Final Report

Orthodontic Wire Mechanical System Tester
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Abstract:

The client Michael Holbert has requested that we design an updated orthodontic wire tension tester. The device is needed for his expanded research into the forces on human teeth and the related application of dental wires in the mouth. The wire tester will allow users to test forces in a three dimensional plain and will allow a large variability of experiments to be done on different types of orthodontic wires.

The device will put an amount of force on an orthodontic wire and then sensors will be used to measure the amount of tension that is applied. The device has two attachments for the wire and the user can position the attachment points from a control panel. The wire can be positioned in any three dimensional alignment 8 centimeters from its zero location. After the wire is positioned, a force will be applied and measured. The data will be displayed on the control panel. This device is an essential update for the previous wire tester that the client had been using. The original device was inaccurate, non-user friendly and it eventually failed due to design flaw. The wire tester we are creating is a complete updated version of the old one; it will perform the functions of the previous device including the option of new types of experiments. It also will greatly lower the possibility of human error which was prevalent in the older device. The positional system is motorized using stepper motors and is done using linear stages that will align the attachments appropriately. Two six axis force torque transducers will be used to measure the applied forces and then output that data to the control panel. All inputs to the computer will be done using an RS-232 serial port. The motors have an RS-485 output and will need an RS-485 converter to connect to the computer.

This project will allow the UConn Health Center to expand their orthodontic research section. It will have a direct benefit towards people studying biomechanics and the effect of forces on teeth movement. The project is expected to be completed and ready for use by April 2007.
1 Introduction
1.1 (Client and Disability)

Michael Holbert, is currently working on his masters at the University of Connecticut Health Center school of dental medicine. He is using biomechanical principles to research tooth movement namely, how frictional forces effect rotational tooth movement. By determining the effect of friction, orthodontists can predict the effect of frictional forces, which are now causing unwanted side effects, and use them to his benefit. He needs an upgraded device that will test the tension on orthodontic wires and its translation of forces onto a human tooth.

Initially, a spring tester was created to assist medical school students in their research of specific orthodontic apparatuses. However, the device was only created to test one particular orthodontic fixture, the T loop, which was background behind the name “spring tester”. The so-called spring tester can now be called the generalized wire tester. Previous testing of wires not in the T loop formation was simply a manipulation of the somewhat primitive machinery. Calibration of this antiquated equipment was painstaking and required a good deal of patience. In order to improve measurements, manual adjustment was constantly required. The spring tester has been out of use for several years due to the unfamiliarity students with the equipment. Modification is required in order for biomechanical orthodontic research to continue at the health center.

There are many limitations of the current spring tester which needs to be changed. One such limitation of the current design is that a screw holds the wire in place. A bracket would have more accurate measurements of the orthodontic wire, since forces act differently on a screw as opposed to a bracket. A bracket consists of a slot, and two tie wings where the wire can be secured. The shape of the wire, and its placement in the slot can result in various mechanical forces which are effective in the movement of teeth. The forces acting on the teeth can be manipulated to achieve particular results which are to be measured using the wire testing apparatus.

The use of a bracket in place of a wire can better represent the mechanical forces acting on teeth. A single force on a tooth will cause tipping, however, the use of a
force combined with a moment causes translation of the teeth. Couples of forces are created by the size and shape of the orthodontic archwire and its placement in the bracket.

Lastly, a rather rudimentary control panel is the only means by which the user is able to modify experimental conditions. In order to improve and modernize this user console, a new user interface must be implemented.

The client is currently at a standstill with his research because the previous wire tester failed. It only allowed a limited variability for experiments and had allowed significant amounts of human error to come into play. Until a new device is created his biomechanic research is at a standstill.

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 on the next page. 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.
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.

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.

1.2 Project Purpose

The purpose of this project is to update a wire tester which has been used in the past. The updated wire tester will be used to study the effects of these frictional 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, and with variability. 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 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.

The new device will not only be easier to use, but it will also have more capabilities. These capabilities include two sensors that have the ability to measure forces and torques in all three planes, and movable brackets accurate to the degree of micrometers in all three planes of space. These added capabilities will allow researchers to collect more data, that is more accurate.

1.3 Previous Work Done by Others

1.3.1 Previous Products

The only previous product was the previous wire tester that had been created to test T-loop wires. The device had significant design flaws and is no longer being used. It had an extremely bulky and hard to use control panel. Many calibrations needed for individual experiments had to be set by hand. Including a protractor attached to it to test degrees of rotation.

The positional system previously used was based on hand cranks and users had to rotate a gear in order to align attachment points. There was also no locking mechanism on the previous positional system. This allowed for the possibility that the attachment points could move during experiments. Due to the large amount of human calibration there was significant human error in the previous device.

The motor used to put force on the wire created movement vertically compared to the attachment of the wire.
This vertical movement was then translated into a horizontal force. This translation was a very roundabout way of applying tension and needs to be replaced. The motor itself is now outdated and also needs replacement.

The entire previous device eventually failed due to design flaw and experiments can no longer be done using this previous product. The sensors on the older product have broken and no longer take readings. The device we are creating will be a necessary update to the older one and it will fix all of the issues that researchers had with the previous product.

1.3.2 Patents

One patent exists which deals with wire tension testing, US Patent number 5,249,472 by Maurice H. Brown. This device is a meter which is devised of pulleys and mechanical scales to determine the maximum tension that wires to be tested can withstand. Though similar in nature, this mechanical device does not correlate with the motorized device with computer interface that will be present in the wire tester to be built. Also, Mr. Brown’s patent does not relate to the specific purpose of our wire tester, which is for orthodontic applications. There are currently no patents out today that deal with tension machines used to calculate forces applied on human teeth. Thus the creation of our device has no limitations and can be made without fear of patent infringement.

1.3.3 Map of The Final Report

This report goes into detail on the design process of this device. It goes over every alternative design that was made and the changes that occurred between each of them. The optimal design will be explained in great detail and then an explanation of the subunits of the device will be made. The subunit section will be very specific and will allow the reader to have a full understanding of how each part of the device will work in relation to the whole. Next the realistic constraints of this project will be mentioned. The constraints gone over will be engineering standards, economic, environmental, sustainability, manufacturability, ethical, health and safety, social and political constraints. Safety issues will then be
discussed in detail explaining how safe the device will be. Next the impact of engineering solutions will be described and will be explained in reference to the impact on a global, economic, environmental, and societal context. There will then be a section on life long learning and how our group needed to have a pro-active learning attitude to design this project. A budget and timeline will then be discussed. The costs will be gone over and tasks required of this project will be given in relation to the time that is needed to complete them. Next individual team members contribution to this project will be described. This will go over what each team member did and how they participated in the design. Finally there will be a conclusion followed by references, acknowledgements and an appendix. The appendix will contain updated specifications as well as purchase requisitions and fax quotes.

2.1 Design Alternatives

2.1.1 Design 1

2.1.1.1 Key Components

2.1.2 Design 2

2.1.2.1 New Innovations

2.1.2.2 Key Components

2.1.3 Design 3

2.1.3.1 New Innovations

2.1.3.2 Key Components

2.2 Optimal Design

2.2.1 Objective

2.2.2 Subunits

2.1 Design Alternatives

2.1.1 Design 1

2.1.1.1 Key Components

Properties of the Kistler 4 Component Dynamometer Type 9272

Kistler is an international company which specializes in measurement technology, specifically in the areas of biomechanics, manufacturing, engines, and plastics processing. Kistler’s 4 Component Dynamometer Type 9272 is a rotating 4-component dynamometer which
measure forces along the X, Y and Z axes; and measures torsion about the Z axis. A picture of the Kistler 4 Component Dynamometer Type 9272 is shown in figure 1.2.1.3.

The Kistler 4 Component Dynamometer Type 9272

There are some important technical specifications that make the Kistler RCD Type 9123C our optimal choice of 4-component sensor sensor. First of all is calibrated to accurately measure all of the ranges of forces and couples that we anticipate will be applied via the wire. Also, with the proper amplification, the Kistler 4 Component Dynamometer Type 9272 will be able to measure the forces with an appropriate sensitivity.

### Kistler 4 Component Dynamometer Type 9272

#### Technical Data

<table>
<thead>
<tr>
<th>Signal Conditioning and Data Acquisition</th>
</tr>
</thead>
<tbody>
<tr>
<td>As mentioned above, the charge generated by piezoelectric sensors is very small and thus can easily be overshadowed by external interference and...</td>
</tr>
</tbody>
</table>
noise. To shield the signal, Kistler produces a multicore, high insulation, connecting cable. Kistler produces a cable designed specifically for this dynamometer. The charge signals then need to be converted into a voltage via a signal amplifier. The system will require four separate charge amplifiers (one for each channel) in which we will be building ourselves.

**Stepper Motors**

For this design we will be using two types of stepper motors. The two motors being used will be 23MDSI Series Stepper Motor/Driver/Controller and the 17MD102S-00. We will use three 23MDSI motors for bracket alignment and we will use two 17MD motors for the degree rotation on the brackets.

The model number of the motor for bracket alignment 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 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 move the brackets.

**Stepper Motors Encoder**

The motor has a built in encoder which will connect to the user interface. This encoder, shown in Fig. 4, is attached to the back of the stepper motor and is approximately 0.70 inches in width.
In Figure 4, “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.

**Stepper Motor for Degree Rotation**

The motor to be used for rotating the brackets will be the 17MD Series Motor / Driver Combination, with model number 17MD102S-00. This motor is also from Anaheim Automations located in Anaheim CA. The 17MD can generate up to 31 oz-in of torque and is smaller than the 23MD motor. It has Microstep divisions of 8, 4, 2 or full step. It has a 12-24V power requirement and a 0.225 degree resolution at the eighth step. The micro step driver operates off an 8VDC minimum to 35VDC maximum and has a
resolution that varies between 200 - 1600 steps/revolution
the dimensions of this motor are shown in figure 5 on the
next page.

The following table shows the length of the 17MD motor
series in comparison to its length and capable holding
torque.

<table>
<thead>
<tr>
<th>Model</th>
<th>Length</th>
<th>Holding Torque</th>
</tr>
</thead>
<tbody>
<tr>
<td>17MD102S-00</td>
<td>2.215”</td>
<td>31 oz-in</td>
</tr>
<tr>
<td>17MD202S-00</td>
<td>2.452”</td>
<td>50 oz-in</td>
</tr>
<tr>
<td>17MD302S-00</td>
<td>2.767”</td>
<td>62 oz-in</td>
</tr>
</tbody>
</table>

Anaheim Automations

We will be using model 102 due to the reduced length
of the motor. A holding torque of 31 oz-in is adequate for
bracket rotation.

This motor comes with a built in driver. This driver
(shown in figure 6) includes inputs for the motor to
connect to a computer and has a built in pulse generator
that can be used.

The MS1 and MS2 switches shown in Fig. 6 control the
resolution of the microstep. These control the square
waves that are generated by the pulse generator. The
direction switch changes the current and as a result
switches the direction that the motor rotates.
A major flaw in the current design is its daunting nature due to the disorganized construction. 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.

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. Obtaining a surplus piece at Yarde Metals is an option being considered. The pieces for sale are
extremely large and heavy as can be seen in Figure 8 below. 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.

The setup of the tester itself will be completely new and innovated. Rather than vertically mounted tension testing motor, a horizontally mounted motor will be used. This will be placed directly behind the bracket on the left hand side of the machined aluminum base. The motors and gear changes will be attached to the bracket apparatus, which will be freely moving from the base. A platform will be fixed atop the base and this will house all of the threading and stepper motors that will provide the adjustment of the bracket on the left hand side. This bracket will be fixed to the platform so that position adjustments can be made. This can be seen in the figure below.

Behind this bracket will be a box housing all of the circuitry and the analog to digital converter. By placing this on the platform itself, the project design becomes more cohesive. With all of the circuitry in that fixed location, it will be much easier to fix a problem and will be out of the way. This circuitry will be stored in the same location as the analog to digital converter.
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. The close up of the sensor apparatus and attachment adjustment setup can be seen in figures 10 and 11 above.

Each of the motors to be used will be equipped with an encoder, which is similar to a microcontroller. This microcontroller 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 may have to be created which will be read by the LabVIEW interface. This will be simple and similar to a PCL, or printer control language, where information is
simply organized by the computer and read by the mechanics of the printer.

The converter will be connected to the user console via a serial port. All of the wiring will be affixed to the serial port and the information will be sent to the computer so that information can be read by the user. Serial Port

2.1.2 Design 2
   2.1.2.1 New Innovations
   A major innovation in our mechanical design is that we put together an overview of how the final product is going to look. We decided that we would use lead screws to move the apparatus. Also, we came up with a drawing of how the movement will work by using different stages for each component of movement.

   Another component new to the second design is the sensor we chose to use. The sensor in the previous design was too expensive (about $33,000), and had handled ranges of forces and torques much larger than what would ever be experiences inside the mouth. We found a new, smaller, cheaper, and more relevant sensor for this design.

   Another major addition to this design is our signal conditioning section. We have added a circuit that will filter and amplify the signal outputted from the sensor.

   Finally, we added a schematic of what our LabVIEW program will look like, and its various functionalities.

   2.1.2.2 Key Components

   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 arm for movement in the x direction as can be seen in Attachment 1. The motors and gear changes will be attached to arm which will be freely moving from the base.

   The position adjustment of the bracket arm attachment will be achieved through the use of stepper motor attached
to a lead screw. The arm will rest on a track, and for the movement in the z direction this track will be placed directly on the base. The schematic for this can be seen in Figure 1.2.1.4 below. The stepper motor will not move, and will be fixed to the track. It will simply move the lead screw which will change the position of the arm. The arm for movement in the x direction will rest on a track that is attached to the arm for movement in the z direction. In this way, the apparatus will be moved in the z direction, but only the top arm holding the bracket attachment will move in the x direction. This will have a setup similar to Figure 1.2.1.4 below.
Setup for movement in Z direction

Position adjustment in the y direction is along track posts, rather than on a track upon which it will rest. This will include the movement of the sensor itself since this setup is located on the attachment on the left side of the device. The schematic for this setup can be seen below.
Arm for Movement in Y Direction Note: posts are used to guide movement rather than tracks as in the X and Z direction

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. This will be simple and similar to a PCL, or printer control language, where information is simply organized by the computer and read by the mechanics of the printer.

Another major component of the design is the sensor, in which we have chose to use the nano17, manufactured by ATI industrial automation. 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, it miniscule size is a major benefit and will make it must 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 schematic of the nano17 with measurements is shown below.
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 circuit needs to be build in order to condition. The signal will be amplified to reduce the effects of noise and interference with the results. Also, most data acquisition systems require a high impedance signal. The input signal will have to be conditioned in order to achieve this. Lastly, we must condition the signal in order to ensure the best resolution of the sensor by optimizing the range of the output signal. 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.

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.

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 to not amplify enough, as setting the gain too low will cause a decrease in the resolution and an increase in the SNR (signal to noise ratio). 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.

\[ V_{out} / V_{in} = 1 + R2 / R1 \]

Basic Non-Inverting Amplifier Configuration

Next, the conditioned signal will be sent to an analog-to-digital converter so that it may be sent and processed by LabVIEW. 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. The figure 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
The purpose of the stepper motors is to move the brackets and align them for experiments. This will be done by the rotation of lead screws. A motor will rotate a lead screw and which will be connected to a bracket. This will cause the movement of the bracket. This movement must be precise and accurate location. 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 bracket.

For this design we will be using two types of stepper motors. The two motors being used will be 23MDSI Series Stepper Motor/ Driver /Controller and the 17MD102S-00. We will use three 23MDSI motors to rotate lead screws causing movement of the attachment points, one 23MDSI motor to create tension on the wire and one 17MD motor which will be connected to one attachment point. When the 17MD motor rotates, since it is connected directly to the attachment point, it will cause a specific degree rotation about the attachment.

The model number of the motor for attachment 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 device will run on a low step motor RPS so as to increase torque to an appropriate level (you can see the torque vs. speed in figure 3 above). 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.

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 force to rotate the lead screws thus moving the attachments.

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 attachments. The diagram below (Figure 1.2.3.4) is a drawing done in Visio of the gear motor attachments.

![Gear Motor Attachment for the 23MD step motor](image)

This gear will be intermeshed with another, which is 3.0 inches in diameter. 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 attachment movement.
The force created on the gear of diameter one follows \( F = \frac{\tau}{L} \) this comes out to be 460 oz-in. This force when applied to the gear with diameter 3.0 in. comes out to be 690 oz-in, using the equation \( \tau = FL \).

**Stepper Motors Encoder**

The 23MD motor has a built-in encoder, which will connect to the user interface. This encoder is attached to the back of the stepper motor and is approximately 0.70 inches in width.

### Hook-Up Drawings

In the figure above, “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.

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.

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 below:

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 to a Microsoft Excel file.

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 below:

![Block Diagram of System I/O](image)

Lastly it is essential that we give the user the ability to calibrate the machine. The calibration function will involve the sensor being completely unloaded, and measuring the input voltage of the channels, then adding a known stress and observing the change in voltage. The program will then set a zero voltage, and will know what increment of voltage is equivalent to what stress. It is essential that the program be properly calibrated to that the data is reported accurately.

### 2.1.3 Design 3

#### 2.1.3.1 New Innovations

A new addition to our third design was the calculations of gear ratios. These calculations allowed us to determine how much torque would be outputted based on different gears used. We could therefore determine which
motors and gears we would need based on the knowledge of how much force we would be applying to the wire.

We also determined that our motors would need friction breaks. This would be essential to the functionality of our machine to allow forces and torques created by the wire would not be translated into free motion of the motor, but would be translated to the sensor when the mechanical forces would be measured.

Also for this design, we removed the degree rotation component of the machine. It was determined by our sponsors that this was an unnecessary component of the design.

Also, we made a lot of additions to the signal processing section. We realized that we would have to have a DC offset so that the voltage range would match that of the ADC. Also, we added a filter that would allow the signal from the sensor to pass, while rejecting any noise.

Finally, we added a section that shows sample calculations, taking into account amplification, for readings of force and torque from the sensor.

2.1.3.2 Key Components

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 below in figure 6:

Nano17 with mini integrated transducer cable

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.

**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 5</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>5</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>Violet/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-C1-A Type Cables
(Hose #HR25-STR-200 mates to 9105-TWE type transducers.
See Figure 5.3 for 12-pin Amphenol drawing.)

**Transducer Cable Wiring**

After a signal is generated from the sensor, the signal needs for be modified before it can be analyzed. A block diagram of these modifications is shown below.
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.

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:
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. The most desirable characteristic of this op-amp is its low voltage noise of 0.92 nV/√Hz.

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. A schematic of a multiple feedback bandpass filter is shown below in figure 13:
Multiple feedback bandpass filter.

We will center the frequency of the bandpass filter at 7200Hz since this is the resonant frequency of the signal. The quality factor describes how quickly the gain on the filter drops off from the resonant frequency. We do not yet know the outband of the signal, and therefore cannot yet determine the quality factor.

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 below.

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

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.

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:

<table>
<thead>
<tr>
<th>Calibration Matrix (Raw):</th>
<th>G0</th>
<th>G1</th>
<th>G2</th>
<th>G3</th>
<th>G4</th>
<th>G5</th>
<th>±Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fx</td>
<td>4.35186</td>
<td>54.91901</td>
<td>-</td>
<td>1210.73767</td>
<td>20.30129</td>
<td>-1302.59</td>
<td>12</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>
<td>12</td>
</tr>
<tr>
<td>Fz</td>
<td>1369.149</td>
<td>5.225805</td>
<td>1360.857081</td>
<td>-22.877115</td>
<td>1373.132</td>
<td>-11.4514</td>
<td>17</td>
</tr>
<tr>
<td>Tx</td>
<td>60.74048</td>
<td>-9025.72</td>
<td>7214.198819</td>
<td>4492.11083</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>-7411.597</td>
<td>4084.762</td>
<td>7863.802</td>
<td>120</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>
<td>120</td>
</tr>
</tbody>
</table>

Sample Strain gauge calibration matrix (un-amplified)

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/the Amplifier gain. We
will be using a +/- 5V for SGhi/lo, therefore out excitation voltage will be 10V. For now, we will assume that the ADC will take an input voltage from 0-10V. Our amplified calibration matrix will then look as follows:

### 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>

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 follows:

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

Stain Gauge \( \Delta V \) Matrix

The matrix multiplication of these values will give the measurements of the strain gauge as follows:

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

Where \([\text{result}]\) =

- 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.
2.2 Optimal Design

2.2.1 Objective

The orthodontic wire mechanical system tester is an innovative product that will combine an outdated machine with new cutting edge technology to create a device that will serve an integral role in orthodontic research. While there are many tension and torsion testers out on the market, none are specifically designed for orthodontic measurements, and are therefore lacking essential capabilities. The orthodontic wire mechanical system tester will aim to accurately mimic the mechanical systems within the mouth while providing measurements of tension and torsion on three planes.

One major innovation in our design over the previous design is that our design will allow for variability in the experimental design. Since the entire mouth experiences the forces due to braces, it is essential to incorporate this into experimental design. This requires a sensor that measures force in all three axes, and moments (torques) around these same axes. The current design focuses on the force in the x and y direction (along the face of the tooth), and the torque in the z direction (moment around the axes perpendicular to the face of the tooth). While this design may be adequate for the measurements necessary, we find it will be optimal to have an apparatus which has the capability to increase variability and include the addition of two other moments, and another axial force.

Another addition to the current design is the attachment the wire or T loop to the sensor using actual orthodontic brackets. This will be a major innovation because the brackets, while they may seem to be simple devices, are actually quite complicated and play an essential role in the application of forces and the movement of teeth. The brackets allow for the wire to produce tension and torsion in three dimensions of space directly on the tooth. Currently a screw device is being used to attach the wire to the sensor, however this screw device only allows for the application of tension and torsion in two dimensions. The addition of our bracket system will allow our machine to produce and measure the same mechanical stresses that are applied to teeth.
A major added feature of our new design will be in the software used to run the experiment. The software will combine all user interfaces into one simple and user-friendly program. This program will allow the user to control all of the variables in the experiment, for example the displacement speed of brackets, and placement of brackets and motors. The program will also display the results of the experiment in real-time in a visual manner. We are hoping to add many capabilities to the program such as: the ability to save experimental data, the ability to compare multiple experimental data side by side. Overall our objective of the software is to provide the user with a simple, easy to learn, yet extremely powerful all in one interface for the user to interact with the machine.

We will also include the use of stepper motors attached to the current lead screws to replace the manual hand cranks. This addition will reduce the amount of error, and increase the accuracy and repeatability of the measurements. The input to the motor will be defined by the user on the console, and the circuitry will be designed in such a way that the motor will undergo a certain number of rotations, and then stop to the placement desired by the user.

A block diagram of this project is shown on the next page in fig 2.2.1
Figure 2.2.1 Block Diagram
2.2.2 Subunits

2.2.2.1 Mechanical

A major flaw in the current design is its daunting nature due to the disorganized construction. This can be seen below in Figure 2.2.2.1.1. 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.

Throughout the entire design, mechanical setup has been kept in mind so that all of the equipment can work together to achieve more accurate movement, precision, and repeatability. The final design features the most effective way this can be achieved. Linear slides, brackets for attachment points, and a cohesive arrangement will let this happen at a reasonable cost.
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 2.2.2.3 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. A photograph of the original device is shown on the next page in figure 2.2.2.1.2.
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. However, in the final design it has been decided that linear slides will be used to achieve...
more accurate movement. These linear slides can be obtained from the same company that supplies the motors, and therefore will easily be connected. This will increase the accuracy, and also minimize any error that could occur in testing.

The linear slides to be used will be purchased from Anaheim Automation. The slide for movement in the x and z direction can be seen in Figure 2.2.2.1.3 below.

![Slide Setup, Anaheim Automation](image)

Figure 2.2.2.1.3 Slide Setup, Anaheim Automation

The linear slide for movement in the Y direction can be seen in Figure 2.2.2.1.4 on the next page. This particular image shows the setup with the motor already attached.
Figure 2.2.2.1.4 Linear slide in Y direction (vertical), Anaheim Automation

Linear slides are a better option than motors connected to the existing lead screws. These will provide a large ratio of cost to performance, since the accuracy of the apparatus will be greatly improved through the use of these positioning stages. Precision will also be improved, which is necessary for such a small testing area. Also, the apparatus will be more reliable through the use of linear stages. Without them, the lead screws could easily fail, and the connection of the motors could be questionable.

The new setup will feature brackets as attachment points, which face each other rather oppose each other. This will create more realistic conditions to those encountered in the mouth. A close-up of the sensor and its attachment to the bracket can be seen in Figure 2.2.2.1.5 on the next page.
In order for movement in three directions to be achieved, this requires two positioning stages to be assembled onto one attachment point, stacked, and on other positioning table attached to another point, which will move in the vertical direction. The mechanical setup for this can be seen in Figure 2.2.2.1.6 on the next page.
Figure 2.2.2.1.6- Mechanical Setup- View 1
Figure 2.2.2.1.6 Mechanical Setup - View 2
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. This will move along the positioning stage. This is another reason why the positioning stage is important, without it, the measurements themselves would not be accurate. If the current lead screws were used, all of the data collection would not be as repeatable or reliable. There will be another stepper motor on the side of the apparatus where the large torque motor is in place, and this will be replaced by a stepper motor configured to move in the y direction, also with the existing lead screws. A closer view of this setup can be seen in Figure 2.2.2.1.7 below.

Figure 2.2.2.1.7 Unigraphics Schematic of X/Z Slide
Figure 2.2.2.1.8 Unigraphics Schematic of Y Slide
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.

2.2.2.2 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:
\[ \sigma = E \varepsilon \]

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

*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
\( \varepsilon \) = 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, it 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 on the next page in figure 2.2.2.2.1:
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 2.2.2.2.3:

<table>
<thead>
<tr>
<th>SENSING RANGES</th>
<th>Calibrations</th>
<th>US-3-1</th>
<th>US-6-2</th>
<th>US-12-4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Axes</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fx, Fy (±lbf)</td>
<td>3</td>
<td>6</td>
<td>12</td>
<td></td>
</tr>
<tr>
<td>Fz (±lbf)</td>
<td>4.25</td>
<td>8.5</td>
<td>17</td>
<td></td>
</tr>
<tr>
<td>Tx, Ty (±lbf-in)</td>
<td>1</td>
<td>2</td>
<td>4</td>
<td></td>
</tr>
<tr>
<td>Tz (±lbf-in)</td>
<td>1</td>
<td>2</td>
<td>4</td>
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</table>

<table>
<thead>
<tr>
<th>RESOLUTION</th>
<th>System Type°</th>
<th>CON</th>
<th>DAQ</th>
<th>CON</th>
<th>DAQ</th>
<th>CON</th>
<th>DAQ</th>
</tr>
</thead>
<tbody>
<tr>
<td>Axes</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fx, Fy (lbf)</td>
<td>1/640</td>
<td>1/5120</td>
<td>1/320</td>
<td>1/2560</td>
<td>1/160</td>
<td>1/1280</td>
<td></td>
</tr>
<tr>
<td>Fz (lbf)</td>
<td>1/640</td>
<td>1/5120</td>
<td>1/320</td>
<td>1/2560</td>
<td>1/160</td>
<td>1/1280</td>
<td></td>
</tr>
<tr>
<td>Tx, Ty (lbf-in)</td>
<td>1/4000</td>
<td>1/32000</td>
<td>1/2000</td>
<td>1/16000</td>
<td>1/1000</td>
<td>1/8000</td>
<td></td>
</tr>
<tr>
<td>Tz (lbf-in)</td>
<td>1/4000</td>
<td>1/32000</td>
<td>1/2000</td>
<td>1/16000</td>
<td>1/1000</td>
<td>1/8000</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>SENSING RANGES</th>
<th>Calibrations</th>
<th>SI-12-0.12</th>
<th>SI-25-0.25</th>
<th>SI-50-0.5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Axes</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fx, Fy (±N)</td>
<td>12</td>
<td>25</td>
<td>50</td>
<td></td>
</tr>
<tr>
<td>Fz (±N)</td>
<td>17</td>
<td>35</td>
<td>70</td>
<td></td>
</tr>
<tr>
<td>Tx, Ty (±Nm)</td>
<td>120</td>
<td>250</td>
<td>500</td>
<td></td>
</tr>
<tr>
<td>Tz (±Nm)</td>
<td>120</td>
<td>250</td>
<td>500</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>RESOLUTION</th>
<th>System Type°</th>
<th>CON</th>
<th>DAQ</th>
<th>CON</th>
<th>DAQ</th>
<th>CON</th>
<th>DAQ</th>
</tr>
</thead>
<tbody>
<tr>
<td>Axes</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fx, Fy (N)</td>
<td>1/160</td>
<td>1/1280</td>
<td>1/80</td>
<td>1/640</td>
<td>1/40</td>
<td>1/3200</td>
<td></td>
</tr>
<tr>
<td>Fz (N)</td>
<td>1/160</td>
<td>1/1280</td>
<td>1/80</td>
<td>1/640</td>
<td>1/40</td>
<td>1/3200</td>
<td></td>
</tr>
<tr>
<td>Tx, Ty (Nm)</td>
<td>1/32</td>
<td>1/256</td>
<td>1/16</td>
<td>1/128</td>
<td>1/8</td>
<td>1/64</td>
<td></td>
</tr>
<tr>
<td>Tz (Nm)</td>
<td>1/32</td>
<td>1/256</td>
<td>1/16</td>
<td>1/128</td>
<td>1/8</td>
<td>1/64</td>
<td></td>
</tr>
</tbody>
</table>

Figure 2.2.2.2.3: ATI Industrial Automation- Nano17 Ranges and Resolutions for various calibrations

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 on the next page in figure 2.2.2.2.4:
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.

The configuration of the mounting of the sensor is a very important part of the design. The brackets must first of all be facing in the same direction, as this is how the brackets will be oriented in the mouth. However, the sensors must be facing opposite directions to allow the sensors to come to close proximity to each other. If the sensors were both facing the same direction, the brackets would only be able to come as close as 17mm (the radius of the sensor*2) to each other. The mounting configuration we designed is shown on the next page in Figure 2.2.2.2.5.
Figure 2.2.2.2.5: Mounting configuration

The shaded in boxes represent the brackets, with the arrows indicating the front of the bracket. A Unigraphics schematic of the sensor is shown on the next page in figure 2.2.2.2.6.
The attachment piece, that will connect the bracket to the sensor, is shown below in figure 2.2.2.2.7.

Next, a unigraphics schematic of the assembly of the bracket/attachment piece/sensor is shown on the next page in figure 2.2.2.2.8.
Figure 2.2.2.2.8 Assembly of the sensor/attachment/bracket

**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 the ISO 9409-1 mounting pattern. A schematic of the tool side of the nano17 is shown on the next page in figure 2.2.2.2.9:
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 2.2.2.2.10 below.

Figure 2.2.2.2.10: Mechanical Setup of Attachment to Sensor. Sensor attachment fits into the sensing reference frame of origin as shown in Figure 2.2.2.5 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 below in figure 2.2.2.2.11:

![Figure 2.2.2.2.11: Nano17 with mini integrated transducer cable](image)

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 2.2.2.2.12 and 2.2.2.2.13. The outputs and their meanings are further explained below in the signal acquisition section.

<table>
<thead>
<tr>
<th>Pin</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>no connect</td>
</tr>
<tr>
<td>B</td>
<td>SG4 output</td>
</tr>
<tr>
<td>C</td>
<td>SG5 output</td>
</tr>
<tr>
<td>D</td>
<td>SG2 output</td>
</tr>
<tr>
<td>E</td>
<td>SG3 output</td>
</tr>
<tr>
<td>F</td>
<td>SG0 output</td>
</tr>
<tr>
<td>G</td>
<td>SG1 output</td>
</tr>
<tr>
<td>H</td>
<td>no connect</td>
</tr>
<tr>
<td>J</td>
<td>SG10 excitation input</td>
</tr>
<tr>
<td>K</td>
<td>SG11 excitation input</td>
</tr>
<tr>
<td>L</td>
<td>Thermistor1 (optional)</td>
</tr>
<tr>
<td>M</td>
<td>Thermistor2 (optional)</td>
</tr>
</tbody>
</table>
Signal Acquisition and Conditioning

Overview:
After a signal is generated from the sensor, the signal needs for be modified before it can be analyzed. A block diagram of these modifications is shown on the next page in figure 2.2.2.2.14.
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 2.2.2.2.15.

One can represent each strain gauges as:
In which one can use the voltage divider law as follows:

\[ V_m = V_{SGHi} - V_{SGLO} = \frac{V_1 + V_2}{R_1 + R_2} + \frac{V_m}{R_1} - \frac{R_2}{R_1 + R_2} \]

The thermister is a resistor 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 on the next page:
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 2.2.2.12. The most desirable characteristic of this op-amp is its low voltage noise of 0.92 nV/√Hz.
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 on the next page in figure 2.2.2.2.18 and figure 2.2.2.2.19:
Figure 2.2.2.2.18: 6th order Butterworth Bandpass Filter Circuit Diagram
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 2.2.2.20.
\[ V_0 = \left( \frac{R_i}{R_a} \right)V_a + \left( \frac{R_i}{R_b} \right)V_b + \left( \frac{R_i}{R_c} \right)V_c \]

Figure 2.2.2.2.20: Basic summing amplifier.

The Circuit:
Figure 2.2.2.2.21 below is a schematic of the circuit with all of the components put together for a single channel.
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 2.2.2.2.22 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](image)

<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 2.2.2.2.22: 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 2.2.2.2.23.
**Figure 2.2.2.2.23:** 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 2.2.2.2.24.

<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-1o 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>0</td>
<td></td>
</tr>
<tr>
<td>08</td>
<td>B(−)</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>09</td>
<td>Gnd</td>
<td>0</td>
<td>Gnd</td>
</tr>
</tbody>
</table>

Figure 2.2.2.2.24: Overview of I/O schematics at computer interface

Testing:

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.

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 on the next page in figure 2.2.2.4.1:

![Figure 2.2.2.4.1: Front panel of use input function](image)

Currently, the only graphs that we have included in our 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 2.2.2.4.2:

Figure 2.2.2.4.2: Front Panel of Data Output Function

**Functionality**

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 to a Microsoft Excel file. Block diagram of this function is shown below in figure 2.2.2.4.3:

Figure 2.2.2.4.3: Block Diagram of Data Export to Spreadsheet

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 out data using the printer port is shown on the next page in figure 2.2.2.4.4.
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 its 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 2.2.2.4.5 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>G0</th>
<th>G1</th>
<th>G2</th>
<th>G3</th>
<th>G4</th>
<th>G5</th>
<th>±Range</th>
</tr>
</thead>
<tbody>
<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>
<td>12</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>
<td>12</td>
</tr>
<tr>
<td>Fz</td>
<td>1369.149</td>
<td>5.225805</td>
<td>1360.857081</td>
<td>-22.877115</td>
<td>1373.132</td>
<td>-11.4514</td>
<td>17</td>
</tr>
<tr>
<td>Tx</td>
<td>60.74048</td>
<td>-9025.72</td>
<td>7214.198819</td>
<td>4492.11083</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>-7411.597</td>
<td>4084.762</td>
<td>7863.802</td>
<td>120</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>
<td>120</td>
</tr>
</tbody>
</table>

Figure 2.2.2.4.5: Sample Strain gauge calibration matrix (un-amplified)

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/the 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 2.2.2.4.6 below.

<table>
<thead>
<tr>
<th>Calibration Matrix (Amplified):</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>
</tbody>
</table>

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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.

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

Figure 2.2.2.4.7: Stain Gauge \( \Delta V \) 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 2.2.2.4.7 above.

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

Where \([\text{result}] = \begin{pmatrix} Fx \text{ N} \\ Fy \text{ N} \\ Fz \text{ N} \\ Tx \text{ Nmm} \\ Ty \text{ Nmm} \\ Tz \text{ Nmm} \end{pmatrix} \]

All of these calculations will be carried out in real time in LabVIEW as the experiment is being run.

2.2.2.3 Motors

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.

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. 2.2.2.3.1 and Fig. 2.2.2.3.2 is on the next page.
Figure 2.2.2.3.1 depicts what the motor looks like and Figure 2.2.2.3.2 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.

The 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 2.2.2.3.3 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.

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 below (Figure 2.2.2.3.4) is a drawing done in Visio of the gear motor attachments.

![Diagram](image)

**Figure 2.2.2.3.4**

Gear Motor Attachment for the 23MD step motor

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:
Then using the equation: Motor Torque*Gear Ratio = 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*(112.5 oz-in) or 337.5 oz-in.

**Motor Encoder**

The 23MD motor has a built in encoder, which will connect, to the user interface. This encoder, (shown in Fig. 2.2.2.3.5), 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.

**Hook-Up Drawings**

In Figure 2.2.2.3.5, “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 below in the figure 2.2.2.3.6.

![Figure 2.2.2.3.6 Motor to Computer Connection](image)

Each unit refers to a motor of figure 2.2.2.3.6, 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 in figure 2.2.2.3.7 below.

Figure 2.2.2.3.7 RS-485 Schematics
In the above figure 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.

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 on the next page in Figure 2.2.2.3.8.
**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:

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

(equ. 2.2.2.3.2)

Where:

- \( \Gamma_{\text{required}} \) = torque created by the motor
- \( F_{\text{desired}} \) = force applied to object
- \( \mu \) = coefficient of friction
r = pitch radius of the screw
p = lead of the thread
R = thrust bearing radius
α = thread angle
β = 2R/p

Using equation 2.2.2.3.2 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.

**Testing of motor 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:

\[ t = F * L \]

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 2.2.2.3.8.

![Figure 2.2.2.3.8 Testing Setup](image)
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.

3 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. Thus a large constraint comes down to the testing of the device. Since the testing cannot be done until we have the parts of the device we run into a large constraint. There must be careful planning and forethought to the design so testing can building can be done simultaneously and give us the best result possible.
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. Thus the data that is obtained from this device must be carefully analyzed before it is put into application. Each human’s teeth will react differently to different forces so the users of this device must take that into account before they use the data acquired. Also, the creation of new software may be unethical if such software for a similar test is already in existence.

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. Therefore clinical trials should be implemented after this data has been obtained. The data is useful and will point researchers into the right direction on how to go about using forces in the mouth. However after they have this direction clinical trials must be done to make sure that every factors has been accurately assessed and considered. This will help to eliminate health constraints.

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. The less the user needs to replace the better the device will run. Thus an important consideration in overcoming this constraint is working towards a high longevity of the device.

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 would be making sure that if a dental wire snapped that there was minimal possibility that a researcher could be injured. The forces that are being applied to the wire are small enough that this type of accident could not occur. Thus safety constraints are almost non existent. The device makes little to no movement and does not produce enough energy to do any damage.

In terms of political constraints a lot of orthodontics today do not use biomechanics research when they apply orthodontic devices to a patient’s 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. Thus the creation of this wire tester could be controversial and the research could conceivably go unused. The orthodontists today would need to be convinced that using the data from this machine is the best way to go about helping their patients. The convincing of the orthodontists is the largest political constraint that exists.

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. 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.
4 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 electrical wires, the wires will not be damaged and the safety of the user will not be in jeopardy.
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.

5 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.

6 Life Long Learning

During the course of this project team members had to expand their knowledge to be able to complete this design. At the very beginning there was a lot we needed to research and by the time we had completed all four designs we had each gone through a significant learning process.

This project demanded that we learn how sensors work and how to apply them. Since our contractors were looking for the cheapest yet best sensor, significant research had to go into choosing what was appropriate. The sensor we ended up going for is a six axis force and torque transducer. A lot of time was put into figuring out how exactly the force transducer worked, how one would go about connecting it to a computer and then how to program it.

Another learning process came from the mechanical structure of the device itself. We needed to figure out the best way to create a three dimensional moving tension application. After researching many possibilities we came up with linear slides and how researched how they are put to use.

We also learned a lot about motors. After researching different types of positional systems we discovered that the best type of motor for our application was a stepper motor. We also looked at many other types of motors and learned about a lot of different motors that are on the market today. Next we looked into how to apply these motors to our system and get them to work. We looked up the requirements for motors that are connected to a computer. Such as how one needs a driver and controller to be able to get motors to work.

Another mechanical aspect that we learned about was how motors apply forces to the gears that they turn. An important part was learning about gear ratio and how one would go about gearing up a motor to create a higher torque. The next step was to find out how a torque on a lead screw is translated into a linear force that will move an object which is threaded to the lead screw. We found
equations that would allow us to calculate the force on the attachment points of our project given the torque output from the motor.

Another source of learning was in the use of new software. Unigraphics CAD, Microsoft Visio, Microsoft Project, the nonstudent version of PSPICE, were all used in the final report. It took time to learn all of these programs, however they will be useful in the future.

Finally we also learned a lot from the machine shop course that we took. The machine shop taught us the necessary skills that we will need to be able to build the parts of our device. We put a lot of time into making sure that we understood these machining concepts so that we can apply them when it is time to put everything together.

Budget and Timeline

7.1 Budget

We were not given a definite limit to our budget from our sponsors; however they have estimated that we will have approximately 10,000 dollars. We have put together a preliminary budget, using all of the more expensive components, and trying to overshoot what we will actually be spending. An outline of our major expenses are shown on the next page:

<table>
<thead>
<tr>
<th>Vendor</th>
<th>Model</th>
<th>Description</th>
<th>Price</th>
<th>Unit</th>
<th>Quantity</th>
<th>Total</th>
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<td>LS100-06-A-N-60-B</td>
<td>3 Axis Slide Motor System</td>
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<td>PCB Assembly</td>
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<td>ATI Industrial Automation</td>
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<td>12-Pin Amphenol Connector</td>
<td>$30.00</td>
<td>each</td>
<td>2</td>
<td>$60.00</td>
</tr>
<tr>
<td>ATI Industrial Automation</td>
<td>Nano 17</td>
<td>6-Axis Force/Torque Transducer</td>
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<td>each</td>
<td>2</td>
<td>$6,600.00</td>
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<td>DigiKey</td>
<td>299-15743-6-RD</td>
<td>Texas Instruments Low Noise 24-bit ADC</td>
<td>$11.91</td>
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<td></td>
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<td></td>
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<td><strong>Total</strong></td>
<td><strong>$11,222.92</strong></td>
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</tr>
</tbody>
</table>

If this stellar machine proves to be too expensive, there are certain parts that we will cut out. First, the major expense of the project, the sensor, can be reduced. The nano-17 is a top of the line sensor, with features such
as its small size (17mm diameter) and its superior resolution. This sensor could be substituted out for a larger, less precise sensor that might put some ease on our budget.

Another possibility of reducing our costs would be the elimination of the 3-axis slide motor system. The benefits of using this system are its ease and accuracy; however it could be replaced by using the existing lead screw and individually bought stepper motors.

7.2 Timeline

<table>
<thead>
<tr>
<th>Task Name</th>
<th>Duration</th>
<th>Start</th>
<th>Finish</th>
<th>Person/Reviewer</th>
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</thead>
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<tr>
<td>Test Signal Output of Sensor</td>
<td>1 day</td>
<td>Mon 1/15/2023</td>
<td>Mon 1/15/2023</td>
<td>No Fieldcase</td>
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<tr>
<td>Control that analog signal is generated when it</td>
<td>1 day</td>
<td>Mon 1/15/2023</td>
<td>Mon 1/15/2023</td>
<td>No Fieldcase</td>
</tr>
<tr>
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<td>Mon 1/15/2023</td>
<td>No Fieldcase</td>
</tr>
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<td>Thu 1/19/2023</td>
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<tr>
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<td>Thu 1/19/2023</td>
<td>Thu 1/19/2023</td>
<td>No Fieldcase</td>
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</tr>
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<td>2 days</td>
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<td>No Fieldcase</td>
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<tr>
<td>12 different Digital Inputs</td>
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<td>1 day</td>
<td>Fri 2/10/2023</td>
<td>Fri 2/10/2023</td>
<td>No Fieldcase</td>
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<tr>
<td>Display digital output on front panel</td>
<td>4 days</td>
<td>Fri 2/10/2023</td>
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<td>No Fieldcase</td>
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<td>Create Control antiWIFI program that will output digital</td>
<td>6 days</td>
<td>Mon 2/13/2023</td>
<td>Mon 2/13/2023</td>
<td>No Fieldcase</td>
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<tr>
<td>Anti-Ziggy functionality</td>
<td>4 days</td>
<td>Tue 2/14/2023</td>
<td>Tue 2/14/23</td>
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<td>Create expects zero algorithm</td>
<td>2 days</td>
<td>Wed 2/15/2023</td>
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<td>Create fuzzy logic function</td>
<td>2 days</td>
<td>Thu 2/16/2023</td>
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<td>Create original GUI editor function</td>
<td>3 days</td>
<td>Thu 2/21/2023</td>
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<td>Create validation graphics template</td>
<td>5 days</td>
<td>Fri 2/24/2023</td>
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<td>Create Excel related functions</td>
<td>1 day</td>
<td>Mon 3/6/2023</td>
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<td>Create Data Read LED</td>
<td>1 day</td>
<td>Wed 3/8/2023</td>
<td>Wed 3/8/2023</td>
<td>No Fieldcase</td>
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<td>Create USB button</td>
<td>1 day</td>
<td>Wed 3/8/2023</td>
<td>Wed 3/8/2023</td>
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<tr>
<td>Test Each motor</td>
<td>9 days</td>
<td>Mon 3/13/2023</td>
<td>Mon 3/13/2023</td>
<td>Scott McNearan</td>
</tr>
<tr>
<td>Apply known load</td>
<td>1 day</td>
<td>Mon 3/13/2023</td>
<td>Mon 3/13/2023</td>
<td>Scott McNearan</td>
</tr>
<tr>
<td>Test for breakers</td>
<td>2 days</td>
<td>Tue 3/14/2023</td>
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</tr>
<tr>
<td>Test for reactivity</td>
<td>2 days</td>
<td>Thu 3/16/2023</td>
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<td>Scott McNearan</td>
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<td>Compare repeated Trials</td>
<td>10 days</td>
<td>Mon 3/20/2023</td>
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<td>Program Encoder</td>
<td>1 day</td>
<td>Mon 3/20/23</td>
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<td>Scott McNearan</td>
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<td>Use nominal WIFI program (with no movement of robot)</td>
<td>3 days</td>
<td>Wed 3/22/2023</td>
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<td>Continue each encoder operates correctly</td>
<td>3 days</td>
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<td>Create GPIOs' connection to encoder</td>
<td>2 days</td>
<td>Fri 3/24/2023</td>
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<td>Scott McNearan</td>
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<td>Isolate faults for each motor</td>
<td>1 day</td>
<td>Mon 3/27/2023</td>
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<td>Scott McNearan</td>
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<td>Attack each encoder to serial port</td>
<td>8 days</td>
<td>Tue 4/4/2023</td>
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<td>Complete outline check</td>
<td>2 days</td>
<td>Tue 4/4/2023</td>
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<td>Task Name</td>
<td>Duration</td>
<td>Start</td>
<td>Finish</td>
<td>Redoorsmen</td>
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8 Team Member Contribution

Scott Michonski:

Researched the motors section of this design and found out the best way to implement them. He contacted electrical specialists to ask advice with the design and looked into the best way one could use motors to achieve a level of accuracy for positioning while at the same time being able to run force tests of up to a five hundred grams. He looked into how motors would work in relation to the gears on the mechanical system and how we would turn the torque from the motor into a force on the attachment points. How the motors would lock in place, how to program the motors driver and controller, and how to connect them to computer console was also part of his contribution to the final design.

He also took the machine shop course so that the group would be able to have access to the machine shop and be able to build the necessary components of the system.

As with all of the group members Scott contributed a third to each report that was written and handed in.

Bethany Lepine:
She researched the use of several types of linear slides and their implementation in the project. She then contacted companies regarding cost, and it was not known whether or not this could be included in the budget. She then researched the use of existing lead screws with new stepper motors, however then returned to the previous idea of using linear slides. She examined the collaboration of the sensors with the setup itself, and researched the connection to the user interface. She investigated the mechanical setup of the project, and used several design programs to create a most efficient setup. This included the use of Microsoft Visio, as well as learning and using Unigraphics software in order to create three dimensional models.

She contributed to the introduction of the report by creating the block diagram on Microsoft Visio, and also assisted with the creation of the timeline in MS Project.

She took the machine shop course to also contribute to the mechanical creation of the project.

Max Feldman:

Max primarily focused his attention on the electrical and computer aspects of the design. He researched various types and models of sensors and decided on which one would fit our needs best. Next using the specifications of this sensor, he designed a circuit that would allow us to interface the sensor to the computer. This circuit required research into various filters, amplifiers, ADC, and various methods of digital data acquisition. Finally, Max came up with a preliminary LabVIEW program that will serve as the central control for the machine.

Also, Max made contributions to coming up with a design for the setup of the sensors. The arrangement of the sensors was essential to the design of the machine as a whole, as this part of the machine must be able to accurately mimic the conditions within the mouth, while at the same time must able to be incorporated into the rest of the design of the machine.

9 Conclusion

Our client, Dr. Michael Holbert, is 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.

The machine that we have designed to aid Dr. Holbert in his research is a wire tester that 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 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 machine that we plan to build is a cutting edge piece of equipment that we believe will not only prove to be resourceful to Dr. Holbert, but also to many doctors performing research down the line. We have designed this machine so that it will be many years before it is obsolete. We have accomplished this by creating a machine that takes measurements of force and torque in all planes of space to an incredible accuracy. Our machine has the ability to move in all planes of space, and can make precision movements accurate to the degree of a micrometer. By creating such a powerful machine, we have ensured that this will not be used only once or twice by a few dentists for limited applications, however that it will be used as an essential component for many doctors’ research for many different applications.

On top of being an extremely powerful machine, our machine is simple and easy to use. First of all, everything is controlled from one, central computer. Experiment
variables are set from this computer, and all data is read, recorded, and analyzed from this computer. User controls from this computer are visual and self-explanatory. Because of the simplicity and centrality of our design, this machine will prove to be useful for years to come for many doctors.

10 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.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

11 Acknowledgements

Edward Lechowicz

Dr. Michael Holbert and colleagues

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Milton Gore with ATI