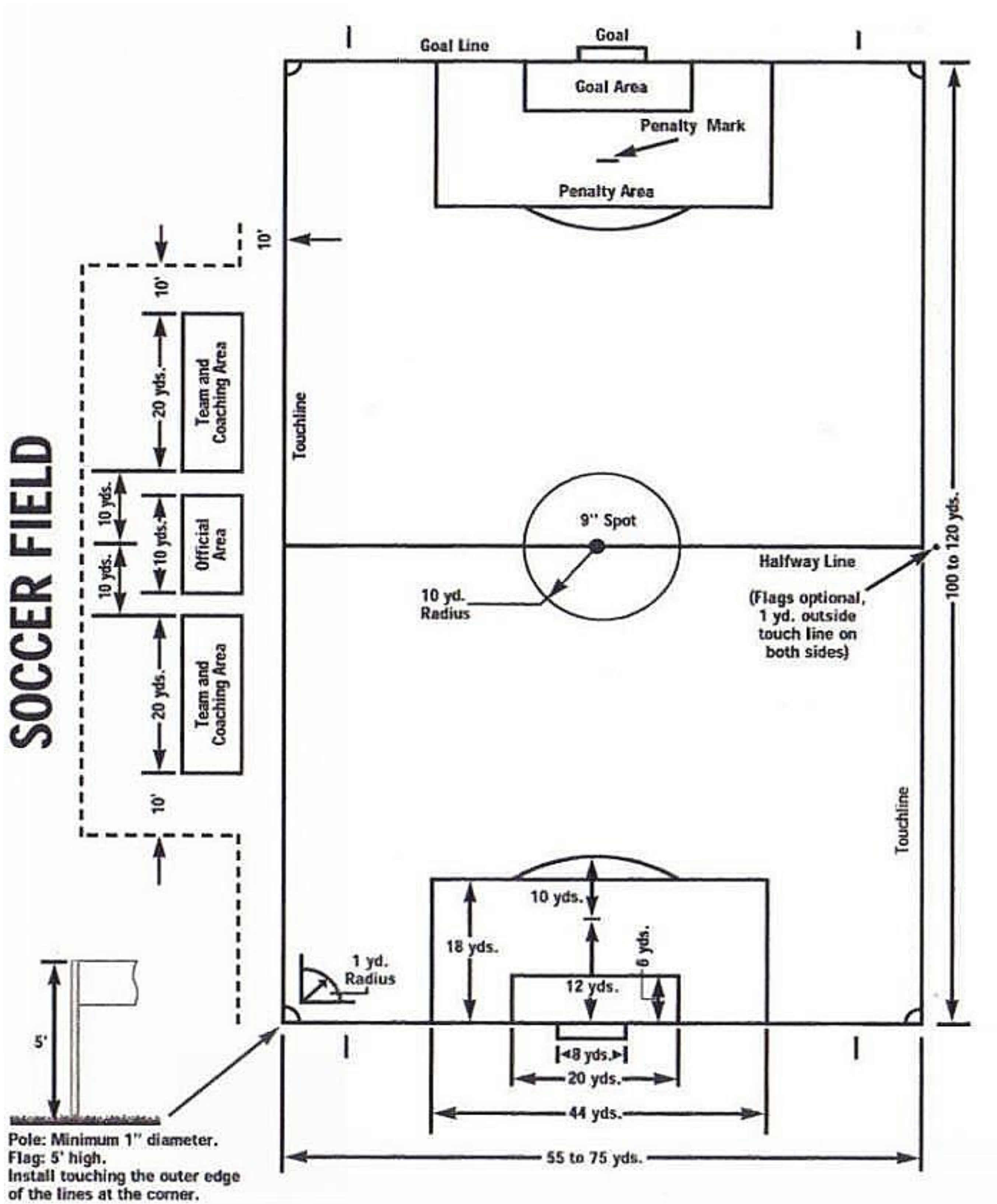

Figure 1: Field Dimensions for U10/12 field

Chapter 2: Customer Needs, Requirements, and Specifications

Customers define the needs, requirements, and specifications for the product. I use my experience with field painting to define what the customer needs with the electric reel.

2.1: Customer Needs Assessment

Soccer organizations, sporting organizations, and the field workers are potential customers. The customer needs a device that unreels and winds string in a faster way to boost time efficiency. This saves money for the field painting organizations. I determine that field painting organizations need this device from past experiences as a field painter. The process of reeling string by hand is time consuming. This device needs controllable behaviors that have adjustable speed and direction control. The reel needs to hold string and detect when unwanted tension occurs [3]. Customers need a portable and user-friendly electric reel. Users also need a safe device that accomplishes the task of reeling the string without injuring anyone in the process. Table I displays these marketing requirements.

2.2: Requirements and Specifications

The basic functionality of the electric reel winds up the string orderly and quickly. I define the requirements and specifications with the understanding of my customers' needs. The electric reel should reel string at a rate of 200 yards of string per minute. This seems reasonable and this speed would significantly improve the reeling process. I assume the electrical device operates on a grassy field. The reel should sense tension in the string to prevent the string from snapping. Tension detection should detect whether a person or an object obstructs the motion of the string. A person should not receive any injuries from the device. Therefore, if a person obstructs the motion of the string, the string should provide no more than 10 pounds of tension on the line. 10 pounds is enough tension to cut someone and cause injury. This safety specification couples with the safety specification that stops the motor's motion when 6A pass through the DC motor. Both of these safety specifications should address the dangers in the string tripping or cutting someone. The last safety concern addresses the vibration of the device to prevent the user from dropping the device. Therefore, the electric reel cannot displace more than 1 in/s of translational motion in free space to prevent too much unwanted movement of the reel [14]. Lastly, the device needs portability and controllability. This allows the user to easily carry and use the device. Overall, the customer needs engineering specification in the design that fulfills the marketing requirements.

TABLE I

ELECTRIC REEL REQUIREMENTS AND SPECIFICATIONS

Marketing Requirements	Engineering Specifications	Justification
5,6	The device holds at least 400 yards of Darice Polyester Kite String	The perimeter of an adult sized soccer field contains 400 yards.
5,6	Overall device weight does not exceed 50 pounds	A weight of 50 pounds or less provides more ability to hold the reel for short durations of time to move onto a cart.
5,6	The device dimensions do not exceed a cubic yard	Limiting the dimensions of the device should allow easier portability when traveling with a vehicle. This also makes the device easier to handle.
4,7,9	Motor should provide no torque when a current of 6A passes through the armature of the motor	This system should stop reeling in the string when the string catches on something along the field.
9	No more than a 10 pounds of tension exerted on the string	The string should not cut a person.
9	The electric reel cannot displace more than 1in/s in free space	Prevents unwanted movements and vibrations caused by the reel.
1,2	The device should collect the string at a rate of at least 200 yards/min	The system should take at the most two minutes to reel in the perimeter of a soccer field.
8	The device needs a switch to turn on and off the spooling device with a source of energy	This specification allows two 12V batteries in series to supply sufficient energy to the device.
1	This device adjusts the reeling speed from 0 yards of string/min to 200 yards of string/min	This allows the user to adjust the speed from nothing to maximum reeling speed.

Marketing Requirements

1. Controllable with multiple rotational directions and speeds
2. Capable of reeling in the string quickly
3. Should distribute the string evenly along the reel
4. The system should sense unwanted tension
5. User friendly
6. Should include portability
7. Should operate on a grassy field
8. Should use a battery supply
9. Safe to operate

TABLE II

ELECTRIC REEL DELIVERABLES

Delivery Date	**Deliverable Description**
2/6/15	Design Review
2/28/15	EE 461 demo
3/3/15	EE 461 report
4/21/15	EE 462 demo
4/30/15	ABET Sr. Project Analysis
5/18/15	EE 462 Rough Draft
5/29/15	Sr. Project Expo Poster
6/5/15	EE 462 Report

Chapter 3: Functional Decomposition

The electric reel takes in power, human interaction, and sensory information to produce angular velocity for the reel. Figure 2 displays the basic input and outputs of the electric reel and gives a basic view of the device's operation. This electrical reel should optimize customer needs by giving the user direction and speed control of the reel.

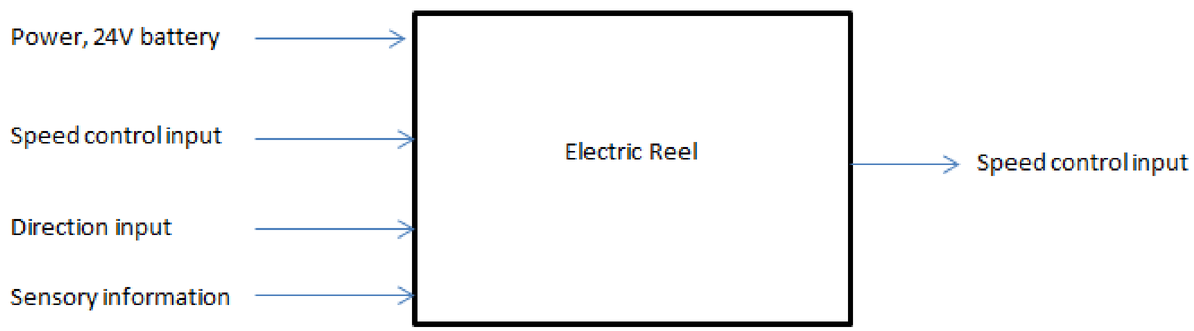

Figure 2: Level 0 Block Diagram

Table III displays more information involving the functionality of the electric reel. Inputs and outputs relate to the level 0 diagram. The functionality part of the table gives an understanding of how the device functions. The functionality of the electric reel complements the marketing requirements. Table I displays the marketing requirements.

TABLE III
LEVEL 0 INPUT AND OUTPUT REQUIREMENTS FOR ELECTRIC REEL

Module	Electric Reel
Inputs	• Power: 24V battery supply • User speed control: variable control • Direction Control Input: Reverse, Forward, and off applications • Trigger recognition: Readings for the string tension
Outputs	• Motor angular velocity: able to reel 200yards/min
Functionality	The electric reel energizes the motor to fulfill user's need. Speed and direction control inputs allow the user to control the motor. This directional control input allows the consumer to rotate the motor forward, backwards, or turn the motor off. The output of the electric reel should have a minimum ability to reel 200 yards of string in a minute in a reverse direction

The level 1 block diagram displayed in figure 3 below displays the same inputs and outputs of the level 0 block diagram, but the diagram goes deeper into specific subsystems. There is a 4 pole double throw/center rest input switch that provides a forward, reverse, or off state for the

motor. A potentiometer (5kΩ) allows the user to control motor speed by sending a signal to the DC Variable Speed Drive to speed up or slow down the motor. The DC Variable Speed Drive provides a voltage to the motor to correlate with the user's angular velocity need. A current relay triggers the motor to turn off when there is too much current passing through the sensor due to disturbances in the string. Users can adjust the current sensor to trigger when the amount of current going to the motor is unsafe. The current going to the motor correlates to the amount of output torque [10].

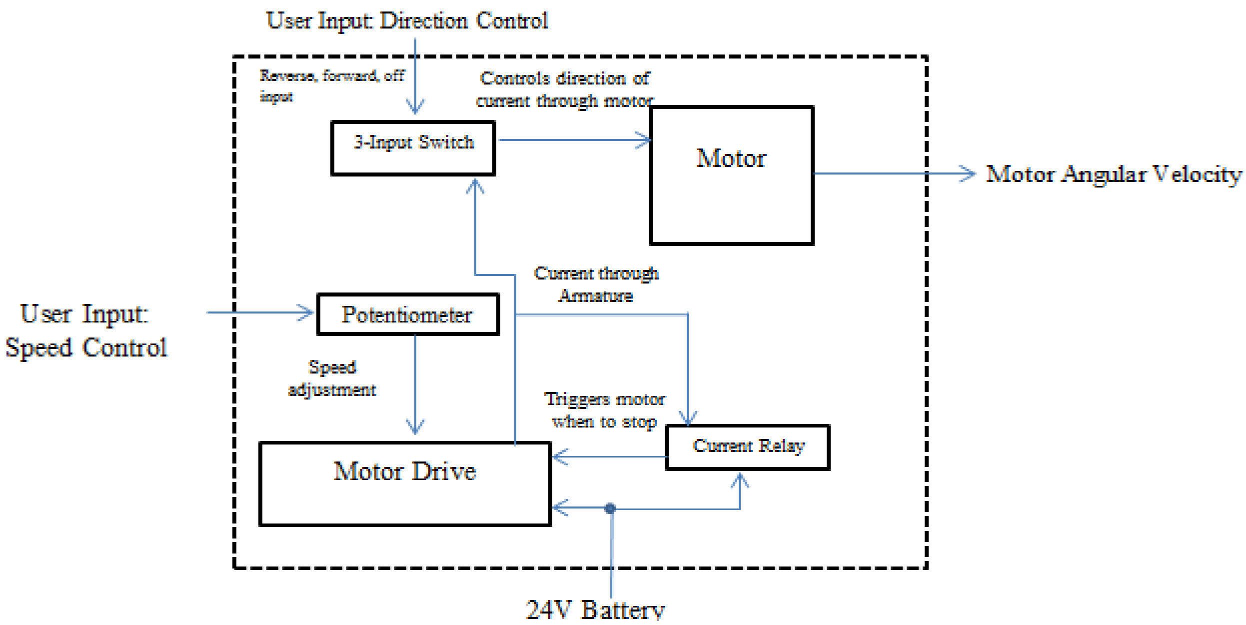

Figure 3: Level 1 Block Diagram

TABLE IV
LEVEL 1 INPUT AND OUTPUT REQUIREMENTS FOR MOTOR DRIVE

Module	Motor Drive
Inputs	• Current Relay Input • Potentiometer Input • 4 pdt input • 24V battery Input
Outputs	• Armature Current
Functionality	The current relay and potentiometer are the two inputs to the motor drive. The current relay detects when there is too much current in the armature and communicates with the drive to shut off the motor. A potentiometer input acts as an analog input to communicate with the driver how much voltage to output to the DC motor. The 4 pdt switch allows a user to put the electric reel in a forwards, reverse, and off position. Lastly, a 24V battery powers the device.

Chapter 4: Design

Designing and building the electric reel follows the establishment of the basic functional view. The level 0 and level 1 functional block diagrams summarize inputs, outputs, and the basic function of the electric reel. I began to research how to specifically accomplish this design once I had a basic view of the functional decomposition. A lot of the research came from various datasheets from the website AutomationDirect [15-22].

4.1 Electrical Design

The DC Variable Speed Drive is an important component of the electric reel [4]. I chose to incorporate the GSD1-12-20C Open-Frame Drive into the design of the electric reel. The motor drive is the central component of the device that the other components build around. Figure 4 presents the motor drive below.

Figure 4: GSD1-12-20C Open-Frame Drive

The DC drive allows the user to control the DC motor. A user is able to control the DC drive through a 0-10V input signal from P2-2 to P2-3. Figure 30 displays this connection. These are two different ports on the DC Variable Speed drive. A potentiometer adjusts an analog input from 0-10V into the drive [17]. Figure 5 displays the potentiometer. Desired reeling outputs come from the minimum speed, maximum speed, acceleration, I.R. compensation, and current limit adjustments to the drive. A user can change the desired outputs by changing the trim pots associated with each individual desired output on the DC drive. I chose this DC drive allowing a

worker to change how the DC Variable Speed Drive drives the motor. For example, if a worker decides the motor's maximum speed is too fast, they will be able to set the maximum speed to a lower speed. The user also has the ability to adjust the I.R. compensation to make the motor speed more consistent.

Figure 5: GSDA-5K Potentiometer

A 4 pdt (4 pole, double throw) switch allows the worker to keep the device off, reel in the string, or unreel the string [18]. The 4 pdt switch is displayed in figure 6. The 4 pdt switch changes the polarity of the DC current going to the armature of the motor. This allows the direction of the shaft of the motor to go into forward or reverse. The middle position of the 4 pdt switch allows the user to stop the motor and wait for the motor to completely stop before reversing the direction of the DC motor. I chose this switch to allow a worker the ability to turn off the device before changing directions of the motor.

Figure 6: 4 pdt Switch

A breaker is the main disconnect between the battery and the DC drive [19]. Figure 7 displays the breaker in the electric reel. In effect, the breaker provides the user with another way of turning the device off. The breaker protects the DC drive from pulling too much current. For example, if more than 15A of current pass through the breaker, the breaker will open. The breaker protects the 14 gauge wire, which has a rating of 15A of current. The breaker and the wire are able to handle the full-load current of the motor of 12.2 A. A worker can fully turn off the device when opening the breaker and disconnecting the battery from the drive.

Figure 7: WMZS2B15 Eaton Breaker

The motor is the component of the reel that translates all of the electrical power into mechanical power [16]. This motor has a rating of 1/4 horsepower, 12.2A full-load, 3996 rpm, and 80 oz-in of torque. Calculations, expert opinion, and research support the selection of the motor. I chose the motor under the assumption that the perimeter of the spool will be one foot and the motor will need an angular velocity of 600 rpm to reel in the string at this speed. Equation 4.1 demonstrates this calculation.

$$(perimeter) \times (\omega) = 200\,\frac{yards}{min} \qquad (4.1)$$

With a rating of 3996 rpm, the motor accomplishes this speed and provides more speed capability. I was hoping to accomplish a reeling speed of 200 yards/min and this motor satisfies this specification. The power of the motor is sufficient for the application of pulling string [5]. String is a very light load and will not require a powerful motor. In effect, a 1/4 horsepower motor works well for the application of reeling string. Figure 8 gives a view of the motor.

Figure 8: MTPM-P25-1JK40, 1/4 HP, 12.2A F/L, 3996 rpm, 80 oz-in Torque Motor

I made a smarter device by adding a current relay [20]. The current relay detects when there is too much current going to the armature. If there is too much current going through the armature, the relay closes the connection on the inhibit part of the drive. The device turns off when the connection on the inhibit is closed and runs when this connection is opened. Adjusting the pot

clockwise will increase the trigger point on the current relay. In effect, the current relay pot allows the worker to make the electric reel more or less sensitive to disturbances in the line. Figure 9 gives a view of what the current relay looks like.

Figure 9: DCS1000-1C-24-F Current Relay

The purpose of the current relay is to detect if there is an extra load. For example, a tangled string on the soccer field could cause the motor to stall and increase current in the armature. For this problem, a current relay (CTR1) trips the inhibit part of the DC drive and turns off the device. Figure 30 displays the trip current to be 6A by opening and closing a contact on P2-4 and P2-5. When the current relay detects 6A, its contact (CTR1)opens. This will de-energize the coil (CR1). The normally closed contact on the inhibitor circuit closes and shuts off the drive. The user will want to turn the 4pdt switch to the off position and hit the reset button to reenergize the coil (CR1). Normal operations will have the coil (CR1) energized and the inhibitor contact (CR1) opened. Figure 10 gives a view of the push button and figure 11 gives a view of the relay

Figure 10: E22PB1A Normally Open Push Button

This push button is normally open [22]. An operator uses this push button to energize the coil and allow the normally closed contact to open on the inhibitor potion of the device. This button can also act as a way to restart the device when current relay trips the drive and shuts off the device.

Figure 11: DCS1000-1C-24-F Relay

The electric reel design uses the relay to safely turn off the drive due to tension on the string. [21]. Figure 11 gives a view of the relay. Running operation occurs when the coil is energized. This closes the NO (normally open) contact and opens the NC (normally closed) contact. The NO contact closes and latches the power to the coil. As a result, the NC contact will latch open and allow the electric reel to run. The electric reel will not run when the coil deenergizes because the NC contact closes on the inhibit part of the circuit.

Another important component of the electric reel is the 24V battery source. The electric reel uses two SLA 12V, 8AH rechargeable batteries in series to produce the 24V. Figure 12 gives a view of the 12V battery. The 24V source supplies electrical energy to the current relay, the DC Variable Speed Drive, the motor, and the tripping branch. Tripping branch refers to the branch with the relay coil and the current relay in series with the push button. Figure 30 displays the batteries supplying energy to the branch. The lifetime of the batteries relates to equation 2.

Figure 12: SLA 12V, 8AH Battery

AH (amp hours) is the measurement of capacity for a battery. Theoretically, if the motor is continuously pulling a full load of 12.2 A, the batteries would need to be recharged in about 40

minutes. The electric reel's motor typically pulls around 4 A in normal operation, which is 2 hours of continuous running time.

$$(current)(time) = capacity \qquad (4.2)$$

Figure 13 displays a decaying function as the motor is pulling more current. The batteries will require recharging sooner when the motor pulls more current.

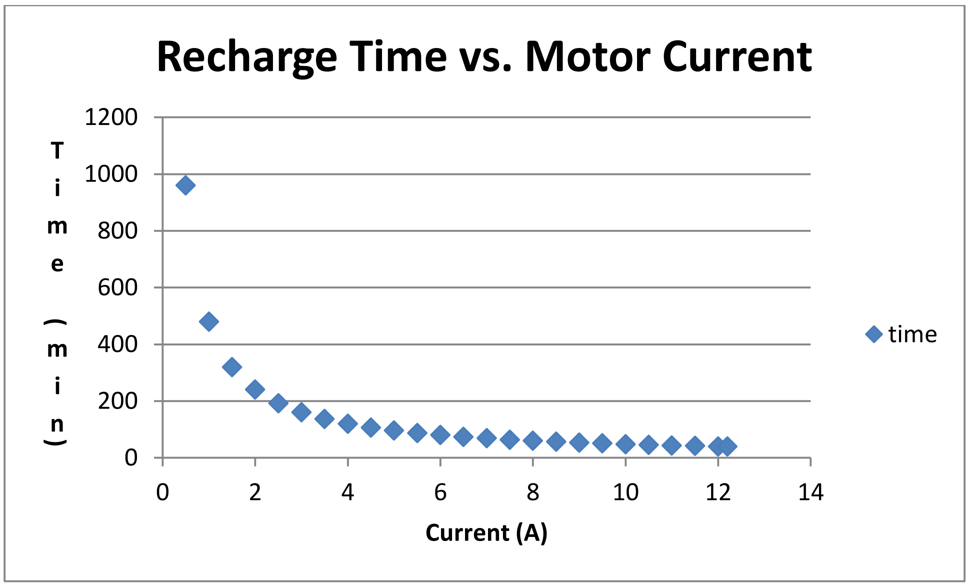

Figure 13: Time until Recharging Battery vs. Motor Current

Chapter 5: Building and Testing

I went through a design, build, and test process to verify the function of the electric reel. The first process involves connecting the electrical components together and demonstrating the motor function with user input. An ohm meter verifies connections and a voltmeter checks the electrical qualities of the hardware. Lastly, I build a structure that securely and safely houses the entire design. This completes a fully operating electric reel.

5.1 First Design, Build, and Test

The first design, build, and test of the project involve building the hardware. This requires connecting all of the electrical components. Figure 30 represents the schematics of the hardware. An Ohm meter verifies the connection of the potentiometer in the enclosure. Wires from the potentiometer, push button, 4 pdt switch, and ground come out of both sides of the enclosure. These wires tie to terminals and connect to the rest of the hardware. I use an ohm meter to test the connections of every component. For example, an ohm meter verifies the continuity of the connection to determine whether the breaker is closed. An ohm meter visually displays when there is an open or closed connection. The ohm meter also determines the NC and NO contacts of the relays through visual inspection. A volt meter determines the battery supply voltage.

I connect and test the electrical design after I verify the components operate. This involves cutting, stripping, crimping, and labeling wires during the building phase. The control wires require 16 gauge wires, and the power wires require 14 gauge. I use the ohm meter to check the connection of the wires to the hardware. This requires me to flip the switch and press the push button to verify an open and a closed connection. The device is off while this testing occurs.

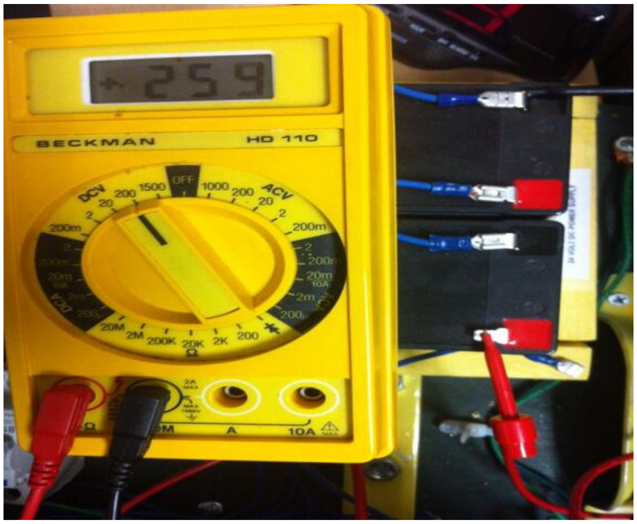

Figure 14: Verifying Voltage across Battery Supplies

After verifying proper connections without power, I power the device on to view voltage readings. The battery voltage reads 24V. Figure 14 demonstrates a working voltage supply for the device. This battery powers the terminals after turning the breaker on. A volt meter views the battery powering the DC Variable Drive, current relay, and the terminal. Next, I energize the relay coil by pressing the push button. The mechanical relay clicks. This means the NO contact latches and the electric reel operates. The adjustment of the potentiometer certifies the motor's speed varying with human interaction. The electrical function of this device works at this point.

The testing process requires the adjustment of the DC Variable Speed Drive and the current relay potentiometers. The DC Variable Speed Drive manual advices someone on how to adjust the trim potentiometers on the drive [15]. The trim potentiometers control max speed, minimum speed, current limit, acceleration, and I.R. compensation. The current relay uses a potentiometer to trigger the NC contact to open and shut off the electric reel. I put an amp meter in series with the armature of the motor to read out how much current the motor is pulling. Figure 18 displays a jumper that an amp meter can easily replace to readout current. I set a trigger point on the pot of the current relay to trigger when the armature current pulls 6A.

5.2 Construction

Construction of the electric reel occurs after designing, building, and testing the hardware. Constructing the device involves creating the structure and integrating the electrical components onto the structure. The purpose of the construction involves creating a structure that mounts all of the electrical components. The electric reel structure consists of 5/8 inch thick wood. A 10 inch height gives enough room to mount the drive, motor, and the current relay. This wall gives the device an "L" shape that provides separation between the electrical components and the motor action. Two metal brackets hold this "L" shape in place. The flat, horizontal part of the reel holds the rest of the electrical components. The flat portion mounts a relay, a panel, a breaker, the batteries, the terminals, and the handles. A wooden block casing with a strap holds the batteries in place. Handles allow the worker to pick up the device, but the device would work better with a cart rolling the reel around. Figure 14 displays the structure of the device.

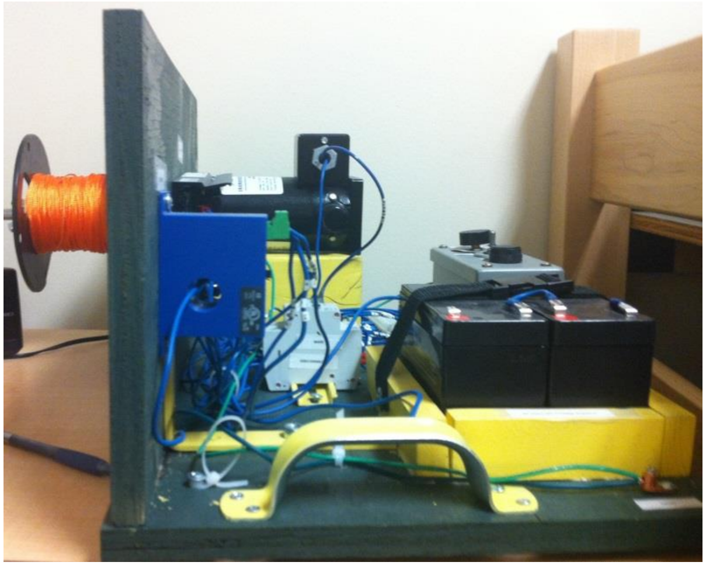

Figure 15: Structure of the Electric Reel

The relay and the breaker easily snap onto a Din rail. Figure 16 gives a picture of a Din rail. This Din rail provides a sturdy mechanical connections for the components, while allowing easy removal if necessary. Wood screws create a mechanical connection between the rail and the wood.

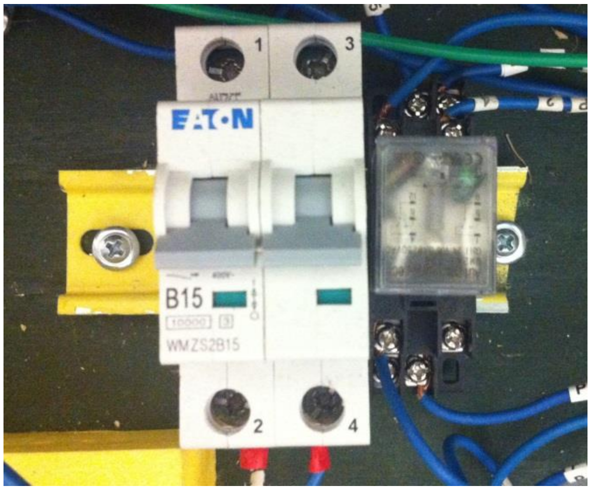

Figure 16: Din Rail with Breaker and Relay attached

A push button enclosure holds the push button, potentiometer, and the switch. These are the three main ways the worker interfaces with the device during machine operation. Holes on the sides of the enclosure provide wires a path to terminal connections. Wires terminate outside of the enclosures. Terminals provide convenient places to terminate wires. Wires connect from the terminals to various parts of the electrical device. There are two terminals that separate the controls (lower current) from the power (higher current). Figure 17 gives a view of the wires coming out of the enclosure.

Figure 17: PBGX3 Push Button Enclosure

A jaw shaft coupling mechanically couples the shaft of the motor to a flywheel. Figure 18 displays the jaw shaft coupling in this project. A wing nut secures the spool in place and provides easy way to remove the spool. This flexible mechanical coupling provides the electric reel with replaceable capabilities. If the worker wants to use another spool to reel in more string, he or she can replace the spool. The electric reel is designed both electrically and physically to give the worker a lot of control of how he or she reels in the string.

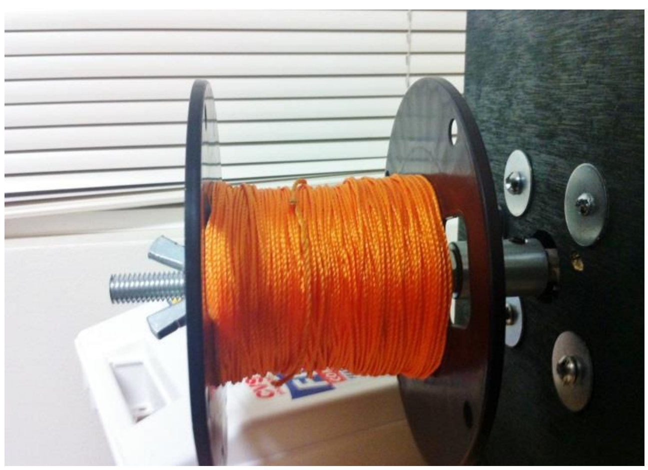

Figure 18: Spool Secured in Place with Wing Nut and Jaw Shaft Coupling to Flywheel

5.3 Final Testing and Tuning

Testing the product after building and integrating involves going through a similar procedure when testing the hardware the first time. An ohm meter verifies connections while the device receives no power. Once verifying connection, a volt meter determines the batteries have 24V across them. Figure 14 certifies 24V across the two 12V batteries in series. I turn on the breaker

to power the device after verifying the 24V across the battery supply. A volt meter determines whether the components are receiving battery power. I put the switch in reverse and slowly increase the variable speed after determining everything has power.

Trim potentiometers on the DC Variable Drive and the tripping potentiometer on the current relay adjust to fit the application of painting a soccer field. To do this, I took the electric reel over to a generic soccer field and went through the process of preparing a soccer field for paint. A worker can adjust the pots directly by seeing the results of rolling up the string at the soccer field. My goal is to roll up the string at a minimum speed of 200 yards/min. The electric reel achieves this target speed. In fact, the max speed of the drive can adjust to a much lower speed and still reach this goal. A worker can go through the same process of adjusting these pots [15]. I adjust the tripping pot to trip the electric reel when detecting 6A of current. To make the judgement of 6A, I had to put an amp meter in series with the armature and see what current comes about under different conditions. I demonstrate the ammeter connections in figure 19.

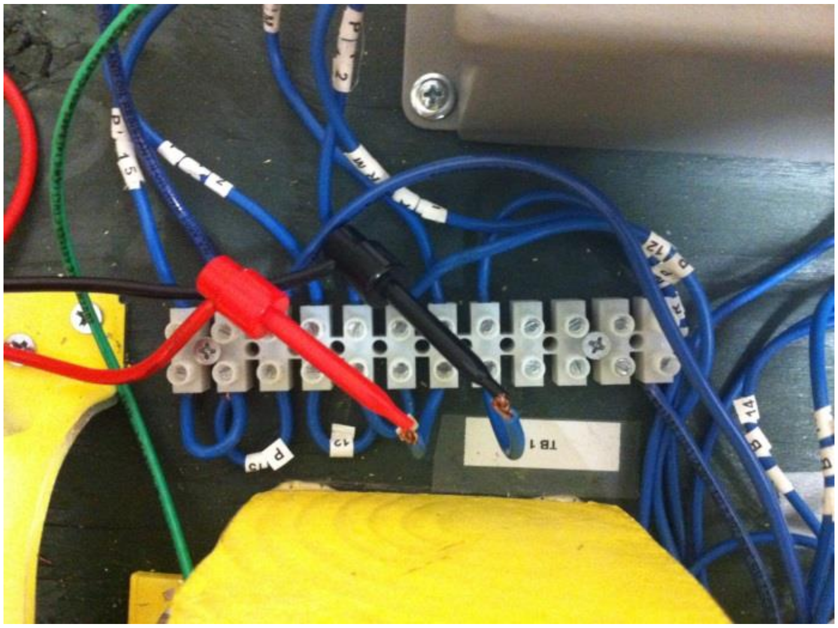

Figure 19: Ammeter Series Connection Used for Testing

A common condition that could warrant tripping the device could come from a string tied to a stake. String may catch on a stake as a worker reels in the string. In effect, I tie string down to a stake and run the reel at an average speed that a worker may reel the string. 6A evaluates to a worthy tripping point when testing the device on a soccer field. Workers can also trigger the current relay by adjusting the pot and visually inspecting when the electric reel trips. Adjusting the tripping potentiometer counter-clockwise makes the device trip earlier and the opposite is true for adjusting the potentiometer clockwise. In effect, the device is user friendly and does not require a significant amount of electrical knowledge to understand how to adjust the tripping point. Figure 29 demonstrates the electric reel testing out on a soccer field.

Chapter 6: Conclusion and Recommendations

The purpose of my project is to create a device that a soccer field production worker could use to boost productivity. CJSL, a soccer organization, could save a lot of money if they implement the use of this device. My senior project analysis addresses the benefits that an electric reel can have economically, socially, and environmentally. I hope the device will effectively decrease the cost of producing a soccer field. If this happens, this could mean lower costs for the players who play soccer. Players may have more ability to play soccer if the costs are lower. I think that more players playing soccer will have a positive effect socially. Children can benefit with from exercising and socializing with friends. If the creation of the electric reel decreases the cost on parents, I will feel largely successful with my project.

I had to go through a process of designing the electric reel before I could start making the product. Before I could design the electric reel, I had to understand my customer needs. Customer needs were easy for me to determine as a worker because I know how workers will incorporate this device into field painting. I want the device to be controllable, safe, and moveable. The device controls need to be able to change direction and change speed if necessary. If there is too much current in the armature, the worker has to have an ability to reset the device to allow normal functions again. This device shouldn't harm anyone in any way and be able to move with the worker.

I went through a phase of determining the function of the device after understanding the customer needs. Level 0 and level 1 block diagrams display the function of the electric reel. These block diagrams display inputs going into the block and outputs going out of the block. I add a Variable Speed Drive to give the user control of the reel. A worker is able to adjust the trim potentiometers on the drive and control the output to the motor of the device. If the device triggers off, the user is able to reset operations by pushing the push button. The breaker provides safety in wires by not allowing more current than the wires can handle. A current relay allows the device to trigger off when detecting a disturbance in the line. This provides a safety feature by immediately stopping the motor if a person interferes with the line. The device weighs about 40 pounds. This would be heavy to carry around, so I made the device compact enough to wheel around in a cart. I verify all of the customer needs of controllable, safe, and moveable on a soccer field. The device is user friendly and a worker can adjust the drive and current relay to fit their specific needs if the field conditions change.

A guiding system would be one addition to make this device better. Workers have to use their hand to guide the string into the spool with the way my device is set up. I would recommend using a control system capable of guiding the string into the spool. This would probably require a servo motor and an expensive control device, but a guiding system could fully automate the device and make this device more user friendly.

Chapter 7: Literature Search and References

[1] R. Ford and C. Coulston, *Design for Electrical and Computer Engineers*, McGraw-Hill, 2007, p. 37

This book displays credibility because of its usage in EE460. I use this source as a reference when producing this technical document

[2] *IEEE Std 1233, 1998 Edition*, p. 4 (10/36), DOI: 10.1109/IEEESTD.1998.88826

This website displays credibility because IEEE distributes the information on this website. IEEE demonstrates highly respected qualities as an electrical engineering source of information. The information on this website provides information involving guidelines.

[3] Henao, H.; Rastegar Fatemi, S.M.J.; Sieg-Zieba, S.; Capolino, G.-A., "Detection of birdcaging in steel wire rope of a hoisting winch system by analysis of load torque and stator current," Diagnostics for Electric Machines, Power Electronics and Drives, 2009. IEEE International Symposium, pp.1,6, Aug. 31 2009-Sept. 3 2009

This article analyzes the stator current of a three-phase induction machine and the torque in the winch system. The stator generates a magnetic field, which provides the machine the ability to rotate. The electric reel uses torque to reel the string into the spool and the article gives some insight on birdcaging. Birdcaging describes the stress a rope goes through due to the motion of a winch. This article seems credible because the article from IEEE magazine, which demonstrates well-respected organization qualities in the electrical world. I use the details from birdcaging to relate the tension from the winch to the electric reel as it collects the string along the soccer field. This article gives me a better idea about how to mechanical assemble the winch. I use this document to explain how to prevent the string from breaking when rolling up the string.

[4] EE255 class notes provided by Ahmad Nafisi

Professor Nafisi was my instructor for my motors course here at Cal Poly. He provides a great source of information when it comes to understanding how a motor and its electrical components work together to produce the electrical device. Prof. Nafisi provides information on how to incorporate the motor and motor drive into the electric reel. I use his information to understand how to efficiently distribute power to the electrical device as well. He provides a credible source of information because he received his Ph.D. degree in Electrical Engineering from University of Southern California in 1983

and has experience in teaching at Cal Poly since 1984. From listening to him class, I have seen that he explains motors and power systems well. I use his knowledge to gain a better understanding of how to put together my device and use his information to support my explanation about how the device functions in my final paper.

[5] Chapman, Stephen J., "Induction Motors" in *Electrical Machinery Fundamentals*. 5th ed. United States of America: Macgraw-Hill, 2011. Print.

In addition to having a professor involved in motors, I use the book from EE 255 often to research details involving the functionality of my electrical motion. The book emphasizes electromechanical devices, which relate to how the electrical device functions. I use this book to effectively explain how this device boosts time efficiency by collecting the string quickly with the use of a motor. Fundamental ideas of induction motors can give a general understanding of how the motor operates. This book provides credibility because the source has a high h-index. Power courses in electrical engineering use this book in the course. The use of this book in the power courses add to the credibility of the source.

[6] Srisertpol, J.; Khajorntraidet, C., "Estimation of DC motor variable torque using adaptive compensation," *Control and Decision Conference, 2009. CCDC '09. Chinese* , pp.712,717, 17-19 June 2009

This article provides informative information on DC motors and torque. I want to use this information as a source describing how a DC motor operates. The article explains how variable torque can affect the efficiency of the motor. The electric reel uses a DC source and some of this information provides useful explanations about how the device sets up. I hope to use this source to relate my DC device to the device in this article.

[7] Bayoumi, Laila, and Youngseog Lee. "Effect of Interstand Tension on Roll Load, Torque and Workpiece Deformation in the Rod Rolling Process." *Journal of Materials Processing Technology,* 145.1 (2004): 7-13.

This article contains useful information involving torque and tension. Specifically, it involves tension caused from the rotational force. Rotational velocity results from torque in the machinery. This source provides credibility because it demonstrates a peer reviewed status according to the engineering search engine at Cal Poly's library. This document describes useful details for the project because the torque and tension in this document relate to the physics involved in a winch. I hope to use this document to incorporate ideas of torque and tension into the design.

[8] Hai Liu; Zhenqing Zhao; Qiang Chen; Jianwei Zhou; Maohua Du; Senyun Kim; Jonghyun Chae; Myungkee Chung, "Reliability of copper wire bonding in humidity environment," *Electronics Packaging Technology Conference (EPTC), 2011 IEEE 13th* , vol., no., pp.53,58, 7-9 Dec. 2011

This article explains how copper wire contains an important way to bond a circuit together in an inexpensive way. A mixture of copper and aluminum wiring may cause open circuits, which can cause the circuit to fail. Copper wire seems able to provide the connection to make a circuit work properly. This source displays credibility because this IEEE article comes from a credible, respected electrical engineering organization. I use this article to suggest that copper wiring demonstrates the best choice when making the electrical reel.

[9] Gear Motors, P , 19:1 Gear Motor w/Encoder. Retrieved: October, 2014 Available: http://www.robotshop.com/media/files/pdf/datasheet-1442.pdf

This manufacturer data sheet adds to the details relating to the gear motor. A gear motor provides a critical part of the electrical reel. This document gives a perspective on some of the details relating to the torque, speed, and size of the gear motor. This document demonstrates credibility because the manufacturer data sheet comes from a commercial website. Specifications should provide correct in order to sell the product commercially. There would create a lot of legal questions if the specifications were not correct. I chose this datasheet because the gear motor seemed reasonable with the quality of torque and speed needed.

[10] Peter B. Lindgren, “Deep water fishing rod and electric reel,” U.S. Patent 6 931 781, July, 17, 2009

This patent adds a viable comparison to the electric reel. This fishing rod has different applications than the electric reel, but has helpful information having similar applications to the electrical reel. A fishing rod has a much larger load than the field painting electric reel, but both inventions have the job of reeling string. Comparing both designs help build a stronger electric reel for field painting. This patent provides credibility because the patent has a primary examiner and attorney attached to the patent. The patent demonstrates a reviewed documentation and has parent cases from the past relating to the present invention.

[11] Prall, M.; Johren, R.; Hannen, V.; Ortjohann, H.W.; Reinhardt, M.; Weinheimer, Ch., "Contactless 2-dim laser sensor for 3-dim wire position and tension measurements," *Nuclear Science Symposium Conference Record, 2008. NSS '08. IEEE* , pp.1025,1029, 19-25 Oct. 2008

This article demonstrates tension detection via light. A light sensor uses light to determine the position and light reflection on the rope. Information about tension digitalizes as information for later use. This sensor seems helpful and contains relative to the electric reel senior project. A marketing requirement involves sensing tension in the string to prevent the string from snapping. This source displays credibility because of the quantity of authors and its affiliation with IEEE. IEEE appears as a credible organization relating to electronics.

[12] Cezario, C.A.; Silva, H.P., "Electric motor winding temperature prediction using a simple two-resistance thermal circuit," *Electrical Machines, 2008. ICEM 2008. 18th International Conference on,* pp.1,3, 6-9 Sept. 2008

The purpose of this IEEE article demonstrates how temperature relates to the motor. Temperature control contains important relevance to prevent the motor from becoming too hot and damage the motor. This source provides credibility because the source appears as an IEEE article with multiple authors. The source contains fairly recent information within the recent decade. This adds to the credibility of the source because the information seems more recent and relevant. I use this source to better understand how to control the temperature that relates to the motor.

[13] Martin, Craig, MD, "Vol. 51, No. 7". Retrieved November , 2014 Available: http://www.bcmj.org/worksafebc/updates-worksafebc

Source comes from an MD and helps give a better understanding of safety concerns of when general pressure cuts the skin.

[14] Kjaer, B , " ". Retrieved November , 2014 Available: http://www.bksv.com/doc/br0094.pdf

Source seems credible because the written source comes from a doctor. This document explain mechanical vibrations.

[15] Ironhorse. (2013, 12 12). “GSD1-12-20C Open-Frame Drive” [Online]. Available: http://www.automationdirect.com/static/manuals/ihdcdrivem/gsd1-um.pdf

[16] Ironhorse. (2014, 3 4) “MTPM-P25-1JK40 24V 1/4HP DC motor” [Online]. Available: http://www.automationdirect.com/static/manuals/ironhorsedcmanual/ironhorsedcm.pdf

[17] GSD. (2014, 4 16). “GSDA 5k pot” [Online] Available: http://www.automationdirect.com/static/specs/gsddcdacc.pdf

[18] Carling Technologies. “H/I Series Toggle switch 4pdt” [Online] Available:

http://www.mouser.com/ds/2/65/H_I-SeriesSW_Details___COS-370160.pdf

[19] Eaton. (2014, 4 16). “WMZS Supplementary Protectors Breaker” [Online] Available: http://www.automationdirect.com/static/specs/suppprot1p3p.pdf

[20] ACUAmp. (2014 10 22). “DC Current Switch Transducer” [Online] Available: http://www.automationdirect.com/static/specs/acuampdcs100.pdf

[21] QM. (2014 4 16) “Electromechanical Relay” [Online] Available: http://www.automationdirect.com/static/specs/qmrelays.pdf

[22] Eaton. (2014 4 16) “Non-illuminated push button” [Online] Available: http://www.automationdirect.com/static/specs/eaton22mmni.pdf

Appendix A: Senior Project Analysis

Project Title: Electric Reel
Student's Name: Stephen Taylor
Advisor's Name: Ahmad Nafisi

1. Summary of Functional Requirements

The electric reel boosts the efficiency of soccer field production. The device holds at least 400 yards of Darice Polyester Kite String. This device weighs about 40 pounds, and the dimensions do not exceed a cubic yard. Motor provides no torque when discovering 6A of current through the armature of the motor. Triggering at 6A is a safety feature of the device and the device will turn off if the armature pulls more than 6A. This electric reel is fail safe and does not harm the worker when power is disconnected. The device collects the string at a rate of at least 200 yards/min. A worker can power the device on and off. Variable reel speed gives a worker the ability to adjust the speed of the motor and guide the string into the spool.

2. Primary Constraints

String tension detection makes the project more difficult. I want to detect when half tension opposes the rotation of the motor. This constraint provides important safety and performance qualities. Opposing string tension can come from many things, but the main objects of focus would involve a person or a weed. Weeds seem common on a grassy soccer field and I would want the motor to stop rotating if the string catches on a weed. I would want the motor to stop for safety reasons if the string catches a person while reeling in. The tension constraint may seem difficult to determine fully due to varying obstacles. Tension detection has to account for both possibilities of people, weeds, and various other opposing obstacles.
The weight of device weighs less than 40 pounds constrains the weight of the object. This makes the physical construction of the device more difficult. Although, the physical dimensions and weight limitations seem reasonable to produce the electric reel. Two 12V batteries and the motor alone weigh about 15 pounds. This means that 25 pounds must make up the rest of the electric reel.

3. Economic

Economic benefit can come from the production of the electric reel. For example, workers, sporting organizations, players, referees, schools, and parents may produce economic flow. This flow of economic production can help provide jobs to people. Parents pay money indirectly to the people producing the soccer fields by paying fees. Soccer organizations pay the workers to

produce the soccer field. Cash flow would move from the parents to the soccer organizations and the workers.

Economic good can also come from the production of the electric reel. Motors, wood, hubs, screws, spools, strings, sensors, batteries, motor drives, switches, relays, and breakers contain parts of the electric reel. The costs in time come from mostly salary and the fixed costs come from materials that make up the electric reel. Benefits come over time from the manufacturing and selling of the product. Table V displays the cost estimates in the project and includes only the labor costs for assembling the reel. The project costs $1866.53 overall with labor and materials. Labor costs $1200 of the total cost and the project involves 60 hours of assembling time at a rate of $20/hr. The cost of the raw materials is $666.53. Cost analysis in Appendix B supports the idea that CJSL should invest in the electric reel.

I am capable of selling the reel to other sporting organizations that benefit from buying the electric reel as well. The process of producing the electric reel lasts until the end of May because senior projects finish around May. An electric reel can contain durable traits useful enough to last for a decade in field production. Costs of maintenance should involve minimal fixing because the 12V batteries are rechargeable and electrical components provide protection. For example, the breaker prevents the batteries from supplying any more than 15A of current. The user needs to clean the electric reel and replace on the spool to maintain quality usage. Paint can dry and cause the string to stick together, which impedes the process of unwinding the string.

4. If manufactured on a commercial basis

Numerous sporting organizations exist globally. Soccer dominates globally throughout the world and soccer requires a field with boundaries. Workers line soccer fields with string to produce straight lines and there exists a demand to produce soccer fields in the world. Tens of thousands of various sporting organizations that involve painting a field would contain interest in the electric reel. I estimate that five thousand reels could sell by the end of the soccer seasons in February 2016. Currently, the cost is$666.53 in cost of materials and $1200 in cost of labor. Manufacturing cost can reduce the cost in labor with a more efficient way of producing the reel. The labor cost involves too much cost if someone individually has to produce the reel. There may need to be some automation to produce the reel at a faster rate. I estimate $50 in manufacturing cost for the production of each individual electric reel. This would take the place of the cost of labor. I estimate that each electric reel costs $1000. Profit can estimate to $10,000 from sales Central Valley soccer organizations for the organizations buying the electric reel. The $10,000 comes would come about if 40 devices sell with a profit of $250 from each device. The estimated cost of running the device involves the cost of a 12V battery over a three month time span. This cost comes from the cost of recharging the batteries after full use.

5. Environmental

The electric reel does not involve many environmental impacts, but the reel may kill some insects. A bigger environmental impact may come from the usage of batteries. These batteries have to go somewhere if the batteries become unusable and the batteries may end up in landfills. Batteries would seem to carry the most environmental concern, but there involve more concerns as well. The device directly affects insects due to the motion of the string along the grass. Indirectly, this may affect the growth of the bird population because insects could lead to less food for birds.

This project may also have a positive effect on the environment. The project does not use any natural resources, but may limit the amount of work days. In effect, there may involve less days of work to paint soccer fields. Assuming the workers drive to soccer fields, this creates less gas emissions into the environment. This may reduce the amount of gas required to complete a soccer field and produce a positive effect on the environment.

6. Manufacturability

Manufacturing an electric reel may involve a difficult process. Mounting the motor to the reel most likely involves some labor work. Automation seems useful when producing the platform, but integrating the sensor, panel, and battery into the reel requires labor. Engineering labor can involve expensive work and create more cost, which decreases the manufacturability of the product. The challenge from the project involves designing the reel in such a way to reduce the amount of labor required to manufacture the product. An effective form of automation can help decrease the cost of production and boost the manufacturability of the electric reel.

7. Sustainability

The device should maintain temperature, but heat may appear challenging when maintaining the device. A motor may require some temperature control if the motor runs for a long time to sustain the device usage. The materials that make up the electric reel involve wood and metal. Metals melt are reusable and easier to recycle than some of the other materials in the electric reel. For example, the use of wood affects sustainability if new trees do not replace the old trees. Some upgrades for the design could come from making the platform out of a dielectric material that does not involve wood, but wood seems easier to connect the project physically together. Temperature control involves another nice upgrade to the device that may improve the life of the electric reel as a product.

8. Ethical

Some ethical challenges involve safety. The IEEE code of ethics state that engineers need to make decisions to ensure safety and welfare for the people. A fast moving string creates danger on a crowded field of people. The device contains an ability to detect tension and stop moving the string, but subtle contact with the string may not detect the presence of a person. This device requires the user to know their surroundings and adjust the speed of motor according to the risk. For example, the motor should not move as fast if a potential risk to injure someone presents itself. The best way to quantify risk would come from the density of people on the field. A user would not want to run the motor at all if bystanders are present. Other workers familiar with the device involve lower risk of injury from the moving string because the workers are aware of the devices presence. Users should apply the golden rule principle when using the device and demonstrate awareness of the presence of people and move the string in a way that makes other people comfortable. I would not want a really fast string moving any less than 5 yards away from me so I would decrease the speed of the string around other people if the string moves this close to others.

Soccer organizations pay workers less overall if the job finishes quickly because the workers receive an hourly wage. The electric reel should make soccer field painting take less time. In effect, soccer clubs pay workers less because the job will take less time. This would create an ethical dilemma because the workers may think it is not fair to pay the workers less when completing the same job. Utilitarian principles may argue for the same payment for the workers to maximize happiness. The soccer organization has the same amount of happiness from the completion of the job, but the workers have more happiness from the same amount of payment. Workers have more happiness because the workers receive the same payment for a job requiring less time. On the other hand, others may argue that happiness will decrease with the soccer organizations due to the cost of the electric reel. Utilitarianism may involve difficulties in proving what maximizes happiness in this dilemma. I would argue to pay the workers the same amount because most of the workers use the money they earn from painting fields to pay off soccer club fees. This should support the idea that more happiness would come from paying the workers the same amount because the soccer club receives the money back.

9. Health and Safety

As mentioned in the ethical section, I think the major safety concern involves the fast moving string. The electric reel functions to give the user a lot of control to judge any potential obstacles. A user needs to judge any people in the surrounding and control the speed of the reel according to the threat. The tension detector supports the user if something unexpected opposes the motion of the string, but the user needs to judge each situation well and not depend on the detector.

Safety concerns come from the temperature and the vibrations of the device. This electric reel needs to dissipate heat in an effective way. A breaker prevents the battery from supplying 15A of current. This will prevent the wire the current from damaging the wire. The user needs to also pay attention when the motor of the electric reel moves the string. Motion from the motor may cause the electric reel to shake, which may make the device uncomfortable to hold. The user may accidently drop the electric reel on his or her foot. This would cause a great safety concern if the electric reel drops on someone's foot while in motion. I use a cart to wheel the electric reel around to provide stability to the system.

10. Social and Political

This electric reel has a large impact socially, but not too much politically. The project impacts soccer organizations, workers, field directors, event directors, schools, children, adults, players, referees, and parents as direct stakeholders. Indirect stakeholders include the companies that make paint, wood, motors, screws, bolts, spools, string, batteries, and metal. The companies that make all of the parts of the electric reel are indirect stakeholders. This project benefits the direct stakeholders by giving some of the stakeholders a job. Workers, event directors, field directors, and referees have jobs from the production of soccer fields. The reel can benefit how well the field appears to the consumers. This effective tool can remove the inefficiencies from reeling the string by hand and allow the workers to focus on other tasks. In effect, the production of the electric reel creates a mutual benefit for the soccer organizations and the players who use the fields. The players enjoy the field and the soccer organization enjoys the business. Indirect stakeholders enjoy the business involved in producing the electric reel. As discussed in the ethics section, the payment of the workers may contain some political dilemmas. The soccer clubs may pay the workers less.

11. Development

There are three large ideas of development during the establishment of this project. I had to learn how to drive the motor, trip the motor, and protect the wire. A Variable Speed Drive controls the operation of the motor. Trim pots allow the worker to adjust max speed, minimum speed, current limit, acceleration, and I.R. compensation. I had to learn how to set these different trim pots to adjust the motor to a working condition. Tripping the motor requires a current relay that changes a contact when discovering a certain amount of current. The drive turns off the device when the inhibit connects to common. I had to discover how to create a tripping branch to turn off the device when too much current travels through the armature of the motor. I did this by putting the current relay contact in series with a relay coil and a push button. The push button energizes the coil when the current relay trips the motor. Lastly, I had to discover how to protect the wires from pulling too much current. I did this by adding a breaker to the battery supply. The breaker will open if more than 15A travels from the battery supply to the device. This was an easy solution to protecting the wires. I enjoyed the discovery creating the tripping branch the most.

Appendix B: Cost Estimate and Gantt Charts

TABLE V: COST ESTIMATES

Number	ITEM	Quantity	Unit price (US $)	Total Cost(US $)
1	Open frame driver	1	180	180
2	Motor	1	121	121
3	Potentiometer	1	14	14
4	4pdt switch	2	23.14	46.28
5	Selector/Inhibitor switch	1	7.25	7.25
6	Breaker for battery	1	18	18
7	Din Rail	1	9	9
8	Pushbutton enclosure	1	51	51
9	DC Current Switch	1	93	93
10	DPDT 24VDC RELAY	1	4.75	4.75
11	MOUNTING SOCKET	1	3.25	3.25
12	NO PUSHBUTTON	1	17	17
13	12 VDC BATTERY	2	18	36
14	Wire (14/16 AWG)		30	30
15	Wood			15
16	Frame	2	5	10
17	handles	2	3	6
18	screws, bolts, assembly			20
19	labor (20 dollars hour)		60 hours	1200
Total Cost	**$1866.53**			

Table V lays out the initial costs for the electric reel. The goal for this economic analysis is to determine whether this project is economical to produce and sell to a consumer. Figure 19 displays a view of an initial investment for the project and the annual benefits come from efficiency cost savings. This would be in the view of a consumer purchasing the product and using the electric reel over time.

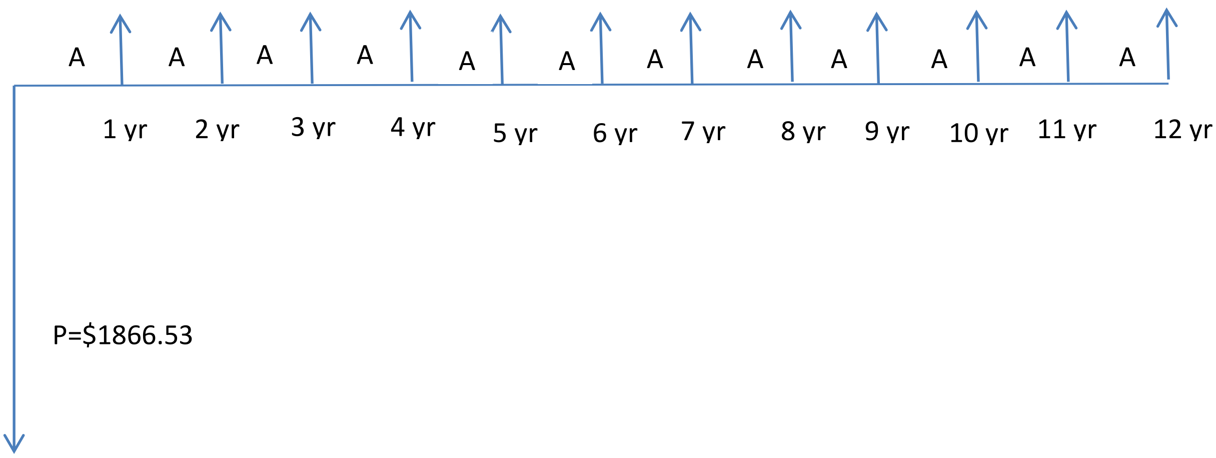

Figure 20: Distribution of Annual Benefits

Analysis 1: How many years will it take to earn the money back on this investment given A=$500?

Figure 20 is a pictorial view of this problem. $500 is a reasonable amount of money the soccer club could save each year by using the electric reel. Given that the interest rate is 6%, I can evaluate the cost and benefit ratio. A cost and benefit ratio of 1 means that the costs equal the benefits. As a result, this means the benefits must equal $1866.53. The annual benefits in figure 19 translate into a present value benefit in figure 23. Equation 3 converts the annual benefits over a certain time range into a present benefit.

$$Present\ Benefit = \frac{(1+i)^n - 1}{i \times (1+i)^n} \times A \qquad \text{eq (3)}$$

n = number of years
i = interest rate
A = annual benefit

The benefits will be $1732 in 4 years and $2106 in 5 years according to equation 3. This means that the device will take somewhere in between 4 to 5 years of work to make this investment worthwhile. These results mean that the soccer organization will earn most of their investment back in about 4 years. Figure 21 demonstrates how the consumer will save money over time

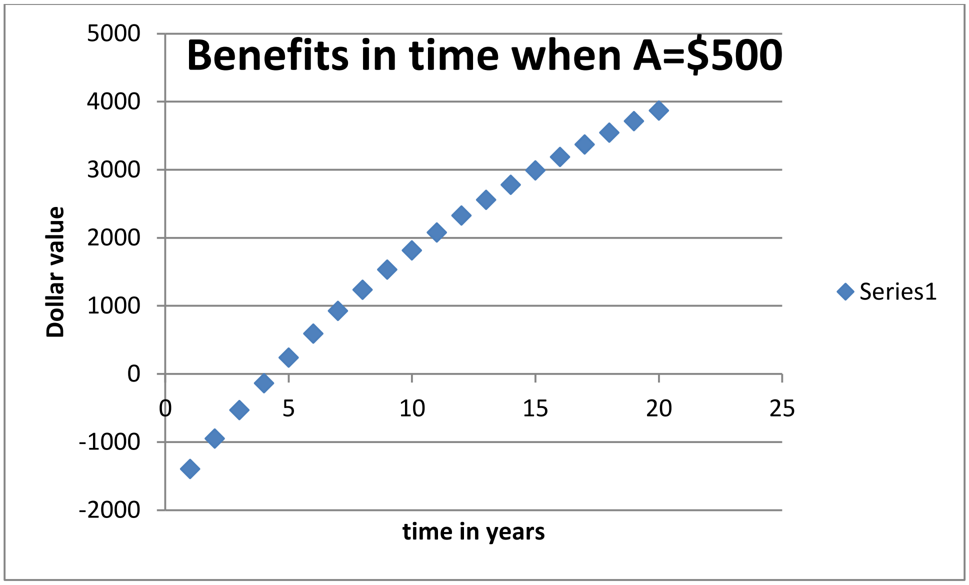

Figure 21: Benefits in Time when A=$500

Analysis 2: What if the selling point to the consumer was when their investment would be returned?

The return of investment may be a selling point to the consumer. What annual rate would the return have to be if the consumer would like their investment returned in 5 years?

$$Annual\ benefit = \frac{i \times (1+i)^n}{(1+i)^n - 1} \times Investment \qquad \text{eq (4)}$$

$$Annual\ benefit = \frac{.06 \times (1+.06)^5}{(1+.06)^5 - 1} \times \$1866.53$$

$$Annual\ benefit = \$443.11$$

The annual benefit would have to be at a rate of $443.11 for a consumer to receive their investment in 5 years.

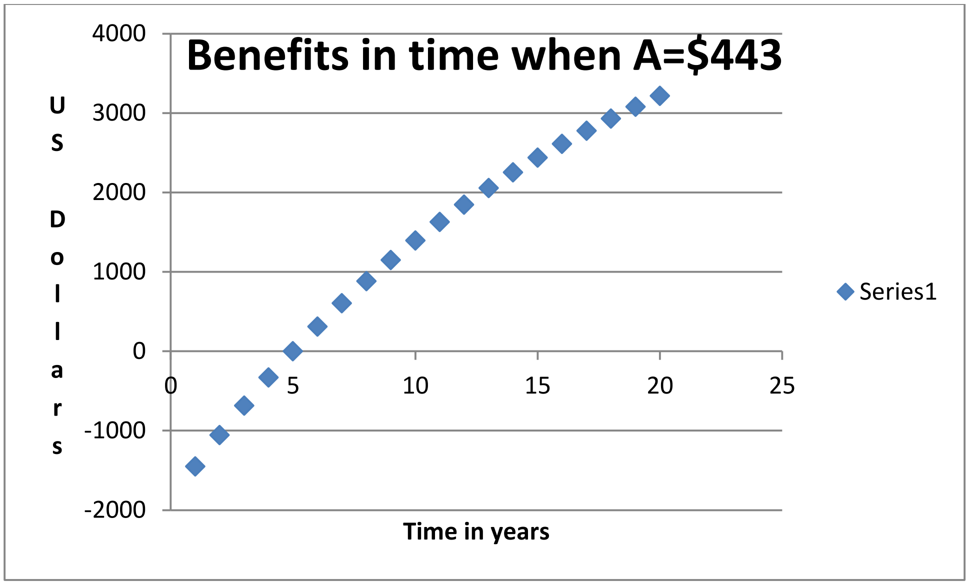

Figure 22: Benefits in time when A=$443

Analysis 3: What is the lowest annual value benefit until a consumer will never return their investment?

$$Investment = \frac{A}{i} \qquad \text{eq (5)}$$

$$A = Investment \times i = \$1866.55 \times .06 = \$112$$

The third analysis demonstrates that an investor will benefit eventually over time if the annual benefits are greater than $112. Equation 5 represents a relationship between investment and annual benefits when the years of use for the product is infinite. This is helpful when arguing to a consumer to invest because an annual benefit of $112 is an easy target to reach. If time is not an issue to a customer, this analysis could help lead the customer to invest.

Figure 23: Annual Benefits put into Present Value

Gantt Charts display information below in figures 24, 25, and 26 to demonstrate how the time on the project distributes.

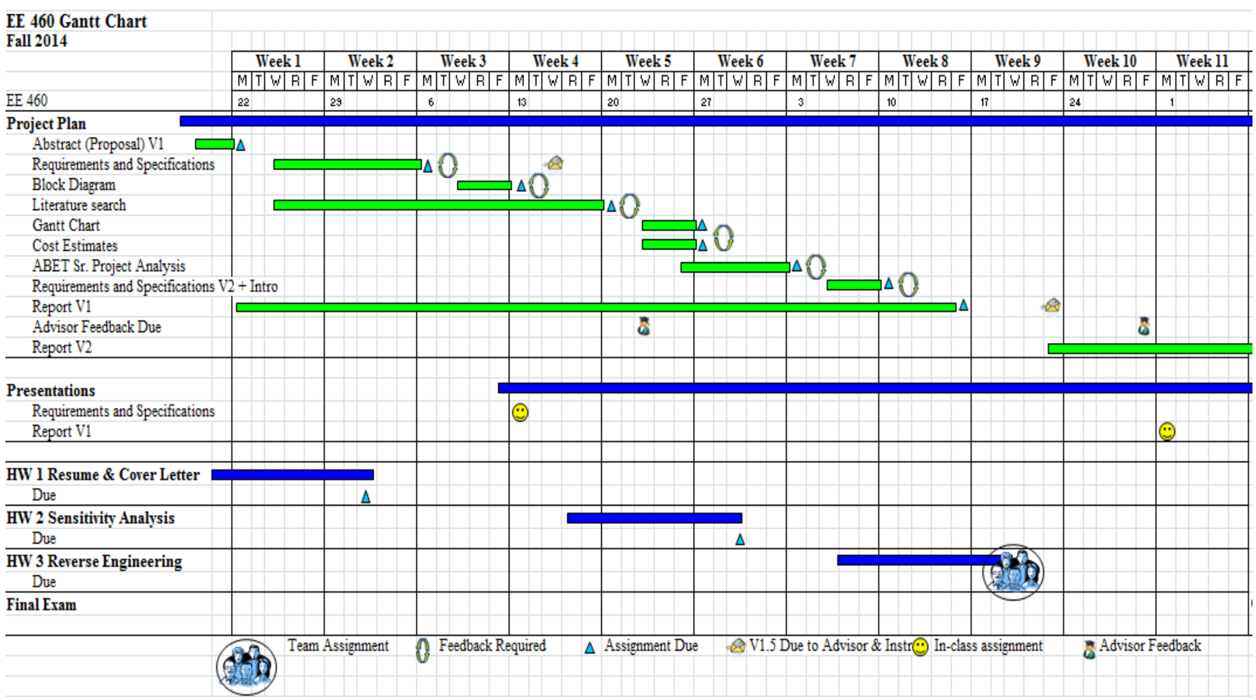

Figure 24: Fall EE 460 Gantt Chart

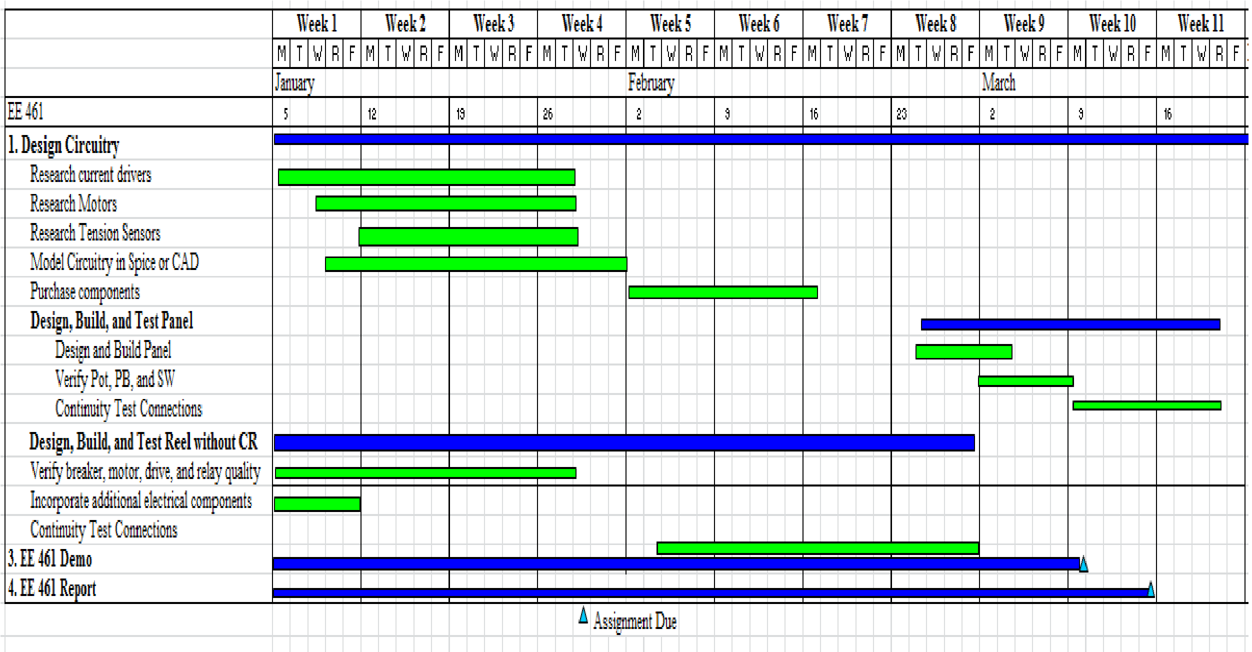

Figure 25: Winter EE 461 Gantt Chart

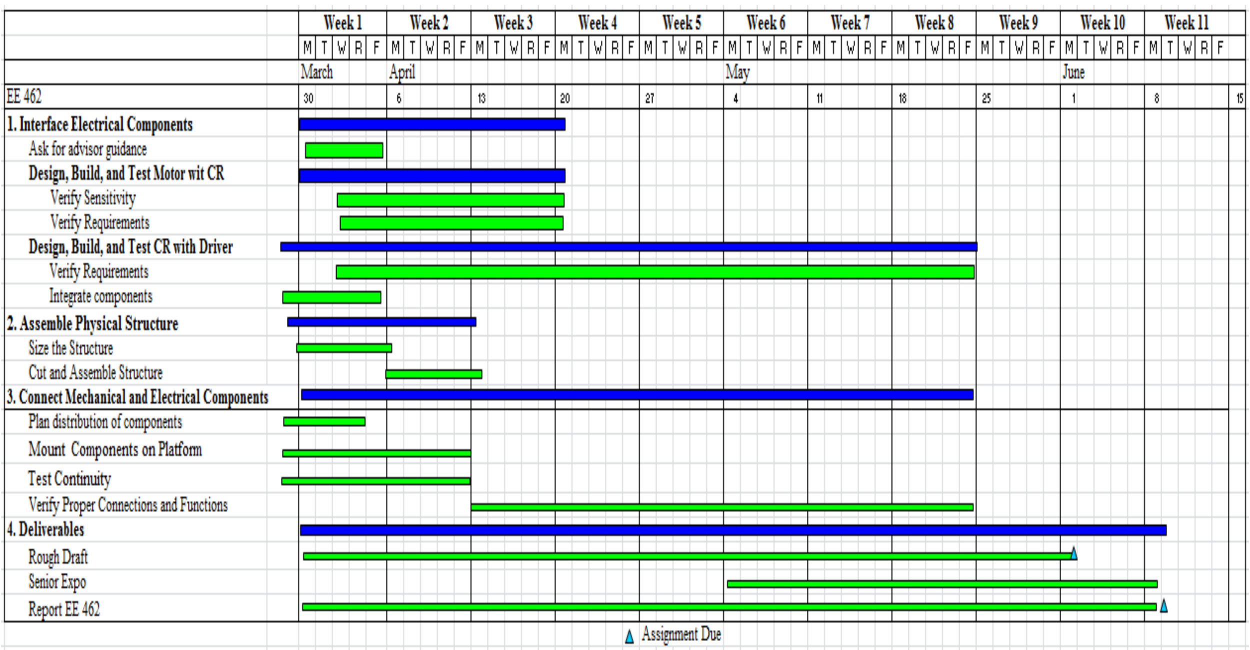

Figure 26: Spring EE 462 Gantt Chart

APPENDIX C — PROJECT PICTURES

Figure 27: Motion Side of the Reel

Figure 28: Electrical Side of the Reel

Figure 29: Electric Reel Testing on Soccer Field

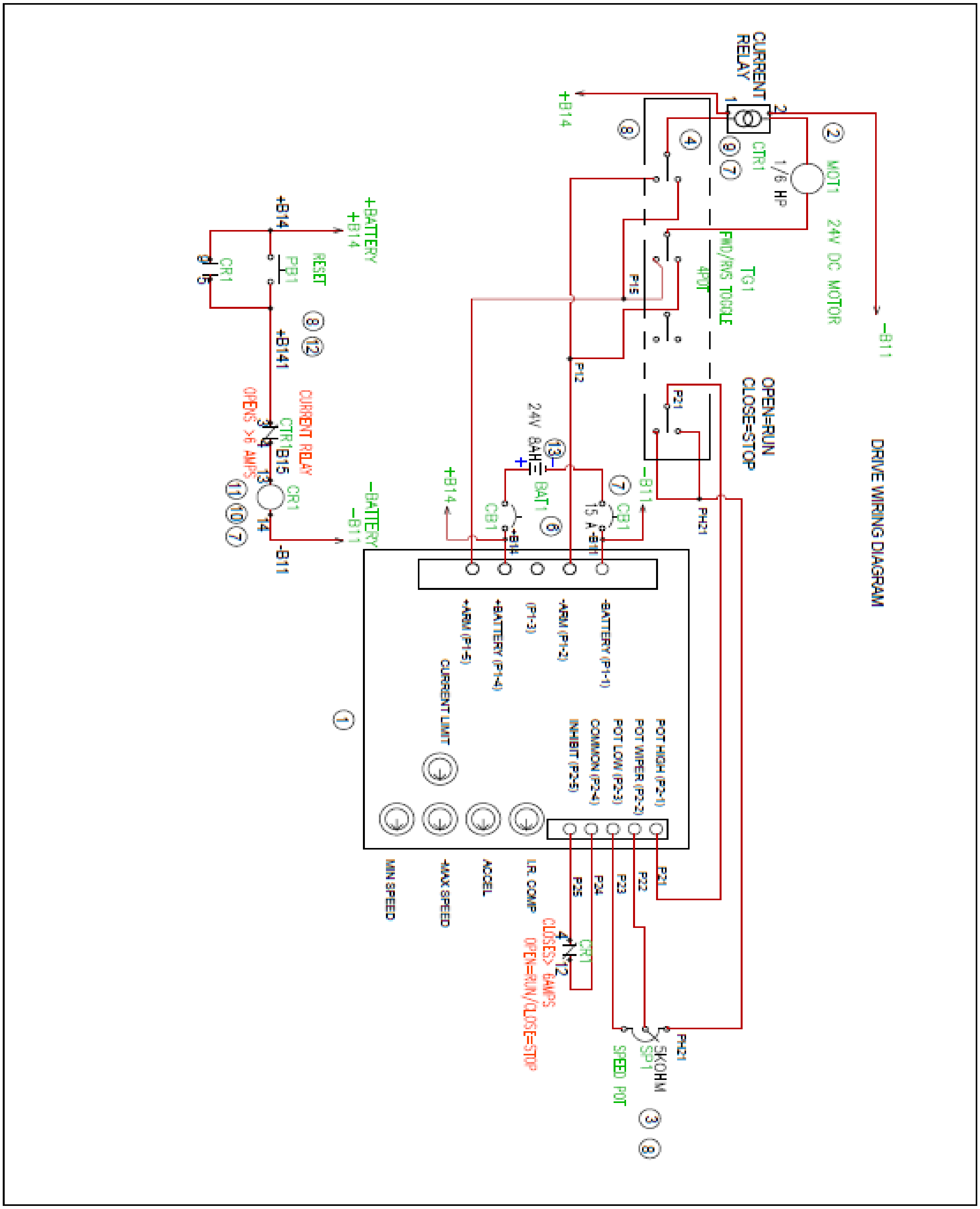

Figure 30: Electrical Schematic of Electric Reel