Optimal Design Report

Miniature Biaxial Testing Device

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1 Optimal Design for Project 26

1.1 Introduction

This project is for Dr. Wei Sun, an Assistant Professor in the Mechanical Engineering department at the University of Connecticut whose research focuses on tissue mechanics with both experimental work and computational models to further the understanding of behavior of soft tissues. The task given by the client is to design a miniature biaxial testing device for soft connective tissues. The device must be portable, as well as small enough to fit underneath a two-photon microscope (see figure 1). The project also involves the design of a type of cookie-cutter mold to cut the tissue into a desirable shape for mounting in the biaxial testing machine. A method of analyzing the orientation of the microfibers viewed through the two-photon microscope will be devised once the biaxial machine is assembled.

![Diagram of the constraints of the experimental area at the two-photon microscope.](image)

*Figure 1. Dimensions of the constraints of the experimental area at the two-photon microscope.*
The selected optimal device is based on Alternate Design 3, but has a few key changes by input from Dr. Sun and the team members. The full updated design can be seen in figure 2 below.

![Figure 2](image)

*Figure 2. Final optimal design of the miniature biaxial machine. The tissue specimen is also included. All units are in inches.*

This structure was selected for its ease in portability and compartmentalized features. The only significant difference of this design is the location of the hybrid motor stepper linear actuators. The motors were shifted to reduce arm length and torque, resulting in better accuracy from the acquired data. The short arm length is a major change from all three of the alternate designs.

Another major change is the location and type of load cell. Originally an in-line bridge load cell was discussed in the third alternate design; however a better in-line load cell that also acts as a clamp-to-arm connector was selected for the final design. These components will be further described in the next section.

As in the preliminary design, the specimen will be held by means of a micro clamp that will prevent the tissue from slipping as well as provide minimal damage to the tissue.
Clamps will be attached to the motor shafts, which are indicated in the above image by the color yellow. The inner cross-shaped area made by the enclosed tracks will be filled with the saline solution to place the specimen. These shafts are what provide the linear deformation to the tissue. Each shaft is individually controlled by a Hybrid Linear Actuator Motor that causes the stretch-contract motion.

Directly diagonal to the camera mount, there is a shaft supporting the mirror clip. The mirror will be more adjustable than the camera, and will thereby allow motion in all degrees of freedom. The key is for the mirror to accurately reflect the specimen deformation, as well as have a small hole in an appropriate location that will allow for a photon beam from the fluorescent microscope to pass through.

The design of the bath is more compact in which it has a constant 7.25 inch side length. The height varies depending on the device structures, however there is a planar surface at the center that is less than the 3 inches as required by the dimensions of the two-photon light microscope.

Furthermore, another convenience is the ability to use the four outer squares as storage containers for cords and cables to the load cell, motor, and power strips. By coiling the cords here, it minimizes space taken at the experimental location, as well as allows for faster setup and removal.

As with the original design, the motors will still be controlled by NI LabVIEW interface hardware by portable laptop at the experiment site. The data will be able to be collected at this location for convenience as well.

1.2 Subunits

1.2.1 Device Base

For this device, the base will comprise of two constituents: an outer frame and an inner bath container. The outer frame is what holds all the components and cords in a configuration compact enough to allow for portability. The frame will have a side length of 7.25 inches and be made of 316 Stainless steel. This material was chosen for several reasons, the first of which regarding strength and support. The stainless steel will be able to provide enough support to the motors without any deformation or excessive fatigue. It is very durable in
numerous environments which is key with respect to device portability. Furthermore, the device will be exposed to biological tissues, and will therefore need to be sterilized for health and safety measures. Stainless steel is not a very porous material, and will therefore be able to be easily sterilized with a topical disinfect. Additionally, there is a high possibility that some of the saline solution may come into contact with the outer frame by means of human error or device malfunction. The frame therefore needs to be able to withstand this medium without fear of quick corrosion.

For the inner bath container, the chosen material will be 316LVM stainless steel, a similar but different alloy. This alloy is commonly used in biomedical applications such as implants due to its high resistance to corrosion. The saline solution has a composition very similar to that of bodily fluids, so therefore, the selection of this material to hold the solution ensures that there will be minimal corrosion and damage to the base. The reasons mentioned above for the selection of material for the outer base also apply for the inner container. The inner bath is designed to have maximum capacity of approximately 333 mL of solution when empty. Upon placing the specimen and specimen stand inside the bath, the maximum capacity will be lowered to approximately 300 mL. The entire base apparatus can be seen in detail in figure 3 below.

![Figure 3](image_url)

*Figure 3. The base apparatus for the miniature biaxial device. All dimensions in the figure are in inches.*
1.2.2- Motor

The motor to be used is the Haydon Size 11 Hybrid Stepper Motor Linear Actuator, 28000 series. This motor is called hybrid because it combines the functionality of a rotational motor and linear actuator into one compact device. The device is programmable using LabVIEW software and, as seen in figure 4, the output of the device is strictly linear motion. The wiring of the device is bipolar and operates at 5VDC, while the current/phase is 0.42 A, both of which are sufficient parameters for the biaxial test. The selected stroke size for the motor will be 0.750 inches, which for typical samples, will be an excess stretch length.

For the device, there will be four motors that will be mounted atop the edges of the saline bath, as depicted in FIGURE #. The motors will be paired with the motor directly opposite on the same axis to provide equiaxial tension. This is important in ensuring that the recorded deformation is true to the assumptions made regarding homogeneous tissue samples and true biaxial testing.

Figure 4. (A) The Hybrid Stepper Motor in extended position. The rainbow colored rods on top are the connections to the cable. (B) An aerial view of the motors on top of the saline base and frame.
1.2.3 - Arms

The arms translating the motion from the linear motor to the tissue clamps will be made of 316LVM stainless steel as well. One end will be fastened to the end of the linear shaft via a small tightening mechanism. The arm will then elbow down into the saline solution. This elbow will be made by screwing on two intermediate shafts. The total length of the arm is 1.38 inches.

1.2.4 - Load Cells

The selected load cell will be the XFTC Miniature Load Cell from Measurement Specialties. It is an in-beam load cell that will dual function as the connector piece from the clamps to the arms. One end of the load cell will be inserted into a small hole near the end of the arm and secured with a screw into the female fitting. The clamp mechanism will be screwed into the other end of the load cell, closing the loop and allowing for testing to begin. The load cell will hold a maximum load of 2 N, which equates to a reading of 181.4 grams. The maximum load able to be withstood by a thin, smooth tissue sample is 150 grams, as tested in Dr. Sun’s Tissue Mechanics Lab.

![Figure 5. The miniature load cell by Measurement Specialties.](image)

1.2.5 - Specimen and Die Cut

A porcine tissue specimen will be used to test the biaxial testing device once it is assembled. The tissue specimen will be a part of the circulatory system located near or within the porcine heart. For instance, the tissue specimen may be a leaflet from a heart valve or a small section of the aorta.
The client would like the specimen to be in a cruciform shape. A die cut will be used to form the specimen into the desired shape. The die cut will be made of one piece of 316 stainless steel. The steel will be welded into the desired shape. Razors will be attached to the face of the steel that will cut the tissue. The proposed shape of the die cut is shown in the figure below.

![Figure 6](image)

*Figure 6. The cruciform shaped specimen after it has been cut by a die.*

The design of the die cut is shown in Figure below.

![Figure 7](image)

*Figure 7. The cross-shaped die cut.*

### 1.2.6 - Specimen Clamps

ERIEM Surgical is a company located in Lake Forest, IL which sells microvascular clamps. A sales representative emailed us quotes for a few different models of clamps and the clamps were found to be pricey for our budget. Individual clamps are sold for approximately two-hundred dollars. These clamps would meet the requirements for our project however as the width of the part of the clamp that grips the specimen is small. Also the clamps are designed to grip veins or arteries which range in thickness from 0.6 to 5 millimeters.

The clamps are attached to a rod which passes through the end of the clamp which does not hold the tissue specimen. Clamp applying forceps also manufactured by ERIEM Surgical can be used to open the clamp in order to grip the sample.
The clamps will be connected to arms in the biaxial testing machine by rods previously described.

1.2.7 - Saline Bath

The bath will be filled with a nine percent per volume saline solution. Salt and warm water will be mixed in the lab to create this solution. It will be maintained at approximately 37 degrees Celsius to emulate human body temperature.

1.2.8 - CCD Camera

One of the imaging modalities to be coupled with our instrument, is the CCD camera. A CCD camera is already in the Wei Sun lab. The CCD camera is a device commonly used in the medical field. An image sensor converts an electrical charge into a digitized signal which can be used as practical information. For our purpose, the sample will be marked with four graphite markers at each corner. The CCD camera will record and track the movement of these markers. This is very important, as it provides us with information on how far the samples are being stretched in each direction. In our design, we propose a mirror which will reflect photons from the sample, onto a CCD camera placed on the side of the device during testing. This, is so that we can obtain data and images of our test with two imaging techniques, the CCD mentioned here, and also the two-photon microscope. Having data from both of these instruments will prove very valuable for the testing of soft tissue mechanics. Each tracking method provides different information about the specimen as it undergoes mechanical testing.

1.2.9 - Two-photon Microscopy

The driving reason for building a biaxial machine of small enough size so that it is transportable, is to be able to couple these tests with imaging via a two-photon microscopy. The two-photon microscope is available in the biophysics building on the Storrs university campus. This technique allows us to visualize the tissue microstructure, namely collagen and elastin fibers, in real time as tests are performed on samples. Samples will need to be stained with fluorescent dye to be imaged. Stains can be chosen which have specific binding abilities to the
desired microstructures. The microscope emits two-photons of light, as these come in contact with the dyes and if there is enough energy a fluorophore will be emitted from the dye. The intensity and wavelength of these fluorophores are transformed into an image. The entire biaxial testing device will be placed underneath the two-photon microscope, which will be centered directly above the sample. The angled mirror also located directly above the sample will require a hole to be cut so that the photon/fluorophore travels are not interfered.

Dual imaging via CCD camera and two-photon microscopy are important when describing the miniature biaxial device. Without these accessories the implementation of this device would have no value. The implications of our miniature design and the advantage it provides is the ability to simultaneously use these two techniques for testing and specimen data acquisition. Below is a diagram which shows how these instruments will be coupled with the miniature biaxial testing device.

*Figure 8. A representative drawing of the camera-mirror-specimen set up at the two-photon microscope station.*
1.2.10 - **NI Stepper motor drives**

Currently, Dr. Sun's lab uses an NI stepper motor driver model number MID-7602 which can be used for our machine. This driver is necessary to control the motors. The specifications for this device are included in the references.

1.2.11 - **NI LabVIEW**

LabVIEW is the software program which will be used in conjunction with the MBTD for motion control. Dave Kaputa, a member of this project in the Wei Sun, lab is in charge of all of the National Instruments and LabVIEW software programming. LabVIEW will be used for a control/user interface. Software to do this and control the driver is currently being worked on by Dave Kaputa. LabVIEW is ideal for this project because it can be employed in various aspects of the device. The first being the control for the NI hardware. Second, LabVIEW has excellent data acquisition capability and can be used to store and collect data gathered during experiments. Finally, LabVIEW can also be used as a data analysis tool for the CCD and two-photon images. Translating these results from tests are important component of this device. Without this capability, the machine would have no valuable contribution to the scientific and engineering world.

2 **Realistic Constraints**

Specimens to be tested using our miniature biaxial device will be on the range of $5\text{mm}^2$ whose small size will present some different challenges. Currently, the biaxial devices in Dr. Wei Sun’s lab are much larger (table top size, about three square feet) and accommodate samples that are closer to $10\text{mm}^2$. Of concern is a mechanism to secure the sample. During testing it must be secured such that the sample is not damaged to the extent which may invalidate the test data. Secondly, a specimen requires enough strength so that there is no slippage of the tissue from the hooks, which would also cause inaccurate data. If slipping occurs the load created by the device will not transfer in entirety to the sample, also generating
inaccuracy. Currently, for a larger sample sutures are hooked onto the sides, however this method will not work in a miniature design. In order to grip the specimen we propose a clamping mechanism to be attached to each side of a cross shaped tissue sample. To obtain accurate results, the tissue must not slip from the clamps or be damaged. This will require a clamp that is strong enough to secure it in place, but not too tight as well. Furthermore, a problem arises if the client would like to use this device on a range of specimen types. A mechanism which works for one tissue sample might not for another. In this report, we describe an optimal mechanism. However, this should be tested experimentally and different clamping mechanisms may be explored.

Related to the small size required of the device makes building this machine difficult. First, scaling this machine down we will need to find components which are sufficiently small. Motors with both small dimensions and low power capabilities are necessary. This is because our sample does not require and cannot handle large loads. The required load to stretch our sample is as small as about two hundred grams. Parts will need to be machined for great precision as some of these components will be on the centimeter or millimeter scale. To provide good data from testing precision is a huge component. The machine currently in Dr. Sun’s lab is state-of-the art and produces very accurate data. There is a need for more testing and more machines with such capabilities amongst the field of characterizing tissue properties. To meet engineering standards, and the same level of quality a lot of care is required during design, machining and assembly. This may require certain components of our device to be machined by a professional.

Another constraint is the transportability of the device and its set-up. First, the weight needs to be maintained at a level that is easy to carry. Set-up at the microscope may require additional time because the device and sample have to be transported to this site. For example, maintaining the specimen in a heated PBS or saline bath may be required to prevent tissue damage. The biaxial device is powered by motors, meaning that when transported a power supply must be available. This may require either battery power, or close proximity to an outlet
The device requires compatibility with the CCD camera and the two-photon microscope. We have proposed a mirror to acquire this dual imaging however the set-up may be challenging. Adjustment and experimentation will need to be explored to determine the exact appropriate set-up. Additionally, in order to couple this device to two-photon microscopy an extra step to specimen preparation will be required. This may require fluorescent staining of the sample before testing and visualizing with the two-photon microscope. A method for tracking and measuring the tissue movement with the microscope will need to be addressed.

Lastly, because the device will be testing dissected tissue samples, proper health and safety regulations must be met and taken into design consideration. The Wei Sun lab is capable of containing tissue samples with proper guidelines. For testing of our prototype device we will need to use our machine in the Sun lab. Furthermore, the two-photon microscopy lab will need to also have the proper tools to support these health concerns.

### 3 Safety Issues

#### 3.1 Potential Electrical Safety Issues

There is a potential risk for electrical shock any time a current comes in contact with water. In this biaxial device, there will be several power and data cables running in near proximity of the saline solution. Precaution needs to be taken so that the wire connections, or any other electrically hazardous sites, do not touch the solution. This could be done by making a cover for the cables, or creating splash guards against outlets.

#### 3.2 Potential Mechanical Safety Issues

Care needs to be taken regarding the moving parts of the device, specifically with respect to the motors. These motors could potentially get overworked and overheated, creating a threatening environment for the device and users. The metal base conducts heat
well, so it is possible that the temperature of the base will rise and potentially cause a minor burn on the handler if they touch the base. A precautionary measure for this could be to be diligent in monitoring the motor and stop tests before the motor heats up. Additionally, gloves can be worn by the handler during any and all transport.

### 3.3 Potential Biological Hazard Safety Issues

This device tests dissected tissue samples from humans, porcine, bovine, and other specimens. There is a high risk for handler infection and contamination from live tissue handling. To combat this, users of the device will be required to wear surgical masks and thick nylon examination gloves. Additionally, proper disposal of the tissue samples as well as thorough cleaning of the entire device prior and post experimental use is also a strong preemptive measure for disease transmission.

### 4 Impact of Engineering Solutions

This device will provide a cost-efficient means of testing small tissue samples. No biaxial testing device has been built before to test tissue samples with areas of five to ten square millimeters. Thus, this device will provide a more accurate means of testing small tissues. Biaxial testing devices designed for larger specimens generally do not properly grip small tissue samples. Data obtained from these testing devices hence is inaccurate to some degree. Secure tissue grips meant for small tissue samples will contribute to the collection of accurate data. The miniature biaxial testing machine will thus provide a way of quantifying the mechanical properties of small-sized heart tissues.

The miniature biaxial testing device would provide an effective way to test small tissue samples which is economically and environmentally friendly. Small tissue samples would no longer have to be destroyed in biaxial testing devices meant for larger specimens. Thus, the amount of tissue samples tested to get reliable data could be reduced by employing the
miniature biaxial testing device. Consequently, not as many preserved hearts would need to be purchased to generate data.

A database of the mechanical properties of the small tissues of the heart would allow the creation of constitutive models pertaining to these tissues. The models could aid surgeons to predict when a patient is in need of surgery more accurately than current methods determine. The models would also help to simulate the behavior of the tissues in response to surgery. Heart valve replacement devices could be assessed before implantation by creating 3-dimensional computational models that replicate the performance of these devices in the body. In this way, the ability of the devices to function properly could be tested without endangering the patients’ lives. The mechanical properties would also help research groups to design prosthetics with properties which mimic those of the heart tissues. The properties of heart valve leaflets would aid in the fabrication of new leaflet materials for heart valve prosthetics. The two-photon microscope coupled with the miniature biaxial testing device would allow the user to view the microstructure as the tissue deforms. The visualization of the changes in the microstructure could help determine the cause of tissue deformation or the mechanisms behind the microstructure changes. The explanation of why the tissue’s microstructure deteriorates would provide information for engineers to design solutions to preventing the tissue deformation. This knowledge could potentially contribute to new drug therapies which stop the mechanisms that cause the microstructure alterations.

5 Life Long Learning

The aorta has three layers called the intima, media and adventitia. The intima is the inner layer which coincides with the interior of the artery. The media is the middle layer, and the adventitia is the outer layer. The aortic tissue is made up of different types of collagen. Type I collagen is the most abundant type present in arterial walls and in the body in general. A research team found that collagen types IV and VI were present in the intima and subintima
layers by using gel electrophoresis [1]. This group also found that the proportions of collagen types III, V and I changed as the atherosclerosis conditions worsened.

The collagen fibers are arranged into fibrils and are concentrically oriented along the aorta. The collagen fibers likewise are arranged in a specific pattern in the valve leaflets. The collagen fibers form a sponge-like network in the leaflets [2]. The collagen fibers are structured as helical fibrils; however some strands stray in alternative directions and weave around the fibrils [2].

Ehlers-Danlos syndrome is a group of inherited connective tissue disorders in which the body is incapable of producing sufficient amount of collagen types I and III. There is no cure for this syndrome presently. Vascular Ehlers-Danlos syndrome affects blood vessels and organs. People with the vascular type of the syndrome have a higher risk than the average person of blood vessels rupture. However, the vascular type is rare and affects only about 1 in 250,000 people.

Two-photon microscopes have been used for cell imaging. Fluorescence signals within tissues are detected to produce the cell images. Green fluorescent proteins could be used to identify particular cells in tissues. Autofluorescence of collagen fibers could also be detected by two-photon laser scanning microscopy (TPLSM). A research group at the University of California, Irvine used this technique to determine collagen density and contraction in engineered human lung tissue [3]. Pulses of UV light were used to excite the autofluorescence of proteins in live tissues. The group then analyzed the raw data autofluorescence signal and converted this data into collagen concentration results.
6 References


Product Websites:

http://www.haydonkerk.com/LinearActuatorProducts/StepperMotorLinearActuators/LinearActuatorsHybrid/Size11LinearActuator/tabid/75/Default.aspx

http://www.haydonkerk.com/LinearActuatorProducts/StepperMotorLinearActuators/LinearActuatorsHybrid/Size11LinearActuator/tabid/75/Default.aspx