Title

Increasing Structural Integrity of Aluminum Conductor Steel Reinforced (ACSR) Transmission Cables with Easy to Install Carbon Fiber Materials

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Increasing Structural Integrity of Aluminum Conductor Steel Reinforced (ACSR) Transmission Cables with Easy to Install Carbon Fiber Materials

A dissertation submitted in partial satisfaction of the

Requirements for the degree Master of Science

in Mechanical Engineering

by

Garrett Charles Diulio

2021

ABSTRACT OF THE DISSERATION

Increasing Structural Integrity of Aluminum Conductor Steel Reinforced (ACSR) Transmission Cables with Easy to Install Carbon Fiber Materials

by

Garrett Charles Diulio

Master of Science in Mechanical Engineering

University of California, Los Angeles, 2021

Professor Rajit Gadh, Chair

These tests were conducted by UCLA's SMERC (Smart Grid Energy Research Center) lab for ALD Technical Solutions through the CALTESTBED Grant/Project. The structural integrity of transmission cables around the United States of America severely limits how much power can be transmitted. More power means more heat and expansion of the cables. Cable expansion can lead to many dangers, so if there is a reasonably easy to install method of increasing the structural integrity of the cable this could prevent future catastrophes. This paper will describe why, how, and how well carbon fiber can help to achieve safer transmission cables.

The thesis of Garrett Charles Diulio is approved.

Robert M’Closkey

Laurent Pilon

Rajit Gadh, Committee Chair

University of California, Los Angeles

2021

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Introduction

There is currently a large net of transmission cables all over the United States. All these cables have enough power running through them to cause extreme injury and/or death to any living thing that comes in contact. This makes it very important for utilities to monitor a variety of variables that can potentially cause catastrophic failure and injury to the immediate areas around these cables. Transmission cables are constantly emitting heat to the atmosphere as high-power electricity surges through. Utilities currently do not allow their cables to heat up past 100°C because heat causes expansion in the cables and forces them to sag to far down. If the cables sag too much, they can eventually touch trees or other flammable objects and cause large forest fires as is well known to the residents of California. Another danger from these cables expanding is cable slap. If you mix strong winds with expanded cable, these cables can swing and “slap” each other. This is an extreme danger that can also cause destruction to the immediate area. Two tests will be described in detail that will investigate a light weight, easy to install carbon fiber material that will increase the structural integrity of the transmission cables. The test setup, test materials, and results will all be discussed in full detail.

Motivation

For the last 70 years the power requirements for the United States have steadily increased. This increasing power requirement shown no signs of slowing down. In Figure 1 it is shown the power requirements since 1950.

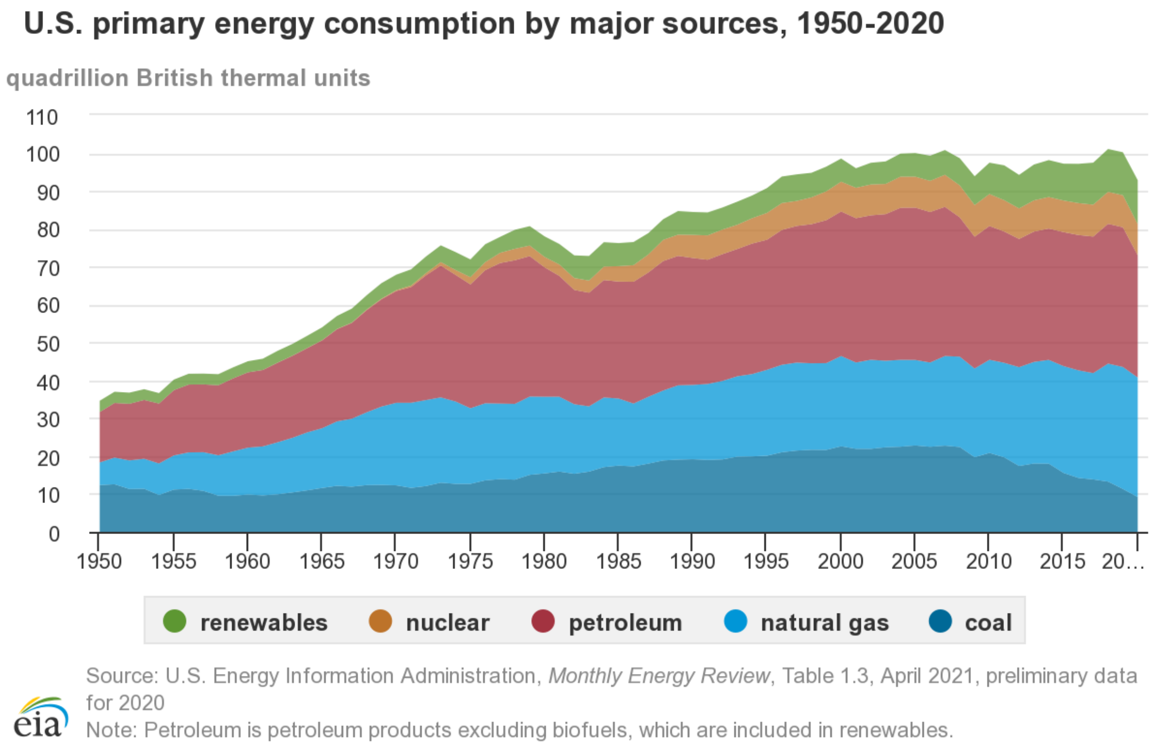


Figure 1 United States Energy Consumption [1]

With this ever-growing power requirement, it brings difficulties with keeping the infrastructure, that makes up the United States electrical grid, up to date. One large part of the infrastructure is the ACSR cable that is used in transmission cables to transmit power over long distances.

The amount of power these cables can transmit at one time is limited by how much expansion occurs when heated up. The heat is caused by current transmitted and when there is too much heat the cable can sag to dangerous lengths. The easiest way to increase the power transmitted over these cables is to increase the current. Increases in temperature (or current) will require increased reinforcement for these cables to mitigate sag.

Excess cable sag has been responsible for many catastrophic fires, blackouts and structural damage. The infamous Southern California “Santa Ana” Foehn winds caused multiple fires in October of 2007. [2] While the number of fires that are caused by power cables are only about 3%, the potential for the fire to be a conflagration is much higher when a power cable causes a fire. It was found that four of the 20 largest fires in California’s history were caused by power cables. [2]

Transmission cables not regulated correctly can be very dangerous, but there is also an ever-increasing demand for power. It will be important to upgrade the transmission cable infrastructure at some point. The only real question is how to accomplish this upgrade safely and cost-effective. Carbon fiber can be the answer because of its lightweight, ease of installation, and cost-effectiveness.

State of the Art Technologies

Data Driven Sag Mitigation

There are two ways that utilities currently detect sag in a cable: Static and dynamic line ratings. Static line ratings (SLR) are typically very conservative and can at times be inaccurate. SLR is determined by IEEE standard 738, “Standard for Calculating the Current-Temperature Relationship of Bare Overhead Conductors”. [3] These standards typically consider static weather conditions, average weather conditions, average wind speeds, and conditions during winter and summer conditions. These parameters do give a good idea of how the utilities should distribute power safely but can also lead to errors that inherently come with using averages and predicted weather. [3]

Dynamic line ratings (DLR) are found by using technology to directly measure the conditions of each cable. This can be done in a variety of ways including weather variables that directly affect the heat balance equations that govern how much current can be sent through each cable, wind speed, ambient air temperature, solar radiation, etc. DLR is beneficial over SLR because it provides data that is more focused on a specific area. The only negative side of DLR is it requires more capital investment from the utilities to obtain the information needed to determine these dynamic line ratings. There must be a balancing act between SLR and DLR for utilities to achieve maximum cost benefit. [3]

Vision based Sag detection

Image processing can be used to detect and verify the validity of the above mentioned SLR and DLR’s that are used for power distribution. If a fixed camera angle is used a coordinate system can be set up. All the camera needs to be able to do is detect the cable. From here the sagging profile can be realized with one sensor. There are many other ways of detecting sag profile such as laser, GPS, tilt sensor, etc. These can also be effective but require much more hardware and coordination. It seems to be much more scalable to use one camera to determine a specific sag profile. [4]

SLiM

The Sagging Line mitigator (SLiM) is one technology that was researched as far back as 2005. [5] The idea for this technology was to shorten the length of a conductor that is experiencing bad weather or extreme heat. It accomplishes this by retracting a stroke length of up to 5''. This allows utilities to keep constant current flow even in bad conditions. Typically, utilities will decrease the power run through these cables if they are experiencing extreme weather. This can lead to a tricky situation because during extreme weather is typically when society needs more power. This technology activates when a shorter conductor is needed

Analysis of Problem

Sag Test Analysis

The Sag test used the concept that if the cable is supported along its length, then the point on the cable with the largest sag will be smaller in magnitude. This idea comes from the Catenary formulas that are typically used to calculated transmission cable sag. Below is a diagram and a couple catenary equations used which is very well known and requires no derivation.

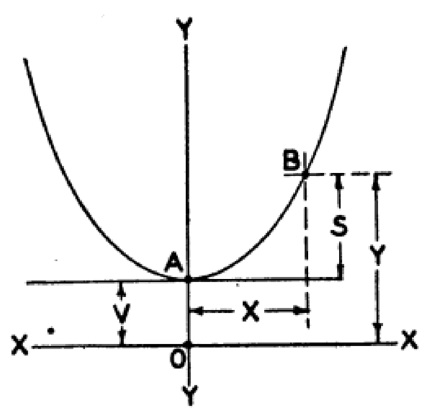


Figure 2 Diagram of Catenary Formula Variables [6]

$$Y = (V/2)(\varepsilon^{X/V} + \varepsilon^{-X/V})$$

$$Y = V\cosh(X/V)$$

$$Z = \left(V/2\right)\left(\varepsilon^{X/V} - \varepsilon^{-X/V}\right)$$

$$Z = V \sinh\left({}^{X}/_{V}\right)$$

$$S = Y - V$$

$$S = V[\cosh(X/V) - 1]$$ [6]

Y = Distance from ground to end of cable length (point B is end of cable where mechanical structure support lies

S= Magnitude of lowest point of cable sag

V = Distance from lowest point of cable sag to ground

X = Distance from midpoint, or greatest point of sag, to end of cable

ε = base of the Naperian or natural system of logarithms equals 2.71828 [6]

These equations are idealized and do not consider the winding, weight, and tension of the ACSR cable, so calculating sag from these idealized equations is not possible. More work must be done to account for the factors mentioned, but the equations do help realize a basic understanding of how catenary problems work. According to the above equations if the variable "X" is minimized then there will be less sag in the system. This will be done by wrapping the cable with a carbon fiber material in such a way that the cable will be supported in the middle. This will effectively reduce X by a factor of 2. To give a better understanding a free body diagram of the proposed idea can be viewed below.

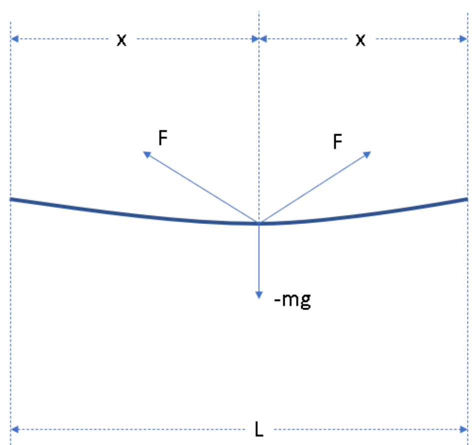


Figure 3 Free Body Diagram of ACSR Cable

Where (F) is the force applied by carbon fiber material that is attached to the middle of the cable and the mechanical support structure at each end of the cable. (-mg) is the force applied to the cable by gravity.

Gallop Test Analysis

To characterize how the carbon fiber performed three sets of data were taken: position, velocity, and motor current. The motor current was used to here to characterize the wind force.

$$T = F \cdot r \; (1)$$

$$T = I \cdot k_t \; (2)$$

With (F) as linear force applied to the actuator carriage, (r) the radius of the pulley inside the linear actuator, (I) the current applied across the electric motor, and (k_t) the motor torque constant. One can see that with a constant pulley radius and motor torque constant the linear force of the carriage is directly proportional to the current across the motor. This was used to characterize the reaction force the cable applies to the motion of the linear actuator.

The controller used in this experiment requires a particular motion trajectory to be specified. This trajectory includes a particular position, velocity, and acceleration to which the actuator must move. This trajectory can complicate the data extracted because it can become difficult to distinguish motor current changes being caused by the cable tension or trajectory requirements. To compensate for this, current values were only compared during similar trajectory accelerations. The data acquisition chosen in this project was when acceleration is zero. This way an increase in current can only be caused by the controller trying to keep a constant velocity.

Sag Test Setup and Procedure

Figure 4 and Figure 5 shows a general picture of the cable holding structure and the method used for wrapping the carbon fiber around the ACSR cable. A mechanical fixture at each end of the lab held an ACSR cable with 4 inches of initial sag. Sensor nodes were distributed evenly along the length of the cable to read the temperature and sag. Two DC power supplies configured in parallel were used in low voltage mode and constant current mode.

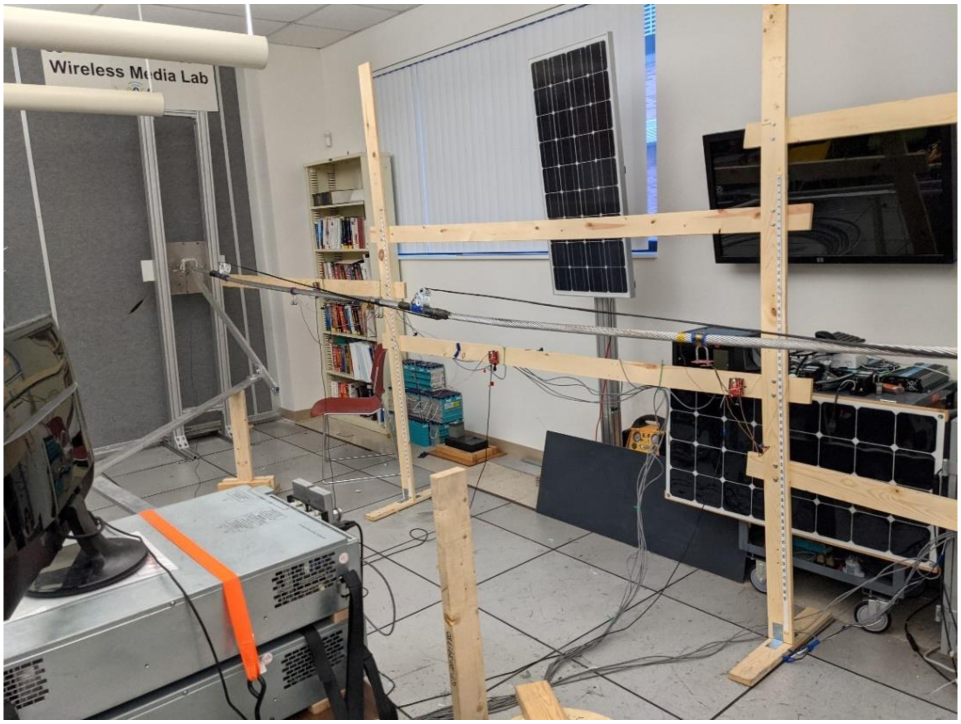


Figure 4 Left side of cable holding structure

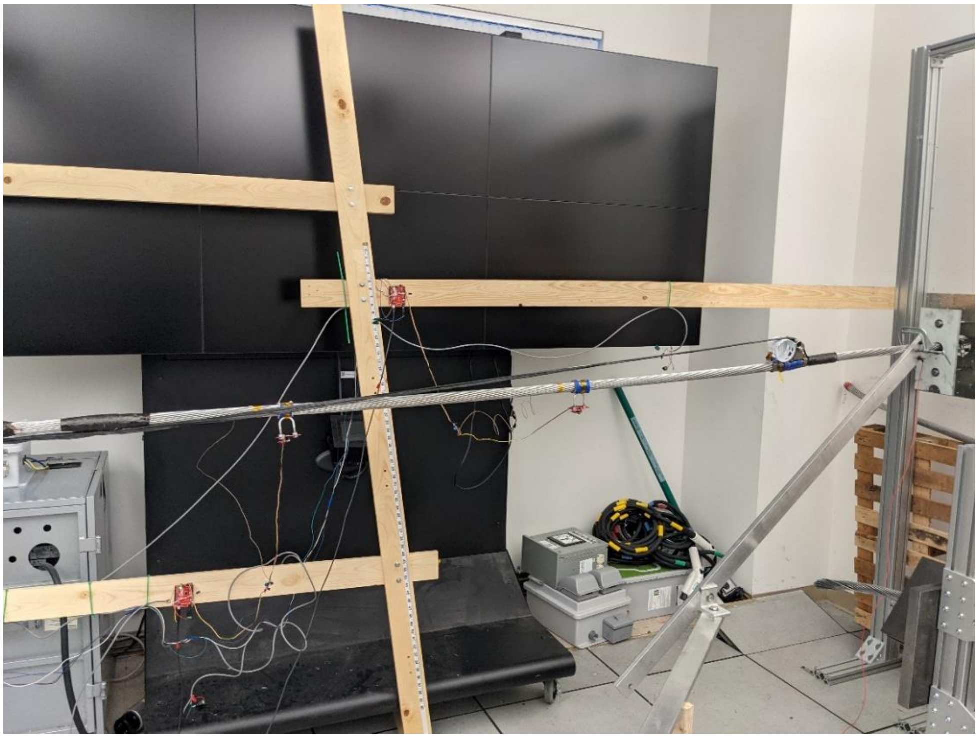


Figure 5 Right side of cable holding structure

The following sections list the components required for the test and for clarity has been split up into three categories:

1. Power cable Structure
2. Data acquisition Electronics
3. Software

Sag Test Power Cable Structure

This experiment was conducted over approximately a 28-foot span. A cable was hung and tensioned at this length and was connect to two DC Power supplies configured in parallel. The cable was tensioned until there was a vertical sag of 4 inches at the vertex of the cable. The tensioning mechanism can be seen in Table 1. The other end of the cable was fixed. After the cable was hung and properly tensioned 1”x 4” aluminum bus bars were used to connect the cable to the DC power supplies. Table 1 also shows the rest of the components used to hang and tension the ACSR cable.

Two SGA10X1K2 AMETEK Power supplies in parallel	
795 Drake ACSR cable	
Cable Holding structure	

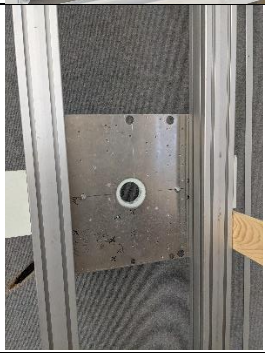
Bus bar	
Carbon fiber	
Cable holding bracket	

Table 1 Power Cable Structure Components

Sag Test Data Acquisition Electronics

The data acquisition electronics in this project were chosen for their ease of assembly and reasonable price. A normally open pushbutton was used as the user interface for the Arduino Redboard. Sparkfun Thermocouples and infrared sensors were the sensors used. They both interface with the Redboard by I2C communication. These sensors and microcontroller were chosen for the Sparkfun Qwiic system. It is an easy to assemble I2C communication package that comes with certain Sparkfun products. Finally, the Arduino communicates with the laptop by using a 15-foot-long USB cable.

Pressure and temperature were taken along the length of each power cable. To take this data, we needed one Sparkfun Redboard, infrared sensor, and thermocouple. These three components made up one node of data acquisition electronics. One node would be mounted at each location of interest. All nodes worked independently of each other to give flexibility on how many points we were able to acquire data from. Because they all worked independently of each other it was necessary to coordinate the boards to all simultaneously take data. This was achieved by wiring a normally open push button switch in parallel to a single digital input of each Redboard.

This project required data acquisition to be taken simultaneously at several locations along each cable tested. The number of nodes and locations of interest changed as the project went along, so it was necessary to make the data acquisition electronics flexible enough to handle these changing requirements. Table 2 lists the components used.

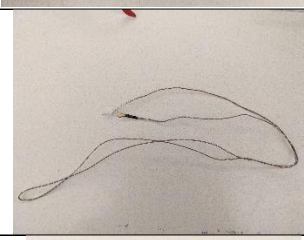
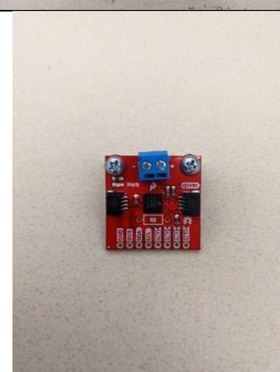
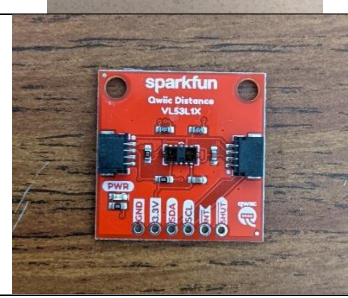
Sparkfun RedBoard	
Sparkfun Type-K Thermocouple	
Sparkfun Qwiic Thermocouple Amplifier-MCP9600	
Sparkfun Qwiic Distance VL53L1X	

Table 2 Data Acquisition Components

Sensors

The sparkfun Qwiic infrared sensor operated from 2.6 to 3.5 Volts with a power consumption of 20mW. The measurement range was from 40mm to 4m and a resolution of 1 mm. The data from the infrared sensor was very sensitive to light. To filter out this noise an average was taken of 1000 data points. This averaging filter realized consistent and accurate distance measurements.

The Sparkfun Qwiic Thermocouple Amplifier had a temperature range from -200°C to 1350°C with a resolution of 0.0625°C. The thermocouple used with this amplifier was a Sparkfun Type K. No filter was used with this sensor because the raw data was consistent and accurate when properly mounted.

Sag Test Software

For this project it was necessary to write two separate scripts. One was imbedded in the flash memory of the Sparkfun Redboard using the Arduino 1.8.16 IDE. The other script was an application local on the laptop which was written in Python 3.8.2. Below in Figure 6 and Figure 7 are decision trees for the Arduino and Python scripts respectively.

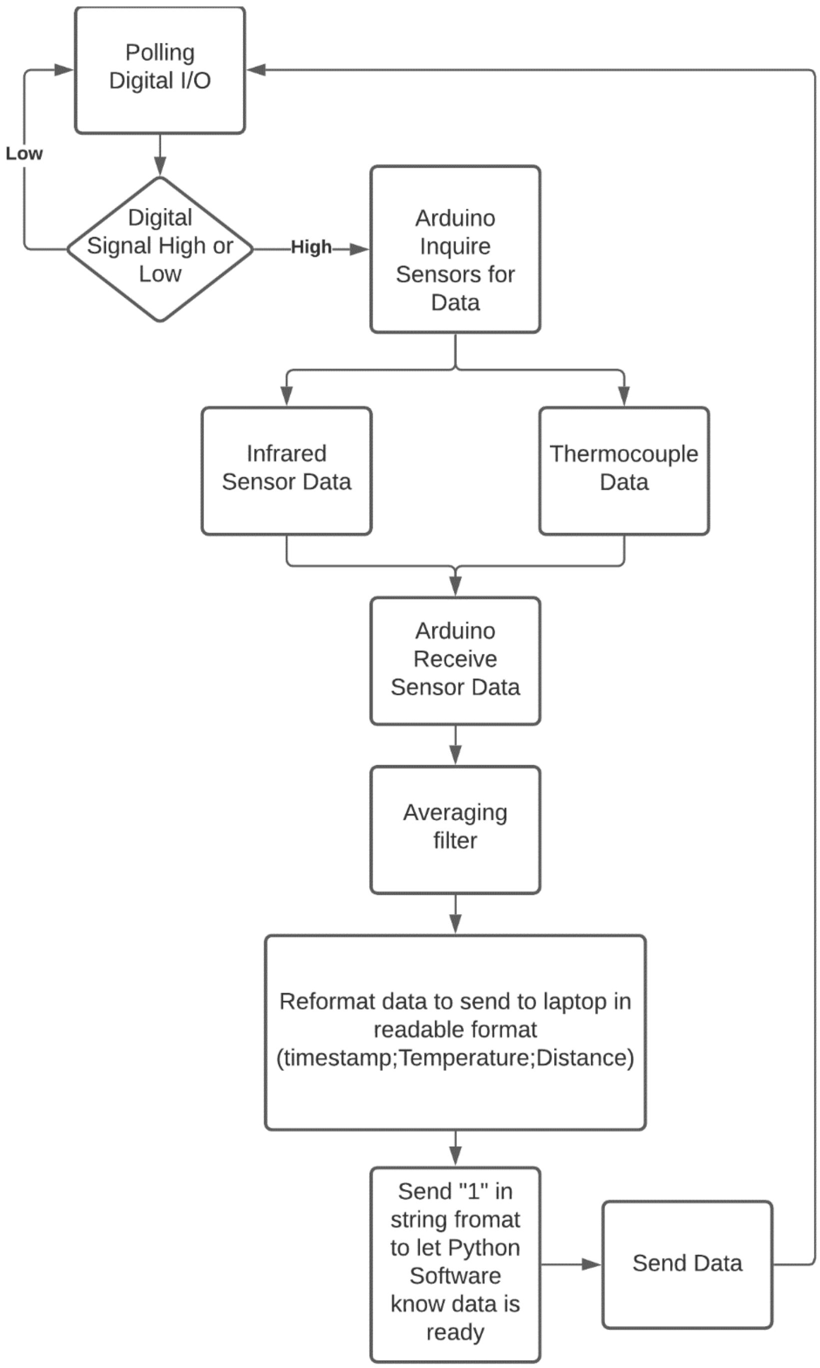


Figure 6 Arduino Software decision tree

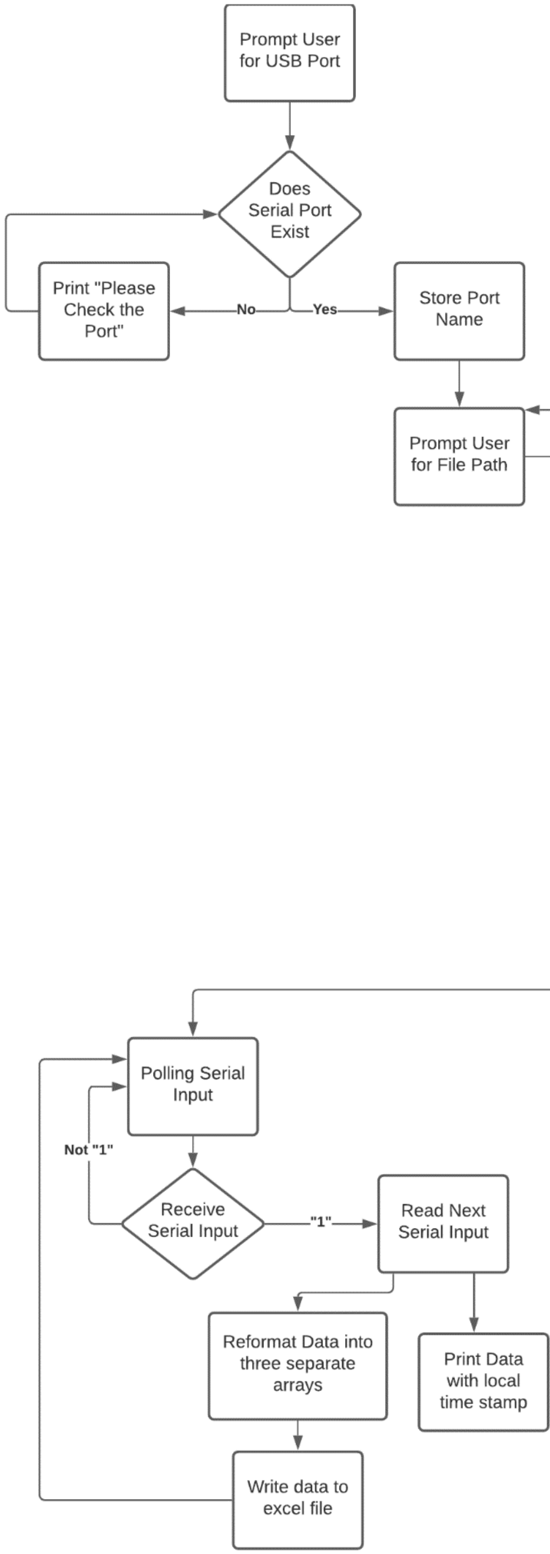


Figure 7 Laptop Software Decision Tree (Python)

The flow of the software in this project is the Arduino script waits on the user to push the data acquisition button. The Arduino then collects the data from the sensors, filters the data, and finally sends the data to the python script. The Python script receives, reformats, and then stores the data in an Excel file in a directory of the users choosing. A graphical representation of this is seen below in Figure 8.

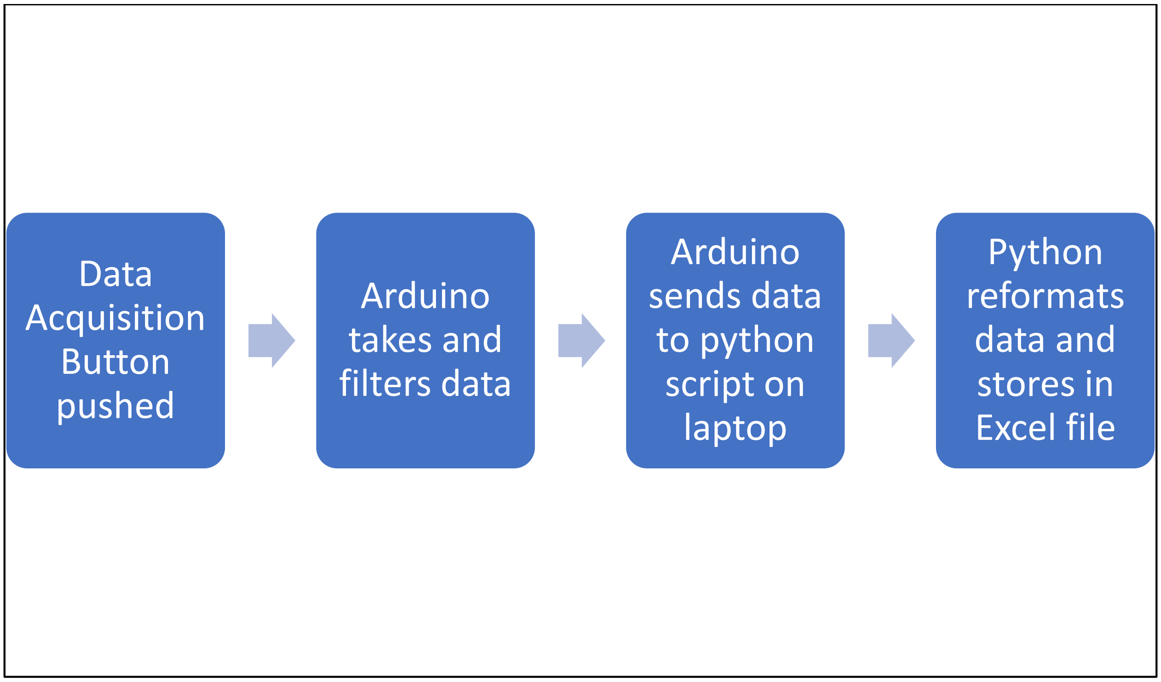


Figure 8 Software Flow

Sag Test Carbon Fiber Preparation

The first step for this test was to first find how an ACSR cable sags when heated up. The next step and main objective of the research was to find how the carbon fiber material can most effectively mitigate cable sag. There were different carbon fiber configurations for the different tests run. In Figure 9 through Figure 11 the different configurations are shown. In all three of these configurations the carbon fiber was wrapped around the middle of the cable. The difference between the three configurations is how the carbon fiber is anchored at the ends of the cable. Figure 9 is anchored at the top of the cable holding structure. Figure 10 is anchored on the ACSR cable. Figure 11 is anchored the same as Figure 10 except that we as a group were getting better at curing and pre-tensioning the carbon fiber. The pre-tensioning method is shown in Figure 12.

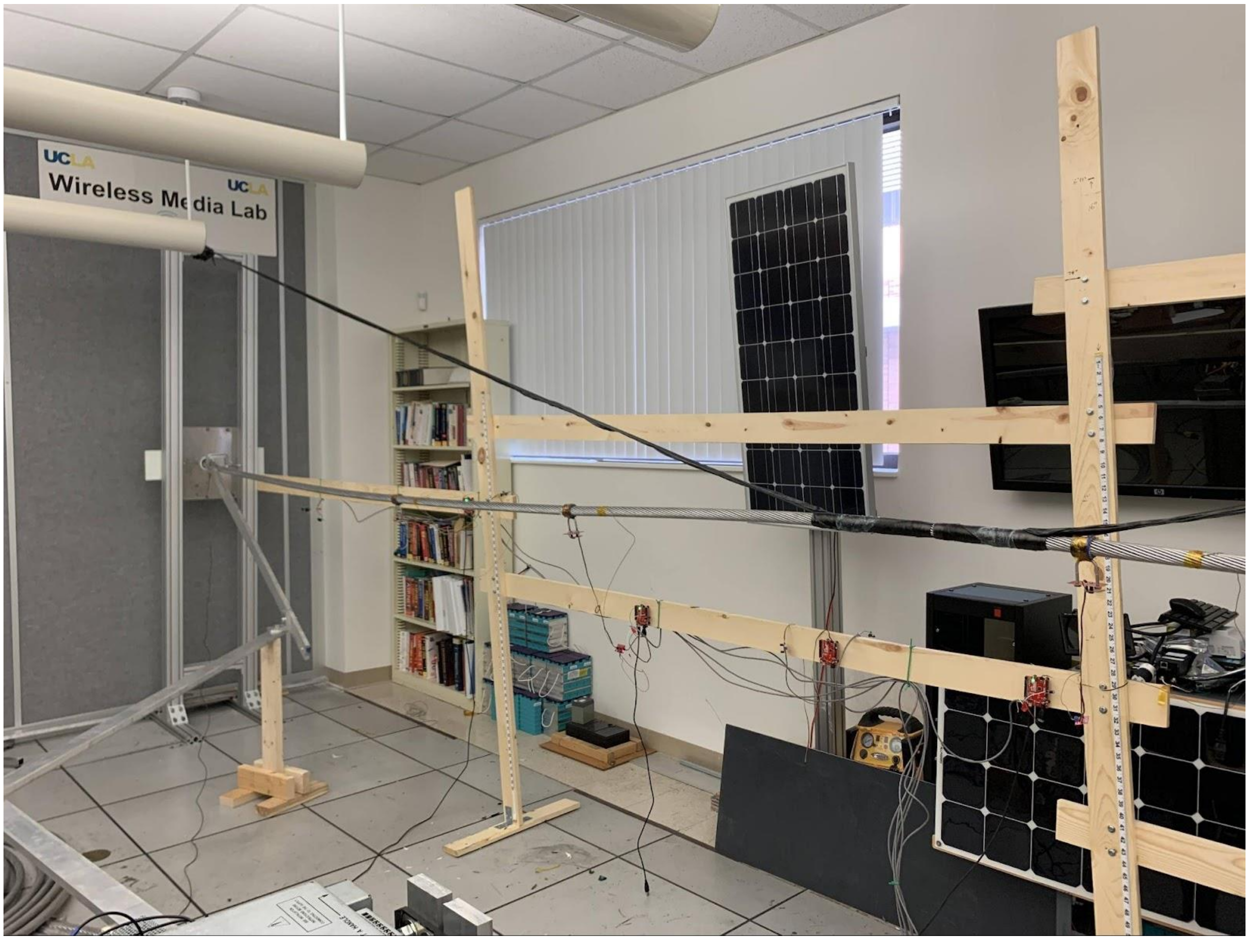


Figure 9 Tests 27-31Carbon Fiber Configuration

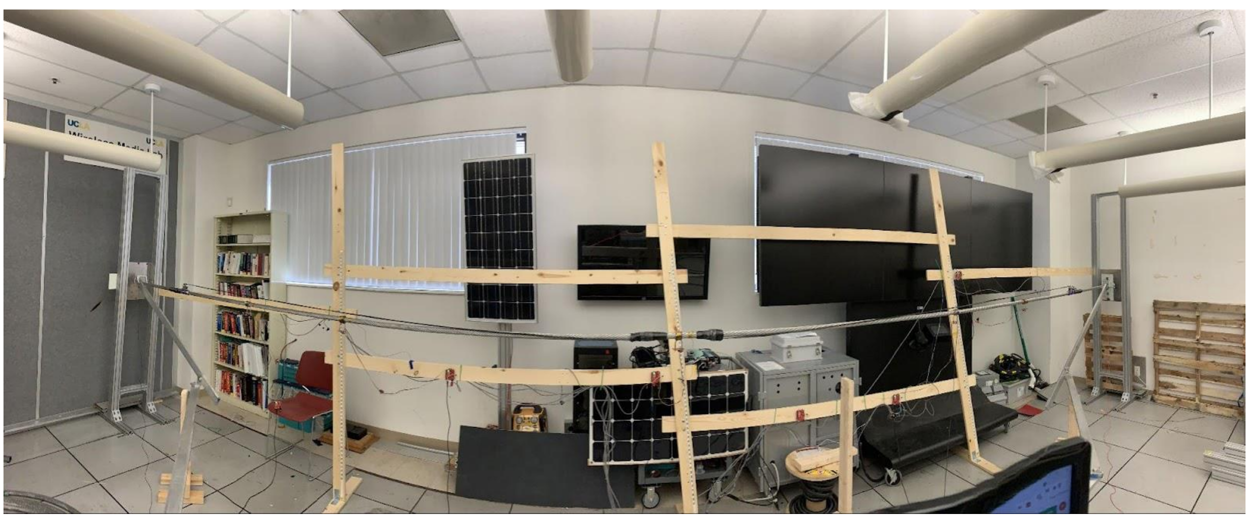


Figure 10 Tests 35-39 Carbon Fiber Configuration

Figure 11 Tests 46-50 Carbon Fiber Configuration

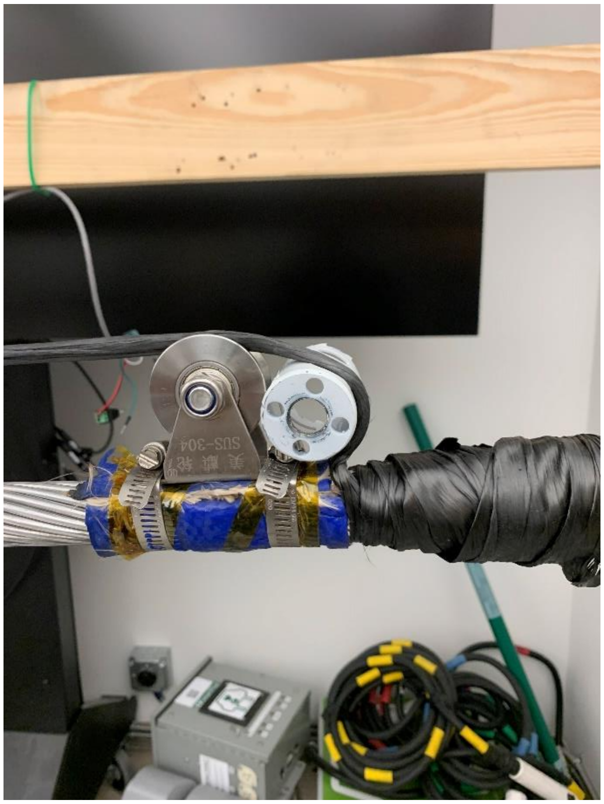


Figure 12 Tests 46-50 pre-tensioning at end anchor points

The wrapping of the carbon fiber was always prepared the day before a test was conducted. The wrapping consisted of cutting to a desired width, wrapping in a predetermined configuration, and finally curing. Note that only the material touching the cable was cured. The curing process required the carbon fiber to be at a temperature of about 120°C for 45 minutes. Curing was achieved by running 1200 Amps through the ACSR cable for about one hour. 1200 Amps brought the cable to a steady state temperature just above 120°C. The carbon fiber was then allowed to cool until the next day when a test was to be conducted.

Sag Test Procedure

This test was completed by applying a constant current across the cable and waiting for the cable temperature to reach steady state. Steady state was determined with the thermocouple sensor. Every 10 minutes a data point of sag and temperature was gathered. After two to three collected data points and no rise in temperature, steady state was said to be achieved.

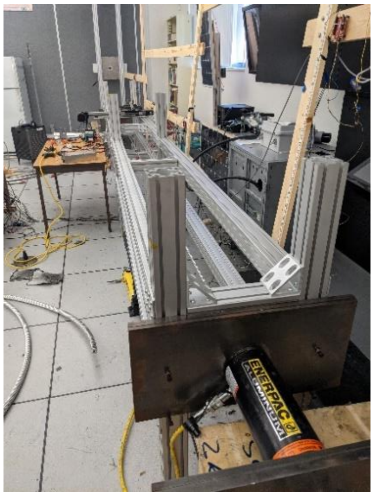
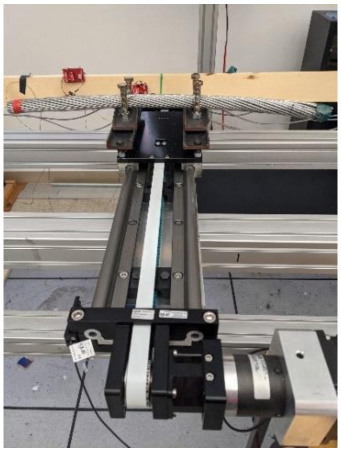
For every test current was slowly ramped up to the target current. For example, if 1400 Amps was the target current, the test would consist of reaching steady state at 300A, 600A, 900A, 1200A, and finally 1400A. This procedure would allow for more safety and gives a clear picture of how the cable sags at varying temperatures and power ratings. Each test would take 4-7 hours.

Gallop Test Setup and Procedure

Mechanical Structure

This test required a structure capable that can support an ACSR cable under tension and a mechanism that can simulate wind applying force to a hanging transmission line. This was achieved with the components in Table 3.

Two SGA10X1K2 AMETEK Power supplies in parallel	
795 Drake ACSR cable	

T-slotted Extrusion Structure	
Igus linear Actuator	

Electric Motor(15:1) gear ratio	
Igus Motion Controller	
Motor AC to DC Converter 48V	

Logic controller AC to DC converter (24V)	
Cable clamp	
Tension Pump	

Table 3 Galloping test components

Data Acquisition

The Data acquired was all taken through the Igus linear actuator software. The same software that is used for control can also be used to extract certain parameters. The parameters of interest are position, velocity, and motor current. A sample graph can be viewed below in Figure 13.

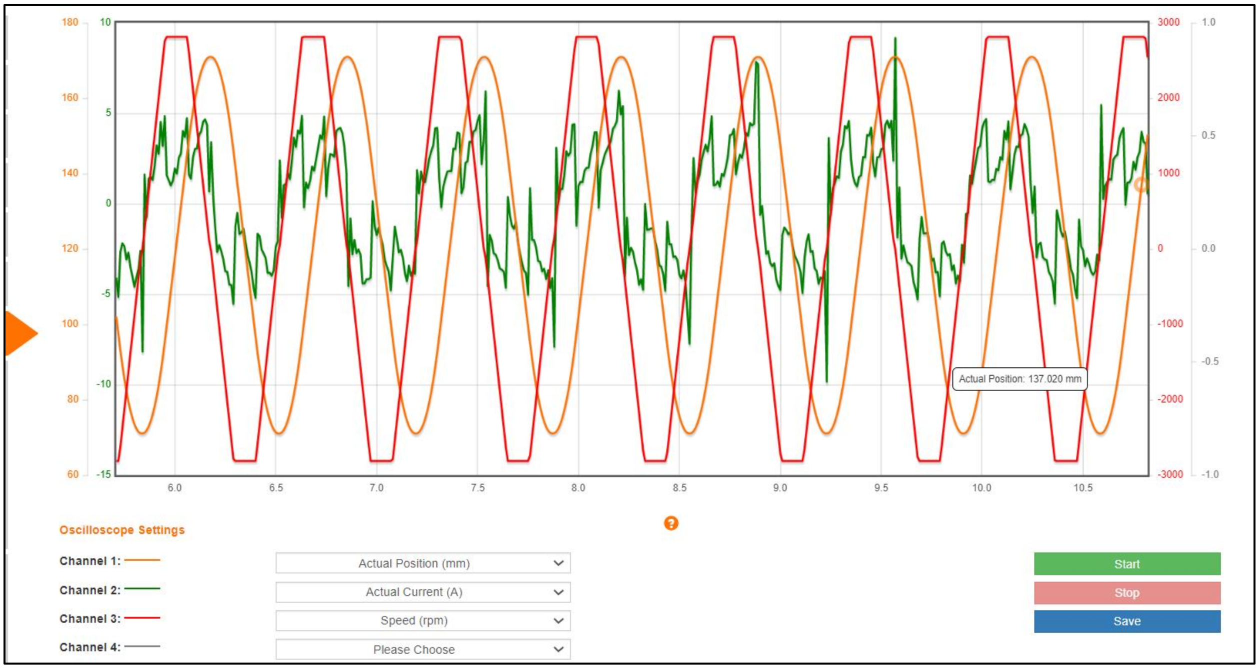


Figure 13 Sample graph of Igus Data Collector

Procedure

The Galloping test was accomplished by hanging an ACSR cable, applying a specific tension, and finally applying a “wind force” to the cable. This wind force was simulated by a linear actuator/electric motor system which applied harmonic motion to the cable. Each test consisted of 100,000 cycles. Each cycle consisted of two position step moves of 100 mm.

The same trajectory was applied to two different cables so the cable that required more current for the motor to perform this trajectory will be stronger against wind. The position and velocity were used to locate the window in which we want to record the motor current data.

The procedure for data collection was to start the data collection every 10,000 cycles and collect 5 seconds worth of data. A screen shot of the graph generated was stored as well as storing a .csv file generated by the Igus Motor controller.

The end goal of this test was to find how well the carbon fiber can increase the structural integrity of an ACSR cable that is disturbed by wind. To accomplish this, tests were first conducted to bare cable. Next, carbon fiber was applied to a different cable and the same tests were conducted.

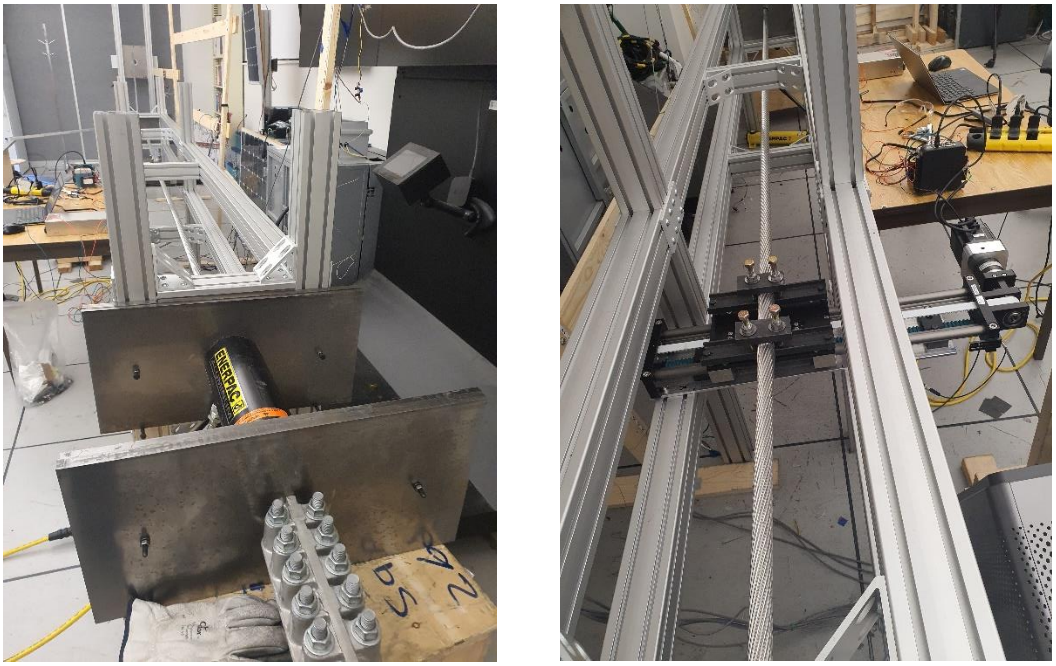


Figure 14 Galloping structure (pump end and middle respectively)

Sag Test Data and Results

Figure 15 and Figure 16 are example plots of the sag plotted versus temperature for bare and carbon fiber reinforced cables, respectively. Figure 17 through Figure 22 there are comparisons between the bare cable and reinforced cable. Figure 17 and Figure 18 are the comparison associated with carbon fiber configuration associated with Figure 9. Figure 19 and Figure 20 are with the configuration associated with Figure 10. Figure 21 and Figure 22 are associated with Figure 11. Each configuration was run five times to test for consistency. Figure 18, Figure 20, and Figure 22 are the sag normalized by the change in temperature as seen in:

$$S_n = \frac{S}{T - T_a}$$

Where S_n is the sag normalized against temperature, S is measured sag in the cable from the initial position at ambient temperature, T is measured temperature of cable, and T_a is the ambient temperature.

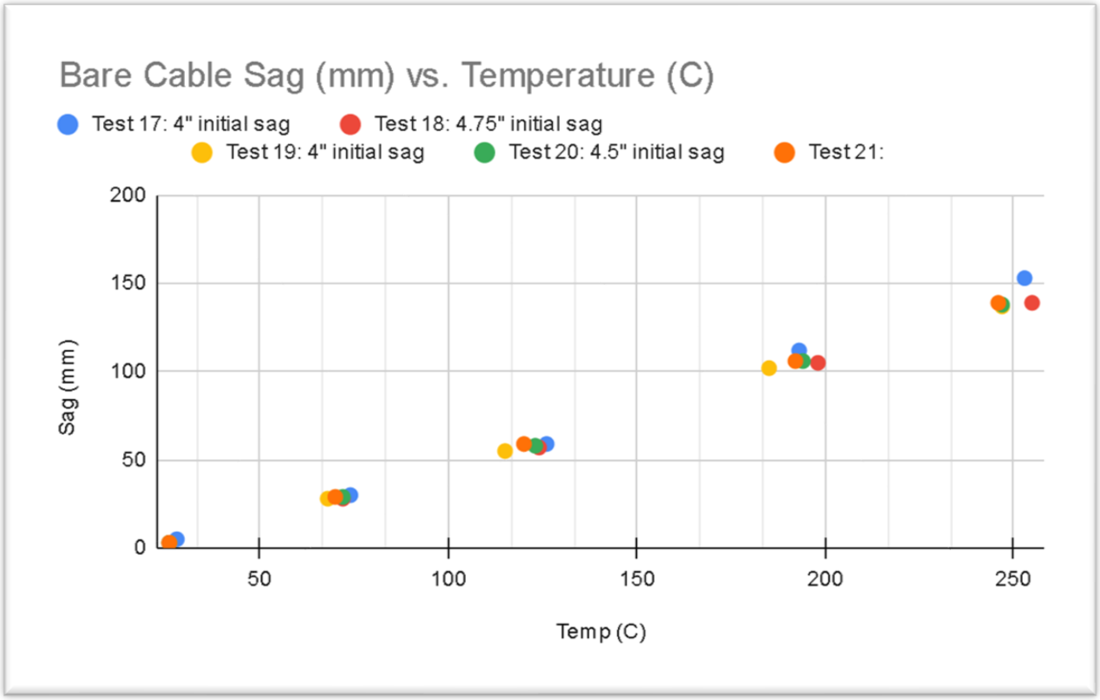


Figure 15 Scatter plot for baseline bare cable tests

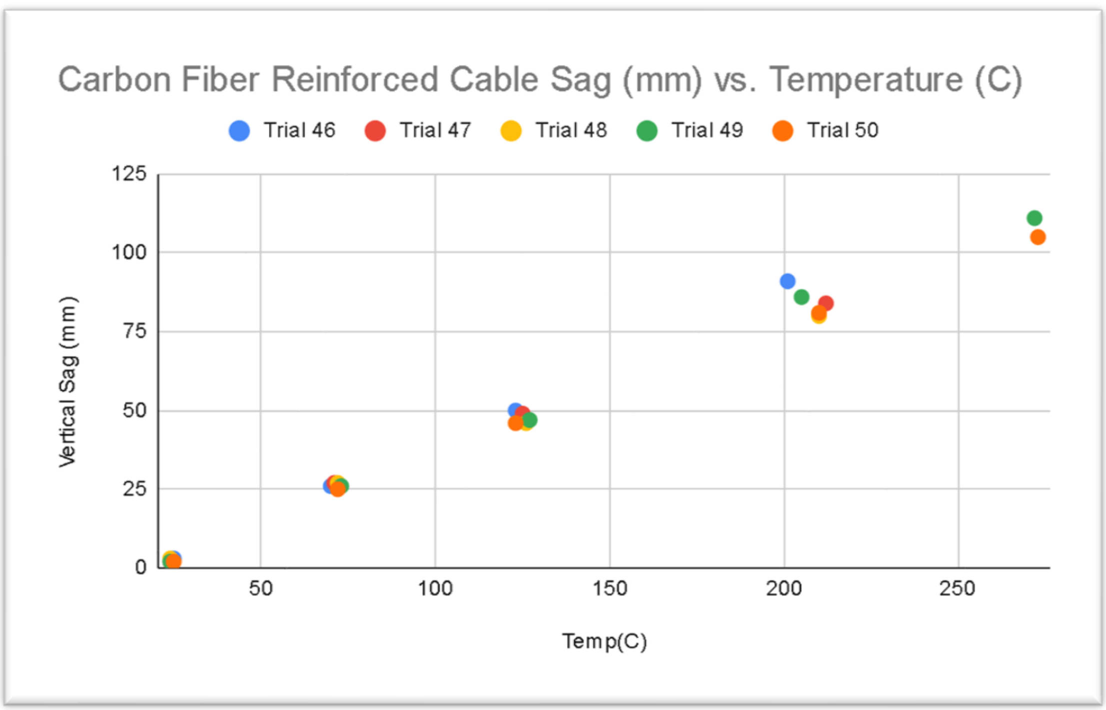


Figure 16 Scatter plot for test 46-50

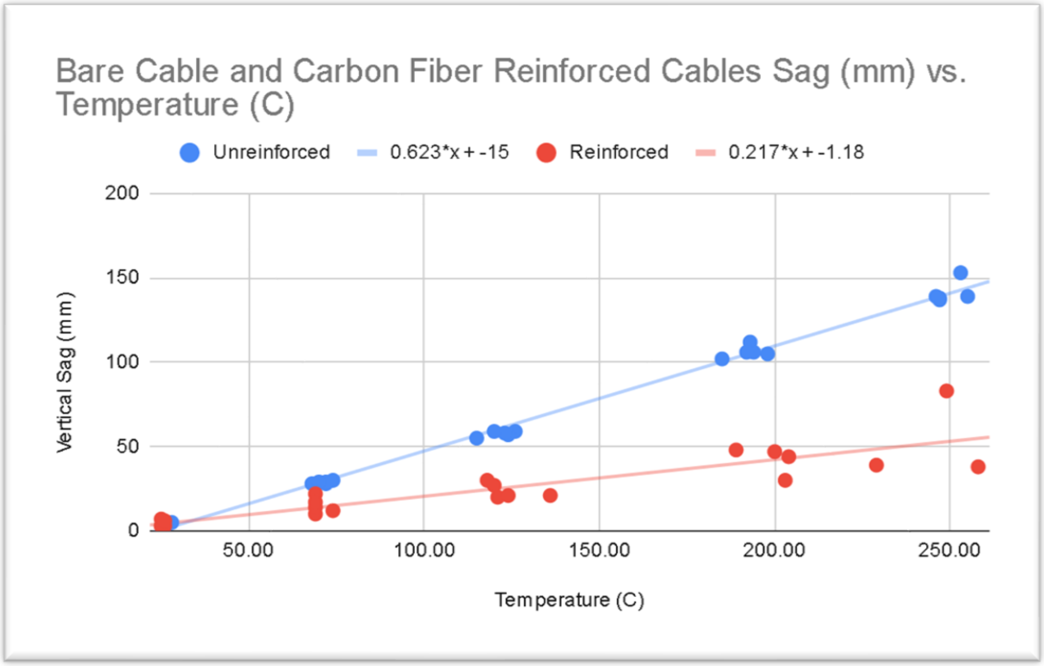


Figure 17 Tests 27-31 comparison to unreinforced (baseline)

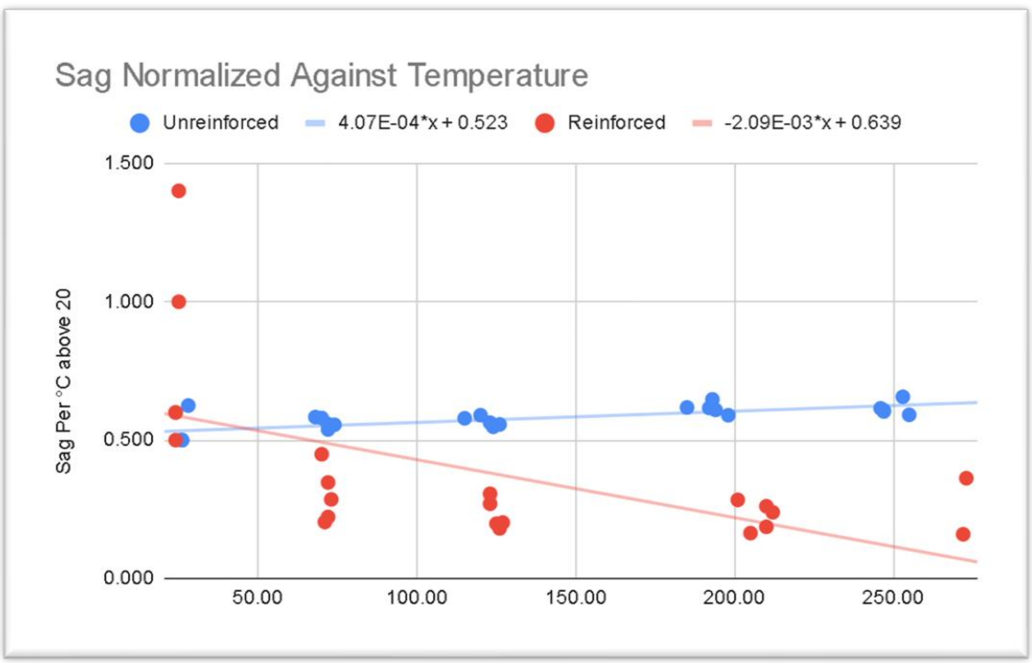


Figure 18 Tests 27-31 Normalized sag comparison to unreinforced (baseline)

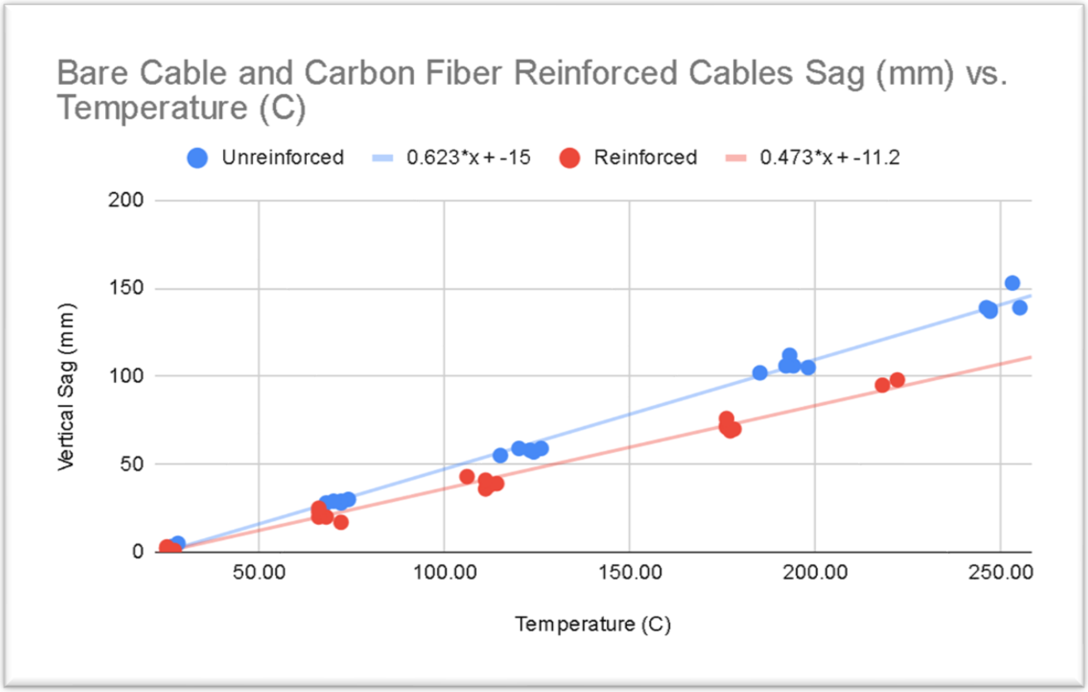


Figure 19 Tests 35-39 comparison to unreinforced (baseline)

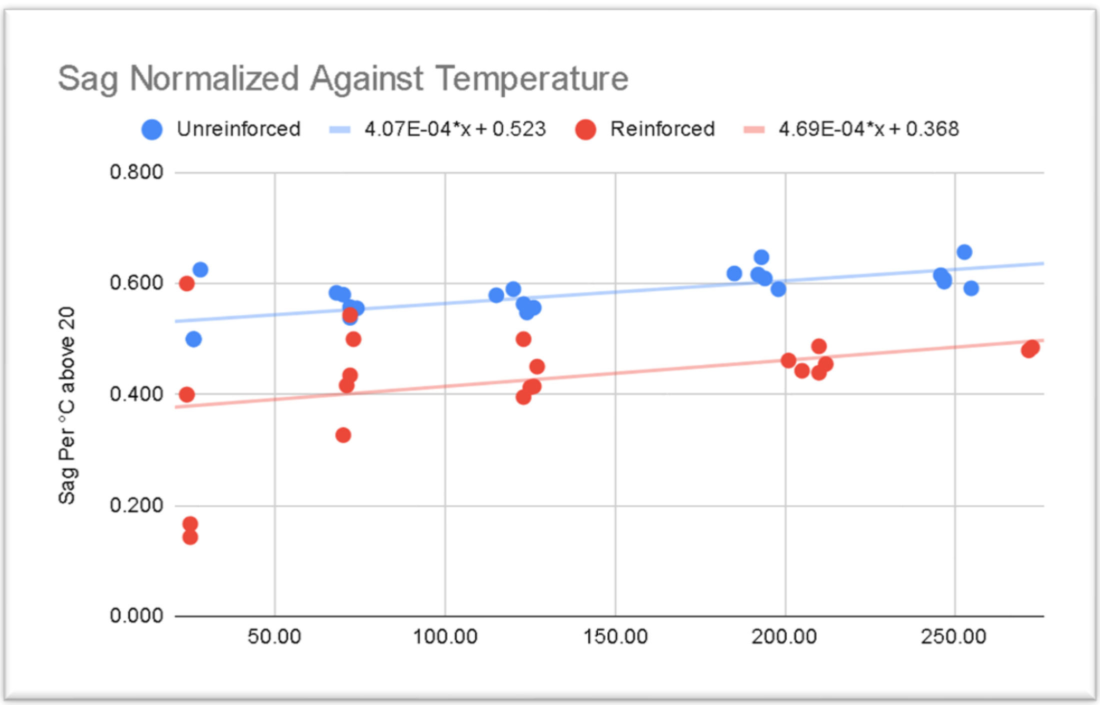


Figure 20 Tests 35-39 Normalized sag comparison to unreinforced (baseline)

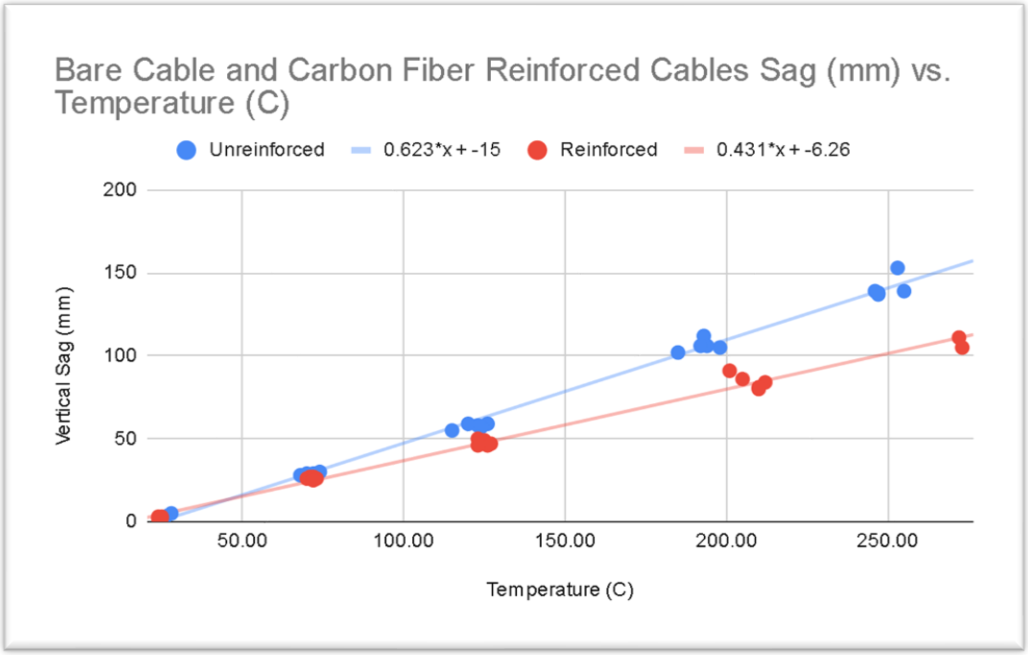


Figure 21 Tests 46-50 comparison to unreinforced (baseline)

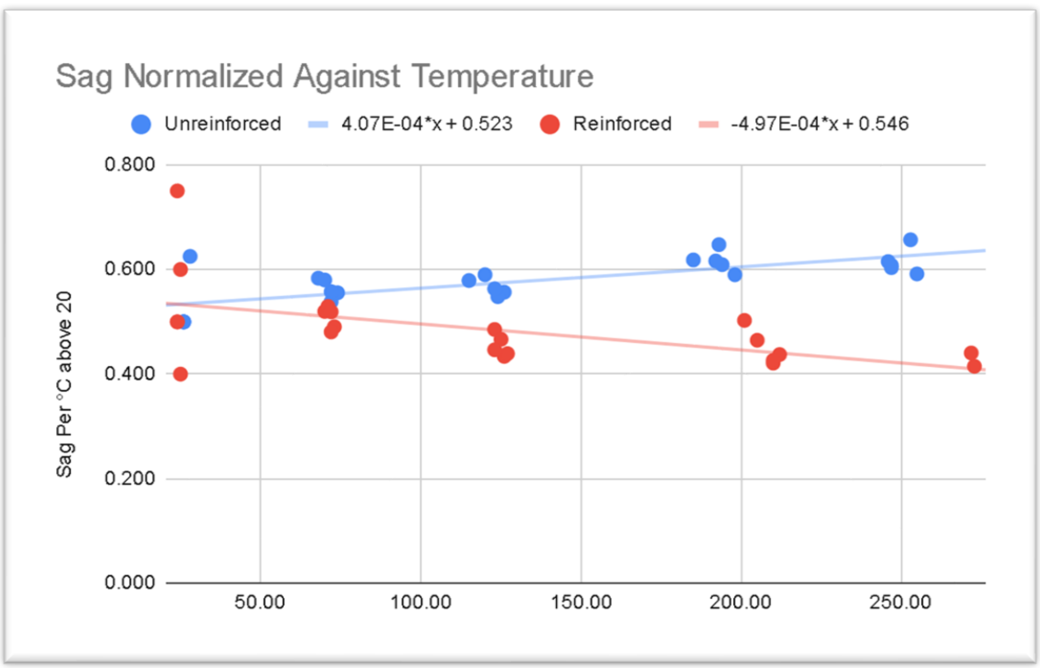


Figure 22 Test 46-50 Normalized sag comparison to unreinforced (baseline)

Gallop Test Data and Results

Data Plots

This section will show the position, velocity, and motor current data at different cycles in the test sequence. Figure 23 and Figure 24 are the data for the unwrapped cable. Figure 25 and Figure 26 are the carbon fiber wrapped cable.

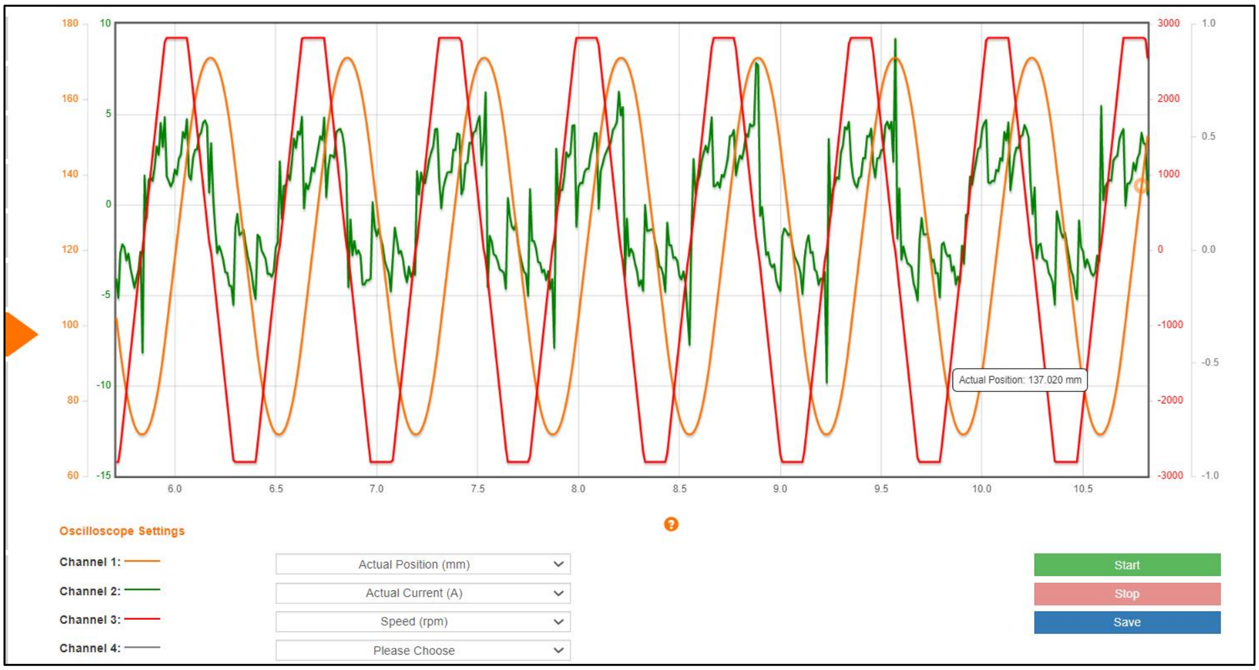


Figure 23 Raw data at 20k cycles unwrapped cable

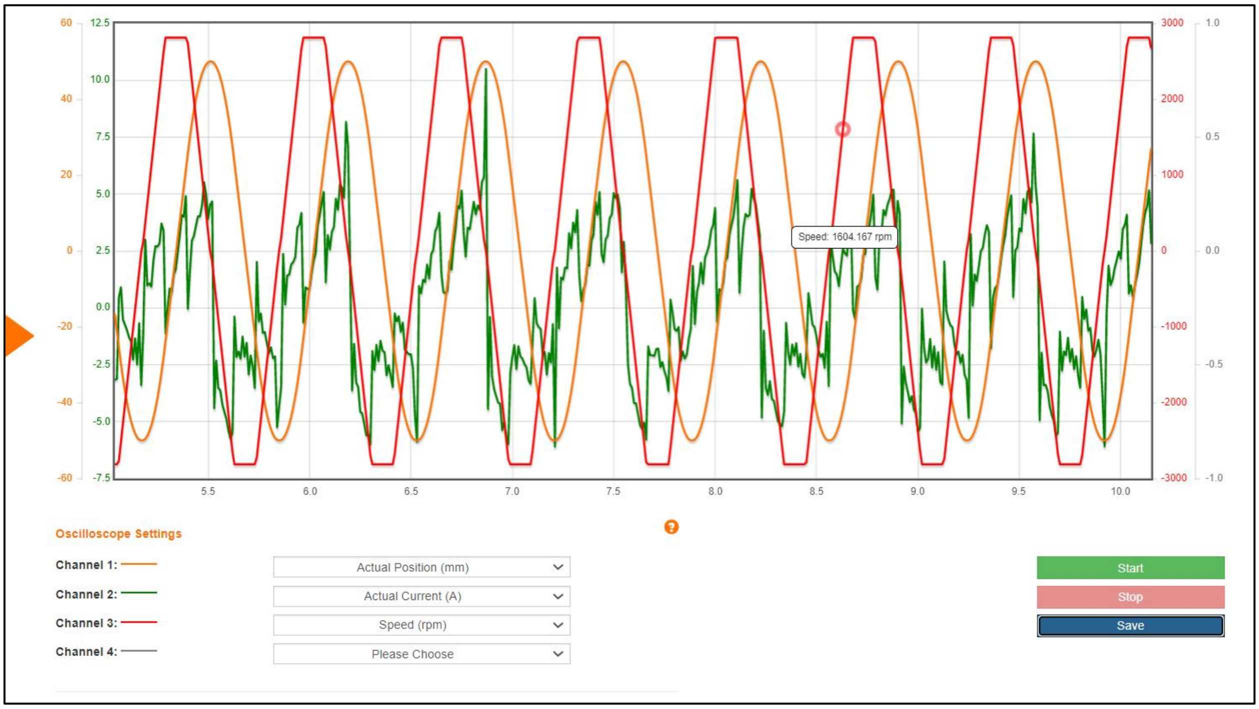


Figure 24 Raw data at 100k cycles unwrapped cable

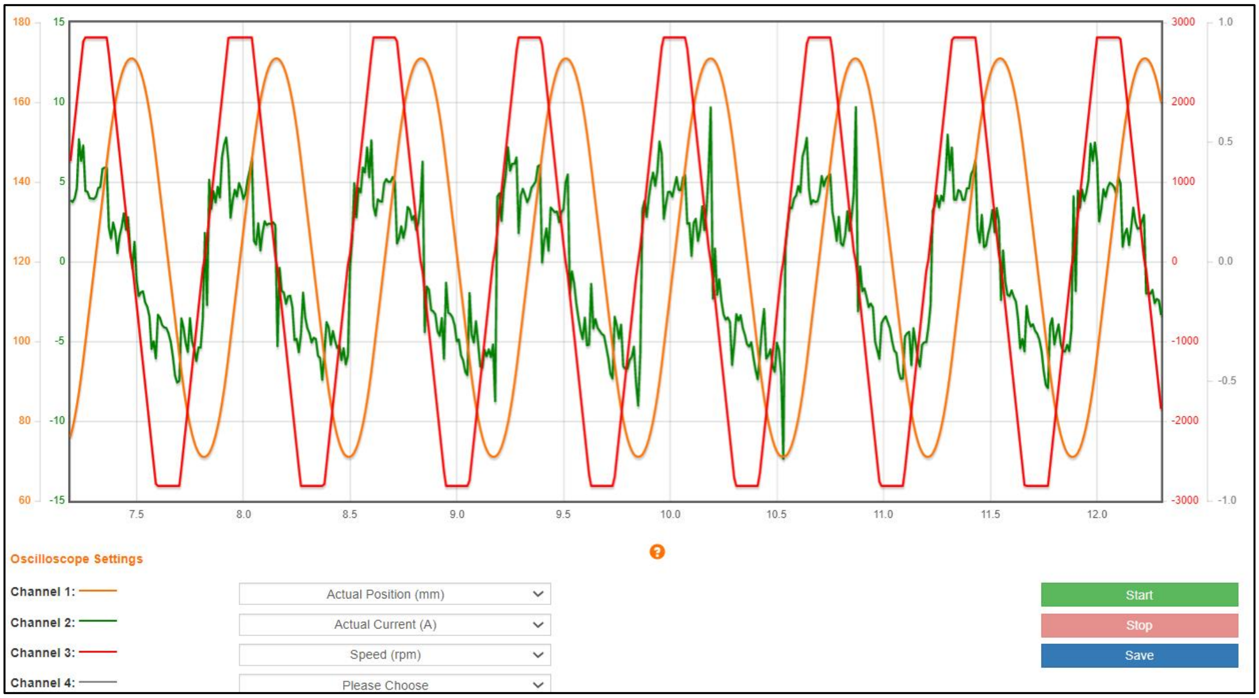


Figure 25 Raw data at 20k cycles wrapped cable

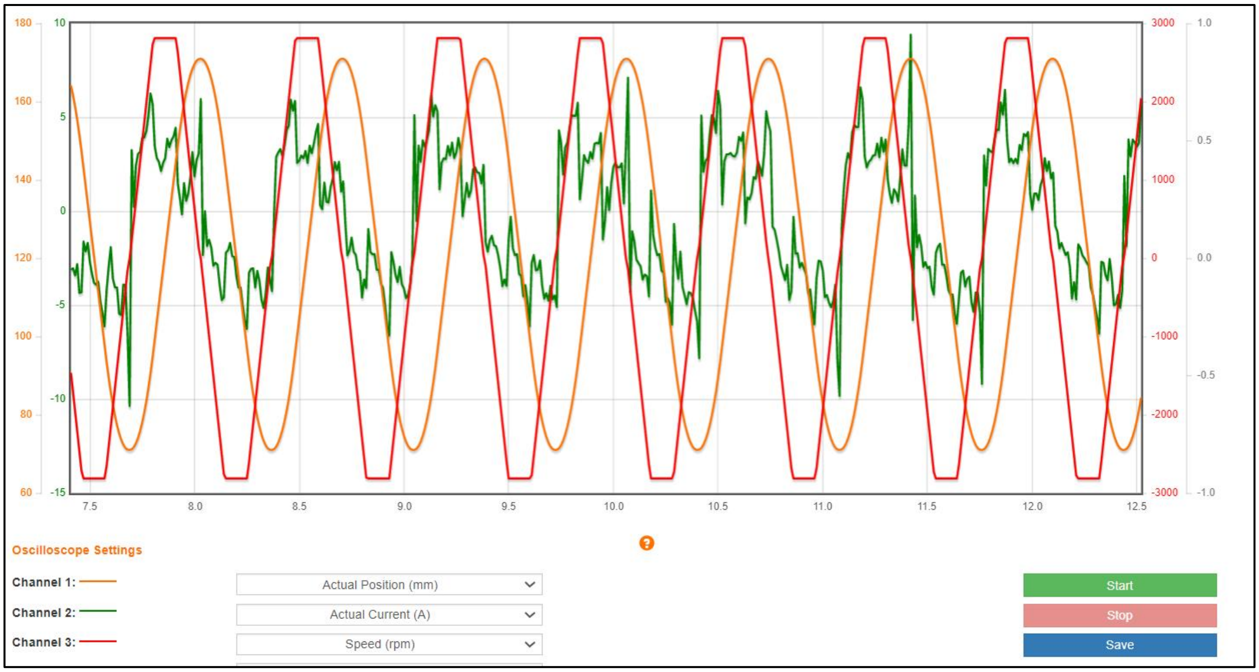


Figure 26 Raw data at 100k cycles wrapped cable

Results

To measure the performance of the carbon fiber the current data points were averaged over a specific window that was determined by the motor position. This window was during zero acceleration and when the motor was moving from the origin towards a max or min position. One example would be when the motor is at position 127 (origin) moving towards position 177 (extreme maximum). This window is where the motor is fighting the cable to move towards one extreme. This is where it can be seen how much resistance the cable gives the motor. In Figure 27 the purple dotted line is the window described.

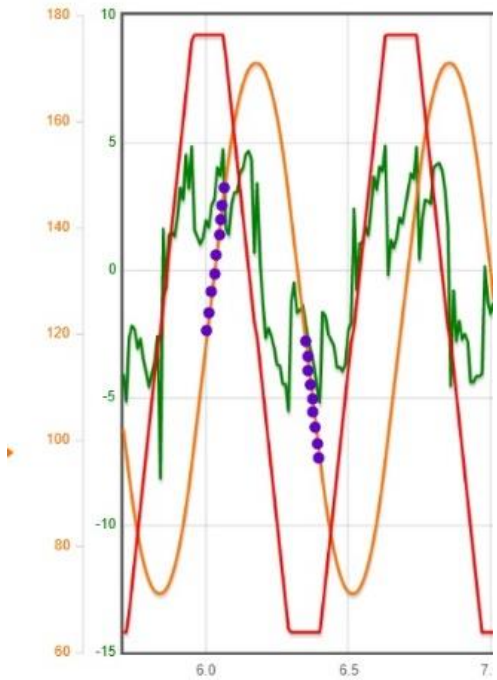


Figure 27 Window of Current data

Gallop test had two test specimens. The first specimen was bare cable, and the second specimen was wrapped in the carbon fiber material. Both specimens were 26/7 ACSR (26 aluminum conductor and 7 steel). Both specimens were tensioned to 2,300 lb (300 psi reading on the pump). Figure 28 and Figure 29 show a comparison between the two specimens. Figure 28 is the difference between the average motor current going in each direction

($I_+ - I_- = I_{range}$) where I_+ is when motor is rotating in the positive direction, I_- is when rotating in the negative. This range was used to take away uncertainty on whether the zero point was in the absolute center of the cable. Figure 29 is using the same data as Figure 28 except it shows the comparison as a percent change from the unwrapped to wrapped cable. The percent change formula uses the difference between the wrapped and unwrapped current versus the max current for the unwrapped test. $\left(\frac{I_{wrapped} - I_{unwrapped}}{I_{unwrapped}}\right)$

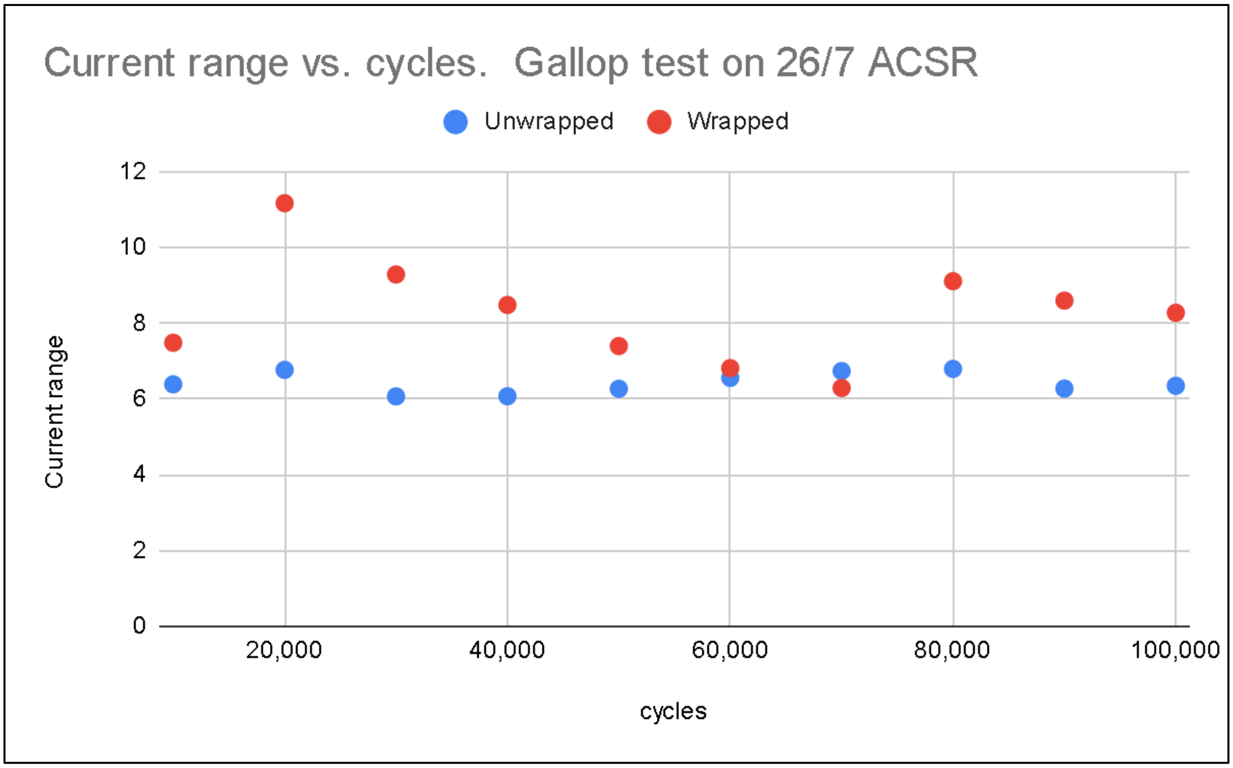


Figure 28 Current Range versus test cycles

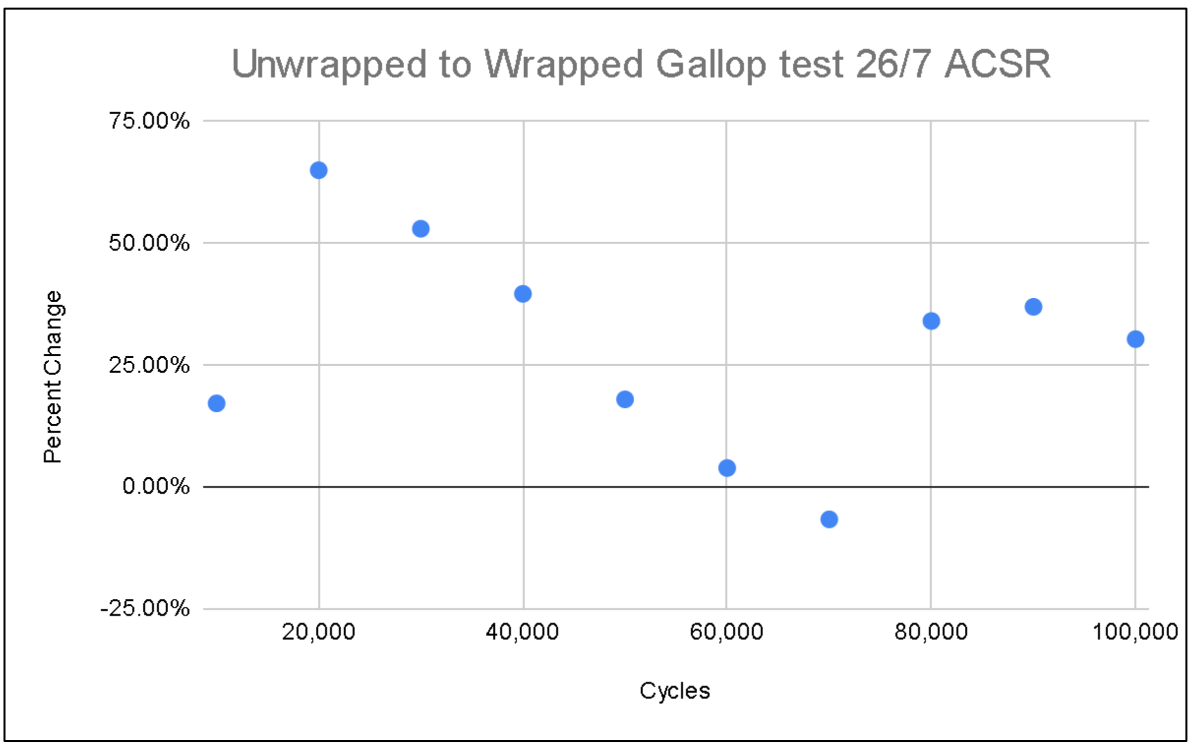


Figure 29 Percent change in force required to gallop ACSR cable

Discussion

Sag

From Figure 15 and Figure 16 one can see that the tests were very consistent. After running 5 test runs for each configuration the infrared and thermocouple sensors recorded consistent readings. When viewing Figure 17, Figure 19, and Figure 21 it is shown that there is a change in slope. That is a 65% decrease in slope (sag/°C) for sag in tests 27-31, 24% for tests 35-39, and 30.8% for 46-50. This change in slope indicates that there is an increasing return the higher the temperature of the cable is. This slope, however, does not tell the whole story.

Figure 18, Figure 20, and Figure 22 show graphs of how the cables sagged normalized versus change in temperature. The carbon fiber reinforced cable, and bare cable start out at about the same sag per temperature, but as the cable heated up the difference increased because the carbon fiber's increase in tension. This, however, is not the case for Figure 20 in tests 35-39. The normalized sag is identical to the bare cable minus an offset. The slope being similar is most likely an indicator that the carbon fiber was not properly pretensioned in this experiment. The carbon fiber did still have some affect at mitigating sag even without a proper tension as is shown in Figure 19 and Figure 20. So, with a proper pre-tension the carbon fiber has an increasing return as a function of tension. It should also be noted that the slope for bare cable was positive while the slope for the reinforced cable was negative. It would be interesting to see how the slope was affected with a better pre-tensioning system for the carbon fiber.

The sag for temperatures less than 100℃ does not see much difference in sag, but as the temperature gets up to 250℃ there is a large difference. Since most utilities do not run transmission cables at higher than 100℃ this may seem like it will not be a viable method for mitigating sag, but there are some other factors to consider. Every cable tested in the lab was 29' 6'' long. An actual transmission cable is typically 500' which will sag more per change in degree Celsius. Because the carbon fiber mitigates sag according to tension in the carbon fiber than this method is still viable. These tests had to compensate for a lack of space for a 500' transmission cable by increasing the temperature to extract how well the carbon fiber decreased sag in an expanding cable. The results do show that the carbon fiber successfully mitigates sag when at the proper tension. It is apparent that the pre-tensioning of the carbon fiber is crucial to its success.

Gallop

The first 10,000 cycle data point seemed to make sense with a 17.18% increase in strength, but then for 20,000 cycles the strength of the wrapped cable increased from 7.48

Amps to 11.16 Amps. This jump seems to come from a variable in how the test was set up. There were multiple operators for this test as it was an 18-hour test. There was probably a difference in cable tension when cycles 10,000 through 20,000 were conducted. The next 5 data points then show the two curves converging linearly until at 70,000 cycles the carbon fiber wrapped cable seemed to be weaker than the unwrapped cable. Then, there was another jump at 80,000 cycles. It seems another operator came in and tensioned the cable differently again. The difference between, wrapped and unwrapped then seem constant from 80,000 through 100,000. The final strength difference between the two cables came to be 30.36%. The reason for conducting 100k cycles was to find how the cables reacted to fatigue over a long period of time. There was not clear enough evidence to show that the cable underwent any meaningful fatigue. There were certain variables in the experiment that need to be rectified before any meaningful fatigue data can be extracted. The variables that caused the uncertainty will be discussed in the Future Work section.

Future Work

Sag

The sag test did have some promising results, but to get a better understanding of the magnitude of sag mitigation some changes must be made.

The first change that should be made is a mechanism which tensions the cable before current is applied. Pre-tensioning the system in this way would greatly increase the impact the carbon fiber can make at lower temperatures. Attempts were made to pre-tension the carbon fiber, but the tensioning would be much greater if done using a mechanism instead of the strength of one person. This mechanism will be even more important with a scaled-up system which has to support a cable that spans a 500' foot length.

Another way to improve this test is to test it at a 500' span. Many difficulties were encountered installing the carbon fiber material on a 30' span, so the same should be expected for 500'. A larger scale system will also realize greater sag values at much lower temperatures. The data collected in the experiment conducted successfully gave a good idea of how this system will work, but magnitude in its performance should be conducted on a system which is more comparable in scale to a real-world system.

Gallop

The next time this test is run more facilities will be needed to use bigger motors or pneumatics to achieve a greater frequency while allowing greater force applied to the cable. This will allow for the cable to be tensioned to a much larger RBS and will take down the test time. Also, there will need to be more analysis done on how rigid these cables are at the desired tension. The motor used in this project was not able to deflect the cable at higher tensions than around 8% of RBS.

Another way to improve would be to use a motor controller that allows the operator to control the input motor current. Directly controlling the current would give the operator a better understanding of the output variables. The data range was severely shortened in this test because this motor controller required a trajectory. This can make it difficult to tell if the controller is changing the current output due to cable tension or motion trajectory requirements. With a constant input current, the output variable would then be the output trajectory of the linear actuator. With a constant current applied a changing trajectory will measure the difference in how a force is dampened by the carbon fiber.

The final way to improve this test would be to directly measure data parameters and have improved resolution with these measurements. Directly measuring the force, the electric motor applies to the cable will take away linear actuator friction and can give a better understanding of the inputs and outputs of the test. Also, directly measuring the tension applied to the cable would be better than using the pressure that the pump applies in this setup because the pump also had to overcome frictions that are not intended for the test. It is also imperative to measure the tension with a digital meter with a much finer resolution than 100 psi. It was difficult for each operator to tension the cable to the same tension with a dial measurement and 100 psi resolution.

Conclusion

In this paper a method for increasing structural integrity of an ACSR transmission cable is proposed and tested. The main objective was to learn the most efficient way to wrap the cable so structural integrity can be increased while keeping installation as simple as possible. Two types of tests were conducted. The first test was to find how the cable sags as it heats up. Different methods for wrapping the ACSR cable were tested. One major conclusion from these tests is that the pre-tensioning of the carbon fiber material is a very important factor. When not properly tensioned there is simply an offset in how well sag is mitigated relative to change in temperature. With proper tensioning, the sag mitigation due to change in temperature should increase linearly. The Gallop test shows how well the structural integrity increased when the carbon fiber was applied to the cable. There were many ways to improve this experiment which were explained in section “Future Work”. There was no legitimate proof showing that the cable fatigued over the span of 100,000 cycles. This thesis proves that carbon fiber is a legitimate material to use for ACSR transmission cables to improve how well these cables can withstand disturbances and heat. Future work should include tests on cables that span the actual length of a real-world transmission cable and should also include larger disturbance forces.

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