Final Design Report: Team #7

Soft Tissue Fatigue Testing Fixture

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Abstract

The main goal of this project is to construct a cyclical loading fixture for testing soft tissue that is compatible with an existing Bose Testbench system. This will be useful for testing tissues that may be components of a bioprosthetic heart valve derived from porcine or bovine or synthetic tissue. The client has requested that twelve samples can be tested at once while providing real time data acquisition and monitoring via NI Labview. This device will be capable of performing pure tensile or compressive testing as well as a combination of the two. This machine will run at 30 Hz for up to 200,000,000 cycles. The data will be sent wirelessly via a Bluetooth system. The primary method of measuring the loads on the tissue will be through strain gauges which will be incorporated into custom designed load cells. These load cells will also feature specifically designed filters and amplifiers to prepare the signal for NI Labview analysis. The tissue specimens and their fixtures will be submerged in a solution bath during testing. The fixture components will be constructed of commercially available polymers as well as some metal alloys.

1.0 Introduction

1.1 Background

The client for this project is Dr. Wei Sun, a mechanical and biomedical engineering professor at the University of Connecticut. Much of his research has been focused on stress and strain analysis of soft tissue. This project is a continuation of his work on wear and durability testing for small soft tissue samples. Currently in his lab, there is a functioning biaxial testing device, as well as a uniaxial testing device capable of holding multiple specimens. A new design is needed for the uniaxial device that will offer easier tissue specimen setup, more accurate data acquisition, and the ability to monitor data as it is being gathered. The new device must also be able to perform cyclic tensile and flexural testing, as well as either pure tensile or flexural testing. These areas of improvement (along with other specifications) are the main focus of this new device.
1.2 Purpose of Project

The incidence of valvular heart diseases has been increasing quickly over the past few decades as a significant portion of the American population ages. These heart diseases include mitral/aortic valve stenosis and regurgitation. If left undiagnosed and untreated, these conditions may lead to myocardial infarctions and ultimately even death. The implantation of artificial heart valves has been considered as a remedy for many decades. Early mechanical heart valves of the 1950’s and the 1960’s have evolved into bioprosthetic heart valves (BHVs) of the present day. BHVs are an especially important development because they do not require anti-coagulant medication after implantation and generally exhibit better biocompatibility. Even though valves derived from porcine or bovine sources prove to be a better anatomical fit in the body, there is still an important need to test each and every device under the appropriate conditions. A typical functioning heart valve experiences a life-time of flexural and tensile stresses. An adequate replacement needs to thrive under these stresses. Therefore, an appropriate testing fixture needs to be designed in order to accommodate both flexural and tensile testing of a BHV tissue sample. In addition to durability, wear characteristics of the tissue sample must also be analyzed. An evaluation of the lifetime of a particular type of tissue is critical in discovering novel methods to improve the quality of life of millions of individuals with valvular diseases worldwide. It is for these reasons that an improved and effective fatigue testing fixture, in addition to the already existing Bose loading machine and software, would prove a valuable asset for analysis and evaluation in the department’s tissue mechanics laboratory.

1.3 Previous Work

1.3.1 Products

Other devices capable of performing tensile or flexural testing have been created. At Clemson University in South Carolina a fatigue testing fixture was designed to perform cyclic tensile testing of up to twelve specimens at once. A schematic of one of the fatigue testing devices is shown in Figure 1.1. For each of the devices, one arm was fixed on the testing surface, while the other was free to move. The movable arms were connected to the testing device that applied the load.
Another device was created at the University of Pittsburgh. This device was able to perform both tensile and flexural testing on twelve tissue specimens at once. This is an important design feature in that it takes into consideration both the stretching and bending of the tissue. This allows the researchers to determine what type of impact these different types of forces each have on the tissue. The design was required to fit within the Bose ElectroForce 3200 test instrument, which is why the triangular setup was used. A CAD design of this device is shown in Figure 1.2. The arm of the Bose test instrument connected to the center of the fatigue testing devices as shown. As the arm moved up and down, the clamps attached to the arm moved as well. This applied equal force and displacement to each of the specimens throughout the experiment.
1.3.2 Patent Search

Initial online patent queries resulted in numerous entries being found. The vast majority of these entries, however, dealt primarily with fatigue testing of entire bioprosthetic or mechanical heart valve replacements. There were a few patents that dealt specifically with tissue testing.

Patent #5902937:

This patent applied by Baxter International Inc. dealt with an in vitro tissue testing device. The main purpose of the design here was to assess the hemo-compatibility of tissue samples when they are placed within a chamber that applies different pressures in a simulated fluid environment.
Patent #20020095994:

The design put forth in this patent (issued in 2002) features a clamping mechanism to hold tissue samples and apply tensile and flexural forces. These operations are performed with the help of motors and small gears.

Patent #20020012125:

The main feature in this design is a testing chamber which houses a tissue sample and can mimic conditions within the body. Mechanical properties of the sample tissue are measured or calculated through optical and mechanical means.

1.4 Map for the rest of the report

The rest of the report will outline the mechanical designs, the strain gage designs, the software and signal processing tools to be used. It will also address non-design aspects such as impact of engineering solutions, health and safety issues, budget and timeline.

2.0 Project Design

This section contains the three alternative designs as well as our optimum design. The optimal design was selected based on economic, environmental, ethical, health, safety, manufacturability, and sustainability criteria.

2.1 Alternative Designs

2.1.1 Horizontal Fixture Setup

The main difference of this design from the other alternatives is that the testing will be done in a horizontal configuration as opposed to a vertical setup. This would require completely different bases, clamps, load cells, and simulated body fluid chambers. The Bose Testbench device would have to be tilted 90 degrees from its current configuration and lowered closer to the base.

The clamps would have to be attached on their sides to the platforms so the tissue specimens will be held parallel to the base and along the axis of the applied force. This will be done by building two platforms that will each hold 12 clamps facing each other. The platform positioned further from the Bose device will be stationary, while the platform closer will be
moved by the Bose device. The load cells will be attached to the stationary platform as in the primary design, but will need to be kept out of the solution.

A horizontal setup would provide a much less difficult specimen setup. Nothing would be over positioned the tissue clamps as with the vertical designs, so it would be much easier to reach the clamps. All of the clamps would be in one row, so the entire device would not have to be rotated to reach any of the clamps. In the vertical designs, only six clamps can be reached at a time; the device must be rotated to reach and setup the others. A horizontal design also eliminates the frustration of clamping the tissue in the proper spot while fighting gravity. The tissue can simply be placed on the clamp in the proper spot, and the clamp can be tightened. The vertical setup requires that the tissue be placed in the upper clamp, then carefully held while the clamp is closed and secured. If the tissue happens to slip down due to gravity, the setup will have to be repeated.

The chamber that will hold the tissue specimens in the simulated body fluid will also be quite different than in the primary design. The arm that connects the movable base to the Bose Testbench device will have to go through one of the walls of the chamber. We will need to design a seal that would go around this arm that would allow it to move back and forth for millions of cycles while remaining water tight. This would be a significant complication and is one of the reasons why a horizontal setup is the primary design.

Another complication is the implementation of the load cells in a horizontal setup. The strain gauges must remain dry during the experimentation in order to function properly. The horizontal setup requires that both platforms be completely submerged in simulated body fluid, so the strain gauges will have to be orientated in a way that keeps them above the solution. This could be done by installing thin strips of metal that would connect the two platforms together. These strips would have to be raised enough so they remain out of the solution. The strain gauges could then be installed on these metal strips. This strain gauge setup would create a lot of issues with recording accurate data. In the vertical setups, the strain gauges are installed right to the connecting arm of each upper clamp, so they will be directly exposed to the forces experienced by the individual tissue specimen in that particular clamp. In this horizontal setup, the strain gauges would not be attached directly to the clamps, but to the supports that keep the
strain gauges raised out of the solution. This separation could reduce the accuracy of any data recorded.

### 2.1.2 Circular Tank

One of the principle components of the fixture of any design is the tank that contains the fluid and the samples. The shape of this tank could be varied in a number of different ways to make way for easier access. A cylindrical tank in junction with a circular fixture (all the clamping units are arranged in a circular manner) may help cut down the time it takes to mount each sample. A circular arrangement also helps maximize the distance between each clamping unit. The cyclical motion of unit can always affect the motion of another since the medium (saline solution) can transmit longitudinal waves.

![Figure 2.1.2.1: cylindrical tank](image)

A turntable setup (often found in microwave ovens) could be implemented on top of the cylindrical tank. The rough sketch above illustrates a basic design. The main advantage of including a turntable is that the user could easily mount each sample individually without having to move the entire tank. All of the clamps in this design would still be oriented vertically and the...
strain gauges will be placed on the nearest connecting rod. The disadvantages of this circular
design would be manifested in difficulties in machining the shape out of acrylic materials. There
might be additional fine threading involved in making attachments of the clamps.

Another important feature that can be varied is the structure and design of the clamp that
holds each tissue sample. The Bose Electoforce 3200 Test Instrument (developed at the
University of Pittsburgh) features a unique clamp design that can be incorporated into the
circular tank above.

![Fig. 2.1.2.2: Bose Electroforce 3200](image)

The fastening mechanism featured in the 3200 instrument design involves a tightening
screw on both the top and bottom clamps. This may allow for easier fastening than multiple
smaller screws. There is still the disadvantage of using screws in the first place. These parts may
get lost easily and the overall fastening of tissues still takes more time than using hinges.
2.1.3 Grid-like Orientation

There are many possible ways to set up the tissue samples for this testing machine. Each orientation has its own advantages and disadvantages. Many different designs were considered, including a circular orientation, a triangular orientation, parallel rows, and a grid-like orientation.

The grid-like orientation is essentially a 3 by 4 matrix of samples. This provides the twelve samples requested by the client. This orientation is very compact, which provides many of its advantages. Its compactness allows it to use a smaller bath than the other designs which could save money on fluids. It also might be cheaper to manufacture. A smaller footprint also means that if the client ever desires the ability to test more than twelve samples simultaneously, than more devices could fit on the same baseplate in order to ramp up testing. Another final benefit is that the sample clips could all be interconnected, giving them less flex. In the parallel row design the rows might flex depending on how long and stiff the arms are. A grid-like setup would have all the clamps closer to the movement bar resulting in less flex. This might mean more accurate results than some of the other designs.

The grid-like orientation is not without disadvantages. The biggest problem is loading the samples into the clips. Already a process that requires maneuvering tiny samples into hard to reach places, having some samples that are completely surrounded by other clamps would make

![Diagram of grid-like orientation](image)

**Figure 2.1.3.1**

The grid-like orientation is not without disadvantages. The biggest problem is loading the samples into the clips. Already a process that requires maneuvering tiny samples into hard to reach places, having some samples that are completely surrounded by other clamps would make
it very difficult to place the samples. Another problem comes with attaching the tissue clamps to
the Bose Testbench system. Ideally the Bose Testbench system will attach via a bar that moves
the bottom tissue samples through the water. This allows the load cells to remain stationary,
which means more accurate results. A grid-like orientation would likely have no room for a bar
to pass through meaning the Bose Testbench would attach and move the upper clamps. Because
the load cells cannot be submerged in the bath they would need to move with the upper clamps
and results could be somewhat compromised. A final problem may come from the fluid
resistance of the bath. Other designs are more open and have many holes in them allowing the
bath solution to flow through. This creates minimal resistance. In this more compact design there
are fewer places for the bath solution to flow through. If there is enough resistance for the strain
gauges to register than this could have a big impact on the results.

2.2 Optimal Design

2.2.1 Objective

The optimal design of the soft tissue fatigue testing fixture is a combination of the best
features of the alternative designs previously thought up, as well as the existing device used in
the UConn BME lab. The proposed design will be able to perform cyclic tensile and/or flexural
loading on up to 12 tissue specimens. Experiments will be able to run at up to 30 Hz and 200
million cycles. Some of the unique features of this design are the ease of setup and operation
and real-time data display through Labview. This device will require less than half of the small
screws used to secure the clamps than the existing fatigue testing fixture, which will greatly
reduce setup time. Each tissue specimen will have its own custom-made load cell to help
calculate the strain it undergoes. The current device uses one load cell for all of the specimens,
which offers little to no help in determining the strain experienced by each individual tissue
sample.

The proposed soft tissue fatigue tester consists of an upper and lower platform with 12
clamps on each to firmly hold the tissue specimens vertically. Both platforms will be kept in a
tank filled with simulated body fluid to keep the tissue from drying out or degrading during
testing. The upper platform will house the load cells for recording data. The data will be sent
wirelessly via Bluetooth to a data acquisition device, which will then send the information into
the LabView program. The program will display the data in real time to allow the user to see how each separate tissue specimen is behaving. The lower platform will be movable, while the upper platform will be secured to the top of the tank. The lower platform will move up and down to apply a load to the tissue specimens, which will be recorded by the load cells on the upper platform. The device will operate in conjunction with the Bose Testbench device, which is essentially a very sophisticated linear actuator. This will apply the load to the lower platform via a connecting rod. The overall device is shown in figure 2.2.1.1.

Figure 2.2.1.1: Proposed soft tissue fatigue tester and Bose Testbench device.

2.2.2 Subunits

2.2.2.1 Mechanical Design

The overall design of the soft tissue fatigue testing fixture will consist of 24 clamps (two for each specimen), the upper and lower platforms, an attachment arm to connect the Bose Testbench device to the lower platform, 12 custom load cells, and the housing to hold the platforms within the simulated body fluid. Each piece is crucial to creating a functioning device, so great care must be taken in ensuring they are all properly designed and assembled to meet the specifications.
The clamps in this device are responsible for holding the tissue specimens during testing. A single test can run for over two months and up to 200 million cycles, so the clamps must be able to keep the tissue from slipping even small amounts for extended periods of time. The first priority in their design is to make sure they can create a very tight grip on the tissue without causing and damaged during setup or testing. This will be accomplished similarly to how it has been in other devices. Each single clamp will essentially be two small pieces of PVC. Two holes will be drilled in each piece to allow the clamp to be secured firmly by screws. The screws will be placed far enough apart so they will not come into contact with the tissue during testing. Figure 2.2.2.1.1 shows a computer design of the proposed clamp.

The second priority in the clamp design is to make the setup much easier to be completed. The current device used in the UConn BME lab is completely disassembled after each experiment is run. This is done to prevent any pieces from rusting. This means that the device must be completely rebuilt prior to running an experiment. It can take one person well over two hours to completely assemble the device and setup 12 tissue specimens. This is due to the large number of very small screws that are used to secure all of the individual pieces of the clamps and platforms. The first way the setup time will be reduced by the proposed design is by reducing the number of individual pieces that comprise each clamp. In the current design, a single clamp consists of three separate pieces, which then must be attached to one of the platforms. This requires the use of eight screws and becomes extremely time consuming when multiple specimens are being tested. The proposed clamps will consist of two separate pieces that will be held together by a hinge. The smaller clamp jaw will be able to flip open to allow the tissue to be placed within the clamp, and can then be flipped shut. Only four screws will be needed (two for securing the jaw, two for attaching the clamp to the platform). Since the two jaws are attached by a hinge, the user does not have to worry about holding either jaw in place while attempting to position the tissue or insert and secure the screws. This is a very frustrating problem with the device currently in the lab.
The upper and lower platforms are necessary to keep all of the specimens lined up properly and to apply the load from the Bose TestBench device evenly to each tissue. The lower platform will be able to move up and down to actually apply the force to the tissue. The upper platform will be kept stationary and will house the custom made load cells. The designs for the upper and lower platforms will be similar, but not exactly the same.

The lower platform must be able to firmly hold 12 clamps, as well as the attachment arm connected to the Bose TestBench device. It also must be able to move through the simulated body fluid with as little resistance as possible. The 12 clamps will be secured to the platform in two rows of six along the two longer sides. They will be secured by two screws to small blocks of PVC permanently attached to the bottom platform. The attachment arm will be connected to the exact center of the platform by four screws. Any edges not coincident with the clamps will have curved edges to reduce the resistance applied by the fluid. Four large sections of the interior of the platform will be cutout to create areas for the fluid to pass through as it moves up and down. The design of the lower platform can be seen in figures 2.2.1.2 and 2.2.1.3.

Figure 2.2.2.1.2: Lower platform with clamps.
The upper platform will have some of the same features as the lower platform. The clamps will be attached to the longer sides of the platform as with the lower platform. The clamps will not be directly attached to the upper platform. Instead a small connecting arm will be secured to the platform. The opposite end of the connecting arm will be attached to the clamp. Each connecting arm is will serve as the load cell for its corresponding tissue specimen. A strain gauge will be placed on every connecting arm to detect any deformation it experiences due to the force applied by the Bose TestBench device.

Large sections of the upper platform will be removed, but not for to reduce drag as with the lower platform. The attachment arm connecting the Bose TestBench device to the lower platform will pass through a section cut out in the center of the upper platform. Small sections of PVC will be secured to top side of the upper platform. These will be used to secure the platform to the fluid housing. This is done to prevent the upper platform from moving at all during testing. The design of the upper platform can be seen in figure 2.2.1.4.
The largest piece of the design is the housing for the simulated body fluid. It will essentially be a watertight tank big enough to hold both platforms. A watertight seal is clearly necessary since the tissue specimens must be kept in simulated body fluid during testing. The tank will consist of five separate pieces of PVC held together by PVC cement. Several types of sealant will be tested to determine which will provide the strongest, most reliable seal. The currently used soft tissue fatigue tester requires that the bottom platform be secured to the base of the tank to prevent it from moving during testing. In the proposed device, the bottom platform will be moved by the Bose TestBench device, so it will not be secured to the bottom of the tank. The fully assembled device and Bose TestBench system is shown in figure 2.2.2.1.5.
2.2.2.2 Strain Gauges

The strain measurement of deformation in each tissue specimen is performed by a load cell, which converts mechanical changes into electrical ones. The components of a load cell are the strain gauge, internal/external wiring, metal casing, and additional circuit elements such as resistors. Since the purchase of individual load cells for the purposes of tissue testing is expensive, custom load cell are designed to be built for this project. The functional component of the load cell is the strain gauge, a thin coil with a nominal resistance and a variable resistance, which changes as the gauge experiences compressive or tensile forces. Some gauges are even sensitive to torsional strain.

Figure 2.2.2.1.5: Complete device.

![Strain Gage Diagram]

Figure 2.2.2.1:

Strain Gage
The figure above illustrates a basic strain gauge design which prominently features the coil (strain sensing part). A strain could easily be incorporated into a Wheatstone bridge circuit. The resulting one-gauge system (shown in the next figure) can be an effective tool in measuring both compressive and tensile strain

“E” represents the supply voltage. The industry standard for supply voltages is 5 Volts. The “eo” value represents output voltage, which are typically in the millivolt range. “E” and "eo" are related by following equation (eqn. 1). GF is the gauge factor, whereas “ε” is the strain.

$$\frac{eo}{E} = \frac{-GF\epsilon}{4} \left( \frac{1}{1+GF\epsilon^2} \right)$$

Equation 2.2.2.1

Fig. 2.2.2.2: Wheatstone Bridge

Fig. 2.2.2.3: Half Bridge Configuration

Two strain gauges can also be incorporated in a “dummy” configuration or in an active configuration. The successive configuration in a
“dummy” circuit nullifies some of the interferences of fluctuating temperature on the resistance values of active strain gauges. A second active strain gauge might account for strain in a different side of a bending mechanical body or can be used to account for compressive strain while the first gauge accounts for tensile strain.

Fig. 2.2.2.4: Two-Wire Connection

The Two-Wire connection illustrated to the left can have additional temperature nullifying effects.

Fig. 2.2.2.5: Possible Calibration Method

An important final step in load cell construction is calibration. The above figure illustrates the tip parallel resistance method where the parallel resistor (resistance “R”) is related to the nominal gauge resistance (Rg), the gauge factor (GF), and the strain (ε). Equation 2 below clarifies the relationship.

\[ R = \left( \frac{R_g}{GF \times \varepsilon} \right) \]

Equation 2.2.2.2
2.2.2.3 Signal Processing

The device uses strain gauges to measure the stress and strain of the twelve samples. These stresses are reported in volts and are outputted to the circuit. However the voltages can be inaccurate because of noise in the signal. Noise can come from many sources. Vibration of the motor could show up in the signal as a change in the stress strain voltages. Noise can also come from nearby electronics such as overhead lights, power lines, or computer consoles. This occurs when nearby electronics give off an electromagnetic field that can cause voltages to appear in the metal wires used to transmit the signal. Finally noise can come from changes in the environment such as changes in humidity and temperature. While these types of noise are generally uniform across the entire signal and as a result are difficult to filter they may be important in the case of this device because of its proximity to a water bath.

Because of all these sources of noise it is important that any signals from the device are filtered. A filter works by repressing some parts of a signal but allowing other parts to go through the filter. In this case the signals from the strain gauges will be allowed to go through while other signals will be removed. In order to do this it is likely that a Butterworth filter (as a LabVIEW subVI) will be utilized.

When the signals are received from the strain gauges they will likely be in millivolts. For them to be read by the hardware used in this device they must be amplified. It is desirable to filter the results before amplifying so that only the desired signal is amplified. This device will utilize a NI amplifier with an adjustable gain. This is good because it will allow the signal to be manipulated to the most ideal magnitude. A disadvantage of amplification is that it is likely that noise will be added to the signal. However because the signal will be filtered again using Labview this will likely not pose a problem.
2.2.2.4 *Data Acquisition*

*NI Board*

The data from the device will enter the computer via a National Instruments Data Acquisition Board. These boards are designed to act as input ports for all sorts of data. In the case of this device the incoming data will be a digital voltage signal.

![NI Board](image)

*Fig. 2.2.4.2: NI Board*

*Data Flow*

As the signal is transmitted from the strain gauges to the computer it will undergo several transmissions and modifications. The figure below is a flowchart outlining the path that the signal will follow from its generation to its final visualization.

![Data Flow Chart](image)

*Fig. 2.2.4.3: Data Flow Chart*
2.2.2.5 Software

Bose Software

The linear actuator that moves the samples in this device is a Bose Testbench Unit. With this motor comes a copy of the Bose Testbench Software. This software can be used to control the linear actuator as well as reporting the force applied by it. This software has a number of issues that mostly involve the reporting of the displacement and force applied. It is also difficult to tare. It is however sufficient for controlling the movement of the actuator and for setting its displacement. The device will be controlled using this software however a custom designed Labview program will record, process, and display all data.

LabView

Our device will be controlled by the Bose Testbench Software but will collect and display all of the data using NI Labview. The data will be collected using the Data Acquisition Module. This part of Labview is very useful because it can generate a sub.vi that would be very complicated to create for each data input. It also allows for easy filtering and analysis of the data. The Data Acquisition Module is used in conjunction with the Data Acquisition Board. It works by reading the signals from the board and putting them into a format that can be understood by Labview.

Fig. 2.2.2.5.1

In addition to acquiring the data all of our data will be displayed using a Labview program. This program will feature charts to display the data in real-time as it is being acquired. It will also record and save data for later analysis. Labview will also
help to filter the signals to get rid of noise from the amplification and transmission processes. Users will have some control over the program such as the ability to specify where to save the data to among other abilities.

3.0 Prototype Construction and Operation

Instead of using actual tissue samples, various analogues such as pieces of plastic, elastic and rigid materials were used for testing. The reasons behind this are two-fold: (1) deformation of the tissue analogs was needed to be observed, which would be impossible in a solution bath with a liner, (2) Tissue samples tend to dry out quickly rendering data collection useless. The first section describes the fixture assembly.

3.1 Acrylic Assembly

The fatigue testing fixture is made up of multiple sections that work together. These different parts include the tank, upper platform, lower platform and connecting rod, upper clamps, and lower clamps. All of these parts are constructed from acrylic. This ensures that there will be no interaction between the solution in the tank and the fixture itself. A detailed overview of each of these parts will be given here.

Tank:

The tank of the fatigue testing fixture serves two purposes: it holds the solution around the tissue and supports the upper platform. It includes four walls and a base platform. The tank was designed to be assembled and taken apart with each experiment. This makes setting up the tissue specimens much easier without having walls in the way of the clamps. In order to make sure the tank is water tight without applying glue, a liner is used. The walls are held together by grooves in the base, the upper platform, and a Velcro strap around the outside. All of these together with the liner create a tight seal between the walls.
The base is constructed of ½ inch acrylic. Four holes have been drilled near each corner so it can be screwed into the base of the Bose Testbench device. The image clearly shows the grooves that the walls are set into. This helps keep the walls steady during testing. The grooves are cut ¼ inch into the base. The long side walls are thicker than the short end walls, so the grooves along the long sides are thicker.
The long walls are made from ⅜ inch acrylic. This provided the necessary thickness to drill holes into the top edge for securing the upper platform. It also allowed a notch to be cut at each end for the short walls to slide into. All of the walls have been marked with tape to clearly show what side of the base they fit into, and the proper orientation of the upper platform.
The short walls are made from ¼ inch acrylic. This matched the thickness of the notches in the long walls. Once the long walls are in place in the base, the short walls can simply slide into their grooves between the adjacent long walls.
The Velcro strap is actually two straps secured together. The strap is placed around the top of the tank and secured as tightly as possible.

Upper Platform:

The upper platform is where the upper clamps are attached. It is secured to the top of the tank walls, which helps keep the tank together during testing. The platform was constructed from 3/8 inch acrylic. In order to accommodate the connecting rod, a section was removed from the center of the platform. This allows the connecting rod to pass through the upper platform without coming into contact with any other parts.
Two holes were drilled on each of the long sides of the upper platform. This allows screws to pass through the upper platform and tighten into the long walls of the tank. Two rows of six holes were drilled around the center of the platform where the connecting rod passes through. These holes are where the upper clamps are held.

Upper Clamp:

Figure 3.1.9: Strain Gage location
The upper clamp doubles as a means of holding the tissue during testing, and as a way of detecting the stress applied to the tissue. The upper clamps were designed so that they would deform during testing when the Bose device applied a load to the bottom platform. This load would stretch the tissue, which would then apply a force on the upper clamps. This force is what deforms the clamp, which has a sensitive strain gage attached to it. An Abaqus simulation was used to help determine the design of the upper clamps.

![Finite Element Analysis](image)

**Figure 3.1.10: Finite Element Analysis**

The amount that the upper clamp deforms is directly related to the material it is made out of, the cross-sectional area, and the applied load. This is illustrated by the following equations.

\[
\sigma = E\varepsilon, \quad \text{(eqn. 1)}
\]

\[
\sigma = \frac{P}{A} \quad \text{(eqn. 2)}
\]

\[
\therefore \frac{P}{A} = E\varepsilon, \quad \text{(eqn. 3)}
\]

where \( P \) = pressure, \( A \) = cross-sectional area, \( E \) = Young’s Modulus, \( \sigma \) = stress, and \( \varepsilon \) = strain.
According to the final equation, the only ways to increase the load without changing the material or applied force is to reduce the cross-sectional area. This was the method used for the upper clamps. The area where the strain gages were placed was made much thinner than the rest of the clamp. The strain gage section was cut to approximately 0.2” x 0.5” x 0.5”. The thin section was made significantly longer than the strain gage itself. This was done to ensure homogeneous strain. Homogeneous strain means that the strain in all locations around the strain gage is the same; one side is not being altered more than the other. The Abaqus simulation shows stress concentrations at the corners of the thin section. The final clamp design was then created in SolidWorks.

![Updated CAD profile of upper clamp](image)

**Figure 3.1.11: Updated CAD profile of upper clamp**

Lower Platform and Connecting Rod:

The Lower platform and connecting rod are the only moving parts of the fatigue tester. The connecting rod is a solid acrylic cylinder approximately one inch in diameter. The lower platform is the same platform used in the old device, but with several modifications.
Figure 3.1.12: Bottom platform and connecting rod front and side views.

The connecting rod is held to the lower platform by two screws. A small piece from the Bose machine is attached to the top end of the connecting rod by four small screws. This piece is then screwed into the Bose machine by a threaded metal cylinder (screw with the head removed). The bottom platform had two sections removed to help reduce the force the solution would apply during testing. This force could skew the data collected by the strain gages, so it is important to
make is as small as possible. The lower clamps are attached to the lower platform by threaded holes in the side of the platform.

![Connecting Rod attachment.](image)

**Figure 3.1.13: Connecting Rod attachment.**

Lower Clamps:

The lower clamps are constructed entirely from pieces reused from the old testing fixture. Each clamp consists of two large pieces and one small piece, along with the necessary screws, washers, and spacers.

![lower clamp pieces.](image)

**Figure 3.1.14: lower clamp pieces.**

![Upper clamp pieces.](image)

**Figure 3.1.15: Upper clamp pieces.**
Much of the assembly of the lower clamps can be done prior to setting up an experiment. This helps reduce the setup time of an experiment. The quicker an experiment can be setup, the less time the tissue will have to dry out. This will improve the data gathered by using tissue specimens in ideal condition.

3.2 Strain Gage and Bridge Configuration

The strain gages used in this project were purchased from Vishay Micro-measurements. The gage designation is C2A-13-250LW-350 with a resistance of 350 +/- 0.6%. The C2A featured encapsulated lead wires that were pre-soldered.
The ideal placement is illustrated above in figures (3.2.2 and 3.2.3). The gage was applied longitudinally with the lead wire coming away from the tissue attachment points. The gage was placed halfway up the thinned section to avoid complications with stress concentrations.

The recommendation for the 350 Ohm gages is 0.5-1.5 Volts for the collection of reasonably accurate data. The excitation voltage is provided by a voltage supplier directly to the bridge, so that all the necessary wire connections occur in one component. The bridge completion modules (BCM-1) were purchased from Omega. They featured mounting holes to which lead wires from strain gage could be attached. Excitation voltages coming from the power supply and output voltages leading to the DAQ hardware could be attached to different mounting
holes in close proximity. The figures (3.2.4-5) below provide a schematic on how lead wires were connected.

The 350 Ohm gages are meant to be attached a 2-Wire quarter-bridge configuration. The resulting equation (eqn. 4) is as follows.

\[
\frac{V_{sig}}{V_{ex}} = -\frac{GF*\varepsilon}{4} \left( \frac{1}{1+GF*\varepsilon^2} \right) \quad (\text{eqn. 4})
\]

The equation could be implemented in the final LabVIEW program to convert the voltage readings (Vsиг) from the completion modules into strain (ε) readings.
3.3 LabVIEW Results of Testing with Elastic Piece

The figure above represents the functional unit block diagram of the LabVIEW program for a single gage. Data comes in through the DAQ VI on the left and is run through a series of calculations (highlighted by the red oval) that determine the raw strain using equation (4). Then the data is filtered using a Filter subVI, which is set a low-pass Butterworth high order level, and displayed as a dynamic indicator and a waveform chart. The math nodes that convert strain into stress and estimated load are highlighted in the green oval. Outside of the loop, the data can be set to write automatically to a text file. There are various user controls such as the gage factor, excitation voltage and Young’s modulus can be changed, depending on the type of gage used.
Figure (3.3.2) is a screenshot of the DAQ VI. In this module the DAQ VI can be tested before it is built. It also allows variables such as the buffer size and sampling frequency to be modified. Any error in sampling frequency, hardware recognition or connectivity can be detected in this window before the program is started.
Above is figure (3.3.3) containing the screenshot of the Filter VI. Here the filter type, order, cutoff frequencies can be selected. For the purposes of using the fatigue testing fixture at loading frequencies of 0.5-30 Hz, a low pass (Butterworth order 5) configuration at a high cut-off frequency of about 40 Hz is used.

Figure 3.3.4: front panel signals.

Figure (3.3.4) depicts the front panel of the program while a low frequency cycle is performed on one elastic specimen at low frequency (0.5 Hz) and low displacement (set at 1 mm in the Bose Software). Above the graph are different tabs where the desired type of data can be selected. Raw voltage, raw strain, filtered strain, stress, and estimated load are displayed as waveform charts.
Figure 3.3.5: Save option.

Figure (3.3.5) is an image of the save option that appears at the termination of an experiment. Users are given an option of where they would like to save their data as well as a chance to title it. Data is saved in a text file and can easily be imported into Microsoft Excel 2010.

Figure 3.3.6: User controls
The user controls depicting in this figure (3.3.6) contains various inputs to change parameters such as the gage factor, the excitation voltage, the clamp length, the clamp width and the Young’s Modulus of the acrylic. It also displays the key area and the filtered strain. Underneath is the large stop button, which is should be pressed as soon as the cycles are finished.

4.0 Realistic Constraints

*Engineering Standards*

The final product of this design must allow for relative ease in mounting tissue samples properly and quickly. The task of securing each tissue sample must not risk damaging any of the moving parts. The screws, hinges, washer or nuts used must be wear resistant and rust-resistant. The mechanical design should also allow for consistent tissue length for all samples. If the tissue lengths are uneven (some samples are slack, whereas others are stretched beyond their normal limit), the resulting strain measurements will be inaccurate. The following points detail possible sources of error and potential remedies.

- **Sudden environmental fluctuations**: Fatigue testing of several tissue samples should ideally last hundreds of millions of cycles in a saline environment experiencing room temperature (25 degrees Celsius). If the nature of the solution changes drastically, tissue samples may wither and dry out. If the temperature in the laboratory fluctuates, the accuracy of the strain gauge readings can be affected drastically. These complications can be avoided by constant monitoring of saline bath conditions and lab environment. The bath tank is designed with a certain thickness and the screws are added in certain places to protect the enclosed fixture from sudden outside contact which can disorient the tissue samples.
- **Recording Errors**: These types of errors might result from inadequate calibration of the Bose TestBench and improper fixture setup. The user needs to adjust the base of the fixture according to the type of fatigue testing being performed at the time.
- **Calculation Errors**: Improper use of constants, mathematical relations or significant digits must be avoided in programming stages or during the strain gage attachment process where circuit elements must be chosen and wire properly.
Strain Gauge errors: The dynamic strain measurement must be accurate enough for reasonable analysis of tissue behavior. Therefore, each and every strain gauge must be calibrated accordingly. The conversion factor that relates the changes in strain to the changes in voltages must be calculated, understood, and recorded properly. Signal processing, which includes filtering and amplification, must be also be precise.

Economic Constraints

The proposed budget for this design is estimated to be close to $400. The raw acrylic or plexiglass materials, circuit elements, strain gauges, and PIC microprocessors are relatively cheap. The usage of Bluetooth modules (each priced around $60) may drive up the costs. The trial and error nature of the calibration of the strain gages and clamp manufacturing may introduce extra costs. Potential accidents or malfunctions should also be considered as possible sources of unforeseen costs.

Manufacturability

The fixture components made up of acrylic or plexiglass are fairly straightforward in shape and size. They can be machined and cut in the School of Engineering Machine Shop. The tank can also be manufactured with relative ease in-house. The base of the fixture may require some additional fine threading (with diameters with less than 2.5 centimeters) which is currently not possible in the machine shop. Professional threading may incur some unforeseen costs and may delay the deadlines of the project.

Environmental Constraints

For fatigue testing data to be relevant, all the tissue samples must be submerged in saline solution throughout the process. The design of the tank is large enough to hold all submerged samples within their clamps. To simulate bodily conditions, the saline solution can be planned to be phosphate buffered to around pH 7.4. This pH condition might prove to be corrosive on any metallic screws, hinges, or washers that may be included in securing the samples.

Sustainability
All of the machined parts, purchased components, and assembled circuitry must be designed to be long-lasting. Disposal of malfunctioning parts or used saline solution must be limited as much as possible to avoid detrimental impact on the environment. Periodical cleaning and maintenance must be performed to avoid wear and general part degradation, which can lead to unnecessary waste of resources. Care must also be taken to limit extraneous electrical intake by the power supplies, industrial amplifiers, the Bose TestBench system, or the strain gauges (each of which require DC voltage of 5V).

Ethics

The entirety of the project will be carried out with the utmost respect for the limitations of budget and constraint of time for the client and any other individuals gracious enough to provide assistance. All purchases will be performed through the proper channels with permission from the right individuals. The expenditure of money will be recorded with detail and any potential serious health or environmental concerns will be announced and reported with punctuality.

Health and Safety

The major health concerns with setting up and running the fatigue testing fixture are related to cutting each tissue sample, proper maintenance of moving parts, and avoiding skin contact with the chemical solutions. Other safety issues are listed and expanded upon in the next section.

4.0 Safety Issues

The most obvious safety threat for this device is the presence of moving parts. As with any machine care must be taken to avoid touching any moving parts. Failure to do this could potentially harm the user and result in severe injury. This device has most of its moving parts enclosed in the tissue bath so this area should never be opened while the machine is in operation. In addition to this the moving shaft must also be avoided while the device working. If the device seems to be too dangerous a guard could be constructed to protect the user.
A safety concern that is not directly related to the operation of the device is the preparation of the tissue samples that will be used in the machine. Each small sample must be cut from a larger tissue using a razor blade. Because of the difficulty in cutting the small size to exact dimensions and the slipperiness of the tissue it is very possible to cut oneself while preparing the tissues. A way to possibly avoid this might be to invest in a hobbyist’s knife which has a handle and is safer. In addition pins could be provided to hold the tissue taut. This could reduce the risk of cutting the fingers holding the tissue. In addition a basic first aid kit should be nearby to deal with any minor cuts that may occur.

Another safety aspect that is important to consider is how loud the device will be. Because it will run for a period of weeks it is important that it will operate at a noise level that will not cause harm even when exposed to it for many hours. The national center for research resources estimates that decibel levels lower than 80 decibels are safe for extended periods of time. This is roughly the noise level of some washing machines. If the device operates at a louder level than this then changes may need to be made to the device. Alternatively hearing protection could be provided.

Another safety aspect to consider is the presence of chemicals in the tissue bath. These chemicals can be a threat in two ways. Firstly it is possible that they could harm the operator of the device. To avoid this, the operator should be aware of the contents of each bath and the risks associated with it. In addition the operator should wear gloves and other safety ware if necessary. If chemicals used in the bath are especially dangerous then it may be desirable for the device to be located near an eyewash station. The second area in which these chemicals could cause harm would be their storage and disposal. It will be necessary to have a strategy for storing and disposing of any chemicals that could be harmful.

An important safety concern is that of electrical safety. Anywhere electricity will be in proximity of water this will be a concern. To avoid any electrical problems all wires will be insulated and held out of the solution. In addition all circuitry will be located as far as possible from the tissue bath and also protected from splashing and drips. To further avoid these problems the electronic components of this device should never be handled while the device is powered. Also gloves should be worn if the device is to be adjusted while it is running.
A final area of safety that must be considered is tissue bath spillage. While this may seem a trivial issue significant amounts spilled during testing. If this continues to be a concern then a more complete enclosure for the bath may be necessary. Care should be taken to avoid spillage as it may lead to slipping. Supplies to clean up the solution should always be on hand.

5.0 Impact of Engineering Solutions

This device will have significant short and long term effects. The biggest impacts will be on the testing done in the UConn BME labs. This device will replace the currently used soft tissue fatigue tester and greatly improve the quality of data gathered. Dr. Sun and those working in his lab will be able to perform a wider variety of experiments in order to obtain greater amounts of very useful information. The testing itself will also be simple to setup and perform. The device could also serve as a learning tool for future students in the BME program. Having a device that is simple to use will allow many undergraduate students to operate and learn a great deal about soft tissue testing. It could also be possible to build copies of this device and have undergraduate labs built around using it, such as in the biomechanics or biomaterials courses.

There are also several important long term effects this device will have. The most important is an improvement in the understanding of different types of soft tissue and how they behave during different types of loading and deformation. The durability and fatigue characteristics of the soft tissues will be better analyzed using this device, which will lead to improvements in the designs of bioprosthetic devices. Many devices that make use of soft tissue are not very durable and must be replaced quite often. Being able to build more durable heart valves and artificial blood vessels will allow more patients to receive these bioprosthetic implants without having to worry about multiple replacements. An overall increase in the quality of life of these patients will undoubtedly occur.

6.0 Life Long Learning

This project is a very valuable opportunity for those involved to learn many different skills. Possibly the most important is learning to work and cooperate as a team. No one person...
could create the best possible designs for any type of device, at least not as well as what could be created when working in a team. Teamwork allows one to get feedback on ideas, to brainstorm and put together input from multiple sources into one single idea. This synergy is impossible to achieve when working independently.

Many technical skills will also be learned and/or improved on in this project. Programs such as LabView and SolidWorks will be used extensively in designing and operating this device. Both of these programs are widely used in industry, so learning how to use them as a student will provide a great advantage when searching for employment. A great deal about signal processing will also be learned while constructing the soft tissue fatigue testing fixture. This includes filtering, amplification, analog to digital conversion, and even programming PIC microchips. There will also be circuit and strain gage assembly, both of which are important skills to have as an engineer.

Constructing the device itself will also be a very useful learning experience. Building the project will require planning and proper budgeting, creating and sticking to a time table, machining parts based on precise specifications, and constructing the separate parts into a functioning device. This one project will be able to provide all of these different chances to learn and improve on different skills, all of which are vital as an engineer.

7.0 Budget and Expenditure

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8.0 Team Member Contributions

James Rollett

My main responsibility for this project was creating the overall design in SolidWorks. This involved getting an understanding of the existing project, and what needed to be improved on it. I decided to make several changes to the design of the clamps and the tank. One of the biggest issues with the old device was the difficult and time consuming setup. I wanted to make this device as easy to setup as possible. After creating the optimal design, we began constructing the individual components. I was in charge of making sure the dimensions of all the machined pieces matched the SolidWorks design.

Shashank Settipalli

My contribution to this group project mainly involved strain gage research and implementation. I made the appropriate purchases for materials other than acrylic. Machining the acrylic pieces was a collaborative effort and I contributed by using the milling machine to machine some clamps pieces and side walls. As part of my assignment to familiarize myself with the Bose software, I wanted to ensure the software controls did not interfere with LabVIEW data acquisition. My additional contributions included testing the device and troubleshooting the LabVIEW program.

Austin McMann

Over the last year my team and I have worked with Dr. Sun on a project to design a tissue testing device. Although we have all been involved in every aspect of the project my main focus has been on the areas of software, data acquisition, and signal processing. One major area that I have been heavily involved in is the Labview program. The Labview program is responsible for receiving the data from the DAQ as well as amplifying and filtering it. Labview is also used to display and record all of the data in various formats. Our Labview program uses several VIs to perform tasks such as filtering the data. These VIs gave us some bugs and overall throughout the year we had many problems with our Labview program. My team members and I worked
together to troubleshoot our program and remove all bugs. Another area that I spent a lot of time on was construction of our device. Our device has many components including 24 clamps, walls, and the connecting rod. This was exacerbated by the redesigns our project went through sometimes requiring us to remake parts in a new design. Many of these components are complicated and took a lot of time on the milling machine to construct. My teammates and I spent a lot of time in the machine shop working to construct all of the parts we needed. A final area that I was involved heavily in was the DAQ setup. In our project we had a long flow of data, from the strain gages, to the bridges, to the DAQ board, to the chassis, to the computer, and finally displayed in Labview. To get the DATA from the bridges to the computer we had to borrow and install a NI DAQ board and chassis. We also had to install a card into our computer to allow the chassis to connect with the computer. My team members and I were able to solve all of these problems with some help from Emily Jacobs and Dave Kaputa.

9.0 Conclusion

The main impetus for designing and building this device is to allow more accurate and useful tests to be performed simultaneously on multiple soft tissue samples. This will be achieved through specific design choices, such as the positioning of the load cells and the allowed range of motion of the movable base. Placing the load cells above the tissue attached to the stationary top section prevents the load cells from moving during testing. Keeping the load cells stationary will prevent any unwanted movement during testing. The load cells won’t pick up any unwanted forces that would be caused by this movement. This will keep the data as uncontaminated as possible. Allowing the base to be moveable within a large range of motion allows for the option of tensile, flexural, or both types of testing. This will increase the amount of data that can be gathered about both of these types of forces and how they each affect the tissue.

The knowledge gained from this type of testing could eventually lead to improved designs of bioprosthetic heart valves and other tissue engineering endeavors. A better understanding of how tissue is affected by fatigue testing will help tissue engineers design valves that can withstand the forces applied while in use for much longer than the current bioprosthetic valve.
lifetime of ten to fifteen years. This device will eventually help improve the quality of life of patients receiving tissue derived organ replacements.
10.0 References


11.0 Acknowledgements

Dr. Wei Sun- We would like to thank Dr. Sun for all the helpful advice and guidance he has given us for the past two semesters.

Caitlin Martin- We would also like to thank Caitlin for helping us design the fixture by providing us regular input.

Dr. Bi Zhang- Dr. Zhang helped us understand optimal strain gage placement.

Emily Jacobs – Emily has been a great TA, generous with her time.

Dave Kaputa- Dave has advised us on LabVIEW programming and troubleshooting

Tom Mealy- Mr. Mealy aided us in strain gage installation.

Serge and Pete – The machine shop staff have been quite generous with their time and input.

Qian Wang- Qian helped us with finite element analysis.

Dr. John Enderle- Dr. Enderle has provided us the opportunity to put our learning to good use.
12.0 Appendix

12.1 Purchase Requisitions and Price Quotes

Price Quotes:

Mansfield Supply
1527 Storrs Road
Storrs, CT 06268-1319

Acrylic Prices:

1/2 inch: $16.95/sq ft
1/4 inch: $6.49/sq ft
1/8 inch: $4.79/sq ft
**PURCHASE ORDER REQUISITION - UCONN BME SENIOR DESIGN LAB**

Instructions: Students are to fill out boxed areas with white background. Each Vendor will require a different purchase requisition.

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**Price Quote: Vendor Accepts Purchase Orders?**

**Vendor:** Omega Engineering, Inc

**Address:**
- One Omega Drive
- P.O. Box 4047
- Stamford, Connecticut 06907-0047

**Phone:** (800) 840-4286 or (203) 359-1600

**Contact Name:** Customer Service Rep.

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**PURCHASE ORDER REQUISITION - UCONN BME SENIOR DESIGN LAB**

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Comments:
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**Vendor:** Vishay Precision Group: Micro-Measurements

**Address:**
- 951 Wendell Blvd.
- Wendell, NC 27591 USA

**Phone:** 1-919-365-3800

**Contact Name:** Customer Service Representative

Authorization: ______________________