Automatic Tensile Tester 4000

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***Abstract* -- To perform a simple material test, one would have to buy an expensive test frame that comes packaged with cumbersome software that takes a computer's entire processor to run. To make the creation and use of these machines more feasible, it needs to: (1) be compatible with interchangeable sensors; (2) feature an easy-to-use interface; (3) have the ability to run without a computer. This paper details our approach to make our machine fulfill these requirements while still making it easy for anyone to use and repair individual parts.**

***Index* -- Material testing, accelerated aging, rectifiers, electric sensing devices, temperature sensors, data acquisition and servo systems**

I. INTRODUCTION

For the process of material testing, one must often purchase an expensive test frame that takes up much space and only allows for only a few experiments. Many times, these machines have specific parameters with which it can be tested and must be sent back to the manufacturer to repair in the event of a technical failure.

The mechanical engineering department at the university of central Florida will build a prototype rig to perform creep and fatigue test under high temperatures. The rig will house the linear actuator, load cell and thermocouple. Special fixtures will be made for each test specimen model to attach the LVDT which measures displacement. Our control box will be portable and sit next to the rig and show all status information of the running experiment. Contain an emergency kill button, along with normal stop/start/pause and resume features. The user interface must be able to run on both Windows and MAC operating systems and full control experiment while the control box is connected.

Creep and fatigue tests are one of the many kinds of tests done with these test frames. Creep testing is generally done under high temperatures for the particular specimen in question and can be done under a constant load, called static notch testing, or under a variable load, call cyclic rupture testing. These tests are used to understand how materials will react in high pressure and high temperature environments such as engine turbines. If these tests can be made more accessible, then many could conduct their own tests without having to pay the exorbitant prices that some places charge.

With this problem in mind, Dr. Gordon approached Alan Beauchamp, Justin Ewing, and Devon Jackson with the opportunity to design and build a test frame that would be able to complete the various tests that he conducts in his lab. He asked that they design a user-friendly interface that can perform any creep crack experiment, while being able to log accurate data, run continuously for months, and be able to run independently of any computer connection.

In addition to the basic specifications, we were asked to make the entire design portable, so that it can be moved to a different location during the test in question. Because of this, the power sources and integrated circuits must be light as a whole and easy to carry.

The graphical user interface (GUI) must be easy to use and intuitive. It should be allowed for the experimenter to conduct a dynamic range of tests with many different parameters; it allows for changing of parameters because of different systems and sensors while the experiment is being initialized. Also there should be a carrying case that has a display and control functions for when there is no computer attached. The control functions that are on the carrying case are start, stop, pause, resume, reset, actuator up/down, and emergency stop. In addition to these buttons, there is also a display screen that shows the status of all the sensors and loop elements.

II. POWER SYSTEMS

Much thought needed to be put into the power and the sustainability of the power because one of the primary requirements is that the project is run for a few months at a time, so much can happen without the ability to perform maintenance on any part of the project.

When we initially started the project, we determined that everything should run from as few different voltages as possible. We came to the conclusion that the best voltages for everything involved would be to run everything from was from 12V and 5V and a lone regulator of 3.3V. These voltages allow us to achieve the optimum range across our integrated circuits, give us a good gain across our load cell, and are easy to find and maintain at a good cost.

To achieve a constant voltage across the many different components, we adopted the practice of using voltage regulators in the various sizes we needed. Even though they did not provide an exact rating of 12V or 5V, they provided a stable source at a voltage that could be accounted for. In addition to the basic inclusion of the regulators, we added polarized capacitors across the inputs and outputs to regulate any sudden differences in the various sources so it would limit harm to any other components in the process.

To further protect any circuits from potential failures, we used multiple regulators each being current-limited to protect from any voltage or current spikes and protect the other components. The regulators have their own fail safes in them to protect from over-voltage. If the regulator fails then everything attached to it loses its power, but everything else is protected. Therefore we can say that the remainder of the circuits is safe from harm until the system can be repaired. This is how the circuit will be implemented:

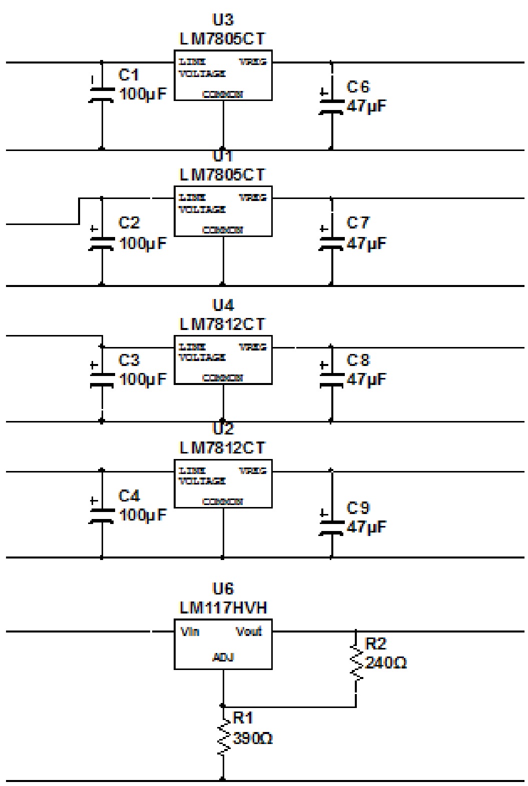


Figure 1 Voltage Regulation and Component Protection

We went with a 30W power source for the primary systems of the project. This source would power the sensors, integrated circuits and data acquisition devices. For the actuator motor, we decided to go with a separate power source due to the high power requirements. This power source must be able to supply the actuator with up to 250W.

III. LOAD CELL

To measure the load that the actuator applies to the test specimen, we use a load cell to measure the force. It directly takes its input from a power source and outputs a signal voltage based on the input. To analyze this signal, we designed many different approaches but we constantly ran into the problem of high signal loss and high inaccuracy at low voltages. What we came up with was a multiple step system to limit losses and improve accuracy over the whole spectrum.

Our problem initially arises from the fact that the tests are to be run in compression and tension, and the calibration sheet that was given was in the positive direction (tension) and we were limited to initially test in only the negative direction (compression). Knowing that many microcontrollers cannot receive a negative voltage, we had to find a way to constantly keep a constant positive voltage flowing to the microcontroller while being able to read whether the load was under tension or compression.

The solution to this problem itself was two-fold. First to read whether the load cell is under tension or compression, we used an open-drain comparator to tell the microcontroller what condition the load cell was under. A HIGH output from the comparator tells the microcontroller that the load cell is under the condition of tension, while a LOW output tells the microcontroller that the load cell is under the condition of compression. Since the output of the comparator is not exactly 0V when the input to the positive terminal is less than the ground, it is necessary that the microcontroller reads logic 0 when the voltage is below around 2V. When the reading should be high, the output of the comparator will be 5V, and therefore be assured of a high reading in the microcontroller. The reading from the load cell will be sampled 100 times ever sub cycle in the experiment and an average will be taken to minimize error and/or false readings. T This is very noticeable at low voltages. he selection comparator circuit is shown below:

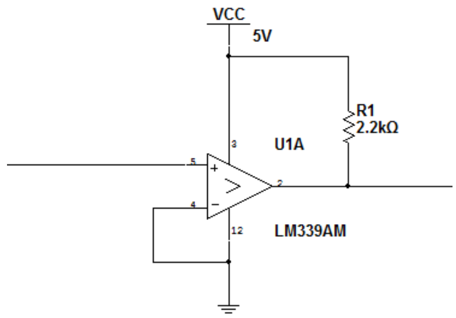


Figure 2 Compression/Tension Sensor

In parallel with this circuit is a full-wave rectifier made with operational amplifiers that is in the same mold as one with diodes. The primary difference between the two is that the rectifier made with op amps does not have the 0.7V loss at the ends. This is very noticeable at low voltages. A loss of 0.7V is equivalent to 200 pounds. Without the diodes, the number of readings at low voltages is reduced. The completed full-wave rectifier circuit is shown below:

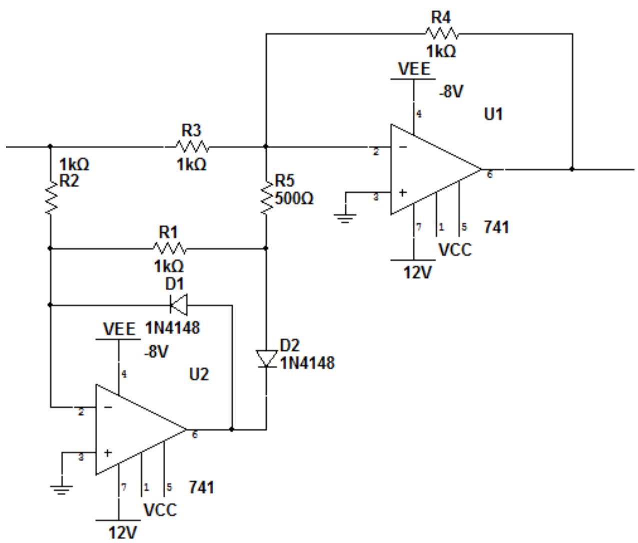


Figure 3 Full Wave Rectifier with Op-Amps

Because the output of the load cell is dependent on the input applied and there could be small variations in the regulator output from time to time, we decided to include a calibration test in the computer interface. The load cell datasheet has a calibration chart with an input/output voltage ratio. This ratio wasn't particularly effective and the linear equation derived from it had many errors over the course of the question. So we designed a calibration test (to be discussed in greater detail later) that would take a few readouts from predetermined points to create a more accurate curve-fit, and more reliable readings in the future.

IV. LINEAR VARIABLE DIFFERENTIAL TRANSFORMER (LVDT)

The linear variable differential transformer will, when combined with the potentiometer from the actuator, give us the displacement (strain) on the test specimen. When the calibration sheet from the LVDT was mapped out in an Excel document, we found that the output of the strain gauge is very linear from 0 to 10V.

A problem arises because the microcontroller only reads voltages from 0-5V. Anything outside of this range causes the microcontroller to blow and possibly damage other areas of the entire system as tests have shown. To reduce the output of the LVDT, we placed both signal leads on either side of two equivalent resisters in a 50/50 voltage divider format. The negative lead is connected to ground so that the reference is to ground. The sensor reading is in between the two resistors effectively cutting the voltage in half.

The next problem we encountered was that there was a noticeable negative voltage when the LVDT was at full extension. This negative voltage was outside of the range of the actual measureable values, therefore did not affect the measurements as a whole. The problem arises when the signal at full extension is relayed back to the microcontroller and could possibly fry the chip. To combat this potential disaster, we placed a signal diode before the signal output to eliminate the negative output. There is a very small voltage loss at the output, but not enough to negatively affect the range of the signals as a whole.

The LVDT selected was in the range of 15mm, but the strain on the specimens is generally less than 1mm. We figured the best way to figure the best way to determine the displacement values due to strain was to have the initial position as zero, and measure the displacement from that point, as determined by the difference in volts output. The voltage difference will be from the initial point and determined by the same curve. For example, if the 2.5V threshold is the initial position, and the input rises to 2.78V, then the difference between the two readings is the total strain placed on the specimen. This will be utilized to accurately define the strain without mapping the entire range of the LVDT.

V. MOTOR

Heavy duty linear actuators are very powerful motors. They are used in many industrial, commercial and automotive designs. So to apply the force on the testing specimen we picked a heavy duty linear actuator. The motor is able to supply up to a 2000 pound force with a 12” stroke running at a speed of 0.24” per second. It can drive up to 20 amps of current maximum but requires a 12 volt DC supply to run. The actuator we purchased came with a potentiometer inside. We took the heavy duty linear actuator and combined it with a rocker switch. Also, since were controlling the motor by a microcontroller we connected it to the h-bridge’s logic level inputs. The h-bridge is an electronic circuit which enables a voltage to be applied across a load in either direction. So we are using the h-bridge to convert those low power control signals into high power outputs suitable for driving the motor, controlling the motor’s direction, and varying the motor’s speed. The h-bridge circuit allows DC motors to run forwards and backwards. The h-bridge we purchased came with the optional heat sink installed, which was able to handle 30 amps continuous, and have a 40 amp peak. So the main objective was creating a circuit for motor control. Our sponsor wanted to be able to control the motor manually. The operations that were required were going clockwise, counter clockwise, and brake. The switch had three pole positions to be able to handle those operations specified.

Force (lbs.)	No Load Speed	Full Load Speed	Full Load Speed
2000	0.24	0.16	20

Table 1: Calculations for speed of the actuator

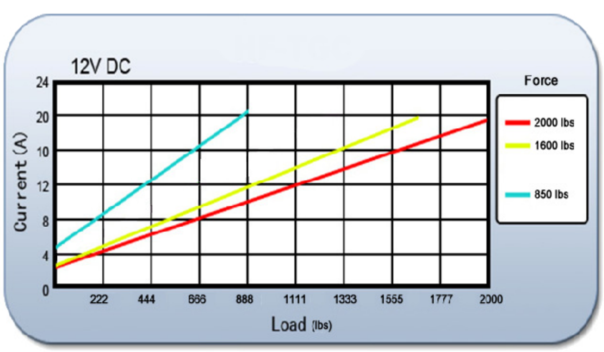


Figure 4 Graphical representation of current v. load

EN1	EN2	IN1	IN2	MTR+	MTR-	Description
0	0	X	X	OPEN	OPEN	Freewheel
1	1	0	0	GND	GND	Brake to GND
1	1	1	1	V+	V+	Brake to V+
1	1	0	1	GND	V+	Turn CW
1	1	1	0	V+	GND	Turn CCW

Table 2: Control Input/Truth table for H-Bridge

VI. THERMOCOUPLE

To measure the temperature that is applied to the test specimen, we will use a thermocouple to measure the temperature. We decided to go with a 36" high temperature Type-K Thermocouple with glass braid insulation purchased from Spark fun .We used a Type K thermocouple to meet the requirements set forth by the sponsor. The requirement was to be able to read temperatures from zero degrees to a thousand degrees Celsius. The thermocouple we picked has degrees that range from -270 to +1372C. The thermocouple has two wires coming out which are red (negative) and yellow (positive). To run the thermocouple we needed an amplifier. So we went with the AD595, which was placed on a bread board for connections. The amplifier only needs a five volt power supply to run it.

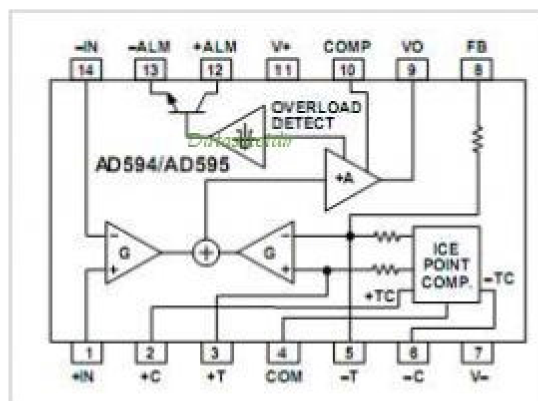


Figure 5 Function Diagram

The specimen will be heated up so we want to be able to see the temperature. But we only get the voltage as an output. So we have to convert the voltage into degree Celsius. The equation for that is Temperature (Degree Celsius) = V_{out} * (100 Degree Celsius/V).

VII. MICROCONTROLLER COMPONENTS

Dual AVR Atmega328p processors are used on the ATT4000. The main Atmega is used to control the feedback loop PID between the actuator and the load cell, calibration of analog devices, analog-to-digital conversions, LCD interface and user communication. The secondary Atmega's responsibility is communication with a SD card for setup files and data logging.

A. Communication Protocol

The microcontroller communicate via the serial protocol using the Newsoftserial library developed by Mikal Hart as it backbone. In our custom protocol the packets are sent via a 64 character data structure, the main operations are read, write and delete. Depending on the operation flag the data logger MCU know what type of data to expect and what to return. Table 3 below shows the packet format to be sent between devices.

Main to Data-logging		
00	read	Position-Filename/EOF/
01	write	Filename/EOF/Data
10	Del	Filename/EOF/
Data-logging to Main		
00	read	NewPosition/DATA
01	write	xxxxxdone
10	del	xxxxxdone

During the experiment the main controller is in constant communication with the data logging controller. Because the internal memory the atemega328p is limited to 32kb each input to the experiment is retrieve from the data logging input file stored on the SD card.

B. PID Controller

Once able to read the experiment parameters, specified by the user through the GUI to the input file, a basic PID algorithm is use to control the force generated by the actuator apply to the specimen. The nature of PID controlled system allows for y the 3 p, i, and d constants to be tuned manually by the user. The algorithm is shown below:

I. load K_p, K_i, K_d constants for the input file

II. for each loop in the experiment:

S = Sample Load Cell

Error = P = Desired Force – (S - Initial weight)

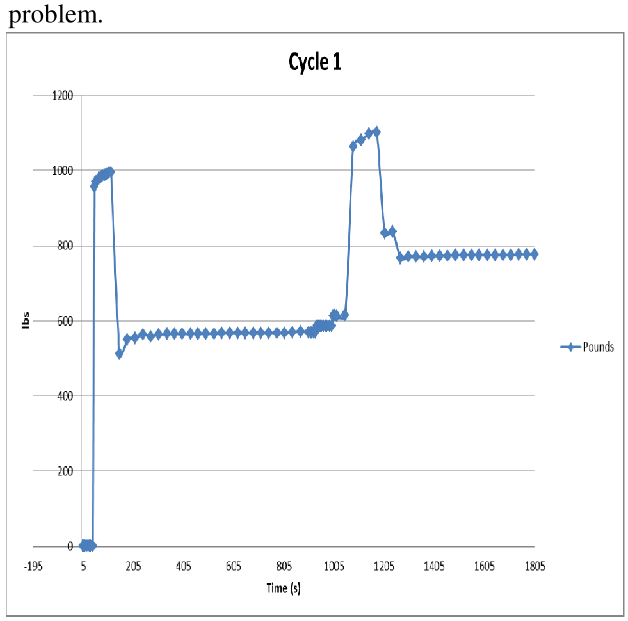
I = I + error

D = error – previous error

Motor PWM signal = $(k_p * P) + (k_i * I) + (k_d * D)$

The graph below shows the accuracy of our PID algorithm with constants using the Lego actuator prototype structure.

Due to the non-stable Lego structure and pressure sensor the over shoot was high, but as see below once the prototyped reached the settling point it was rather consistent till the next step in the experiment was reached. A stable rig and a calibrated load cell should solve this problem.



VIII. Input/output file

All information for running in experiment will be loaded on to the SD card and allow users to run experiment with or without connection to PC. All data will also be logged on to the SD card. All data will stored in a comma-separated-variable format which will allow for the user to open and graph, or manipulate there data with any spreadsheet program. This also allow for the user to create custom input files using excel generated from an equation.

A. Output File

By design the ATT400 should log temperature, load and strain applied to the specimen, one problem that arose was what should be logged and how should we be logging it. After consulting the mechanical engineers it was decided that the data logger one the device will only record raw values. The user must convert all values using either the custom GUI or by another means. The second problem which arose with the output was that our sponsor decided that they want to vary the data logging rate seeing that if one is running a year-long experiment sampling every hour or 30 minutes may be more appropriate. To deal with this request each cycle in the input file consist of a data log rate variable, allow the user to log every x minutes in one step of the entire experiment. Second as extra added feature if the user is connected to the custom GUI data is log every cycle.

A. Input File

The input file is formatted to allow the device to run without any human or computer interaction once the start button is pressed. The format the input file consists of:

Line 1: Kill Switch values
Line 2: PID Constant Values
Line 3: Load Cell Conversion Factors
Line 4: Thermocouple Conversion Factors
Line 5: LVDT Conversion Factors
Line 6: Cycle size, number of repeats, total time for one full cycle
*Line 7: Cycles 0... **
(Desired load, time, data log rate)

Each cycle is retrieving from the SD card when needed this allows for a infinite amount of cycle to be executed. This method was kept simple to allow the users to generate these input files using linear equations with excel, or the custom built GUI.

IX. GUI

The custom GUI allows the user to setup a experiment, view output files, and create a calibration file among other features. The interface runs all operating systems that use java and has a serial connection. The interface is broken up into 4 tabs main, input file, output file and calibration. Each tab is a user-friendly innovative environment giving the user total control.

A. Main

The user interface for the ATT 4000 needed have a main screen that would allow user to connect to all devices, place specimens, connect, disconnect and reconnect to view current status. The main interface calls controls connections to all ATT4000 devices connected to one's computer. Using the RXTX JAVA library created by Trent Jarvi, the main tab of the custom GUI receives and sends information from the main Atmega328p. Below in figure 6 the intuitive GUI interface designed with mechanical engineers in mind.

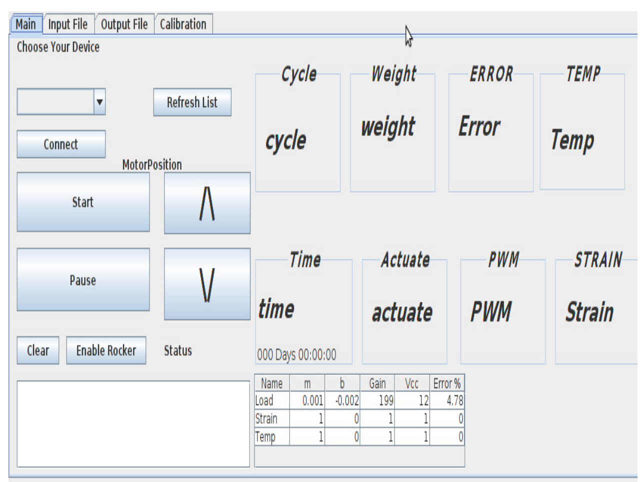


Figure 6 Main GUI

B. Input

The input GUI needs to be very simple, yet dynamic giving the end user the ability to custom design any necessary experiments. To make this process extremely inviting, we decided to go with a simple table based input file GUI structure. The user has the option of dynamically or manual inserting the experiment run time, conversion factors, PID values, and a special flag which will trigger the main controller to either perform or not conversion on the input data.

C. Output

Raw data is retrieved from the analog-to-digital converter on the atmega328p. This data file once loaded on the custom GUI is convert the ADC values to force in Pounds, strain in millimeters and using to the conversation factor table on the output tab on the GUI. The interface also allows for the user to create and load a range file if the input file is still available. This range file will allow the user to quickly view and export different cycles of data without leaving the GUI.

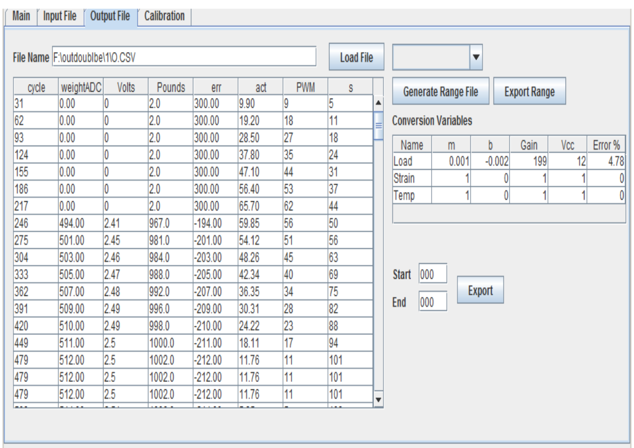


Figure 7 Output file GUI

XI. Calibration and Analog-to-Digital Conversion

The atmega328p come with a built in 10 bit analog to digital converter. One of the most important aspects of the ATT 4000 is the ability to maintain accurate conversion between force and Analog-to-digital values. The PID control loop which controls applied for is solely based on the ADC to lbs. conversion. Each load cell comes with a calibration sheet from the company which would you to convert from mV/V to pounds. The user must then convert lbs. -> mV/V -> Volts -> ADC and reverse on get back to pounds. Each step in the conversion loses precision. We decided that self-calibration is the best method on achieve optimum accuracy. We incorporated a calibration capture program which will allow the user to calibrate any load cell using an existing calibrated system and load cell. Below is the figure of the simple calibration GUI.

The calibration tab in the GUI will allow the user to load a calibration file connect to the ATT 4000 and then simply apply a known force and record the raw value from the analog-to-digital converter on the atmega328p with the simple click on a button. Once you complete your calibration you can save the calibration file and fit a linear regression line give you an approximate direct conversion equation which you can insert into the input file of your experiment. Turing the above conversion step into a simple ADC → lbs. and lbs. → ADC

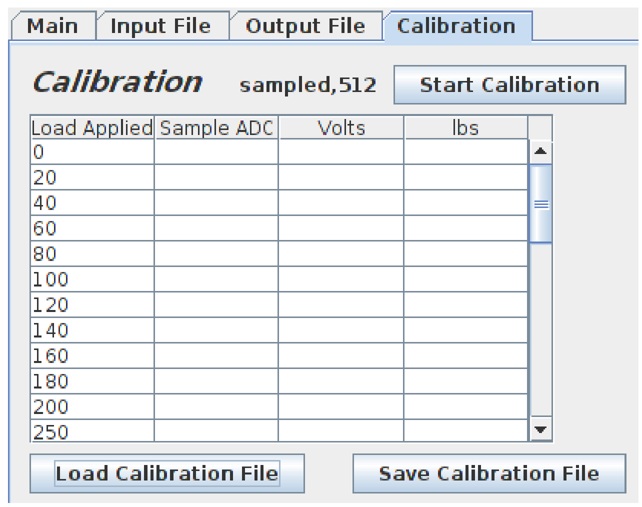


Figure 8 Calibration Interface

X. LCD Interface

When the device in not connected a computer, the user will receive information on the status of the current running experiment such as current load, temperature, strain, etc. which will be displayed on the LCD interface. Two status outputs per page each page being cycled every 5 seconds. We utilize a 2 x 20 RS 232 enabled LCD display with max232 for communication between the Atmega and the LCD. The board is design to also be upgraded to a 20 x 4 serial LCD powered by 5 volts.

XII. CONCLUSION

We have design and developed a base system which will be able to run extend experiments with minimal computer or human interaction. We noticed that calibration, the key to a successful our system, without system calibration the load cell reading will always be off. This would cause the PID controller to not function properly. We also learned that starting every experiment measurement at its zero point allows all calculations to be done with ease with the microcontroller. Finally we are currently using the built in 10 bit analog-to-digital converted in the main atmega328p in upgrade to a 24 bit analog-to-digital converter would allow more precision in our reading. Version one has proven that a low cost stress test rig could be created to run creep and fatigue test.

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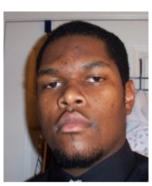
BIOGRAPHY

Alan Beauchamp is computer engineer student at the University of Central Florida. After graduation he will continue his with a career path working for Harris Corporation; while furthering his education within the next year with a master's degree in the field of computer engineering and/or mechatronics.



Justin Ewing is currently a senior at the University of Central Florida, and will receive his Bachelor's Degree in Electrical Engineering in May of 2011. After graduation, he will continue to pursue a career in electrical engineering and later continue his studies for a Master's in Electrical Engineering with a focus on power engineering.

Devon Jackson is currently a senior at the University of Central Florida, and will receive his Bachelor of Science in Electrical Engineering on May 6, 2011. He was a four year athlete in wrestling. He accomplished All-American status. While being a student athlete he worked at a co-op at the Orlando Utilities Commission for three years. After graduation, he will continue to pursue a career in electrical engineering and later continue his education and achieve a Master's in Business. Also, have thoughts of completing the FE and PE exams.

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