Optimal Design Report
Orthodontic Wire Mechanical System Tester
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1.1 Introduction

The purpose of this project is to update a wire tester which has been used in the past. The spring tester that has been used consists of a torque motor, and two attachment points where an orthodontic T-loop is attached. The torque motor applies a tension to the wire and the resulting forces in the x and y direction, and the moment in the z direction are measured using two sensors. The updated wire tester will be used to study the effects of these forces, as well as any other applicable forces that can occur within a patient’s mouth. This device will allow the prediction of every relevant force that occurs with the application of an orthodontic device. Once these forces have been discovered, one will be able to calculate the exact position of a patient’s tooth after application.

The device to be designed will be user friendly and will allow the experiments to be implemented with ease. Researchers need a way to easily set up experiments, to run them quickly, and to retrieve data accurately. The new device will have a user-friendly console which will allow the parameters of experiments to be created from a single computer. This makes experimental runs go much faster and research time will be cut down dramatically. Reducing experimentation time is essential in research projects and ultimately helps useful data to reach the public in a timely and inexpensive manner.

The apparatus to be created consists of two attachment points for a piece of orthodontic archwire, each mounted on a post. The attachment points will also allow for the variability of using an actually orthodontic bracket for the attachment point, again adding a more realistic element to the force measurement. Each post is attached to an arm for stability and position adjustment. The arm on the right hand side will be configured to a stepper motor which will move in the positive x direction, which will in turn move the attachment point and thus apply tension to the wire. A sensor connected to the attachment point on the left will be used to measure the forces. All of the position adjustment will be achieved through the use of lead screws connected to stepper motors.

The sensors to be used will measure the forces acting on the tooth. Although the tension is applied in the positive x direction with the stepper motor, the positioning of the attachment points allows the translation of these forces into other directions. A force body diagram of the tooth system can be seen in Figure 1.1.1 below. In the past, only the A sensor system is therefore required to test the forces acting on the tooth in six directions. The device used previous to our design required the use of two sensors, which can be seen in Figure 1.1.2 below, however with the use of a sensor that can test in six directions, all forces that could act on teeth will be measured, and a more accurate model will be developed.
Figure 1.1.1 Force Body Diagram of Tooth Force of Orthodontic Archwire

Figure 1.1.2 Photograph of current apparatus
Two sensors behind attachment points.
As briefly explained in the preceding paragraph, the force applied in one direction is translated when the position of an attachment point is altered. It can be said that the application of forces depends on the positioning of the brackets. Therefore, it is imperative that the position of the brackets is accurately determined. This is accomplished in the use of stepper motors equipped with the gears that turn a lead screws.

Figure 1.1.3 Protractor setup on Attachment

Additions to the conditioning and acquisition of the signal have been added to section 1.2.3. These additions include specifics of the signal itself, how the circuit will be implemented, and how the signal will be converted and sent to the computer. Another major addition to the design is in section 1.2.4, in which specific calculations of the signal are shown. Based on the excitation voltages and amplification gains used, specific calculations to get from a voltage (of the output signal) to a mechanical force (tension of torsion) are shown. We have also determined the models of op-amps (for amplification) and ADC (for DAQ) that we will be using.

The biggest change to the design was a step taken back from our more advanced design elements, such as the use of ball slides rather than lead screws with stepper motor attachments, in order to be more economical. The current mechanical components are still in working condition, and therefore can be used in our design. We did not change the use of the six direction sensor, although now two sensors will be used to test the force on both brackets. The difference in price between the sensor in this design and a less accurate sensor with a lower resolution is not that large, and the capabilities of this sensor surpass all others.
The user console that will be created to not only allow for manipulation of settings, but also display the data as experimentation takes place. Thus the retrieval of accurate data will be very simple. The console will allow for immediate conversions of forces into other units stipulated by the researcher. An important part of the updated project is to not only allow for a higher level of accuracy but also to make experiments much more user-friendly. One of the objectives is to create a device that will not require prior knowledge to run. It should be very straightforward and simple to utilize. This device will make the work of researchers much easier. A new addition to our labVIEW program is the mechanical and force zeroing functions.

The client of our project is Dr. Michael Holbert an orthodontist at the University of Connecticut Health Center School for dental medicine. The UCHC is one of the top research funded dental schools in the U.S. and is a highly respected university. Michael Holbert is working towards his masters and is currently doing research in the field of biomechanics and the effects of forces on tooth movement. He has been focusing his studies on how frictional forces within the mouth can effect the movement of teeth. Many orthodontists today do not consider these extra forces within their patient’s mouth. Unwanted movement side effects can occur to a patient with braces. It is Dr. Holbert’s objective to find a way for orthodontists to be able to predict the exact movement due to friction and then be able to use it to their advantage. It is critical that this biomechanical principle is studied; it will allow orthodontists to be able to better serve the community.

A general overview highlighting the main components of our project and how they will interact with each other and the user is shown in figure 1.1.4 on the next page.
Figure 1.1.4: Project Overview Block Diagram
1.2 Subunits

1.2.1 Mechanical Components:

A major flaw in the current design is its daunting nature due to the disorganized construction. This can be seen below in Figure 1.2.1. By noting this flaw and redesigning a flow to the device that will be more understandable and pleasing to the eye, the end result will be much easier to grasp, which is necessary for those that have no prior knowledge of engineering design or of the equipment in use itself. Not only will the manual components be replaced, the hardware will be condensed and therefore will be much more manageable. The circuitry and motor input and output information will also be contained in one unified area that will create a sleeker design and will also make repair easier.

To insure the accuracy and repeatability of the ball slide, we will test the micrometer for its accuracy without the attachment of the motor. The specific rotation length is delineated on the outside of the micrometer. By manually turning the micrometer to the same length for a repeated number of trials and recording results, the accuracy can be determined. With this type of testing is must be recognized that a good deal of human error exists.

To test the accuracy of the sensor readings, known weights will be hung from the sensor so that various tensions and torques are applied. It is essential that we also test the accuracy of readings when compound loads are applied. This will be done by hanging multiple weight simultaneously.

Figure 1.2.1.1 Photograph of Current Design.
Note: Haphazard Setup leads to disorganization

The current design for the base and platform is an aluminum alloy. This will be the same for our design, aluminum alloy will be used for the base and mechanical chassis. Since only a small segment of aluminum alloy plate will be needed, a supplier would most likely not be the best option. The material for this apparatus will need to be relatively strong, with a Young’s Modulus much larger than that of the wire to be tested, so as not to affect the consistency of results, also a thicker piece of metal could be used so that the base does not flex instead of the wire. This will be at least 0.75”.

All of the aluminum material will be provided and machined by Ultimate NiTi technologies, inc. This company has offered their services to us for precision cutting of the alloy material we plan on using. Precision of the apparatuses holding the brackets will then be guaranteed due to this machining process, done by professionals and specific to the project. Since the testing is on such a small scale, small errors in position and attachment alignment can pose major challenges to the testing.
The setup of the tester itself will be completely new and innovative. Rather than using a vertically mounted tension testing motor, which is seen in Figure 1.2.1.3 below, a horizontally mounted motor will be used. This will be placed on the stage for movement in the x direction. The motors and gear changes will be attached to arm which will be freely moving from the base.

Figure 1.2.1.3 Motor and Connections to Apply Tension on original device

In the optimal design, much of the current mechanical components will stay the same. The position adjustment of the bracket arm attachment will be achieved through the use of stepper motors each attached to a lead screw apparatus for each position. The lead screws currently being used are still in good condition and will allow for measurement that will accurate enough. The current design of the wire tester uses hand cranks to achieve position adjustment, so by replacing these with stepper motors, the accuracy and ease of use will be increased. Therefore, the optimal design mechanical setup will remain the same for the most part.

The torque motor currently used to apply the force to the wire will not be used. The force will instead be applied by the stepper motor to change direction along the x axis. There will be another stepper motor on the side of the apparatus where the large
In order for the information to be processed from the motors and sensors by the LabVIEW software, the signal needs to be converted into information that can be read by the computer. This is shown in Figure 1.1.1 on page 2 to be an analog to digital converter. This converter will encompass several aspects to have all of the equipment operating properly.

Each of the motors to be used will be equipped with an encoder, which is similar to a microcontroller. This encoder will allow the input and output information to be translated into commands read by the motor. To have all of the microcontrollers working properly, a brief program will be created which will be read by the LabVIEW interface. All of the information will sent to the computer via two serial ports each with 8 electrical connections to a USB converter. These two ports will accommodate all of the electrical connections necessary in our design. Some of the outputs of the motors can be configured to go through the same circuit and therefore require the same electrical connections. These ports are explained in more detail in section 1.2.2 and seen in table 1.2.2.18 on page 20 of this report. The USB information is easier read by the LabVIEW interface, and therefore a serial to USB converter will be used, which costs around 15 dollars.

1.2.2 Force and Moment Transducer: ATI Industrial Automation- Nano17

Overview

ATI Industrial Automation is an international company which specializes in measurement technology, specifically in the areas of biomechanics, manufacturing, engines, and plastics processing. The Nano17 converts components of force and torque into analog strain gauge signals. The Nano17 provides six components of measurement: Fx, Fy, Fz and Mx, My, Mz. The sensor relies solely on Newton’s third law when taking its measurements, that to every action there is an equal and opposite reaction. Within the sensor there are beams which, when loaded, flex according to Hooke’s law:

\[ \sigma = E \cdot \varepsilon \]

\( \sigma = \) Stress applied to the beam (\( \sigma \) is proportional to force
\( E = \) Elasticity modulus of the beam
\( \varepsilon = \) Strain applied to the beam

\textit{Equation 1: Hooke’s Law}

Semiconductor strain gauges are then attached to flexing beams. As the beams flex, the Silicon strain gauges experience a change in resistance according to the following:

\[ \Delta R = S_a \cdot R_o \cdot \varepsilon \]

\( \Delta R = \) Change in resistance of strain gauge
\( S_a = \) Gauge factor of strain gauge
\( R_o = \) Resistance of strain gauge unstrained
\[ \varepsilon = \text{Strain applied to strain gauge} \]

*Equation 2: Strain Gauge Change in Resistance*

When a current is passed through the strain gauge, the change in output voltage (from the unloaded output voltage) is then used to measure the strain. These changes in resistances (internally in the sensor) are measured by the changes in the output voltage.

One of the main benefits of the nano17 is that the strain gauge is made out of silicon, as opposed to the convention foil strain gauge. The silicon strain gauge produces a signal 75 times stronger than most foil strain gauges. Because the signal is larger, there is less need for amplification. When any signal is amplified, any noise that is also present in the signal is amplified. Therefore, the output of the nano17 will show less noise in the results.

Another major benefit of the nano17 is its size. Because we will be mounting a very small wire onto the sensor, and the sensor itself will be mounted on a post, its miniscule size is a major benefit and will make it much easier to work with and to use. The sensor weighs 9.1 grams, has a diameter of 17mm and a height of 14.5mm. A photograph of the sensor is show below in figure 1:

![Nano17 Sensor](image)

*Figure 1.2.2.1: ATI Industrial Automation- Nano17*

A schematic of the nano17 with measurements is shown on the next page in figure 2:
Another desirable feature of the nano17 for our application are the ranges and resolutions of the gauges. Most sensors are rated for forces ranging in the kilo-Newton degree, however have smaller resolutions. Since the forces and torques we will be measuring will be applied by a thin wire, it is not necessary to have a sensor capable of these types of measurements. However it is essential that the sensor have a high resolution, for precise measurements of the mechanical system. The nano17 fulfills this requirement, and is capable of measuring the ranges of forces and torques that will be applied to it. A table of the sensor ranges and resolutions for various calibrations is shown below in Figure 3:

![Figure 1.2.2.3: ATI Industrial Automation- Nano17 Ranges and Resolutions for various calibrations](image-url)
**Mounting the Sensor**

The mounting of the sensor will be a delicate process that will be essential to the accuracy of the readings of the sensor. It is essential that the transducer be mounted to a strong structural device. If it is not, loads applied to the sensor will then be translated to the mounting device, therefore making the readings of the sensor useless. A schematic of the mounting side of the nano17 is shown below in figure 4:

![Schematic of the mounting side of the nano17](image)

**Figure 1.2.4: ATI Industrial Automation- Nano17 Mounting Side Schematic**

ATI provides the customer with a mounting adapter to aid in the mounting process. One end of the mounting adapter will attach to the support beam, while the other end will attach directly to the nano17. The mounting adapter uses M2 taps and 2.0mm dowel pin holes for interfacing. Holes of this specification will be drilled into the support beam.

**Mounting the Wire**

The secure mounting of the wire is essential to obtaining accurate measurements from the transducer. If the wire is able to freely move within the mounting device, the readings from the sensor will be useless. However the mounting device must be able to easily detach and re-attach new wires. It is also essential that the wire be mounted directly in the center of the sensor so that applied forces are not translated into torques. The mounting on the tool side of the sensor follows follow the ISO 9409-1 mounting pattern. A schematic of the tool side of the nano17 is shown on the next page in figure 5:
Figure 1.2.2.5: ATI Industrial Automation- Nano17 Tool Side Schematic

We will create an interface that at one end, attaches to the tool side of the sensor (following ISO 9409-1), and at the other end attaches to the wire. The mechanical design of this interface can be seen in Figure 1.2.2.6 below.

Figure 1.2.2.6: Mechanical Setup of Attachment to Sensor. Sensor attachment fits into the sensing reference frame of origin as shown in Figure 1.2.2.5 above.

Transducer Cable

The transducer cable is an essential part of the device because it will be carrying un-amplified signals. Any noise that is added to this signal will have major effects on the readings of the sensor. Two of the major sources of noise in which we will try to eliminate are: noise from electrical fields and noise from mechanical stress. ATI provides the customer with a transducer cable specifically designed for the elimination of noise. A rendering of the nano17 with the attached transducer cable is shown on the next page in figure 6:
To reduce the effects of noise from mechanical stress, it is essential that the cable not be bent to less than the minimum cycled bending radius of the cable, which is 2.5 times the cable's diameter (for the Nano17, this is 40mm). If the cable bends to a radius smaller than this value, failure of the cable can occur due to fatigue. The cable itself is 65.7mm long, meaning that the circuitry for the sensor be relatively close to the sensor itself. The wiring of the transducer cable is shown below in figures 7 and 8. The outputs and their meanings are further explained below in the signal acquisition section.

**Figure 1.2.2.7: Connector Pin Out - Amphenol #703-91T-3635-01**

<table>
<thead>
<tr>
<th>Transducer Pin</th>
<th>Wire Color</th>
<th>12-pin Amphenol</th>
<th>Signal</th>
</tr>
</thead>
<tbody>
<tr>
<td>6</td>
<td>Red</td>
<td>K</td>
<td>SG</td>
</tr>
<tr>
<td>10</td>
<td>Black</td>
<td>J</td>
<td>SG</td>
</tr>
<tr>
<td>1</td>
<td>Brown</td>
<td>F</td>
<td>Gauge 0</td>
</tr>
<tr>
<td>7</td>
<td>Yellow</td>
<td>G</td>
<td>Gauge 1</td>
</tr>
<tr>
<td>17</td>
<td>Green</td>
<td>D</td>
<td>Gauge 2</td>
</tr>
<tr>
<td>8</td>
<td>Blue</td>
<td>E</td>
<td>Gauge 3</td>
</tr>
<tr>
<td>13</td>
<td>Violet</td>
<td>B</td>
<td>Gauge 4</td>
</tr>
<tr>
<td>9</td>
<td>Grey</td>
<td>C</td>
<td>Gauge 5</td>
</tr>
<tr>
<td>2</td>
<td>Orange</td>
<td>N/C</td>
<td>N/A</td>
</tr>
<tr>
<td>3</td>
<td>Brown/White</td>
<td>N/C</td>
<td>N/A</td>
</tr>
<tr>
<td>4</td>
<td>Blue/White</td>
<td>N/C</td>
<td>N/A</td>
</tr>
<tr>
<td>6</td>
<td>Grey/White</td>
<td>N/C</td>
<td>N/A</td>
</tr>
<tr>
<td>11</td>
<td>Red/White</td>
<td>N/C</td>
<td>N/A</td>
</tr>
<tr>
<td>12</td>
<td>Yellow/White</td>
<td>N/C</td>
<td>N/A</td>
</tr>
<tr>
<td>14</td>
<td>White</td>
<td>N/C</td>
<td>N/A</td>
</tr>
<tr>
<td>15</td>
<td>Black/White</td>
<td>N/C</td>
<td>N/A</td>
</tr>
<tr>
<td>16</td>
<td>Orange/White</td>
<td>N/C</td>
<td>N/A</td>
</tr>
<tr>
<td>18</td>
<td>Yellow/White</td>
<td>N/C</td>
<td>N/A</td>
</tr>
<tr>
<td>19</td>
<td>White/Black</td>
<td>N/C</td>
<td>N/A</td>
</tr>
<tr>
<td>20</td>
<td>Green/White</td>
<td>N/C</td>
<td>N/A</td>
</tr>
</tbody>
</table>

Table 5.1 - Wiring for 9105-C-H type Cables (Pin nos. 1-25, 9-20, N/C mate to 9105-TWF-type transducers. See Figure 5.3 for 12 pin Amphenol drawing.)

**Figure 1.2.2.8: Transducer Cable Wiring**

**Signal Acquisition and Conditioning**

**Overview:**

After a signal is generated from the sensor, the signal needs to be modified before it can be analyzed. A block diagram of these modifications is shown on the next page in figure 1.2.2.9.
The Signal:
The internal circuitry of the signal consists of six half bridge strain gauges to 
sense the applied load. Each pair works as a voltage divider to produce a signal 
proportional to the magnitude of the load. The readings at SG0, SG1, SG2, SG3, 
SG4, and SG5 will be the output signals. A schematic of the circuitry of the 
sensor is shown below in figure 1.2.10.

One can represent each strain gauges as:

\[
V_m = V_{SG,III} - V_{SG,LO} = V_1 + V_2 = V_m \frac{R_1}{R_1 + R_2} + V_m \frac{R_2}{R_1 + R_2}
\]

The thermister is a resister used to measure change in temperature for calibration 
purposes. We have not decided yet if it is necessary to incorporate this 
component of the sensor into our design.
The output signal of the sensor (without filtration and conditioning) has a resonant frequency of 7200Hz is all six channels. This signal is not AC coupled.

Amplification:
The first step in the signal conditioning process is amplification. One must be careful to not amplify the signal too much, as setting the gain too high will result in early AC saturation (therefore decreasing the range on the sensor). However one must also be careful not to amplify too little, as setting the gain too low will cause a decrease in the resolution and an increase in the SNR (signal to noise ratio). We will use a basic non-inverting amplifier configuration, shown below:

\[ \frac{V_{out}}{V_{in}} = 1 + \frac{R_2}{R_1} \]

*Figure 1.2.2.11: Basic Non-Inverting Amplifier Configuration*

Each sensor comes with a spreadsheet with individually calculated TWE calibration values. Calibration must be done specific to each sensor, therefore specific values in the circuit cannot yet be determined.

Because the output signal is so weak, it is possible that very large amplifications are necessary. When one designs circuits producing gain in the areas of 50dB, the gain becomes unstable. If this much amplification is necessary, we will use two amplifiers in series to eliminate this problem.

The Op-amp that we plan to use is made by national semiconductor-LMH6624 - Single/ Dual Ultra Low Noise Wideband Operational Amplifier. A schematic for this can be seen below in figure 1.2.2.12. The most desirable characteristic of this op-amp is its low voltage noise of 0.92 nV/√Hz.

*Figure 1.2.2.12: National Semiconductor-LMH6624 Schematic*

Filtering:
Filtration of the signal from noise will be done using a multiple feedback bandpass filter. A bandpass filter is a device which allows certain frequencies to
pass through while rejecting frequencies outside of this range. For our design we will be using a 6th order Butterworth filter with a bandpass region from 5200-9200Hz (centered at the resonant frequency 7200Hz). The circuit diagram and frequency response of the circuit are shown below:

![Figure 1.2.2.13: 6th order Butterworth Bandpass Filter Circuit Diagram](image)

![Figure 1.2.2.14: 6th order Butterworth Bandpass Filter Frequency Response](image)

**DC Offset:**

The DAQ’s ADC will have an input range for the voltage of the input signal. This needs to be matched by adding a DC offset in order to ensure the ADC is quantizing the signal with the best resolution possible. A DC offset will be added to the circuit by use of a summing amplifier. The properties of a basic summing amplifier using an op-amp are shown on the next page in figure 1.2.2.15.
The Circuit:
Figure 1.2.2.16 below is a schematic of the circuit with all of the components put together for a single channel.

\[ V_0 = \left( \frac{R_f}{R_a} \right) V_a + \left( \frac{R_f}{R_b} \right) V_b + \left( \frac{R_f}{R_C} \right) V_c \]

Figure 1.2.2.15: Basic summing amplifier.
ADC:
After the signal is conditioned and amplified, it must be converted to a digital signal so that it may be sent and analyzed by the computer. This will be done by using an ADC.

An essential factor of the ADC is the sampling rate. The nyquist frequency is described as the 2x the maximum frequency of the signal. The sampling rate of the ADC must match the nyquist frequency. Choosing a sampling rate too slow will result in a sampling error of the data, making the data useless. Over sampling of a signal is a technique that is sometimes used to eliminate the effects of random noise (by sampling the same signal multiple times and taking the average) and is also used in anti-aliasing (eliminating the jagged edges of a digital signal). We are still investigating into which sample rate will prove to be best for our purpose.

Another factor to consider when choosing an ADC is the bit count of the chip. It is essential that this will not be the limiting factor of the resolution of the sensor. Using 16 bit ADC = $2^{16} = 65536$ quantization levels. A 16-bit ADC will ensure that the number of quantization levels of the converter is not the limiting factor in the resolution of the readings, but that the sensor itself will be the limiting factor. Figure 1.2.2.17 below shows the resolution for each of the calibrations offered for the nano17 using a 16-bit ADC:

Nano-17 Resolution using 16-bit ADC

<table>
<thead>
<tr>
<th>Calibration</th>
<th>US 3-1</th>
<th>US 6-2</th>
<th>US 12-4</th>
<th>SI 12-0.12</th>
<th>SI 25-0.25</th>
<th>SI 50-0.5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fx, Fy</td>
<td>+/- 1/5120 lb</td>
<td>+/- 1/2560 lb</td>
<td>+/- 1/1280 lb</td>
<td>+/- 1/1280 N</td>
<td>+/- 1/640 N</td>
<td>+/- 1/320 N</td>
</tr>
<tr>
<td>Fz</td>
<td>+/- 1/5120 lb</td>
<td>+/- 1/2560 lb</td>
<td>+/- 1/1280 lb</td>
<td>+/- 1/1280 N</td>
<td>+/- 1/640 N</td>
<td>+/- 1/320 N</td>
</tr>
<tr>
<td>Tx, Ty, Tz</td>
<td>+/- 1/32000 in*lb</td>
<td>+/- 1/16000 in*lb</td>
<td>+/- 1/8000 in*lb</td>
<td>+/- 1/256 N*mm</td>
<td>+/- 1/128 N*mm</td>
<td>+/- 1/64 N*mm</td>
</tr>
</tbody>
</table>

Figure 1.2.2.17: Resolution of Nano-17 using 16-Bit ADC for various calibrations

We are planning on using the Texas Instruments ADS1255IDBT A/D converter (Digikey part #: 296-15743-6-ND). Desirable characteristics of this chip include it’s 30kHz sampling rate and its 24 bit resolution. This chip can be seen on the next page in figure 1.2.2.18.
Figure 1.2.2.18: Texas Instruments ADS1255IDBT Schematics

Where:

- AVDD = analog power supply = +5V
- AGND = analog ground, 0V
- VREFN = negative reference input
- VREFP = positive reference input
- AIN0 = analog input = 10mA continuous, 100mA momentary, 0-5V
- DVDD = digital power supply = +1.8V
- DGND= digital ground, 0V
- DOUT= digital output (ranges from +1.8-+3.6V)

DAQ:

Organized communication between the computer and the circuit board (which will control the sensor and the motors) is essential so that an organized, well written program can be created to control each device. We are planning on using a serial interface for this purpose. Digital data will be sent via a serial cable to the serial port of the computer. An overview of the input and output schematics is shown below in figure 1.2.2.18.

<table>
<thead>
<tr>
<th>Port</th>
<th>Signal</th>
<th>I/O (to/from computer)</th>
<th>Constant</th>
</tr>
</thead>
<tbody>
<tr>
<td>00</td>
<td>SG-lo Excitation (Pin J)</td>
<td>O</td>
<td>0V</td>
</tr>
<tr>
<td>01</td>
<td>SG-hi Excitation (Pin K)</td>
<td>O</td>
<td>5V</td>
</tr>
<tr>
<td>02</td>
<td>SG 0 Output (Pin F)</td>
<td>I</td>
<td></td>
</tr>
<tr>
<td>03</td>
<td>SG 1 Output (Pin G)</td>
<td>I</td>
<td></td>
</tr>
<tr>
<td>04</td>
<td>SG 2 Output (Pin D)</td>
<td>I</td>
<td></td>
</tr>
<tr>
<td>05</td>
<td>SG 3 Output (Pin B)</td>
<td>I</td>
<td></td>
</tr>
<tr>
<td>06</td>
<td>SG 4 Output (Pin C)</td>
<td>I</td>
<td></td>
</tr>
<tr>
<td>07</td>
<td>A(+)</td>
<td>O</td>
<td></td>
</tr>
<tr>
<td>08</td>
<td>B(-)</td>
<td>O</td>
<td></td>
</tr>
<tr>
<td>09</td>
<td>Gnd</td>
<td>O</td>
<td>Gnd</td>
</tr>
</tbody>
</table>

Figure 1.2.2.18: Overview of I/O schematics at computer interface
1.2.3.1 Background

The purpose of the stepper motors is to move the attachment points and align them for experiments. This will be done by the rotation of lead screws. A motor will rotate a lead screw which will be connected to a wire attachment. This will cause the movement of the attachment point. This movement must be precise and accurate. The movement of a stepper motor is done by a series of small rotations called steps; each step has a specific degree to its movement. A computer program will keep track of the steps moved and by doing this will be able to calculate the exact position of the attachment.

1.2.3.2 Stepper Motors

The motor being used for positioning will be 23MDSI Series Stepper Motor/Driver/Controller. We will use three 23MDSI motors to rotate lead screws causing movement of the attachment points.

The model number of the motor for attachment point alignment via lead screw is 23MD306S-00-00. This motor comes from Anaheim Automation which is located in Anaheim CA. It is a high torque step motor and can produce up to 230 oz-in of torque. It also has a built in driver and controller, which will eliminate the need for excess space. The motor and its dimensions are shown below in Fig. 1.2.3.1 and Fig. 1.2.3.2 is on the next page.

Figure 1.2.3.1
Stepper Motor Anaheim Automations
Figure 1.2.3.2 (all units in inches)
Anaheim Automations

Figure 1.2.3.1 depicts what the motor looks like and Figure 1.2.3.2 shows the size of the motor itself. The units are in inches and the length of the motor is 5.828 inches in length. The motor is large enough to supply adequate torque, while still small enough as to reduce bulk space of this device.

In the motor is a built in driver. This microstepping driver operates off of a range of direct current voltage from 12V minimum to a max of 24V. The torque to RPS ratio can be seen in Figure 1.2.3.3 on the next page. This graph contains four model types 306, 206, 106 and 006. Since we are looking for a high torque as well as a high RPS, the motor we will use model 206.
The device will run on a low step motor RPS so as to increase torque to an appropriate level. This is necessary so that the torque (when geared up) is high enough such that there is enough mechanical advantage to adequately rotate the lead screw. The motors will run at 5 rotations per second, producing a torque of 112.5 oz-in.

1.2.3.3 Gears Applied To Motor

A gear will be attached to the rod that is sticking out of the 23MD motor. Another larger gear will be intermeshed with this one. When the motor rotates its force will be geared up and the larger gear will provide adequate torque to rotate the lead screws thus moving the attachment points.

The metal rod that protrudes from the center of the 23MD motor has a diameter of 0.230 inches. The gear attached to this rod has a diameter of 1.0 inches. The hole inside this gear is 0.230 inches. The larger gear will be 3.0 inches in diameter. The edge of this gear will be connected to the lead screw, which moves the brackets. The diagram on the next page (Figure 1.2.3.4) is a drawing done in Visio of the gear motor attachments.
As shown above, the one inch diameter gear will be intermeshed with the 3.0 inch in diameter gear. The center of the gear with 3.0 inches will be connected to the lead screw. As the larger gear rotates the lead screw will turn and thus creating movement of the attachment points. The 3 inch diameter gear will have 60 teeth, the 1 inch gear will have 20 teeth. This will produce a gear ratio of 3:1. Using the gear ratio equation:

\[
\text{Gear Ratio} = \frac{\text{Output gear teeth \#}}{\text{Input gear teeth \#}} \quad (\text{equ. 1.2.3.1})
\]

Then using the equation: \( \text{Motor Torque} \times \text{Gear Ratio} = \text{Output Torque} \), we can calculate the exact torque applied to the lead screw. Since the torque at the smaller gear is 112.5 oz-in, the torque of the larger gear will be \( 3 \times (112.5 \text{ oz-in}) \) or 337.5 oz-in.

### 1.2.3.4 Stepper Motors Encoder

The 23MD motor has a built in encoder, which will connect, to the user interface. This encoder, (shown in Fig. 1.2.3.5 on the next page), is attached to the back of the stepper motor and is approximately 0.70 inches in width. The circuits shown for the motors are inside the motor.
In Figure 1.2.3.5, “Input 1” and Input 2” are used to change between one of two profiles. The profiles deal with speed, acceleration, index number and complete time. Both make settings according to their pre-programmed values. When the on/off switch is closed the motor will be activated, when the switch is open the motor will be off. The “hard +” and “hard –“ are inputs which determine the maximum number of steps that the motor can make in either direction before it is stopped. The “Output 1” is an open collector that has the ability to sink 50mA. The index on this connection is set as the number of steps that the motor will take. This number can be altered with the computer language being used. VIN is connected to an external voltage which must be between 12-24DC. The RS-485 is the connection between the user control interface and the encoder. We will use an RS485 converter to connect the motors to an RS232 serial port. The RS485 converter allows a direct connection between the motor and the computer. All motors in this device can be connected to the RS232 port. An example of the RS485 converter is shown in figure 1.2.3.6 shown below.
Each unit refers to a motor shown in Figure 1.2.3.6, the RS485 is capable of working with multiple motors. The RS485 plugs directly into an RS232 serial port and then converts RS232 voltage signals to RS485 differential signals. Lines TD(B) and TD(A) are data lines. Wire A is the output from the computer and line B is the input into the computer. Each unit has its driver turned off until it is selected by the computer. Once a motor’s driver is selected it turns on and communicates directly with the computer. After the motor finishes it’s function the driver is then turned off.

The schematics of the RS485 are shown below in figure 1.2.3.7.

In figure 1.2.3.7 above the J1 connections are the connections from the RS485 converter to the RS232 serial port. J2:1 and J2:2 are the data A and data B are the inputs and outputs to the motor respectively. J2:3 is the ground connection with the motors.

To program the encoder we will be using SMC60 Win programming software. This software comes with the motor and has a variety of pre-programmed coding. It also has the option to code your own programs. This code will be integrated to our labVIEW program. The inputs of the labVIEW dealing with motors will be sent to the SCM60 program which will in turn control the motors function.

1.2.3.5 Motor Brakes

To stop the motors we will be using motor friction brakes sold by Anaheim Automations. All motors purchased from this company have the option of including these brakes. The friction brakes are connected to the voltage input which runs the motor. When voltage is applied the an electromagnetic force is created by the magnet
which pulls the armature away from the friction. This allows the friction disc (which is connected to the motor shaft) to rotate freely. When the voltage is interrupted, there is no longer a magnetic field and the armature presses against the friction disc. This holds the motor shaft from rotating, locking it in place. This application can be seen in figure 1.2.3.8 below.

![Diagram of the locking mechanism](image)

**Figure 1.2.3.8**
Anaheim Automations: Diagram of the locking mechanism

### 1.2.3.6 Force Application

We will apply the force to the wire based on the motors rotating the lead screws. The equation to translate torque into linear force on a lead screw is:

\[
\Gamma_{\text{required}} = F_{\text{direct}} \left( \frac{2\pi \mu r + p \cos \alpha}{2\pi r \cos \alpha - \mu p} \right) r + R \mu 
\]

(equ. 1.2.3.2)

Where:

- \( \Gamma_{\text{required}} \) = torque created by the motor
- \( F_{\text{direct}} \) = force applied to object
- \( \mu \) = coefficient of friction
- \( r \) = pitch radius of the screw
- \( p \) = lead of the thread
- \( R \) = thrust bearing radius
- \( \alpha \) = thread angle
- \( \beta = 2R/p \)
Using equation 1.2.3.2 the torque created by the motor can be altered to produce the desired force on the wires. This will be achieved via labVIEW communication to the SCM60 Win program which will allow varying torques.

1.2.3.7 Testing of Applications

To test the capability of the motors, we will make a setup of lead screws that are connected to a 3 in. diameter gear. Next we will hang weights of 225 oz. at the side of the gear. 225 oz will create the same torque that the motor would at the edge of the 3 inch gear. The motor, when geared up, produces a torque of 337.5 at the center of this gear. It can be seen that this weight will produce the same torque by using the torque equation:

\[ t = F \times L \quad \text{and} \quad 337.5 \text{ oz.-in} / 1.5 \text{ in} = 225 \text{ oz.} \]

This test will be used to make sure that the motor will be able to rotate the lead screw with ease. The basic setup of this test can be seen in figure 1.2.4.1 below.

![Figure 1.2.3.9](image)

Testing of motor with weight attached

Another application test for the motor will be to make sure that the attachment points consistently move the correct length with a specific number of gear rotations. This test needs to be done to make sure that there are no forces that are pushing back on the attachment point which would create incorrect movement. This will be done by rotating the lead screw a number of times with the attachment point connected to it and measuring the length that the attachment moves. With the attachment point at zero position, the gear will be rotated 20 times and then the attachment point’s movement will be measured. Next the attachment point will be put back into zero position and we will repeat the experiment. This will be done a minimum of 10 times to ensure accuracy of movement; which is critical to using this device for research.

We will also need to make sure that there is no backdrive in the lead screw during experimentation. This is important because if the forces created by the tension experiment are great enough to cause the attachments to backdrive we will need to improve our locking mechanism. This experiment tests the friction in the motor brake to make sure that it is sufficient to counter any force that could create unwanted movement.
Thus, force tests will be applied to every type of position with the motors locked in place. Before and after the experiment the position of the attachment points will be measured. Forces applied will be from ranges to 100-800g from time ranges of 1 minute to an hour. If the attachment points do not move, then the current application will work perfectly. If they do move then a better type of motor brake will be needed.

1.2.4 Software: LabVIEW

User Interface
LabVIEW will act as the sole interface between the user and the machine. By placing all user controls and data displays in one, easy to use program, the machine as a whole will be more user friendly and therefore more productive in its application.

The user will be able to input the starting position and the displacement speed of the moving bracket in the X, Y and Z directions along with the angle of the starting bracket (ranging from -90 to 90 degrees). Front panel of the user input functions are shown below in figure 1.2.4.1:

![Figure 1.2.4.1: Front panel of use input function](image)

Currently, the only graphs that we have included in out front panel are the most basic displays of force vs. time and moment vs. time. We are however planning on reading into the capabilities of LabVIEW and making the data display as dynamic, interactive, and informative as possible. Some ideas include having the user define what is displayed, allowing the user to have multiple custom graphs displayed simultaneously, display of mechanical properties of the wire, and anything thing else that LabVIEW will allow us to do. A preliminary design of the front panel of the data output function is shown on the next page in figure 1.2.4.2:
Another capability that will be essential to the functionality our virtual instrument will be its ability to export data. Much data analysis and comparisons will be done optimally in other programs besides LabVIEW, and therefore it is essential that the program have the capability to export raw data. As we have further contact with our client, we will determine exactly where the data will need to be exported to. However, to start, we will ensure that all four data streams (vs. time) will be able to be exported to a text file and a Microsoft Excel file. Block diagram of this function is shown below in figure 1.2.4.3:

We will also allow the user to save experiment initial conditions. Therefore, if one wishes to do multiple trials of a particular experiment, one need not manually enter data each time. This added capability will make the machine easier to use, and will eliminate the likelihood of a human error due to incorrect data entry.

The most complicated part of our program will be the ability to simultaneously input and output multiple data streams. While we are still looking into more possible solutions, we have preliminary decided to use a printer port interface. The block diagram to simultaneously input and output data using the printer port is shown on the next page in figure 1.2.4.4.
Lastly it is essential that we give the user the ability to zero the machine. The wire tester will have two different zero modes: mechanical zero and force zero. Mechanical zero, when activated, will simply return the movable insertion point back to it’s zero, and will return the bracket angle back to zero.

There are will be two different force zeroing options, Fx force zeroing and Fy force zeroing. When Fx force zeroing is activated, the position of the insertion point will be moved around so that Fx=0. The position (X,Y,Z) will be displayed to the user, along with the resulting Fy and Mz. When Fy force zeroing is activated, the position of the insertion point will be moved around so that Fy=0. The position (X,Y,Z) will be displayed to the user, along with the resulting Fx and Mz.

**Calculations and Analysis**

ATI provides a custom calculated calibration sheet specifically for each sensor they produce. A sample of this calibration sheet is as follows. G0-G5 represents each individual strain gauge in the sensor. The values in the table in figure 1.2.4.5 below represent the voltages (in mV) across the strain gauges when maximum load/tension is applied in the specific axis.

<table>
<thead>
<tr>
<th>Calibration Matrix (Raw):</th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th>±Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>G0</td>
<td>G1</td>
<td>G2</td>
<td>G3</td>
<td>G4</td>
<td>G5</td>
<td>±Range</td>
</tr>
<tr>
<td>Fx</td>
<td>4.35186</td>
<td>54.91901</td>
<td>-67.86725934</td>
<td>1210.73767</td>
<td>20.30129</td>
<td>-1302.59</td>
</tr>
<tr>
<td>Fy</td>
<td>-34.6124</td>
<td>-1500.72</td>
<td>-17.97192247</td>
<td>763.471234</td>
<td>-46.365</td>
<td>682.2596</td>
</tr>
<tr>
<td>Fz</td>
<td>1369.149</td>
<td>5.225805</td>
<td>1360.857081</td>
<td>4492.1108</td>
<td>-8291.88</td>
<td>7863.802</td>
</tr>
<tr>
<td>Tx</td>
<td>60.74048</td>
<td>-9025.72</td>
<td>7214.198819</td>
<td>-8291.88</td>
<td>4161.016</td>
<td>120</td>
</tr>
<tr>
<td>Ty</td>
<td>-8721.08</td>
<td>-352.109</td>
<td>5191.855812</td>
<td>-4990.1471</td>
<td>29.51916</td>
<td>-5289.06</td>
</tr>
<tr>
<td>Tz</td>
<td>-60.4914</td>
<td>-5175.03</td>
<td>331.4062911</td>
<td>-4990.1471</td>
<td>29.51916</td>
<td>-5289.06</td>
</tr>
</tbody>
</table>
Since these signals will be amplified, one can then create a calibration matrix for the amplified signal. The optimal amplification can be determined when the range of the ADC is known. This matrix is calculated by taking the values in the above matrix, multiplying them by the excitation voltage/amplifier gain. We will be using a +/- 5V for SGhi/lo, therefore our excitation voltage will be 10V. For now, we will assume that the ADC will take an analog input voltage from 0-5V. Our amplified calibration matrix will then look as shown in the table in figure 1.2.4.6 below.

```
Calibration Matrix (Amplified):

<table>
<thead>
<tr>
<th></th>
<th>G0</th>
<th>G1</th>
<th>G2</th>
<th>G3</th>
<th>G4</th>
<th>G5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fx</td>
<td>0.145062</td>
<td>1.830634</td>
<td>-2.26224</td>
<td>40.35792</td>
<td>0.67671</td>
<td>-43.4195</td>
</tr>
<tr>
<td>Fy</td>
<td>-1.15375</td>
<td>-50.0238</td>
<td>-0.59906</td>
<td>25.44904</td>
<td>-1.5455</td>
<td>22.74199</td>
</tr>
<tr>
<td>Fz</td>
<td>45.63831</td>
<td>0.174193</td>
<td>45.3619</td>
<td>-0.76257</td>
<td>45.77107</td>
<td>-0.38171</td>
</tr>
<tr>
<td>Tx</td>
<td>2.024683</td>
<td>-300.857</td>
<td>240.4733</td>
<td>149.737</td>
<td>-276.396</td>
<td>138.7005</td>
</tr>
<tr>
<td>Ty</td>
<td>-290.703</td>
<td>-11.737</td>
<td>173.0619</td>
<td>-247.053</td>
<td>136.1587</td>
<td>262.1267</td>
</tr>
<tr>
<td>Tz</td>
<td>-2.01638</td>
<td>-172.501</td>
<td>11.04688</td>
<td>-166.338</td>
<td>0.983972</td>
<td>-176.302</td>
</tr>
</tbody>
</table>
```

Figure 1.2.4.6: Sample Strain gauge calibration matrix (amplified)

When a load is applied to a sensor, one must insert the values of G0-G5 into a matrix, and subtract the unloaded voltage value from these values to determine change in voltage for each strain gauge. These changes in voltage will be inserted into a matrix as shown below in figure 1.2.4.7. This matrix is the input signal to be read by LabVIEW.

\[
\begin{align*}
\Delta V G0 \\
\Delta V G1 \\
\Delta V G2 \\
\Delta V G3 \\
\Delta V G4 \\
\Delta V G5
\end{align*}
\]

Figure 1.2.4.7: Stain Gauge ΔV Matrix

The matrix multiplication of these values will give the measurements of the strain gauge as follows, where the calibration is measured above in figure 1.2.4.6, and the change in voltage is shown in figure 1.2.4.7 above.

\[
[\text{Calibration matrix}] \times [\text{change in voltage}] = [\text{result}]
\]

Where [result] =

- Fx N
- Fy N
- Fz N
- Tx Nmm
- Ty Nmm
- Tz Nmm
All of these calculations will be carried out in real time in LabVIEW as the experiment is being run.

### 1.2.5 Testing/analysis

To test the capability of the motors, we will make a setup of lead screws that are connected to a 3 in. diameter gear. Next we will hang weights of 225 oz. at the side of the gear. 225 oz will create the same torque that the motor would at the edge of the 3 inch gear. The motor, when geared up, produces a torque of 337.5 at the center of this gear. It can be seen that this weight will produce the same torque by using the torque equation:

\[ t = F \times L \]

and

\[ 337.5 \text{ oz.-in} / 1.5 \text{ in} = 225 \text{ oz.} \]

This test will be used to make sure that the motor will be able to rotate the lead screw with ease. The basic setup of this test can be seen in figure.

Another application test for the motor will be to make sure that the attachment points consistently move the correct length with a specific number of gear rotations. This test needs to be done to make sure that there are no forces that are pushing back on the attachment point which would create incorrect movement. This will be done by rotating the lead screw a number of times with the attachment point connected to it and measuring the length that the attachment moves. With the attachment point at zero position, the gear will be rotated 20 times and then the attachment point’s movement will be measured. Next the attachment point will be put back into zero position and we will repeat the experiment. This will be done a minimum of 10 times to ensure accuracy of movement; which is critical to using this device for research.

We will also need to make sure that there is no backdrive in the lead screw during experimentation. This is important because if the forces created by the tension experiment are great enough to cause the attachments to backdrive we will need to develop a locking mechanism. This experiment tests the friction in the lead screw to make sure that it is sufficient to counter any force that could create unwanted movement. Thus, before motors are applied to the mechanical system, force tests will be applied to every type of position that the attachment points will be in. Before and after the
experiment the position of the attachment points will be measured. Forces applied will be from ranges to 100-800g from time ranges of 1 minute to an hour. If the attachment points do not move, then the current application will work perfectly. If they do move then a locking mechanism will be needed to make sure that the lead screws will stay in place.

To insure the accuracy and repeatability of the position adjusting lead screws, we will test the lead screw for its accuracy without the attachment of the motor. The specific rotation length can be calculated, and by manually turning the lead screws to the same length for a repeated number of trials and recording results, the accuracy can be determined. With this type of testing is must be recognized that a good deal of human error exists.

To test the accuracy of the sensor readings, known weights will be hung from the sensor so that various tensions and torques are applied. It is essential that we also test the accuracy of readings when compound loads are applied. This will be done by hanging multiple weight simultaneously.

2. Realistic Constraints

Manufacturability elicits numerous constraints. These include the inclusion of our parts with the motor on the machine, the availability of parts, and the inability to test the software without complete mechanical apparatuses, yet the inability to test the apparatuses without the software. Everything needs to be built simultaneously to ensure that all parts work together properly. There are no known standards that will effect the use of the device.

For each wire to be tested, certain considerations need to be made. Some of the wires to be tested are easily deformable, some have much higher elastic constants and are not as easily deformed, and some are shape memory alloys, and have the ability to return to their original shape after a minimal amount of deformation is enacted. Therefore, it must be ensured that each test is specific to the type of wire used, and the forces are measured bearing these properties in mind. Standard wires with the resultant forces known obtained from the Ultimate NiTi wire company will be tested as constants to ensure proper calibration.

Ethical considerations include the use of certain testing procedures on patients. The force vectors may not be the same in the mouth, so this must be taken into consideration before applying these results in a clinical setting. Furthermore, the results achieved cannot be utilized for any other information aside from the force applied by the wire. While future research may allow for the capability to relate the results obtained to forces enacted in the mouth, for this device, solely the force on the wire is being tested.
Health issues include the force testing that may be too large for the mouth to handle, yet experimental data may conclude otherwise. The experimental result may not be as reliable if utilized in the mouth purely on the bases of forces rather than on the bases of prior experience and clinical trials. Health issues may arise in the use of the device, requiring mechanical safety necessary to prevent injury, such as keeping hair and clothing away from moving parts.

Since the device we are creating is meant to test application of dental wires there are minimal safety constraints. There will be no direct testing done on people, just testing done to learn how things will affect a human patient. Thus the only safety constraint exists in the use of the apparatus by the researcher. One would have to make sure that if a dental wire snapped that there was minimal possibility that a researcher could be injured.

Another major constraint on the device is the economic factor. While we have not been given any concrete budget limitations by our client, it is essential that we produce a machine that not only performs all of the required tasks, but one that does so while requiring the smallest amount of monetary recourses. This is important because had this been a project requested of actual engineering companies, the client would make the request to multiple companies and hire the company with the smallest proposed budget. Economics are also important if one were to manufacture and sell the product. Buyers would shop for the cheapest product that would successfully fulfill all of their needs.

Sustainability of the device will also serve as a constraint on the project. Since this product will be used by dentists and not by engineers, it is essential that there is very little to no maintenance required of the machine. As far as the software end of the project goes, this should not serve as a problem. However, whenever there are moving mechanical parts in a machine, there is the potential for mechanical failure. We will aim to keep the sustainability requirements of the machine to a minimum by using the most reliable motors (within our budget) and ensuring the mechanical integrity of the apparatus. Also, by keeping all of the equipment fairly easy to use, the use of this device will be sustained as future researchers will be able to use the wire tester.

Furthermore, the control of accuracy of data is a constraint on the project. The calibration of the sensors, the force applied by the motors, and the position adjustment of the attachment points themselves all affect the accuracy of the results. In order to control the accuracy of the attachment point positioning, the posts upon which the attachment points are attached need to be secured to the arms (shown in Attachment 1). These posts need to be secured and welded so that the force applied does not affect the position of the attachment point. Also, the motor that adjusts the degree rotation of the attachment point on the right side will need to have a locking mechanism, or a brake so that the motor does not rotate once the force is applied, thus effecting the force measurement.

In terms of political constraints a lot of orthodontics today do not use biomechanics research when they apply orthodontic devices to a patients mouth. It might
be difficult to get doctors to start using this device to make sure the correct forces were being used for their patients.

After this device was used to test a vast array of wires it could be determined that a specific type of wire was better than others. This could increase the cost of braces and perhaps a new type of brace application might be implemented. A new brace application could increase a patient’s social awkwardness. This social constraint is purely hypothetical and is not a constraint on the device itself. It is a constraint on the results the wire tester might show.

3 Safety Issues

A main focus of our design is to ensure the safety of the individuals who will be using the machine. Possible safety hazards of the machine have been reviewed and addressed in our design.

First of all, there is a mechanical safety hazard of the machine. Because the machine will have moving parts and rotating gears, the user runs the risk of being injured if their fingers/clothing are in the path of the moving parts. To address this issue, we have created a design which minimizes the exposure of the moving parts. The majority of movement in the apparatus will be caused by the rotating threads (powered by the motor), which in turn will move the platform that the second bracket is attached to. This function allows for the user to add variability to their experiments. If the user’s hand, clothing, or other body parts were to coming into contact with this rotating thread it would get jammed under the platform, causing great damage and pain to the user. To account for this we have created a design where the threads and motors will be mounted under the platforms, as opposed to on top or adjacent to the platform. Plastic guards will also be utilized to prevent the catching of clothing or hair. These will be placed around the threadwire apparatuses. This design feature will greatly reduce the likelihood of the user accidentally being entangled in a moving part.

Also, since our machine will combine electrical components and moving parts, there is a risk of that a moving part will interfere with one of the electrical wire, causing a possible short which could cause damage. To account for this, we have put the sensor on the stationary bracket, the bracket closest to the circuitry of the wire tester. Because of this design feature, the majority of the wires will be located far away from the moving parts of the machine. There are however some wires that need to be run to the moving bracket (these wires will control the motors). These wire are at the most risk for interfering with moving parts. To account for this potential safety hazard, we will have all of the wires run together, in a plastic tube along the bottom of the platform of the device. Therefore in the case that moving parts do come into close proximity with the
While we feel that we have addressed the safety hazards of this machine very thoroughly, there is still the small chance that there will be a malfunction or accident that puts the safety of the user in jeopardy. To account for this, we will have two emergency stop buttons incorporated into the design. The first stop button will be in the LabVIEW interface. When this button is pressed, the motors will stop and therefore all moving parts on the machine will become stationary. This stop button however will not interrupt experiments as power to the sensors and motors will not be shut off. In the case of an emergency in which all functions must be halted immediately, there will be an emergency stop button that will be located on the machine itself. When this stop button is activated, all power to the wire tester will be halted immediately, therefore stopping function of the motors and sensors. If this button is activated the experiment will be halted and data will most likely be lost.

4 Impact of Engineering Solutions

This proposed product will have a significant economic impact by improving orthodontic research, and thereby, improving orthodontic procedures. After completion, this device will allow researchers to be able to test the properties of a wide range of orthodontic applications, and will therefore allow a greater understanding of orthodontic devices. The capability to do this research will allow a better understanding of how forces interact on orthodontic wires, and will allow a better understanding of how to apply wires to the human teeth.

The direct impact of this research on economy could be a reduced cost of orthodontics. Since the force applied to human teeth will be better understood, the time that a patient needs to wear braces could be lowered. This improvement would be possible since braces could be applied more efficiently and orthodontists could apply braces while taking more forces into account than they had previously. This reduced time of needing braces would result in fewer visits to the orthodontist and could reduce the cost of braces.

Not only would application time be reduced, but research can be done into a better type of orthodontic wire. Researchers could work on studying the advantages of using one wire over another and then search for the best choice. This could result in finding a cheaper material and also a material with better properties. If a wire were to be discovered that held its tension better than previous ones and was cheaper, it would have an impact on our dental economy. As a result, if research were to be done that allowed a lowered cost of braces, the customers that orthodontists had would grow.

If research was done which allowed for cost reduction there would be an impact on our economy. Families that were not as wealthy could afford this luxury and the business of orthodontists would increase. This increased business would increase the
money going into dentistry and as a result provide more money towards orthodontic research.

Global effects of this device would be similar to that of economic effects. As our country gained more knowledge on braces and the effects of wires, other countries would pick up interest as well. Other companies throughout the world might desire the capability to perform similar research and would desire our product.

Another global effect comes back to cost. Not only would a reduced cost help our economy, it would also create more jobs for orthodontists by increasing customers. This would also spread the capability to purchase braces by lower income people in other countries. As the application of braces decreases in cost, more people across the globe will be able afford it. The lives of people in other countries will be improved via the orthodontic improvements that this research device will allow.

The environmental impact of this device is not directly seen. However, as with any device that requires an electrical input, environmental effects must be considered. The motors, the sensors, and the computer console all require the use of electricity. The use of electricity as a whole may be reduced as a result of this apparatus. That is due to the possible decrease in time of braces use. Should the forces on teeth be more accurately calculated, the exact movement of teeth may be predicted. This prediction may result in a much faster process. Should it take less time for one to achieve straight teeth and the wanted result, it is therefore likely that it this will result in less time for braces wear.

Also, the materials used, such as aluminum, are taken from the environment. This use of natural resources can be seen as somewhat detrimental. However, this does not need to be taken into consideration on a large scale because of the small amount of aluminum materials necessary for this project.

As far as society is concerned, the results obtained from this wire testing device could make an enormous impact. Should the device be able to measure quantifiable results on the forces involved in the movement of teeth, the impact on the field of orthodontics could be quite large. Currently, the use of calculations in the movement of teeth is nonexistent. Orthodontists use what they know to accomplish the movement that they have previously completed in similar cases. However, by calculating the exact movement of teeth and predicting what the mouth will eventually look like, the orthodontists job will have been made that much easier.

This returns to economics, where the easier the orthodontists job, the more patients he or she is able to take in, and the more people that can benefit from braces. This will bring down the cost of orthodontics. Society as a whole can benefit from the availability of braces and the confidence that comes with straight teeth. While it is somewhat extreme to consider the wire testing device to have such a large scope of impact, it is interesting to note that the application of the wire tester is one that is directly involved with healthcare research. Although widespread braces wear is not the main goal,
simply cutting down the time for braces wear can vastly improve the orthodontic profession, as well as the comfort of the patient. This accuracy in force measurements may completely change the field of orthodontics, decreasing the amount of time and improving accurate movement.

The engineering solution that has been found for the proposed problem is one that will have a positive impact on society, the economy, and will be prevalent on a global scale. As far as environment is concerned, the scope of our project is not one in which the environmental problems caused by the production of energy can be addressed. As far as our project itself is concerned, the environment is not at risk.

5 Lifelong Learning

Thus far in the development of designed, lifelong learning has been extremely prevalent. From the idea of the project itself, to the mechanical design, the entire project has been new and something which has not been thought of before. The first part of lifelong learning established was that of the orthodontic appliance itself. Considering the forces acting on human teeth is not something that has been taught in classes. Viewing teeth as movable objects that react when a force is applied was new to us. Not only are mechanical forces responsible for repositioning teeth, the idea that there is a possibility of calculating these forces and predicting the approximate movement of the teeth is innovative. This shows that the world of medicine and dentistry and the fields related is completely different than the technological world with which we as engineers are familiar.

Although braces are commonplace in the lives of adolescents, it is interesting to think that the idea of mechanical systems that are present in enormous structures are also present in orthodontic fixation devices. In order to understand the equipment used in the mouth, one must understand the way in which this is portrayed in the field of orthodontics. The relation of the forces applied to the teeth and the resulting movements has its own language, which needs to be understood in order to recognize the forces acting in particular directions and their relationship to the movement in teeth.

Different methods of data acquisition were investigated in order to determine the most efficient and accurate way of measuring forces. Methods of signal processing in the use of sensors to obtain an optimal signal to be analyzed and interpreted. Different types of sensors to perform these tasks were investigated, and ultimately, the use of a sensor which can gather information from 6 different references was determined to be the best solution. The interpretation of data from sensors in this type of setting was completely new.
Other parts of the project were equally as challenging to grasp. Motors had not been utilized in engineering labs in the past, however, after research, the motor to accomplish the task was found. A stepper motor is capable of moving in a predictable and measurable way so that the exact number of turns can be part of the input. In this way, the positioning of the attachment points of the brackets can be defined. This replaces manual adjustment, and is thus more user-friendly. Whereas motors were not considered before, they are now understood.

Mechanical components and their involvement with other parts is not something that has been fully developed outside of this project. However, upon researching the materials that could best be used to create the base of the project, and also the most cohesive design possible could be created. The interaction of the computer console and the mechanical components and the use of the analog to digital computer is also previously not defined and will be further developed.

While this project uses the mechanical principles, the software interfaces, and electrical understanding that have been applied in other classes, the actual implementation of all of these components in an operating apparatus required much more research. The application of forces on the teeth, the use of LabVIEW software to control mechanical devices, the use of motors, and the mechanical setup itself required a good deal of further work which was extremely informative, and will develop into further investigation.

Another thing learned that will be invaluable to a future in the field of engineering is the way in which to receive information from vendors. To get price quotes, or to find someone that is willing to meet one’s needs, it is imperative that one knows how to discuss these matters with the vendor. Through the development of this device, numerous vendors were contacting, and while some were helpful, others did not respond to requests.

While working on this project, another major lesson learned thus far has been teamwork. In order to get anything done on a group project, the team must work together. Although each member has ownership of a particular part of the device and its workings, all must be aware of the entire project’s development. Finding meeting times that work for every group member, and making sure everyone is on the right page has been a challenge. This is one lesson that will continue throughout this year.

The biggest lesson learned in this particular design is that money is the final decision maker. Although with the use of ball slides a higher degree of accuracy and repeatability would have been achieved, these qualities are not as important for this particular design, and therefore the ball slides were eliminated. Our mechanical design is therefore going to be a simpler, more organized version of the current design, using existing components. The budget is in the end what makes the final decision on what parts of the project are most important to fund.
6 References:

http://en.wikipedia.org/wiki/Thermister
http://en.wikipedia.org/wiki/ADC
http://en.wikipedia.org/wiki/DAQ
http://en.wikipedia.org/wiki/LabVIEW
http://www.ni.com/labview/
www.amphenol.com
www.yardemetals.com
www.anaheimautomation.com
http://www.anaheimautomation.com/integratedmotors.htm
www.wikipedia.org
www.usbport.com
www.national.com
http://www.linearmotion.biz/
http://pergatory.mit.edu/2.007/contests/2000_sojourner