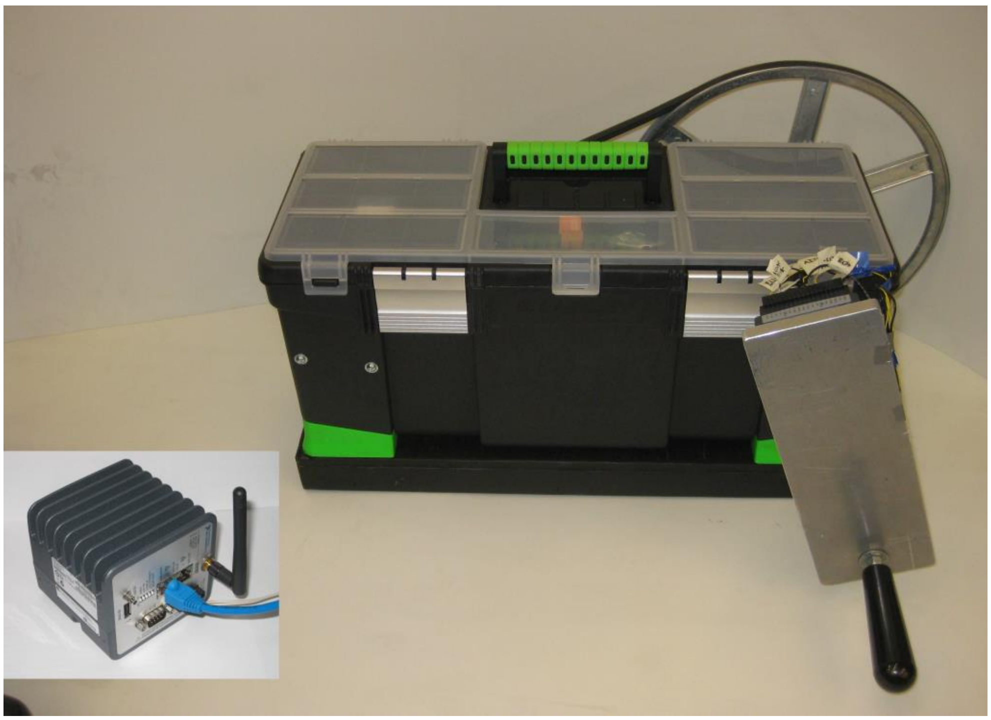
ME 4054-Design Projects May 7, 2013

# Fluctuating Stress Experiment for ME 3221

Volume 1




**Team Members**

Michael Daniels
Robert Jennings
Stephanie King
Erik Sauber
Aaron Schmitz
Zhengmu Wang

**National Instruments Advisors**

Sunaina Kavi
Samuel Strickling

**Department of Mechanical Engineering Advisor and Client**

Professor Susan Mantell

# Contents

# Team Contributions

## Michael Daniels

1. Acted as functional lead during this project by delegating tasks earlier on in the project to team members, holding exclusive meetings with professors and teaching assistants (Professor Durfee, Professor Mantell, Brian Jennings, and Damian Harris), updating the Gantt chart and scheduling team meetings.
2. Design research and selection of strain gauges
3. Acted as one of the two main point of contacts with National Instruments
4. Fabricated the crank handle, installed the strain gauges and bond terminal pads, built the wooden stand that the generator was bolted to and wired and labeled the strain gauges on the transmitter,
5. Purchased tools necessary for the lab experiment (paint, bolts, nuts, washers, adjustable wrench, screwdriver, C-clamps, batteries, electrical wiring, allen wrenches, command strips, non-slip adhesive pads, polyurethane and RTV silicon sealant), drove out to a National Instruments representative's house to pick up the needed receiver and picked up ordered materials for the crank (the plate and shaft ordered from Discount Aluminum & Steel).
6. Worked with two others to code the LabVIEW program.
7. Created the video deliverable requested by National Instruments.
8. Worked with one other student to compile and finalize the bill of materials.
9. Trained both Zhengmu Wang and Robert Jennings on how to install the strain gauges.
10. Assisted Zhengmu Wang with obtaining test results.
11. Created research slideshows on information pertaining to strain gauges and dynamometers.
12. Conducted and setup lab run through experiments with two teaching assistants and one student.
13. Created post-lab run through surveys for those involved, took active notes on what improvements needed to be made on the lab procedure during the lab run through sessions.
14. Tested Erik Sauber's hardware setup video tutorials on the National Instruments transmitter and receiver.
15. Assisted with CAD parts and drawings.

## Robert Jennings

1. Identified and listed improvements for the previous bicycle design based on visual inspection of the apparatus and by witnessing a lab being performed by ME3221 students with Stephanie.
2. Created a spreadsheet to efficiently calculate the stresses generated by a given crank geometry.
3. Selected material for shaft based on calculated stresses.
4. Ran finite element analysis of crank in ANSYS
5. Worked with Michael to ensure that adequate stresses would be read by the strain gauges.
6. Generated engineering drawings of finished CAD assembly.
7. Created a manual for the teaching assistant

## Stephanie King

1. Interviewed professors and teaching assistants and observed a laboratory section preforming prior fluctuating stress experiment with Robert
2. Researched other fluctuating stress experiments and patents related to stress measurement
3. Validated calculations stress and strain calculations and helped develop specifications for the shaft and handle

4. Developed the design requirements and design validation procedure and requirements
5. Constructed and edited student laboratory manual
6. Purchased stock aluminum
7. Drafted problem definition section, developed mid-project presentation and structured, compiled comments and edited the completed design report, including the appendixes

## Aaron Schmitz

1. Interviewed lab/class professors to determine customer requirements.
2. Consulted with Erik on the identification and selection of parts. Identified the generator the team ultimately selected and discussed important device specifications with the manufacturer (PrestoWind). Selected a distributor for the product. Additionally, requested quotes and product information from several manufacturers and distributors that were not ultimately selected for the project.
3. Created the bill of materials including part description, number, manufacture, quantity, cost and as necessary distributer and unit.
4. Worked as LabVIEW lead for the latter portion of the semester. Implemented several specific features including calibration, basic data processing, output file structuring, and the general flow/control of the program. Performed debugging of the program and worked with Michael to verify expected strain gauge operation (sine and square wave outputs).

## Erik Sauber

1. Was the team technology lead.
2. Chose and supported a file storing, management, and collaboration suite to improve team efficiency.
3. Responsible for keeping the group website up to date and is the permanent group scribe for meeting minutes.
4. Responsible for many of the different concepts considered.
5. Started the team down the path of concept selection using a Pugh matrix in week 3 of the semester allowing the team to spend more time on concept development and procurement.
6. Worked with Zhengmu to create the CAD drawings for this project.
7. Worked with MEnet on purchase and setup of a computer with LabVIEW.
8. Identified the appropriate DAQ, worked with National Instruments to procure the DAQ. He was never told that the DAQ had a huge lead time. Instead, he was lead to believe that it should be shipped in 5-14 days not 4-8 weeks.
9. Setup and troubleshot the NI WSN-9792 receiver and NI WSN-3214 to work with our personal laptops.
10. Started the LabVIEW programming with elements of my original code making it into the final draft.
11. Created troubleshooting guides and videos for setting up and initial programming of the NI WSN 9792/9791 and NI WSN 3214.
12. Edited, revised, and rewrote sections of design report assignments 2, 3, and 4.

13. Wrote evaluation section of design report volume 1 and outlined volume 2 of the design report for design report assignment 4.
14. Attended and took notes for Brian Jennissen mock lab test.
15. Worked out power equations for the generator.

## Zhengmu Wang

1. Measured dimensions of the generator.
2. Drew the CAD model of crank and the finished generator.
3. Assisted Michael Daniels to install stain gages.
4. Interviewed Professor Rusen Yang with Robert Jennings.
5. Conducted the stain gage reliability test.

## Executive Summary

A new fluctuating stress experiment for ME3221 was developed to demonstrate cyclic stresses in an every-day application to students. The design process began by identifying, interviewing and observing the customers. Feedback from customers (the professors, teaching assistants and students of ME 3221) indicated that there were four major design requirements. The experiment must measure multiple stresses, and at least one of them must be cyclic. The teaching assistant must be able to set up the apparatus quickly. The apparatus is durable and reliable, so that it will last at least 10 years as a laboratory experiment. The experiment must be engaging and instructional. Designs were developed to fulfill these requirements and then tested during the evaluation phase.

The final apparatus design developed measures the bending and torsional stress on the shaft of a hand-cranked generator, as seen in Figure 1. Data will be collected from a set of strain gauges that are bonded to a free section of the crank shaft. The strain gauges are connected to a National Instruments WSN 3214 wireless node made specifically for strain measurements. It conditions the signal and transmits it to a National Instruments WSN 9791 receiver connected to LabVIEW. The data is then displayed in a LabVIEW virtual interface as bending strain at 0 and 90 degrees as well as the torsional strain. Accompanying the apparatus, the design includes a student and teaching manual which cover the experimental process and the maintenance of the apparatus respectively.

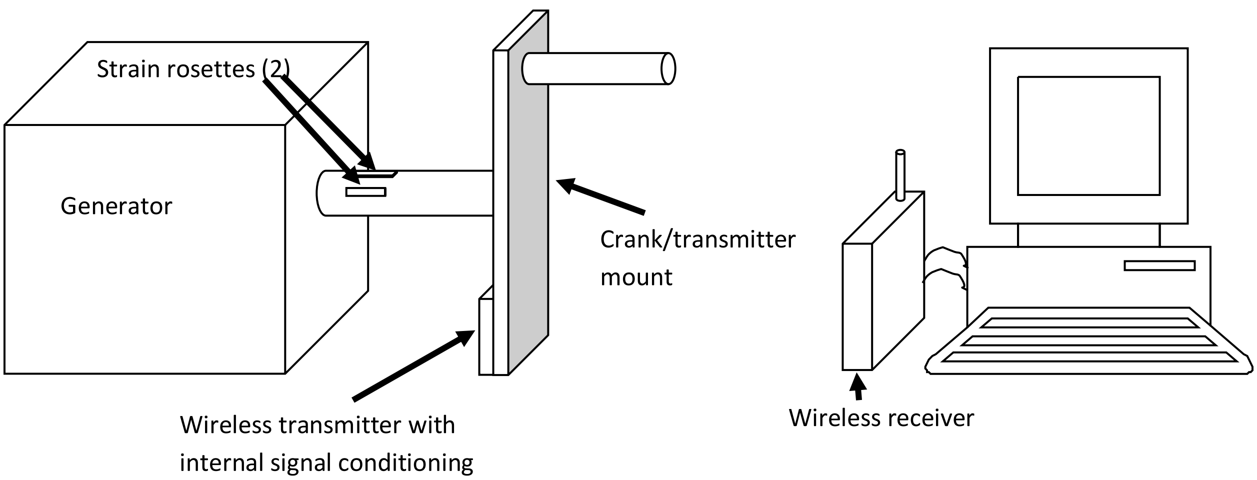



**Figure 1: Line drawing of experimental apparatus**

When in operation, the apparatus will engage a minimum of two students: one is operating the crank on the generator while one monitors the LabVIEW virtual interface. The new apparatus' performance improves upon the old one with higher quality data from the strain gauge. Additionally, the new apparatus only takes a maximum of 10 minutes for a teaching assistant to prepare the apparatus for student use. Finite element analysis of the aluminum crank has shown that the fatigue life of the crank is 1E8 cycles which are much greater than the 5E5 cycles expected in the life of the product. Measured bending strains were found to fluctuate between 25 and -25 microstrain and torsional strains of over 25 microstrains. Strain gauge data was within 10% deviation and within 10% of theoretical values.

# Problem Definition

## Problem Scope

The purpose of this project is to create a reliable fluctuating stress experiment for ME 3221 Design and Manufacturing lab to replace or supplement the current bicycle stress experiment. The designed experiment coordinates with the lecture, demonstrates the relationship between applied forces and stresses, and incorporates the relationship between strain rosettes and principal stresses. Strain data is given to students for analysis. Documentation on troubleshooting, setting up, and performing the experiment is provided for teaching assistants and students. A video showcasing the experiment and a case study is presented to National Instruments in return for the opportunity to use their equipment.

## Technical Review

This laboratory experiment covers the measurement of stress in a cyclic environment. There are two stress components to this experiment. There is a constant torsional resistance, which is produced by power dissipation within the dynamometer. This is described by Equation 1 and Equation 2:

$$P = T \cdot \omega$$

**Equation 1: Rotational Power [1]**

$$P = V \cdot I = I^2 R = \frac{V}{R^2}$$

**Equation 2: Electrical Power [1]**

Since the current (I), resistance (R) and angular velocity (ω) all remain constant, within human error, the torque (T) and torsional stress will also remain constant. The bending stress caused by the force applied on the crank handle will be sinusoidal. The rotation of the shaft causes the measurements to differ while the force applied remains constant, because the geometries change. It should also be noted that in this experiment, there are two locations where bending stress are measured, 90 degrees offset from each other, as seen in Figure 2. While these two measurements will have equal magnitudes, they should be offset by that $1/4^{th}$ of the period, because the forces are acting on them are offset by $1/4^{th}$ of a full rotation.

This experimental setup uses strain rosettes to measure the various strains on the crankshaft. The rosettes selected for this application have strain gages oriented 45° from each other. Each individual strain gauge acts as a variable resistor, which is then interpreted using a Wheatstone bridge. Since the shaft is a 3-dimensional surface, the orientation of the rosette is significant in measuring the torsional strain. This orientation of the strain gages measuring torsion are demonstrated in Figure 2Equation 1:

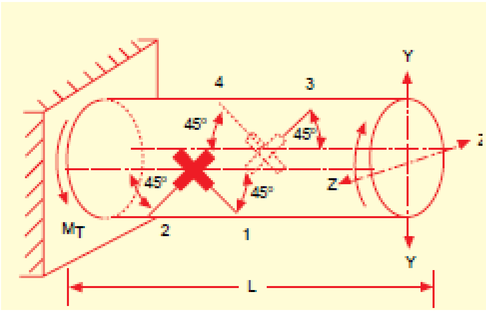



**Figure 2: Orientation of 2 strain gages (part of a strain rosette) that measure torsional strain [2]**

Using the strain direct strain measurements, the bending and torsional strain are then calculated. These raw strain measurements are translated using Equation 3 and Equation 4:

$$\gamma = 2 \times \epsilon \;@\; 45° = \frac{\tau}{G}$$

**Equation 3: Torsional Strain [2]**

$$\epsilon_B = \epsilon_B$$

**Equation 4: Bending Strain [2]**

Since the strain gages are mounted on a rotating shaft, data must be transmitted from a rotating surface to a static one. This was accomplished using National Instruments wireless data acquisition equipment. In previous experiments, slip rings were used to transfer strain data. A wireless data acquisition system was selected for its superior signal quality and ease of use. The wireless data acquisition has built-in signal conditioning, making data collection easier. All slip-rings evaluated for this design had internal resistances that would interfere with the signal quality. Using wireless data acquisition eliminated the need for long shielded wires and avoided noise from the slip ring.

In this new experiment, wireless transmission devices are employed. In the original experiment, a slip ring was used. Slip rings transmit data by holding static electrical conducting brush against the moving center which transmits the signal [3]. This method has been used previously by the University of Minnesota in the bicycle experiment and California State Polytechnic University, Ponoma [4] in experiments to teach students about stresses on a rotating beam.

The current cyclic stress experiment at the University of Minnesota examines stress on the pedals of a bicycle. Like generator experiment, the torsional and bending stresses are measured, where the torsional stress remains constant and the bending stress is cyclic. The torsional resistance by a frictional resistance against the back wheel of the bicycle. A person pressing down on the bicycle's pedal creates the bending force on the crank. Rosettes are then used to measure the strain near the bearing supports of the bicycle. The resistance from the strain gages was transmitted through the slip ring and to a computer where the stresses were calculated.

## Design Requirements

Design requirements were developed using interviews with the professors, teaching assistants and students of ME 3221. The results of the interviews were then evaluated and ranked based on how often a requirement was mentioned, how economical and feasible the requirement was and which of the customers identified the requirement. A summary of the design requirements, their relative importance and the measurements performed to validate the design is found in Table 1.

**Table 1: design requirements for Fluctuating Stress Experiment for ME3221.**

| # | Design Requirement | Reason |
|---|---|---|
| **1** | Measures stresses, including at least 1 cyclic stress | The objective of this laboratory experiment is to demonstrate the measurement of stresses in a cyclic environment. During the idea development phase, interviews with professors, our primary consumer, indicated that the measurement of cyclic stress was essential. Stresses |
| **2** | Apparatus set up is quick | During demonstrations performed by teaching assistants and interviews with them, the previous cyclic experiment took about an hour to set up and calibrate. As a result, the experiment was only calibrated once during the entire week of labs, despite non-zeroed values at the end of the week. |
| **3** | Apparatus is durable and reliable | Our primary customer indicated that this experiment must last at least 10 years with minimal. This is the equivalent of 280 lab sessions, or approximately 55,000 hours. |
| **4** | Apparatus is engaging and instructional | All of the customers interviewed, the students, the teaching assistants and the professors, indicated that the experiment should be something will real-life value and something that the students could interact with. |

Each of these designs requirements were tested later using the evaluation plan listed in section 5.

# Design Description

## Summary of Design

The hand crank generator is instrumented to measure fluctuating stress. The torque required to operate is created by internal circuitry. When the crank is turned, the reactive cyclic stresses at the base of the crank are measured by two strain gauge rosettes. The strain gauges are connected to a wireless transmitter that is mounted to the crank arm. The wireless transmitter then translates the varying resistance of the strain gauges to a voltage using a built-in Wheatstone bridge. An analog to digital conversion occurs converting the analog voltage signal into a digital signal. The digital signal is then transmitted to a receiver which is connected to a computer with LabVIEW. National Instrument's LabVIEW software is used to interpret, record, and display the strains produced by the crank. A line drawing of the system has been provided in Figure 3.

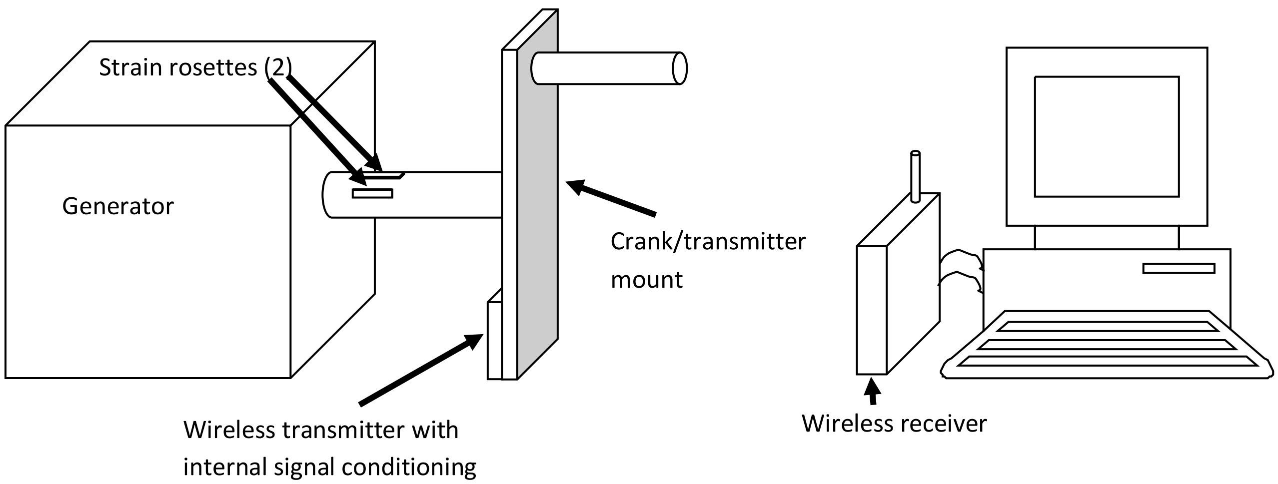



**Figure 3: Design Overview**

## Detailed Description

### Functional Block Diagram

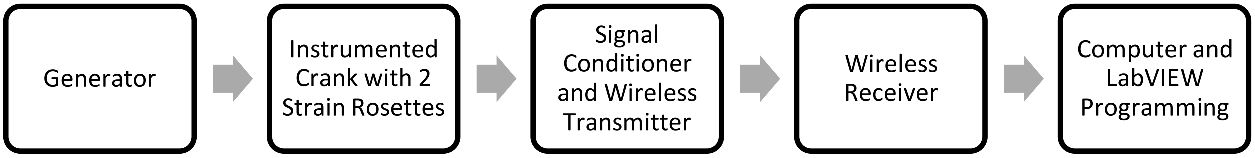



**Figure 4: Functional block diagram**

### Functional Description

#### *Generator*

Using knowledge of mechanical and electrical power, Equation 1 and Equation 2 were combined to create Equation 5.

$$T = \frac{VI}{\omega} = \frac{V^2}{R\omega}$$

**Equation 5: Generator Torque**

The objective of this experiment is to effectively measure stresses, so the larger the stress, the more accurate the measurement. Since the resistance is inversely proportional to the torsion, the stress was maximized by connecting the two leads of the generator (minimizing the resistance). The voltage produced and the current were designed to be stable, so experimental torsion values could be compared to ideal values.

#### *Crank and Shaft*

The original steel shaft of the generator was replaced with an aluminum shaft to allow for greater stresses and larger strain readings. Refer to Figure 6 for a visual of the physical dimensions that is described. The ¾" diameter shaft is 18" long, with the strain gages mounted 4" from the handle of the crank. The vertical mounting plate, which acts as both a crank arm and the location where the signal conditioner and the wireless transmitter is mounted, is also aluminum with the dimensions 12" x 3" x ½". The aluminum shaft and the crank arm are welded together. The handle is repurposed from the pre-fabricated generator. A hole was drilled through the crank arm, and a 3/8", 16 thread steel bolt and threaded nut were used to screw in the handle. Some slack was left in the bolt in order to maintain the free rotation of the handle.

#### *2 Rosette Strain Gauges*

Each individual strain gauge acts as a variable resistor. Each strain gauge is integrated into the built in Wheatstone bridge of the WSN 3214 wireless transmitter. The output voltage of the Wheatstone bridge is transmitted by the WSN 3214 wireless transmitter to the receiver. The strain gauge is most sensitive in the direction of the primary sensing axis. Strains perpendicular to that are relatively insensitive. This is important because it gives the person installing the strain gauges more control over what direction the strains will be recorded.

### *Signal Conditioner and Wireless Transmitter*

The wireless signal conditioner strain node used is National Instruments WSN 3214. As shown in figure 3, the wireless strain node is attached to the crank lever arm by adhesive strips. The wireless strain node has built-in internal Wheatstone bridges that provide the excitation voltage needed to record the change in resistance from the strain gages. The changes in resistance are converted into a voltage by the Wheatstone bridge. The analog voltage signal is converted to a digital signal by an analog to digital converter in the wireless strain node. The digital signal is then transmitted wirelessly to the wireless receiver.

### *Wireless Receiver*

A National instruments WSN 9791 gateway is being used to receive the transmitted signal from the wireless strain nodes. As Figure 8 suggests, this device acts as pass through device pulling data from the National Instrument's less common IEEE 802.15.4 spectrum and sending it to the computer via Ethernet port [5]. "IEEE 802.15.4 is a low tier, ad-hoc, terrestrial, wireless standard in some ways similar to Bluetooth [6]." Low tier refers to a wireless network that is dependent upon the distance between the wireless radios. This type of wires network experiences decreasing signal quality and strength at larger distances and locations with many wireless radios. Ad-hoc means that the wireless radios support peer to peer connections only. Ad-hoc is an advantage in our location due to challenges with integrating with local wireless infrastructure and the crowded nature of the 2.4 GHz IEEE 802.11 spectrum. The different signaling methods used in IEEE 802.15.4 will prevent interference between the IEEE 802.11 network [6].

### *Computer and LabVIEW Programming*

The computer sends the digital data signal from the receiver to LabVIEW. The LabVIEW virtual instrument translates the digital signal back to analog using a digital to analog conversion. The LabVIEW virtual instrument converts the analog signal into strain data using Equation 6. This signal is recorded and processed before being written to an Excel-compatible data file. The file has nine columns – three for each of the three measurements: a timestamp, an offset from the start of the program in seconds, and the raw strain value.

$$\gamma = 2 \times \epsilon \text{ @ } 45° = \frac{\tau}{G} = \frac{\tau}{\frac{E}{2(1+\mu)}}$$

**Equation 6: Shear Strain**

In addition to this bare minimum functionality, the LabVIEW program supports a few additional features. Most importantly, the program includes a calibration process that allows the user to programmatically calibrate the device with step by step instruction. As well, the program includes two graphs which display the moments and torques in real time, two graphical indicators that show the signal strength and battery power of the wireless node, and an advanced flow-control that makes it easy for the user to make multiple measurements.

## Overview Drawings

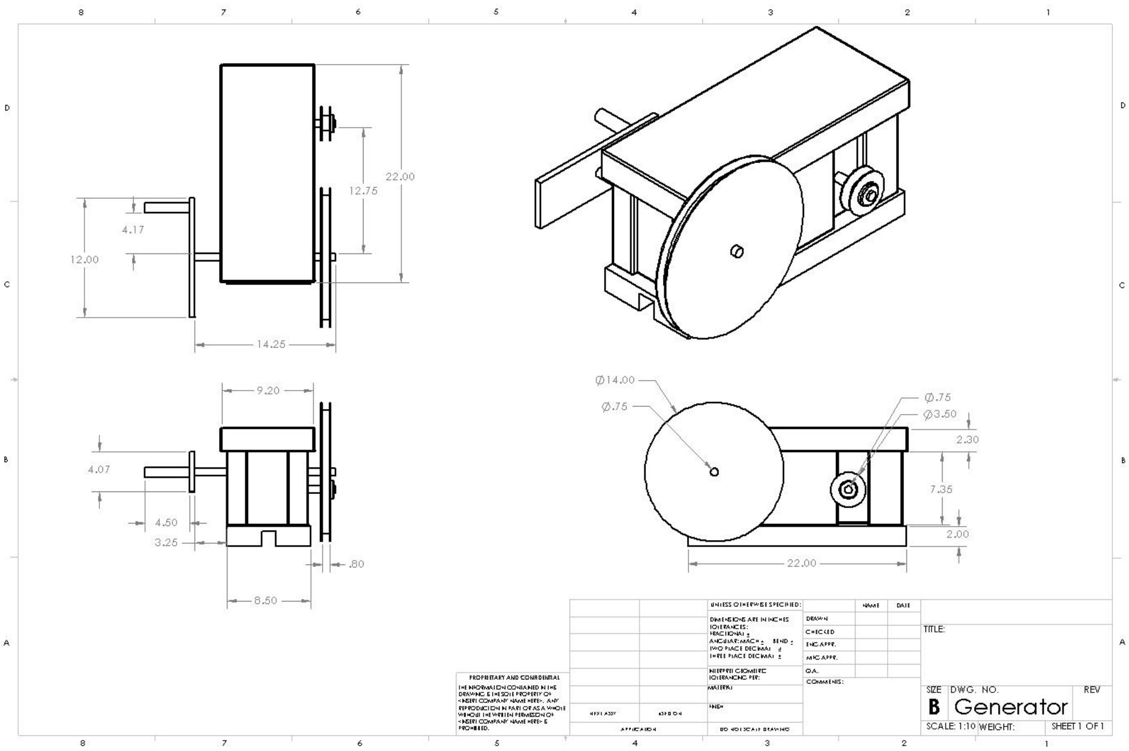



**Figure 5: Generator**

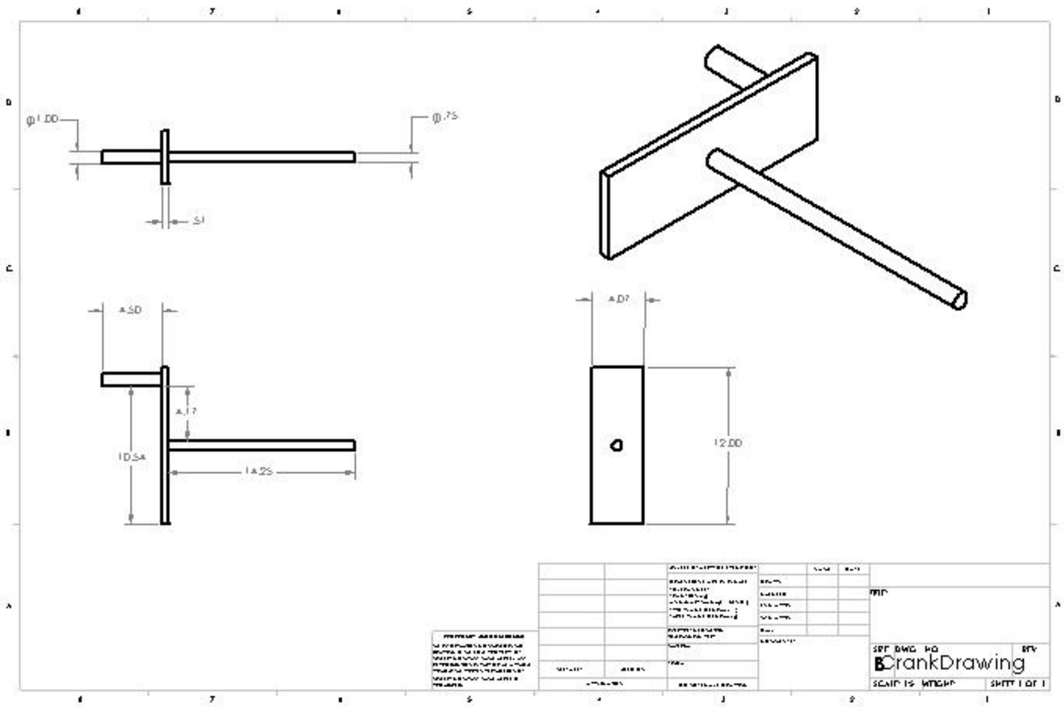



**Figure 6: Crank Dimensions**

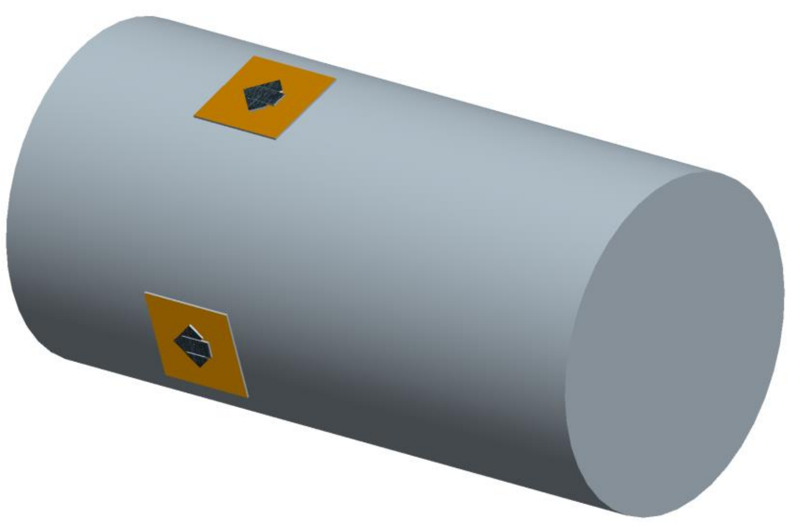


**Figure 7: Strain Gages and Bonding Terminal Pads**

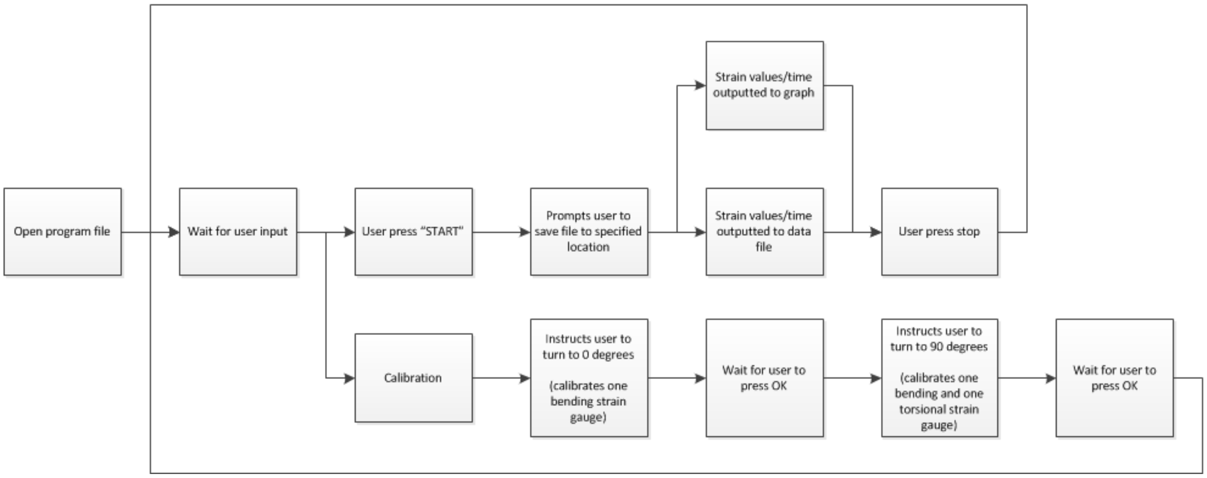



**Figure 8: LabVIEW Simplified Block Diagram**

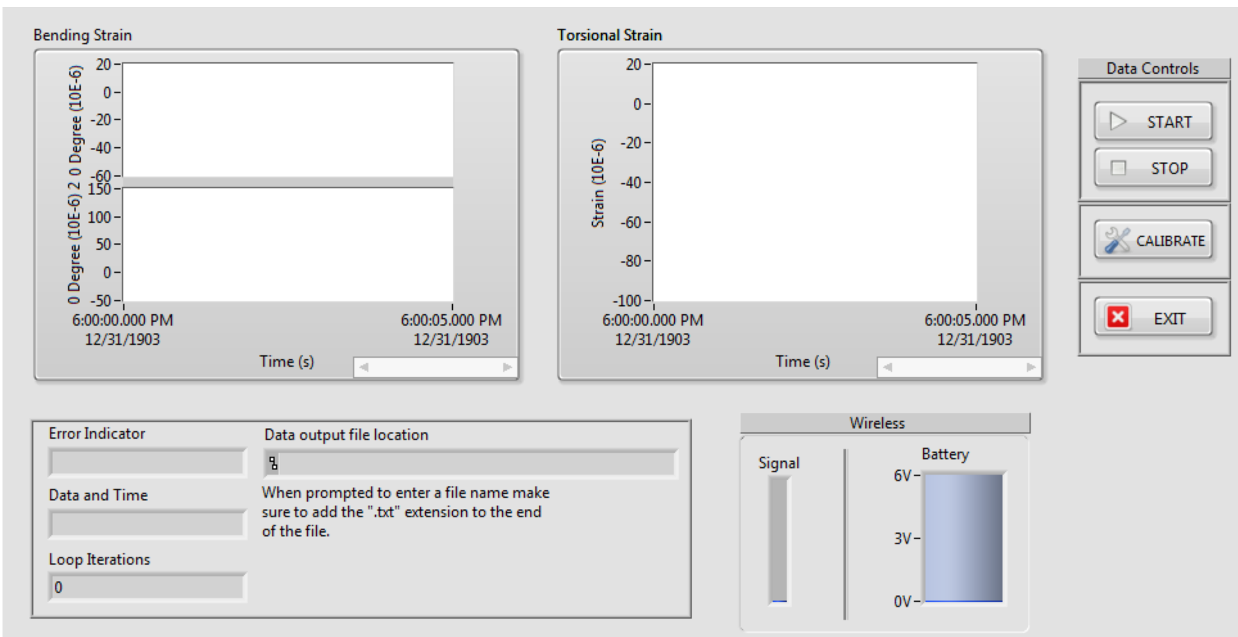



**Figure 9: Front panel of LabVIEW program**

## Additional Uses

In addition to being used as a laboratory experiment, the hand crank generator can be used for its intended purpose of generating energy using human power. The hand crank generator can also be modified and attached to the back of a bicycle in order to create greater stress and to collect more energy. The current laboratory experiment could also be expanded upon by measuring output power of the generator and the angular velocity of the experiment in order to determine the efficiency of the system. The current apparatus is also mobile, so can also be used as a demonstration during lecture rather than a laboratory experiment.

# Evaluation

## Evaluation Plan

The design requirements from section 3 were translated to testable requirements. The minimum acceptable or passing requirements were defined in more detail in the chart below.

| Rank | Purpose | Evaluation Procedure | Passing Requirements | Pass/Fail |
|---|---|---|---|---|
| **1** | Measures stresses, including at least 1 cyclic stress | Measure bending strain values over 1 cycle | Bending strain fluctuate between -25 and 25 microstrain, with at least 1 measurement greater than 25 microstrain | Pass |
| **1** | Measures stresses, including at least 1 cyclic stress | Measure torsional strain values over 1 cycle | Torsional strain greater than 25 microstrain | Pass |
| **2** | Apparatus set up is quick | Time the amount of time it takes for one TA to take the apparatus out of storage, turn on computer and run calibration with the assumption that the TA has not reviewed the instructions and will have TA lab manual available | Less than 30 min | Pass |
| **3** | Apparatus is durable and reliable | Time the amount of time it takes starting from when all students arrive, including instruction time and testing procedure, and ending when students are dismissed | Between 30 and 120 minutes | Pass |
| **3** | Apparatus is durable and reliable | ANSYS analysis will be performed on the shaft and handle of the generator. Expected lifetime will be extrapolated from that analysis. | Greater than 100,000 cycles | Pass |
| **3** | Apparatus is durable and reliable | Shaft will be dropped from table height so strain gage faces down. Strains will be measured before and after the drop and compared | Strains differ less than 10% | Pass |
| **3** | Apparatus is durable and reliable | Test the measured strain, then heat pseudo-shaft up in 100 degrees F ambient and cool to room temperature then re-measure the strain | Strains differ less than 10% | Pass |
| **3** | Apparatus is durable and reliable | Without instruments to enhance ability, pull the attached strain gage in opposite direction of | Not able to shear off epoxy or break strain gage | Pass |

| | | | | |
|---|---|---|---|---|
| | | pseudo-shaft | | |
| **3** | Apparatus is reliable | Wireless system will be run continuously for a week. | Wireless system still has power after 1 week | Pass |
| **4** | Engaging and instructional | Count number of students actively working on apparatus during procedure | 2 students | Pass |
| **4** | Engaging and instructional | Data collected was compared to expected values based on simplified geometry and theory | Difference of less than 25% | Pass |

## Evaluation Results

### Measures stresses, including at least 1 cyclic stress

This evaluation determines the measureable range of cyclic stresses produced during the laboratory experiment on order to ensure reproducible data output. The fully instrumented was tested by attaching 5 pounds of weight to the crank arm and collecting strain data as the arm completed a full rotation. Bending and torsional strain data was collected. The process of rotating the arm and collecting strain data was then repeated without loading, to test the range of strain values produced by a human arm. The strain data collected was compared to the minimum passing requirements. For the bending strain, the measurement was required to fluctuate between -25 and 25 microstrain. The experimental values exceed that by 75 microstrain (total of 100 microstrain). The torsional strain was expected to remain constant during the non-loaded experiment, and measure at least 25 microstrain. The experimental values were consistent with the expectation, and measuring 80 microstrain.

### Apparatus setup is quick

The purpose of this evaluation is to ensure the setup time required for the first experiment after long-term storage and the time required for setup before each lab is less than 30 minutes. This minimizes the required preparation time for teaching assistants. The fully disconnected experimental apparatus was stored on another table more than 20 ft. away from the test site. The apparatus was carried, by the teaching assistant, over to within 5 to 10ft. of the test site computer. The wireless data acquisition equipment was turned on and synced with the computer's wireless receiver. The test site computer was turned on and the LabVIEW application started. A calibration was completed following the calibration instructions in the teaching assistant's manual. Using a stopwatch, the time between when the teaching assistant first handled the device and when the teaching assistant completed calibration was recorded. In this experiment, the set up time was measured to be less than 10 minutes, within the minimum acceptable value of 30 minutes.

### Apparatus is durable and reliable

The purpose of the evaluation is to prevent unexpected downtime and repairs of the experimental apparatus. The shaft, wireless system and strain rosettes are the components identified as the most likely to fail. The shaft was analyzed because it is made of aluminum, while other components either have a warranty or were made of steel. The main concern with both the shaft and the wireless system was longevity. The wireless system runs on batteries, which will not have an infinite life. The strain rosettes were analyzed due to the reliance of this experiment on their sensitivity and because of their delicate design.

The reliability of the shaft was estimated using duty cycle calculations learned in Design and Manufacturing I, then evaluated using an ANSYS simulation. The results for the recommend operating conditions are expected to last for infinite life. The wireless transmitter batteries can be left in the transmitter for the week, but should be removed before long term storage. During testing, the batteries were left in the transmitters. Over the week, they did not lose power. It is recommended that the batteries are removed during storage to prevent corrosion.

The strain gages were tested in extreme conditions, testing before and after the treatment to assure the accuracy of the experiments. The tests performed on the strain gages were: heating it up to 100 degrees Fahrenheit then cooling it to room temperature, pulling on the wires (simple wire test) of the strain gage with. The measurements before and after the treatment were required to be within 10% of each other, and the results show that none of the tests had a significant effect on the measured strains (full results are found in the Appendix).

### Experiment is engaging and instructional

The purpose of this evaluation is to make sure that students are forced to think about what the experimental data means. To ensure that the students were actively engaged during the experimentation, the number of students using the apparatus was counted. Using the computed data from the *measure stress evaluation*, the forces were backed out and the expected and measured data was compared and determined to be within 25% of each other. The expected force was 8 lbs. and the measured data showed 10 lbs. The dimensions and density of Al-6061-T6 were used to estimate the weight of the aluminum bar [7]. The DAQ weight was based off of the information found in the WSN-3214 user manual [5].

## Discussion

### Strengths and Weaknesses

Although the developed design fulfills the customer specifications, there are areas that may be improved. While the wireless data acquisition system provides a clutter free and compact strain rosette usage, there is room for user and computer error. First, the data acquisition will not collect if the wireless DAQ system is not synced with the bridge correctly. Accordingly, we have developed detailed guides for the teaching assistants to allow them to successfully operate the equipment in a lab session.

The second possible type of error is of the computer type. This error maybe caused by future software or network updates. To mitigate this risk, we have created detailed guides for the software and hardware setup. These guides are written for an advance to expert computer user level. Since any software and hardware communication errors, by their very nature, will likely have to be solved in conjunction with MEnet, this should not be a problem.

### Next Steps

Due to time limitations not all possible features of the hand crank generator are fully developed. The first that comes to mind is an engaging visual display using the electric power output from the generator The LabVIEW interface could be improved to be more user-friendly and attractive. Redundant measurement equipment may be added for comparison purposes. For example, a sensor system to verify RPM could be added and compared with the RPM deduced from the strain output. The generator could be reconfigured to output electrical power.

There is opportunity to add additional equipment to this fluctuating load experiment. One such example is the addition of load sensing bolts. Besides producing another way to visualize when the experiment see stress peaks during the cranking motion, the data from the load sensing bolts could be used to find structural characteristics of the tool box.

Additions to the student lab manual can be added if the proctors feel that the lab does not fill enough of the class period. Students can be instructed to find the efficiency of the apparatus in converting the mechanical energy to electrical energy. The cranking speed and resistance torque can be varied together or individually. Resistance torque can be varied by adding resistance in between the generator leads. Students can be instructed to look at the changes in total efficiency and the different magnitude of strains due to changing these variables.

If data repeatability becomes a problem because of the belt slipping too much under high load, then the belt drive system could be replaced with a chain drive. The addition of the chain drive must be done carefully as it adds a greater potential for pinch points. Depending upon the lubrication choose for the chain, the chain could get students covered in grease. To prevent this we recommend using a wax chain lubricant.

Due to DAQ limitations, the strain gages were placed on the crankshaft in the orientation that we expected to see bending and shear strain. A future modification could be done to rewire the DAQ to fully use 1 of the 2 strain rosettes mounted on the crankshaft. Additionally, another strain rosette could be slapped on in a random orientation and wire that one up. The original intent of this apparatus was to put both rosettes on at different random orientations and use two WSN 3214's to collect the data. This way students could see that it doesn't matter which way you orientate a strain rosette.

The final design, however, is a functional apparatus with accompanying manuals and procedure. The design may be implemented without any additional modifications and assigned directly to a teaching assistant. Should a duplicate experiment be constructed, the expected construction time is 2 months, while the described modifications should take up to 2-3 months to procure.