Shear Stress Sensor Design

EML 4552C-Senior Design- Spring 2012

FINAL PROJECT REPORT

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Executive Summary

The senior design project, Shear Stress Sensor Design*,* is a project sponsored by Dr. Benjamin Dickinson at Eglin Air Force Base Research Laboratory. The purpose of this project is to characterize cholesteric crystals in the hope that they can be used for a shear stress sensor. This will be done by relating the color change that the cholesteric crystals exhibit when a force is applied to the applied force. There is a need for an accurate shear stress sensor because the shear force is directly related to the drag on an air vehicle. With the ability to know the shear forces being applied on a vehicle, an adjustment can be made to lessen the drag; which saves fuel consumption for the aircraft. Current shear stress sensors are limited to lab use, i.e. debris causing error and complexity of calculation, or not cost effective for mass production.

The light reflected off of the cholesteric crystals will be measured with a spectrometer and the force exerted on the crystals will be measured with a load cell. The instruments being used are extremely sensitive and require a testing apparatus that will increase the repeatability of the test results. To create a pure shear force, a linear servo is used to transmit motion to a shear block which then applies the force to liquid cholesteric crystals. Once experiments are completed, analysis between the voltage from the load cell and wavelength from the spectrometer will be done to determine the shear force applied. The voltage from the load cell is converted to the force applied by the servo motor, which can be used to determine the shear stress of the specimen. If the experiment is successful in correlating the shear force to wavelength, further experimentation on a more expensive polymer cholesteric crystal can be performed. The reasoning behind testing a polymer is because the liquid crystal has the ability to be displaced with motion, thus making installation in a shear sensor difficult.

The testing apparatus concept was created by a graduate assistant over the summer but never completed. To complete the design a holder for the light source and fiber optic cable, a shear block, and a method to measure angles for the light source and spectrometer fiber optic cable were deemed necessary. After preliminary experimentation with a light emitting diode light source and spectrometer, it was found that the angle between the two is important because the spectrometer can only read the crystals when the light source is reflecting directly into the spectrometer. The LED spectrum was deficient in the area associated with blue light. As a result a BluLoop light source was ordered. A BluLoop light source is a quad LED light source, in which four different LED’s are combined to have a full spectrum of intensities throughout the visible spectrum.

Accurate and fast data acquisition is key to testing the cholesteric crystals as the change in wavelength happens quickly along with the load applied. LabVIEW was chosen as the appropriate data acquisition software because it can read and store data quickly from both the spectrometer and load cell with a easy to use user interface.

Initial testing shows that the wavelength of light reflected off of liquid crystals changes when a force is applied. A cholesteric Polymer test showed angle dependency between the light source angle and spectrometer angle. This angle dependency test was also used in the initial testing of the liquid cholesteric crystals as a proof of concept that the liquid crystals will change wavelength when deformed by a shear force. Since this proof of concept was also positive for the polymer form of the crystals it is assumed that the polymer will also show color change when undergoing a shear force and that the polymer should be considered as a viable test media.

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Introduction
There currently are not small, inexpensive, and accurate methods of measuring shear stress. The current methods aren't able to decouple the normal force from the shear force. It is hypothesized that a thin layer of cholesteric crystals could have the ability to decouple normal force. The project topic was thought up by Dr. Oates of Florida State University. Dr. Dickinson of Eglin Air Force Base realized that this is an important problem that needed to be solved and offered to finance the project. The testing apparatus, originally started by a graduate student over the summer, was partially completed and needed to be completed before any testing could begin. Once the testing apparatus is completed, research can begin on whether a change in cholesteric crystals wavelength can be related to the force exerted on them.

Project Scope:

Needs Assessment:
A testing apparatus for cholesteric crystals is required to characterize the crystals and to determine if the crystals are able to be used as a consistent visual meter for shear stress.

Problem Statement:
There currently isn't a shear stress sensor that only measures shear stress in real world scenarios. The current methods unintentionally measure part of the normal component of pressure on the body as the shear stress or are not affective outside of lab use due to varying conditions. The current methods are also large and expensive; the cholesteric crystals attributes indicate that they might be able to only measure the shear component of stress, decoupling the shear from the normal stress. The cholesteric crystals can also be modularly attached to materials and measured with only a fiber optic spectrometer. This would make it possible to cheaply measure shear stresses outside of the lab environment.

Background:
Liquid crystals are not a new item, but they have not successfully been used to determine shear stress. They are most commonly known for their use in liquid crystal displays. Dr. Dickinson from Eglin Air Force Base is the sponsor providing the funds for the project; however the faculty advisor Dr. Oates will be providing most of the background information along with a lab and materials. The physical design portion of the project will be to create a testing apparatus, but combining the apparatus with software that can accurately collect and analyze data will be the bulk of the project. The data collected will show how cholesteric crystals react to shear stress under various conditions. Dr. Dickinson and Dr. Oates both hope to use this data to determine if this method of testing shear stress is viable for use on aircraft, underwater applications, robots, and other equipment. There are currently other shear stress sensors existing, but there isn't a method that is widely used and simple. There currently isn't much research in regards to using liquid crystals for sensing shear stress but there is a patent for a shear sensor using the polymer form of the cholesteric crystals.

Previous Technology:

In the last few years, skin friction has become an important parameter in the aircraft industry because a reduction in drag directly correlates to a reduction in fuel consumption. As a result, many techniques for measuring shear stress have risen; but scientists are still having challenges with them. Some can only be used just in laboratories while others are very expensive. The upcoming section highlights different methods for measuring shear stress along with their advantages and disadvantages.

MEMS-based techniques

Microelectromechanical systems (MEMS) are, by definition, devices that have been fabricated using silicon micromachining technology. In general, it allows high resolution, time-resolved, quantitative measurements in a controlled wind tunnel environment. However, the open nature of these sensors is not well suited for dirty environments in which debris may be trapped in the sensor gaps.

The three types of MEMS sensors are direct sensors, thermal sensors and laser based sensors. An example of direct sensors is shown in the figure below. In this case, the displacement of the floating element is a function of wall shear-stress. Therefore, it can measure the integrated force produced by the wall shear stress on a flush movable "floating" element.

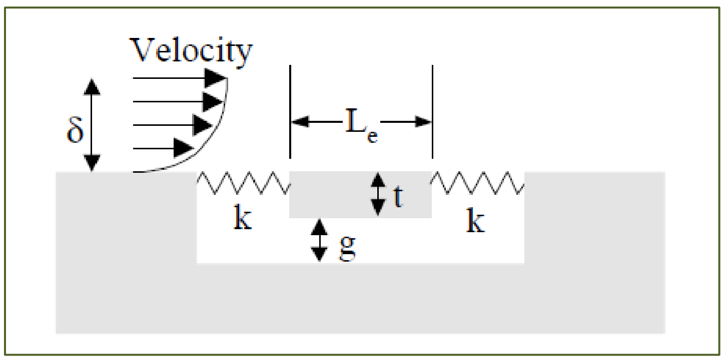

Figure 1- MEMS Direct Sensor (Naughton)

Thin-Oil-Film techniques

Thin-oil-film is a quasi-direct means of measuring skin-friction where the motion of the oil film is sensitive to shear-stress, gravity, pressure gradients, surface curvature of the oil, and surface tension. As fluid passes over the model, the oil thins. To quantify the thinning rate of the oil, the oil thickness "h" is measured, normally via interferometry. It is possible to correlate the measurement of the oil thickness to local skin-friction using a form of the thin-oil-film equation.

The figures below show the interference fringes in interferometry and a schematic of an image-based oil-film technique. The common components of the measurement apparatus are the light source, a detector camera, and a suitable model surface.

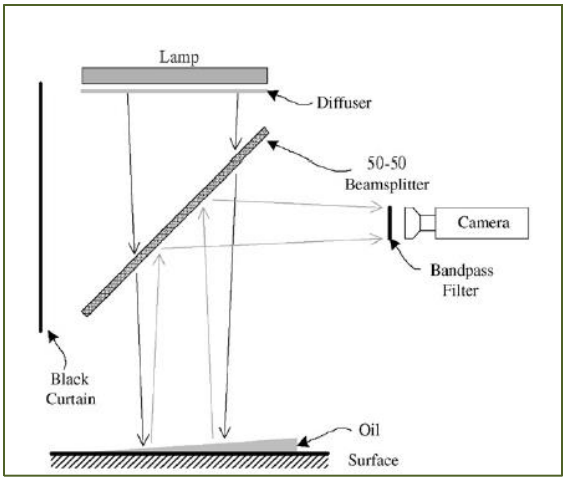

Figure 2- Schematic of image based oil film technique (Naughton)

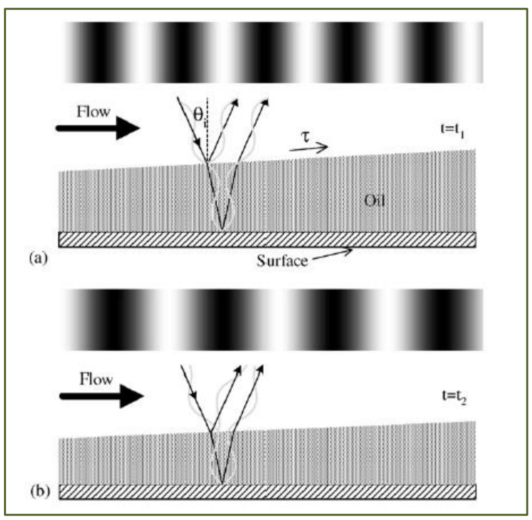

Figure 3- Interferometry finges (Naughton)

Single points, line, 1D, and 2D techniques are all different forms of Thin-oil-film shear stress measurement. The advantages vary depending on the method selected, but the main limitation is the optical access required.

Liquid crystals coating techniques

Liquid crystals are a group of substances that display characteristics of both liquids and solids. When a shear stress is applied to the crystals, there is a change in the birefringence and also a selective reflection of light from the liquid crystal layer. The major classifications are isotropic, pneumatic and chiral/cholesteric. From these cholesteric is the material with more important properties to changing forces.

The advantage of cholesteric crystals are that, as it does not need electricity; it can be used in dirty environments. However, there are some limitations such as the color dependence based of the illumination and observation angles, as illustrated in Figure 4. These limitations constitute a problem for scientists who want to apply this technology outside the laboratory. As a result, the optical access, calibration and accuracy have to be considered before its use.

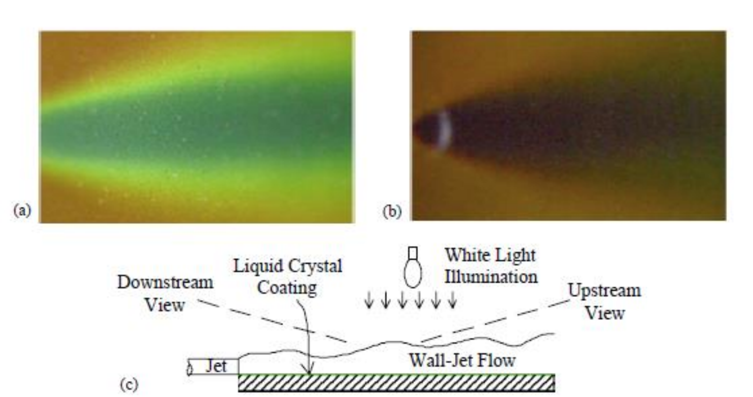

Figure 4- Viewed from different points, distinct change in color is observed (Naughton)

Figure 5 shows a patent scheme based on a laminate structure of a crystal polymer substrate attached to a test surface of an article.

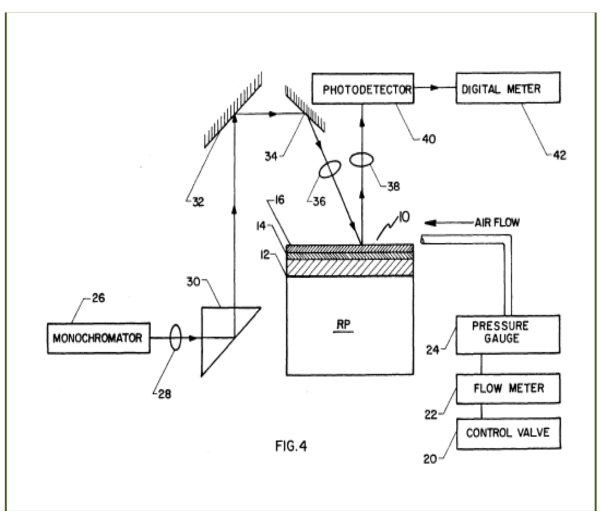

Figure 5- Patent 5223310 – Shear stress measurement apparatus (Singh)

Theory

One of the methods for shear stress measurement is executed through a liquid crystal thin film. This material has properties that allow a correlation between the load applied and the wavelengths reflected. However, one of the problems of this method is the decoupling between shear and pressure. An ideal sensor must be able to collect just shear data, although in most applications such as aircraft, the pressure component also exists. Analysis has been conducted considering theoretical cases with plane strain and beam theory as well as numerical approaches with finite-element method (FEM) to verify the possibility of decoupling. The first section, which is related to the physical system, shows the equations and assumptions made for the different types of load, geometry, boundary conditions, and results. The second section is reserved for the alternative design based on the Euler-Bernoulli beam theory.

Finite Element Method

To model the problem described there were two kinds of loads studied. For the first one, which is constant through the x-domain, the plane strain theory can is applied. For the second, represented by oscillating load, the Timoshenko equations are more appropriate for the modeling.

Homogeneous Load

For homogeneous loads analysis can be simplified by applying the plane strain theory. In this case, the strain normal to the x-y plane ε_z, and the shear strain $\varepsilon_{xz}$and ε_{yz} are assumed to be zero. This assumption can be done because the dimension of the structure in one direction (z), is very large in comparison with the dimensions of the structure in the other two directions (x and y coordinates axes).

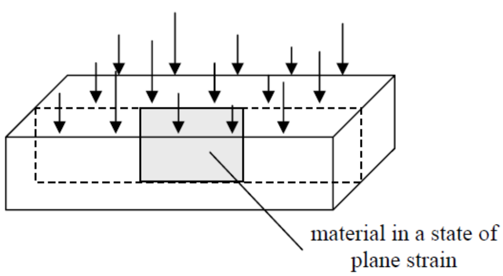

Figure 6- Material in a state of plane strain

Recalling the equations for the Hook's Law,

$$\varepsilon_{xx} = \frac{1}{E}\left(\sigma_{xx} - \nu\left(\sigma_{yy} - \sigma_{zz}\right)\right)$$
$$\varepsilon_{yy} = \frac{1}{E}\left(\sigma_{yy} - \nu\left(\sigma_{xx} - \sigma_{zz}\right)\right)$$
$$\varepsilon_{zz} = \frac{1}{E}\left(\sigma_{zz} - \nu\left(\sigma_{xx} - \sigma_{yy}\right)\right)$$
$$\varepsilon_{xy} = \frac{1}{2G}\sigma_{xy} \quad \varepsilon_{xz} = \frac{1}{2G}\sigma_{xz} \quad \varepsilon_{yz} = \frac{1}{2G}\sigma_{yz}$$

Where ε is the strain, σ the stress, and the x y z correspond to the Cartesian coordinate system. To solve the problem, the simplifications described must be applied to these equations.

Considering Plane Strain,

$$\varepsilon_{zz} = \varepsilon_{xz} = \varepsilon_{yz} = 0$$
$$\sigma_{xz} = \sigma_{yz} = 0$$
$$\varepsilon_{xx} = \frac{1}{E}\left(\sigma_{xx} - \nu\left(\sigma_{yy}\right)\right)$$
$$\varepsilon_{yy} = \frac{1}{E}\left(\sigma_{yy} - \nu\left(\sigma_{xx}\right)\right)$$
$$\varepsilon_{xy} = \frac{1}{2G}\sigma_{xy}$$

Figure 7 shows the model subjected to a homogeneous shear load, where the value for c is related to the thickness and L to the length. In this case, theoretically, the normal strains go to zero, and the only force measured would be the shear, as stated in Table 1.

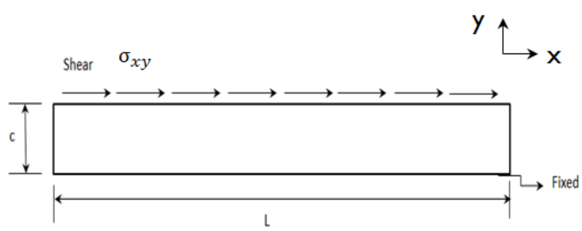

Figure 7- Scheme of a homeogeneous shear load applied in the thin film

Strains	**Strain Ratio**
$\varepsilon_{xx} = 0$	$\frac{\varepsilon_{xy}}{\varepsilon_{xx}} \to \infty$
$\varepsilon_{yy} = 0$	$\frac{\varepsilon_{xy}}{\varepsilon_{yy}} \to \infty$
$\varepsilon_{xy} = \frac{1}{G}\sigma_{xy}$	

Table 1- Strains and Strain Ratio for homogeneous shear

The quantitative value of shear the load can vary, and its range is one of the objectives of the beam theory approach; however, for the simulations 0.5 Pascal's was adopted for the shear load.

Oscillating Load

For a more realistic case, the homogeneous shear load can't be applied; there will be always a pressure component. Based on that, Timoshenko's theory is used to approximate the oscillating load. Although the load function is not known, it is possible to derive loads with Fourier series and this theory.

Before dealing with shear, the pressure analysis has been considered. The pressure case is the original condition treated by Timoshenko's equations. As a result, it is possible to verify the pressure case with the FEM model. The equations were developed based on the plane strain theory and a cantilever beam, but with sine boundary conditions. Figure 8 shows how the force is applied; the value of c related to thickness, L related length, and A to amplitude.

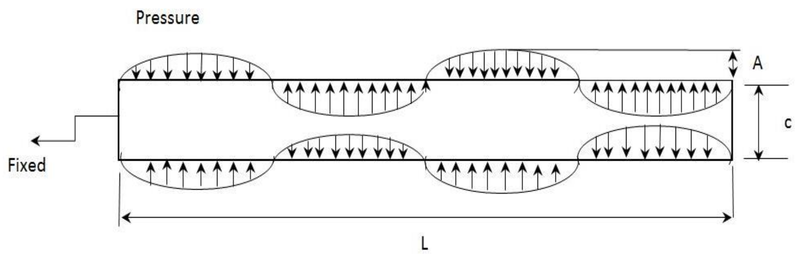

Figure 8- Scheme of an oscillating pressure applied in the thin film

$$\sigma_x = \sin\alpha x[C_1\alpha^2\cosh(\alpha y) + C_2\alpha^2\sinh(\alpha y) + C_3\alpha(2\sinh(\alpha y) + ay\cosh(\alpha y)) + C_4\alpha\left(2\cosh(\alpha y) + \alpha y\sinh(\alpha y)\right)]$$

$$\sigma_y = -\alpha^2\sin\alpha x[C_1\cosh(\alpha y) + C_2\sinh(\alpha y) + C_3 y\cosh(\alpha y) + C_4 y\sinh(\alpha y)]$$

$$\tau_{xy} = -\alpha\cos(\alpha x)[C_1\alpha\sinh(\alpha y) + C_2\alpha\cosh(\alpha y) + C_3\left(\cosh(\alpha y) + \alpha y\sinh(\alpha y)\right) + C_4\left(\sinh(\alpha y) + \alpha y\cosh(\alpha y)\right)]$$

where α=(4π/L), and L is the film length. Constants C depend on the boundary conditions of each load distribution. For the pressure load, the values for the top and bottom are

$$For\ y = +c$$

$$\sigma_y = -B\sin(\alpha x)$$

$$For\ y = -c$$

$$\sigma_y = A\sin(\alpha x)$$

In the equations above, the unit normal has to be considered when implemented in the FEM software, in addition A=B.

After solving the problem, the resultants constants are:

$$C_1 = \left(\frac{A+B}{\alpha^2}\right)\frac{\sinh(\alpha c) + (\alpha c)\cosh(\alpha c)}{\sinh(2\alpha c) + 2\alpha c}$$

$$C_2 = \left(\frac{A+B}{\alpha^2}\right)\frac{\cosh(\alpha c) + (\alpha c)\sinh(\alpha c)}{\sinh(2\alpha c) - 2\alpha c}$$

$$C_3 = \left(\frac{A-B}{\alpha^2}\right)\frac{(\alpha)\cosh(\alpha c)}{\sinh(2\alpha c) - 2\alpha c}$$

$$C_4 = \left(\frac{A-B}{\alpha^2}\right)\frac{(\alpha)\sinh(\alpha c)}{\sinh(2\alpha c) + 2\alpha c}$$

Shear Load

In this case the boundary conditions are cosine loads, instead of sine. Figure 9 shows how the force is applied, where the value for c is related to thickness, L to the length and A to the amplitude.

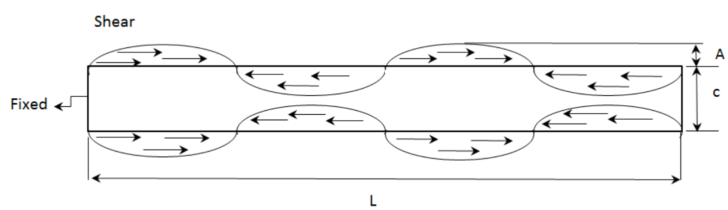

Figure 9- Scheme of oscillating shear load applied in the thin film

Constants C depends on the boundary conditions of each load distribution. For the shear load, the values for the top and bottom are:

$$For\ y = +c$$
$$\sigma_{xy} = -B\cos(\alpha x)$$
$$For\ y = -c$$
$$\sigma_{xy} = A\cos(\alpha x)$$

For the equations above, the unit normal has to be considered when implemented in the FEM software and generally A=B.

Consequently, the resultant constants are:

$$C_1 = \frac{(A-B)(c)\sinh(\alpha c)}{\alpha(2c\alpha + \sinh(2c\alpha))}$$
$$C_2 = -\frac{(A+B)\,(c)cosh(\alpha c)}{\alpha(-2c\alpha + \sinh(2c\alpha))}$$
$$C_3 = \frac{(\mathrm{A}+\mathrm{B})\sinh(\alpha c)}{\alpha\,(-2c\alpha + \sinh(2c\alpha))}$$
$$C_4 = -\frac{(\mathrm{A}-\mathrm{B})\cosh(\alpha c)}{\alpha(2c\alpha + \sinh(2c\alpha))}$$

Finite Element Model

The first step in modeling the problem is finding the differential equations. The strong form for solid mechanics problems is set below:

$$\rho f_x + \left(\frac{\partial \sigma_{xx}}{\partial x} + \frac{\partial \sigma_{xy}}{\partial y}\right) = \rho\, \ddot{u}_x$$
$$\rho f_y + \left(\frac{\partial \sigma_{xy}}{\partial x} + \frac{\partial \sigma_{yy}}{\partial y}\right) = \rho\, \ddot{u}_y$$

Where σ is the stress, u is the displacement; ρ is the density and f *is the problem function. As in this case the problem is stationary,* ü *is zero. In addition,* f *is also zero.*

After integration by parts the strong form equations, the final weak form can be written as:

$$\int_{\Omega} \left[\left(-\frac{\partial w_1}{\partial x}\sigma_{xx} - \frac{\partial w_1}{\partial y}\sigma_{yy}\right)\right] dV + \int_{\Gamma} w_2(\sigma_{xx}n_x + \sigma_{xy}n_y)dS = 0$$

$$\int_{\Omega} \left[\left(-\frac{\partial w_2}{\partial x}\sigma_{xy} - \frac{\partial w_2}{\partial y}\sigma_{yy}\right)\right] dV + \int_{\Gamma} w_2(\sigma_{xx}n_x + \sigma_{yy}n_y)dS = 0$$

Where $\mathrm{w}_1 \mathrm{and} \mathrm{w}_2$ *are the weight functions for x and y and* $\mathrm{n_x} \mathrm{and}\ \mathrm{n_y}$ *are the normal vectors*

The final matrix for the thin film problem considering the plane strain theory is set below:

$$\varepsilon_{zz} = \varepsilon_{xz} = \varepsilon_{yz} = 0$$
$$\sigma_{xz} = \sigma_{yz} = 0$$

$$\begin{bmatrix} \sigma_{xx} \\ \sigma_{yy} \\ \sigma_{xy} \end{bmatrix} = \frac{E}{(1+\nu)(1-2\nu)} \begin{bmatrix} (1-\nu) & \nu & 0 \\ \nu & (1-\nu) & 0 \\ 0 & 0 & \left(\frac{1-2\nu}{2}\right) \end{bmatrix} \begin{bmatrix} \varepsilon_{xx} \\ \varepsilon_{yy} \\ \varepsilon_{xy} \end{bmatrix}$$

Another form to write this matrix is:

$$\sigma_{xx} = c_{11}\varepsilon_{xx} + c_{12}\varepsilon_{yy}$$
$$\sigma_{yy} = c_{12}\varepsilon_{xx} + c_{11}\varepsilon_{yy}$$

$$\sigma_{xy} = c_{66}\varepsilon_{xy}$$

The values for the constants vary according to the Poisson ratio and Elastic modulus

The Elastic modulus considered as 0.5 GPa and a Poisson ratio range of 0.33 to 0.49.

Verification

Before simulating the real conditions, the FEM model has to be verified with the Timoshenko's theory. For simulation, a typical beam of 2 m long and 1 m thick was chosen, while the boundary conditions varied according to the type of load. For implementation the equations noted in pressure and shear stress were applied in the COMSOL software to simulate the thin film behavior.

For a pressure load, as expected, the model has pressure (red) and compression (blue) phases. Comparing the normal stress σ_{yy} from the simulation with the obtained from the analytical solution, a confirmation of the theory is assumed. Figure 10 shows the simulation result with the corresponding error.

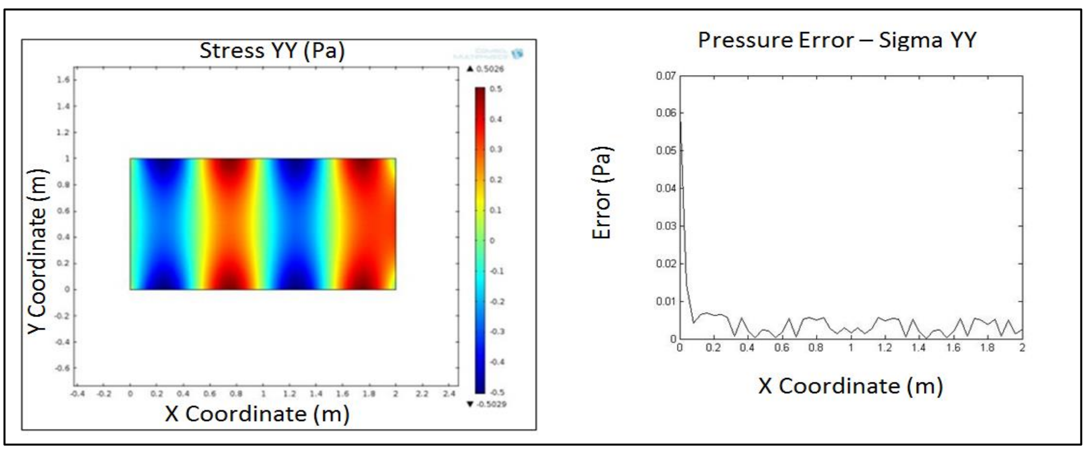

Figure 10- Verification with oscillating pressure loads

The figure in the left shows the simulation results, while the right shows the error

In the simulation of shear load, as expected, the model has pressure (red) and compression (blue) phases. Comparing the shear stress σ_{xy} from the simulation with the obtained shear stress from the analytical solution, the theory is confirmed. Figure 6 shows the simulation result with the correspondent error.

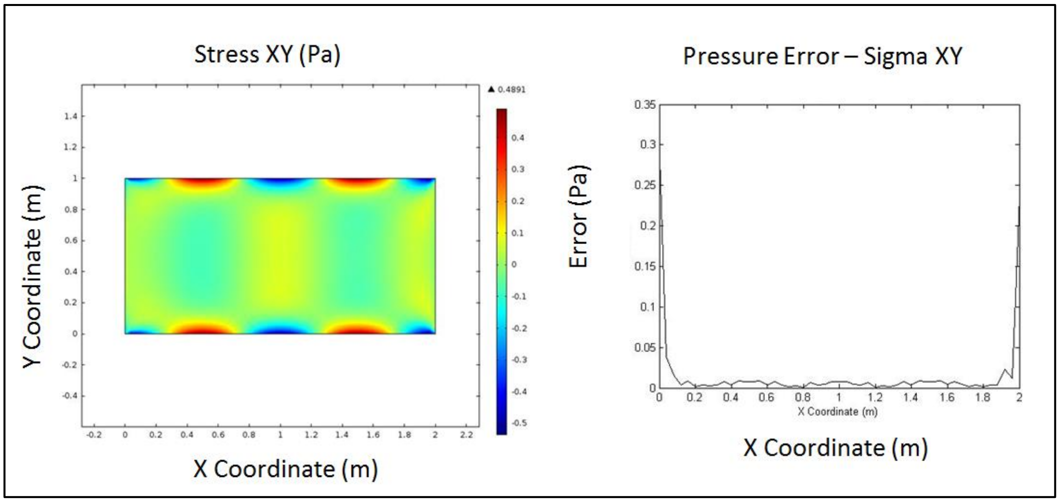

Figure 11- Verification of oscillating shear load

The figure in the left shows the simulation results, while in the right displays the error

Simulation

In the real case, instead of two loads being applied (one at each side of the beam) there is just one on the top. The constriction is at the bottom and not at one of the sides. The thickness c is very small compared to the length (c<<L). Figure 12 shows where the boundary load and fixed constraint is located.

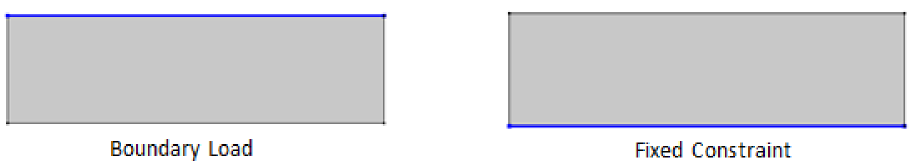

Figure 12- Boundary load and fixed constraints

As the load is applied on the top the following equation is recalled:

$$For\ y = +c$$
$$\sigma_{xy} = -Bcos(\alpha x)$$

where $\alpha = (4\pi/c)$

This assumption was made in order to see the effect of the shear stress for short periods of the load. Figure 13 shows the stress being applied in the thin film.

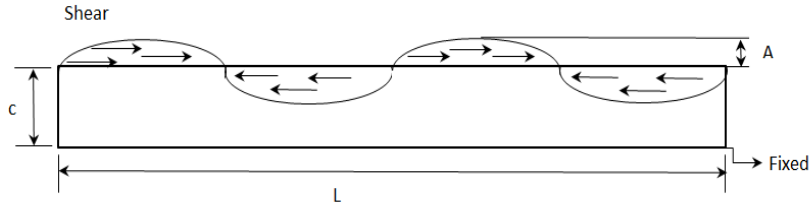

Figure 13- Real condition- Scheme of an oscillating shear load

The value for c is related to the thickness, L to the length and A to the amplitude.

For the simulation in Figure 14, the beam was considered a thin film with L=2m, c= 3×10^{-4} m and Poisson ratio 0.49. As in the Timoshenko model, there are also pressure and compression phases. For the ideal case, the stress through the thickness should be constant. Experimentally, this allows accuracy in the wavelength reading as the load applied at the top is the same at the bottom. However, analyzing the results is possible to conclude that it doesn't occur. The stress is almost constant just for some points. As the thickness decreases, this condition is achieved.

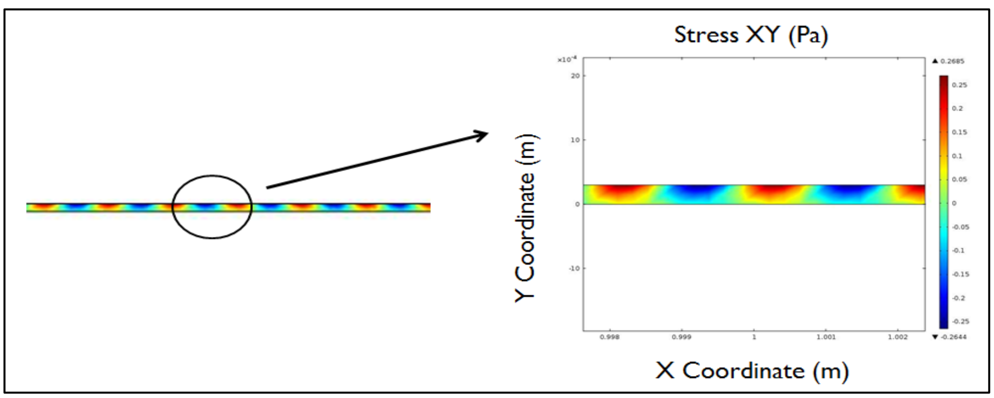

Figure 14- Real condition(c<<L) - Oscillating shear load

In the oscillating load there is not only shear being applied; the pressure component is also present. The ideal decoupling is one in such the ratio between the shear stress and normal stresses goes to infinite, meaning that the shear strain is infinitely higher than the normal strains. This happens for the homogeneous case, as shown in Table 1. For the oscillating load, analyzing, Figure 15, is possible to see that the maximum ratio between the shear strain and normal strains is about 1.5 and not infinite. This condition is achieved for very small thickness; therefore, decoupling is not possible for the shear and the normal if a realistic approach is conducted.

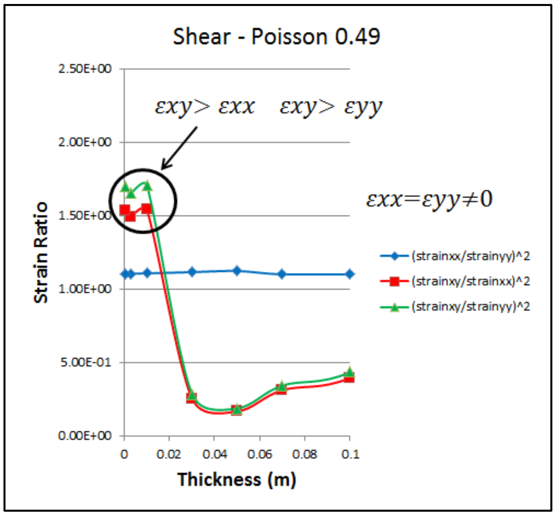

Figure 15- Real condition (c<<L) - Decoupling analysis

Thickness x strain ratio.

If the period of the load is modified (change in α) such that it becomes big compared to the beam, the oscillating load can be approximated to a constant load, shown in Figure 16.

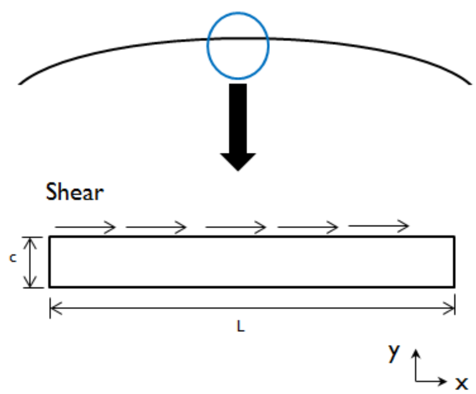

Figure 16- Approximation of big period load

In this case, the prior calculations for plane strain and homogeneous load can be applied and the decoupling is possible.

Euler-Bernoulli Beam Theory

An alternative design for decoupling the normal and shear forces is by using the Euler-Bernoulli beam theory. In this case the Cholesteric crystal polymer is located over another material (PMDS for example). When the shear is applied, the beam is deflected an angle θ causing a sensor normal to the material to see a color change, which can be related to the force applied to the beam.

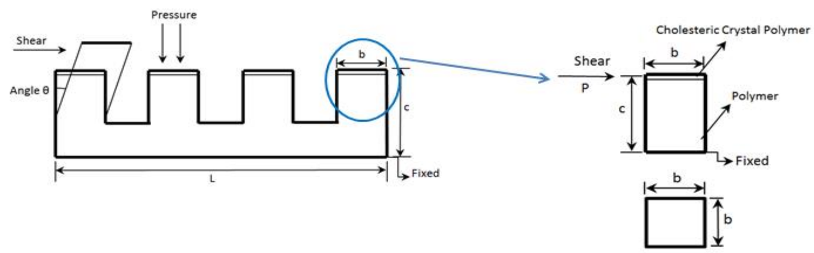

Figure 17- Beam theory with polymer

If pressure is applied, the wavelength intensities do not change because the angle of the polymer does not change. As a conclusion, the change in wavelength is possible just for shear; thus, the decoupling of the shear stress and pressure is achieved.

The deflection for a beam is shown in the below equation, which correlates to an angle of the polymer cholesteric crystal.

$$y = \frac{P}{6EI}(-x^3 + 3c^2x - 2c^3)$$

where x represents the distance from the constrained part

The deflection angle can be written as:

$$\Theta = \frac{P}{6EI}(-3x^2 + 3c^2)$$

When the above equation is used considering a square cross section, the deflection angle can be found through:

$$\Theta = \frac{Pc^2}{2EI} = \frac{6Pc^2}{Eb^4}$$

$$\sigma_{xy} = \frac{P}{b^2}$$

$$\alpha = \frac{c^2}{b^2}$$

$$\Theta = 6\ \frac{\sigma_{xy}\ \alpha^2}{E}$$

To maximize the angle Θ, α has to be maximized, that implies increasing the thickness, c, and decreasing the width, b, of the film.

Previous Design Work:

This project was started by a graduate assistant over the summer. We received the testing apparatus, as shown in Figure 18, at the beginning of the semester and were told to proceed. In addition to the apparatus, we have been given a linear servo motor, a linear load cell, and a fiber optic light sensor. The reason that the shear stress is being measured this way is because the material being tested is in a liquid form, since the material is in a liquid form it cannot be tested in a wind tunnel or in a liquid such as water. The glass slide is where the cholesteric liquid will be subjected to the shear stress. The servo motor will be mounted on the opposite side of the baseplate from the liquid crystal slot and attached to the servo motor is a load cell to determine the forces being exerted.

Figure 18- Previous design apparatus

Improvements on Previous Work:

The given apparatus, motor, and load cell were a good starting point. To complete the project, adjustments from the previous design needed to be made. The first change that needed to be made was to the block holding the motor. The motor block was improperly dimensioned but was still a good design, so the component needed some additional machining to be mounted properly to the baseplate. To improve the design the following would need to be redesigned: shear block with the ability to heat the material, a support for the shear block, a connecting rod that would join the load cell and the shear block, a light sensor holder that would be able to vary the angle of observation, a variable angle light holder, and longer legs. Also after testing began, a determination that the 0.5 Newton load cell that was supplied by the optics lab was insufficient, so a 10 Newton load cell was purchased and adapted to the apparatus.

Objectives:

The first objective was to design, machine, and assemble the testing apparatus. A LabVIEW visual interface needed to be created to control the experiments and record data. Once this phase was complete, collecting as much data as possible is the main product of this project. The first phase of testing is for the cholesteric liquid crystal characteristic determination. The liquid crystal will be used to characterize the cholesteric material and provide a proof of concept for using cholesteric crystals as a shear stress sensor. Initially the following need to be determined: the maximum and minimum shear values that the materials can record, if the material has an endurance limit, and the materials sensitivity to shear. The objective is then to determine how the material reacts under static and dynamic shear loads along with how the material reacts to different temperatures, light sources, and measurement angles. Once the liquid crystals are characterized, a polymerized form of the cholesteric crystals will be ordered and the same experiments will be run on the polymer. The polymer is very expensive and takes a significant amount of time to make; which is why there first needs to be a proof of concept with the inexpensive liquid crystal. The preceding objectives were developed at the start of the project and are intended to be covered during the summer and the following school year by another senior design team if not completed this school year.

Constraints:

Some design constraints were imposed because of the fact that the testing apparatus was inherited. The first main constraint is space. The baseplate that was passed down by a previous graduate student was 12” by 4.5”. The light sensor is about 3” long and its cable isn’t able to bend well. When the cable is bent at 90 degrees it needs about 6” of vertical length to bend. This means that the legs for the apparatus need to be at least 9” long. The light sensor must also be able to view the material from any angle from 0 to 80 degrees; with 0 degrees being normal to the crystals. The light that is going to be used must be white so that it contains the best wavelength distribution across the visible color spectrum. The light must also be adjustable like the spectrometer. The heat source for the experiment will be able to generate temperatures up to 300°F and needs a 28V power source capable of supplying 10W of power. The range of applicable loads is 10 Newtons due to the load cells maximum limit.

The time available for the project development is a constraint. A polymer form of cholesteric crystals have been ordered from Wright-Patterson AFRL, but due to the process of creating the samples the delivery will not occur before the end of the spring semester. Since the project is mostly research based there aren’t many constraints. The main goal is to find the constraints of the cholesteric crystals, such as; maximum and minimum stress measurements, endurance, and temperature limits.

Concept 1:

Figure 19 below shows the design for concept one with the design of the light and sensor holder. The light and sensor holder are the same pieces except a flipped location for the light and sensor circular holder. The apparatus shown has the light/sensor bracket with a set screw on the top, so that the bracket can be easily moved or taken off of the apparatus' base plate. The reasoning behind the circular holder is for the ability of the holder to rotate along the bracket, thus giving the ability for the experiments to make the placement of the sensor/light a variable. Since the method of measuring shear stress with the cholesteric liquids is a new concept having the ability to see how the data is altered with the differing angles could be important to the project. For the shaft support, a U-shape is used to hold up the shaft as to reduce the chance of a rotating moment due to the length that the shear block is from the motor driver.

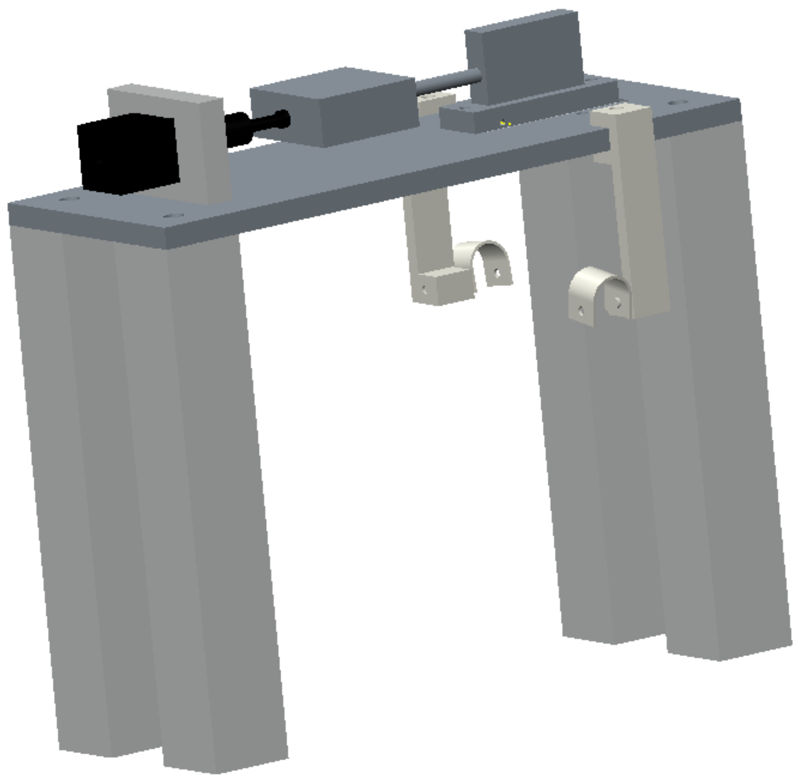

Figure 19- Concept 1- Dual Light Sensor Holder

Concept 2:

Shown in Figure 20, the fiber optic light sensor would be held in a rectangular block with a set screw. The rectangular block would then fit into a circular track and be bolted to the track. The angle of the block could be adjusted by sliding the block around the tack. The main problem with this design is that while the block is slid around the track, the axis of rotation of the sensor would change and point at a different point on the slide. It would be difficult to change the angle of the sensor so that the axis of rotation would stay the same as they previous position that the sensor was in.

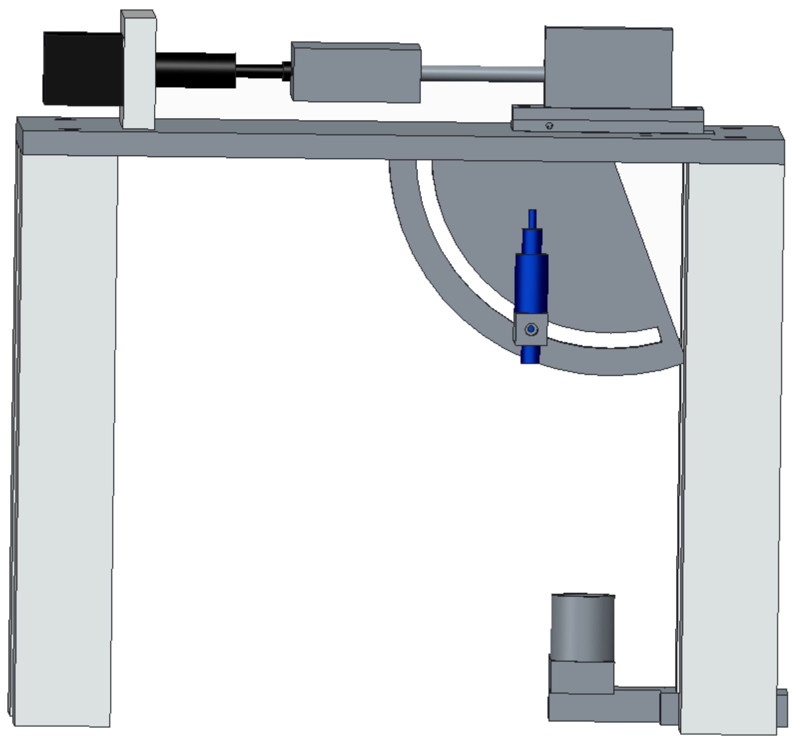

Figure 20- Adjustable sensor holder with degree indicating quarter disk

Concept 3:

Figure 21 shows the concept 3, based on a wheel for the fiber optic sensor holder attached to an arm. The desired angle could be adjusted by sliding and fixing the wheel. The simple design allows easy fabrication and cost reduction, as little material is required. However, the angle test range is lower than the others. In addition, this design is more susceptible to errors, as the fiber optic will not see the liquid crystals response throughout its range of motion.

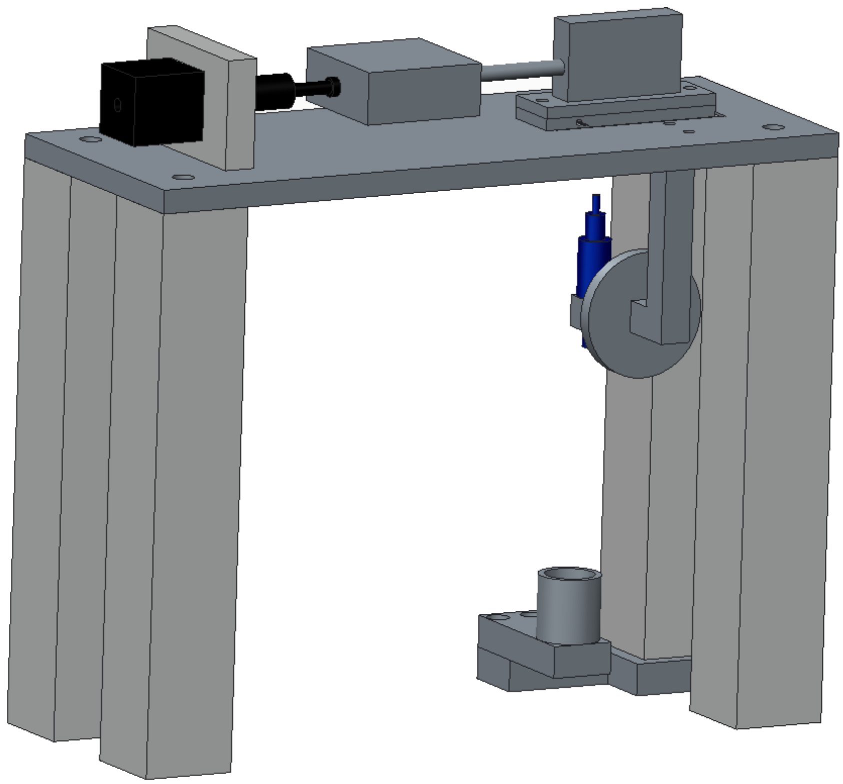

Figure 21- Concept 3- Wheel fiber optic sensor holder

Decision Matrix

Score Range (1-5) - Higher scores correlate to more ideal

		Concept 1		Concept 2		Concept 3	
	Weight	Score	Weighted	Score	Weighted	Score	Weighted
Ease of Use	0.20	2	0.40	4	0.80	4	0.80
Reproducibility	0.30	3	0.90	5	1.50	4	0.60
Accuracy	0.30	2	`0.60	4	1.20	1	0.30
Cost	0.15	3	0.45	2	0.30	3	0.45
Size	0.05	2	0.1	3	0.15	4	0.20
Total	1.00		2.45		3.85		2.35

Table 2-Decision Matrix of Design Concepts

Interim Design:

The decision matrix was used and along with the input from Dr. Oates and Matt Worden (Graduate Assistant), it was determined that it would be best to combine concepts two and three. After discussing the light source with both Dr. Oates and Mr. Worden, the ability for the light source to be another variable would not be ideal. Placing the light holder at the base of the apparatus without it being able to move is theoretically more effective. The shear block support will be an elevated linear bearing, in which the shaft will be able to slide through. By using a linear bearing a minimal amount of friction will be generated, effectively supporting the load cell and shear block to stop the moment that would more than likely occur due to the length in which the shaft will have to translate. The location of the linear bearing is to be between the load cell and the shear block because of the limited area on the opposite side of the shear block. In the interim design (see Figure 22) the quarter measuring circle is used as the holder for the wavelength sensor, as to have an accurate form of measuring the degree and rotation of the sensor.

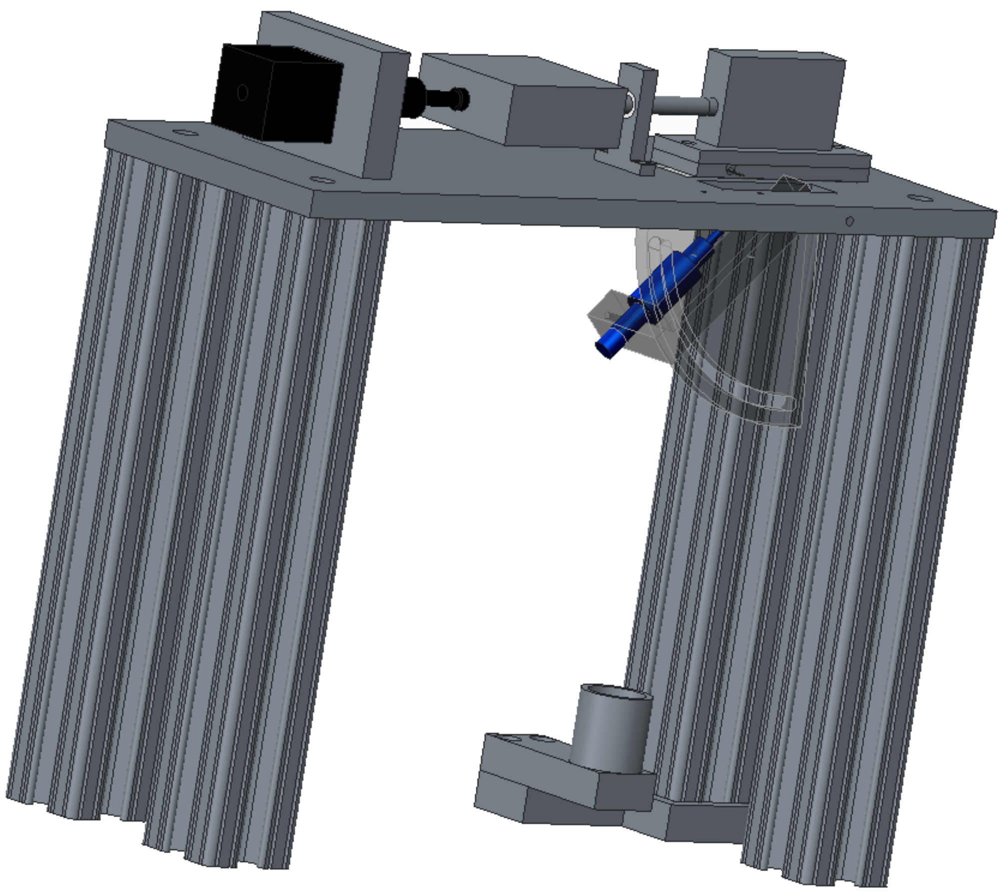

Figure 22- Interim design concept after the recommendations from Matt W. and Dr. Oates

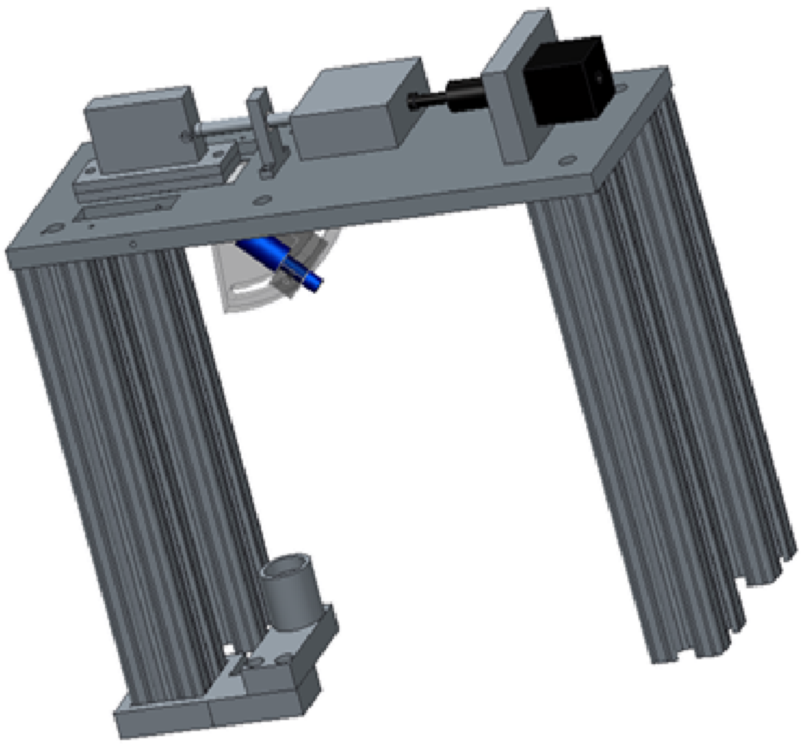

Figure 23- Angle of interim design to show the light source holder

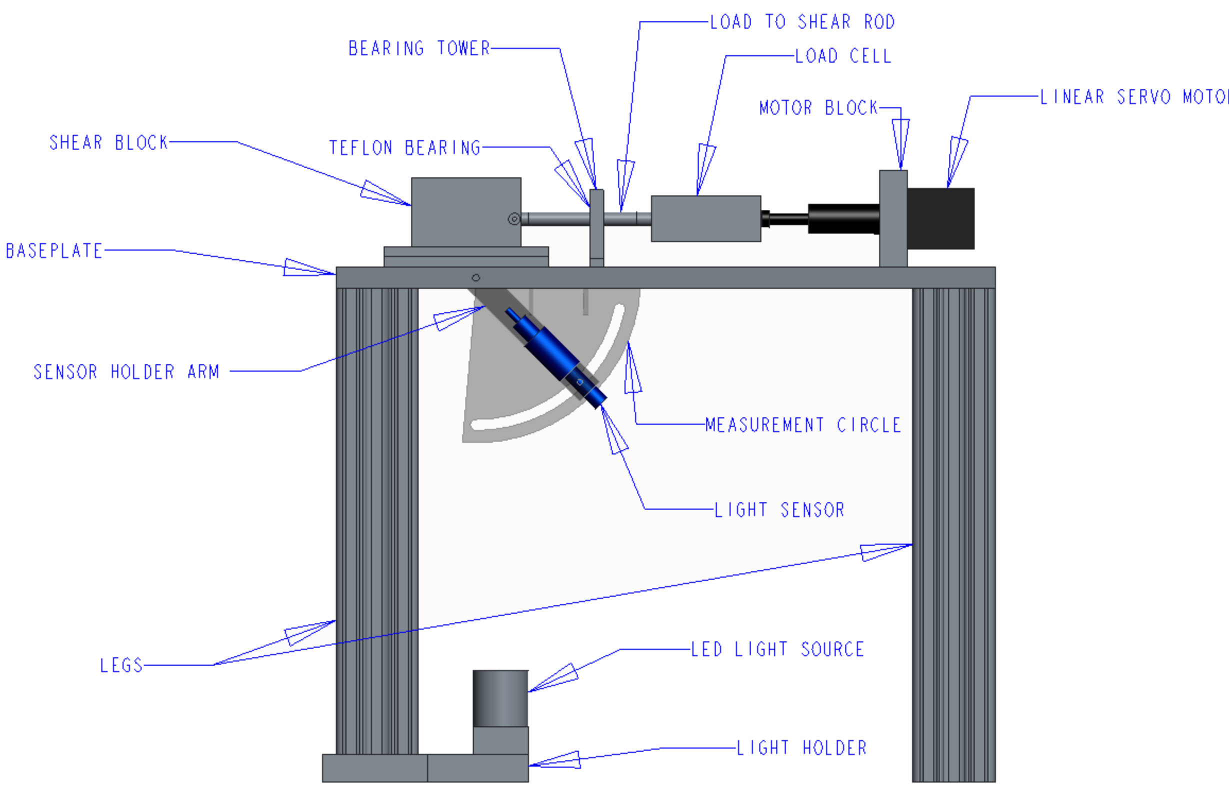

Figure 24- Interim Design Drawing

Shear Block Design:

The shear block is designed to house a heating pad and apply a shear force caused by the linear servo motor. The shear block is made out of three rectangular pieces of aluminum. For the upper face of the bottom section an area has been milled out to allow room for a .007" heating pad and insulation. The heating pad is placed in the milled area between the aforementioned bottom piece and a similar piece of aluminum on top. Another piece of aluminum is placed perpendicular to the surface of the top piece holding the heating pad. The perpendicular piece is meant to reduce the moment caused by the lateral force of the servo motor. If an L-type bracket were used, the end of the shear block would be forced into the material while the side closest to the motor would be forced up. This would result in a nonlinear distribution of force across the material and cause the readings to vary across the glass slide. Also the bottom section of the shear block has been modularized as to have variable thickness of the cholesteric crystals and to display how the crystals react. Along with having the variable thickness the bottom sections have particular attributes in the U-shape and extended shape (see Figure 25) to contain the cholesteric crystals, so there will be minimal amount of thickness change due to motion.

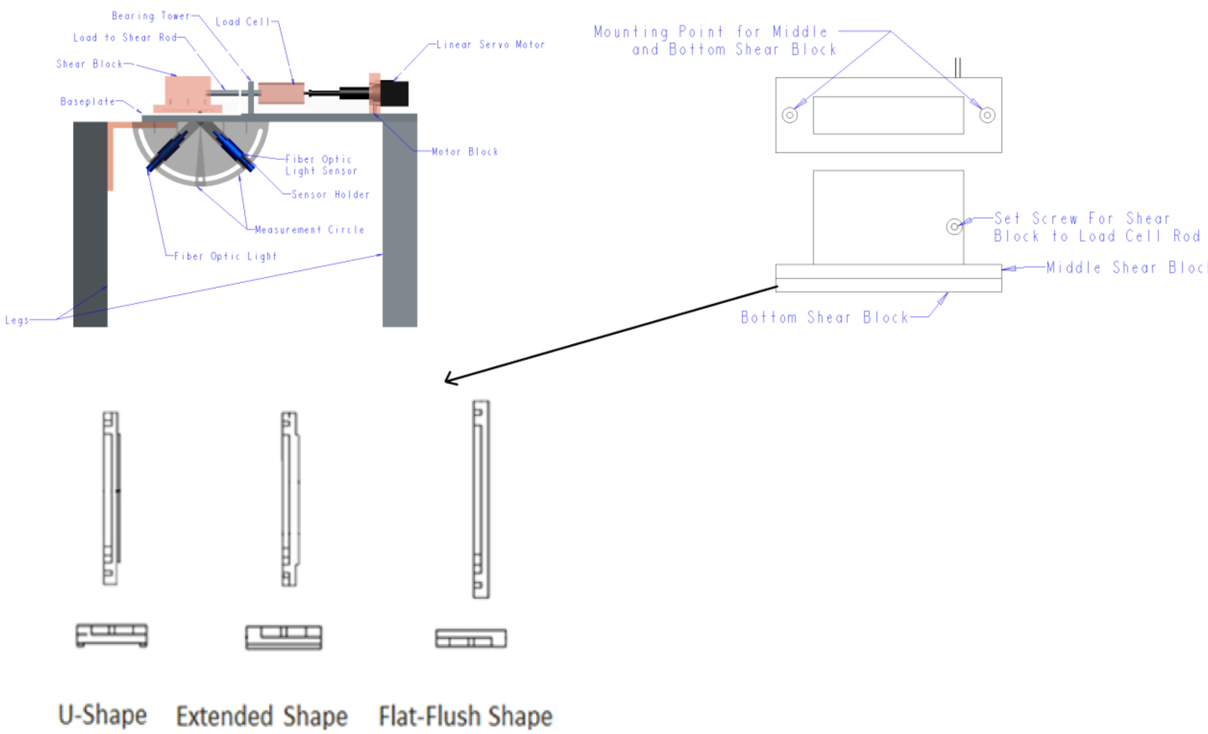

Figure 25- Shear Block Enhanced

Final Design:

The final design is a slight variation of the interim design. The improvements to the interim design are the movement of the light holder and the selection of the BluLoop light source. The BluLoop light source is selected because the lack of a complete spectrum from the light emitting diode (LED). A BluLoop light source is a quad-LED, made by Ocean Optics. Having a quad-LED fixes the issue of the LED because four specific LED's are combined to give a full visible spectrum of intensities. The light holder was moved because it was found through experimentation that the light holder and spectrometer work best when the reflection of light off the crystals hits the spectrometer directly. In any other orientation the signal from the spectrometer is weak or nonexistent. When the light source is orthogonal to the cholesteric crystals, like in the previous design, the light reflects directly back at the light source. This means that the spectrometer must be orthogonal to the cholesteric crystals to get the best reading, due to the distance traveled by the light. It also means that the spectrometer can't be moved otherwise the reading degrades. Based on the laws of reflection the best configuration between the spectrometer and light source is most likely to be a mirror of each other across the plane orthogonal to the crystals. As a result the spectrometer and the light source must be adjustable to test different angles of the spectrometer and the crystals. To make the light source adjustable the measurement circle idea was adapted to fit the light source. Both the light source and spectrometer will travel on a fixed track that will ensure accurate positioning. Since the baseplate is relatively short, the legs had to be extended off of the baseplate to make room for the additional measurement circle and light source holder arm.

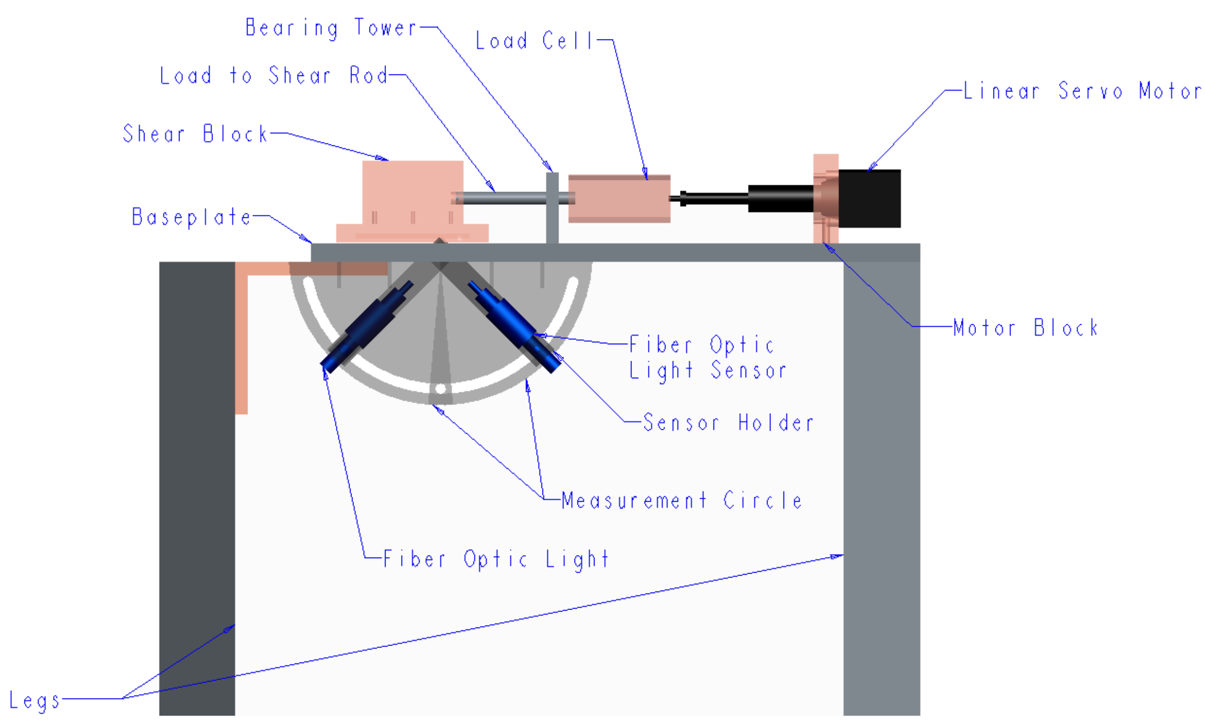

Figure 26-Final Design

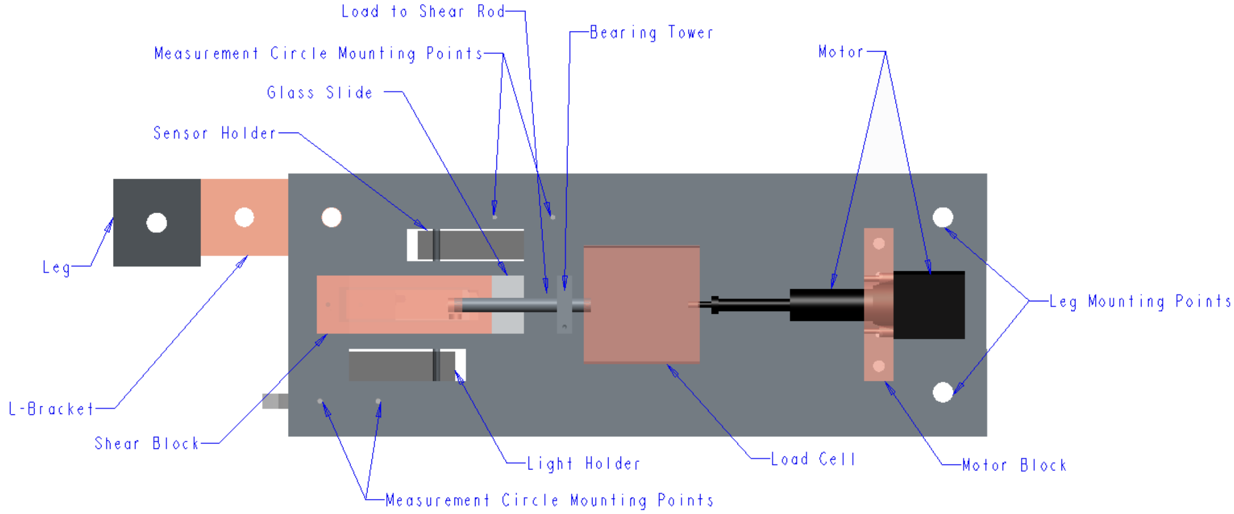

Figure 27-Final Design Top View

Components

Load Cell

The load cell is used to measure the shear force exerted on the cholesteric crystals by the shear block. The output of the load cell is in Volts and must be calibrated before use to determine the relation between force and voltage. The load cell works in tension and compression by transducers converting the mechanical energy to an electrical energy.

Manufacturer:
Interface Inc.
Part:
Load Cell- SMT1-10N
http://www.interfaceforce.com/smt-s-type-overload-protected-load-cell-us-metric-p-31.html

Manufacturer:
Interface Inc.
Part:
Force transducer
Model SMTI – 10N
Capacity – 10N
Serial – 693890

Manufacturer:
Interface Inc.
Part:
Strain gage amplifier
Model SGA/A
Supply voltage – 110-230 V_{AC} / 50-60Hz
Supply power – 4-10 W
http://www.interfaceforce.com/sga-acdc-powered-signal-conditioner-p-95.html

Figure 28- Interface Load Cell-SMT1-10N

The load cell is overload protected in both tension and compression. The safe overload protection is 10 times greater than its capacity.

Accuracy (Max Error)
Nonlinearity -%FS – 0.05%
Hysteresis -% FS – 0.03%
Non-repeatability -% RO – 0.02%
Creep, in 20 min - % - 0.025%

Linear Servo Motor

The linear actuator is needed to apply the shear force to the crystals. Its linear characteristic allows the movement to be one degree of freedom, which will cause a shear force on the liquid crystals. The motor is a stepper motor, which means that the speed and distance that the actuator moves can be regulated through programming. This is ideal for accurately changing the force that is applied to the crystals.

Manufacturer:
Haydon Kerk
Part:
28H41-2.1-915
prototypes.haydonkerk.com/ecatalog/hybrid-linear-actuators/en/28H41-2.1-915

Specifications

Series	28000
Actuator Type	Captive
Step Angle	1.8°
Linear Travel per Step (in.)	0.001
Dimensions of Backing(H x L x D) (in.)	1.1 x 1.1 x 1.1
Dimension of Screw Length (in.)	11
Maximum Thrust (Chopper Drive, 100% Duty Cycle) (lb)	7
Power (W)	4.2
Wiring	Bipolar

Figure 29- Haydon Kerk Linear Servo Motor- 28H41-2.1-915

Motor Driver

The motor driver is the component that stores and delivers the operating instructions to the linear servo motor. Connected by a USB cable to the PC, the motor driver from Haydon Kerk uses the *Idea Software* to encode a program and sends the information to the servo motor in the form of electrical pulses which controls the stepping motion resulting in the prescribed distance, velocity, and acceleration. The motor driver chosen is the PCM4826-1046 because it corresponds to the servo motor being used in the experiment.

Manufacturer:

Haydon Kerk

Part:

PCM4826-1046

www.haydonkerk.com/LinearActuatorProducts/IDEAStepperMotorController/PCM4826StepperMotorController/tabid/332/Default.aspx

Drive input Voltage	**Maximum Drive Current (per phase)**	**Communication**	**Maximum Temperature**
12-48 V_{DC}	2.6 A_{rms}	USB(Mini B Connector)	70°C

Figure 30-Haydon Motor Driver PCM4826 1046

Spectrometer

The use of a spectrometer will allow the collection of light to determine the intensity at different wavelengths. This equipment consists of a fiber optic cable attached to a 2MHz analog to digital converter and outputs the signal via USB. The sensor is able to detect light between 200nm and 1025nm.

Manufacturer:

Ocean Optics

Part:

XR-Series Miniature Fiber Optics Spectrometer

USB2000+XR1

http://www.oceanoptics.com/Products/xrseries.asp

Spectrometer Type	Grating	Spectral Range	Optical Resolution
USB2000+XR1	#31.500 lines/mm, blazed at 250 nm	200-1025 nm	1.7-2.1 nm

Figure 31-Ocean Optics USB 2000 + XR

BluLoop Multi-LED Light Source

The BluLoop light source is a quad-LED source; used to integrate four different types of LED's to have a complete visible wavelength spectrum in comparison to other single LED or Halogen light sources.

Manufacturer:

Ocean Optics

Part:

BluLoop Multi-LED Light Source

www.oceanoptics.com/Products/bluloop.asp

Dimensions (H x L x D)	62x60x150 (mm)
Weight (kg):	0.5
Power consumption:	up to 12 W
Wavelength range:	395-750 nm
Bulb lifetime:	>10,000 hours
Temperature:	5-35 °C

LED's Used

Type	Wavelenth (nm)
Blue	420
Cyan	505
Cold White	454
Warm White	570

Figure 32- BluLoop Light Source from Ocean Optics

DAQ Board

In order for the computer to receive data from the load cell a Data Acquisition Board (DAQ Board) is required. There are several DAQ boards available, but the one that was chosen for the experiment is a National Instrument- BNC 2110. The lab in which the experiments are currently being held already had the DAQ board, so choosing another DAQ board was not a necessity. Another type of DAQ board can be used as long as it has a ±10V input and output.

Manufacturer:

National Instruments

Part:

DAQ Board- BNC 2110

Specifications:

- BNC connectors for analog I/O
- Terminal block for digital and timing I/O connections
- Interfaces to X Series, M Series, E Series, S Series and analog output devices
- Shielded Enclosure
- Simplifies the connection of analog signals, some digital signals, and two user-defined connections to the DAQ device

Figure 33- BNC 2110-Noise Rejecting, Shielded BNC Connector Block

Breadboard

The Breadboard is the component in which the relay and electrical wires are connected to, for the automatic shutoff of the load cell. A breadboard is used to connect multiple electrical circuits through wires that are built in to the component. With knowledge of electrical systems it is possible to design circuits and relays on the bread board with ease.

Manufacturer:

E-call Inc.

Part:

EIC-104(165-40-1040)

Specifications:
2 Terminal strips, Tie-point 1260
4 Distribution strips, Tie-point 400
Board Size (in.): 6.5x4.33x0.33
Plate Size (in.): 8.46x5.12x0.05

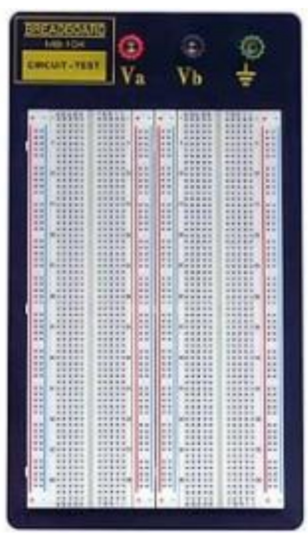

Figure 34-eic-104 Breadboard

Relay

For the prototype a R57-1D.5-12 relay was used to assist in the automatic shut-off of the system. A relay is a component that opens and closes a circuit, in the case of the prototype; the relay grounds the input pin of the microcontroller to trigger an interrupt in the motors movement program. The relay was chosen because the DAQ board can output a maximum of 0.3W and the relay has a smaller gate power requirement.

Manufacturer:

NTE Inc.

Part:

Relay- R57-1D.5-12

NTE Type No.	Norm. Voltage VDC	Contact Arr.	Coil Res. Ohms (typ)	Max Pickup VDC	Min. Drop Out VDC	Max Curr. Amps	Times		Diag. No.
							Max. Separate	Max. Release	
R57-1D.5-12	12	SPST-NO	1200	9.0	1.0	5.0	400µs	75µs	D27C

Figure 35- R57-1D.5-12 Relay

Multi-meter

A multi-meter is very beneficial to help in solving issues in the experiment. The multi-meter is the main tool that is used in determining if and when current is flowing along with how much.

Manufacturer:

Gardner Bender

Part:

GDT-311-(13 Range- 3 Function Digital Multi-meter)

Specifications:

- For testing AC/DC voltage and current resistance
- DC voltage- 250 V_D
- AC voltage - 500 V_{AC}

Figure 36-Gardner Bender GDT-311 13 Range - 3 Function Digital Multi-Meter

Power Supply

To supply the power to the microcontroller 2-pin and 10-pin I/O, a power supply with the capabilities of 12.0- 24.0 Volts and 0.3-1.0 Amps is needed. Also the power supply must have 2 channels, so the separate pins of the microcontroller can receive their specific power.

Manufacturer:

GW Instek

Part:

GPS-2303

Specifications:

- 2 Independent Isolated Outputs
- 0-30 DCV / 0-3 DCA
- Four "3 Digits" LED Displays
- 0.01% Load and Line Regulation
- Low Ripple and Noise
- Output ON/OFF Switch
- Over Load and Reverse Polarity Protection

Figure 37-GW Instek-GPS-2303-Power Supply

Electrical Setup

Do not give power to anything until all connections are securely made.

Initial Setup

- Attach the relay to the bread board.
- Attach one BNC connector to the DAQ board input and one to an output.

Load Cell Setup

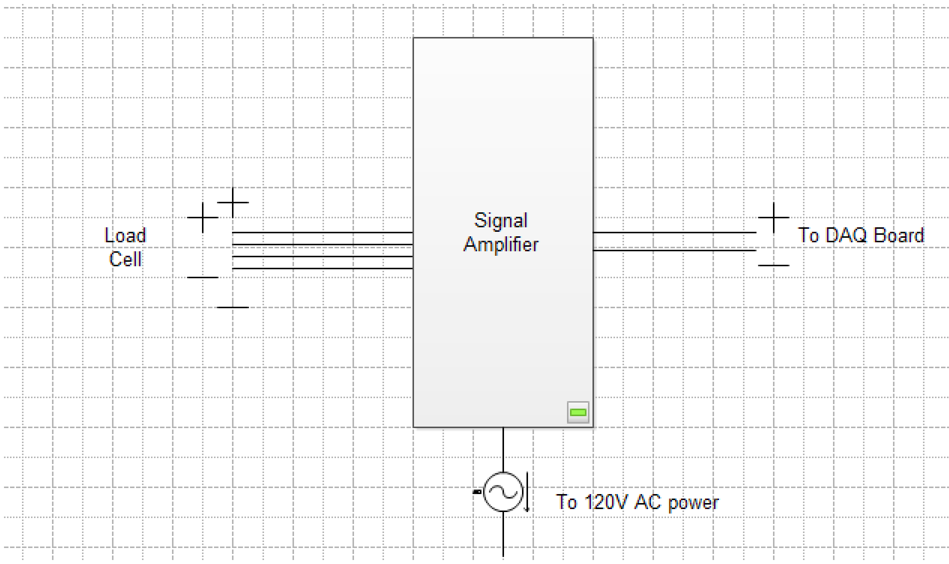

Figure 38- Load Cell to Amplifier to DAQ Board Wiring Diagram

Figure 39-Location of the Amplifier Terminals

- Attach the load cells 4 leads and the shield wire to the J2 terminal in the strain gauge amplifier. Ex. Figure 40

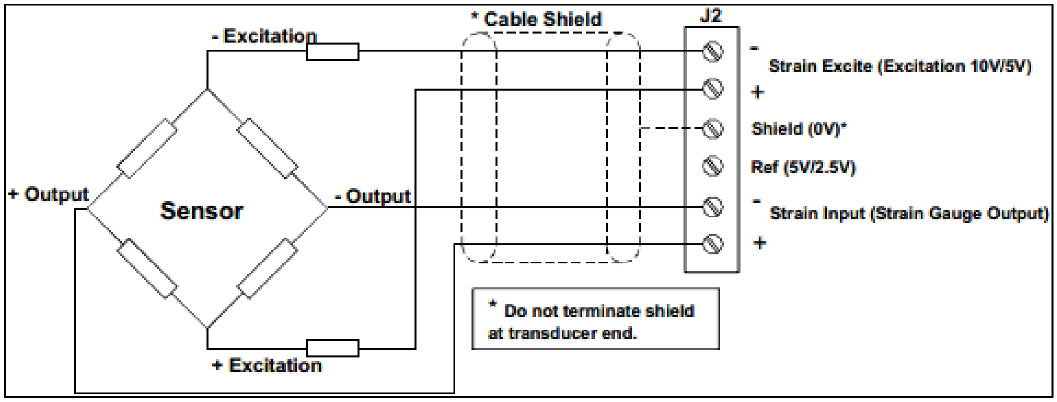

Figure 40- Load Cell to Amplifier Connections

- Attach the output cables to the J1 terminal and to the BNC connectors attached to the DAQ Board. Ex. Figure 41

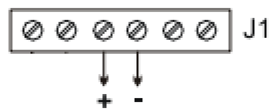

Figure 41- Amplifier Output

Microcontroller Setup

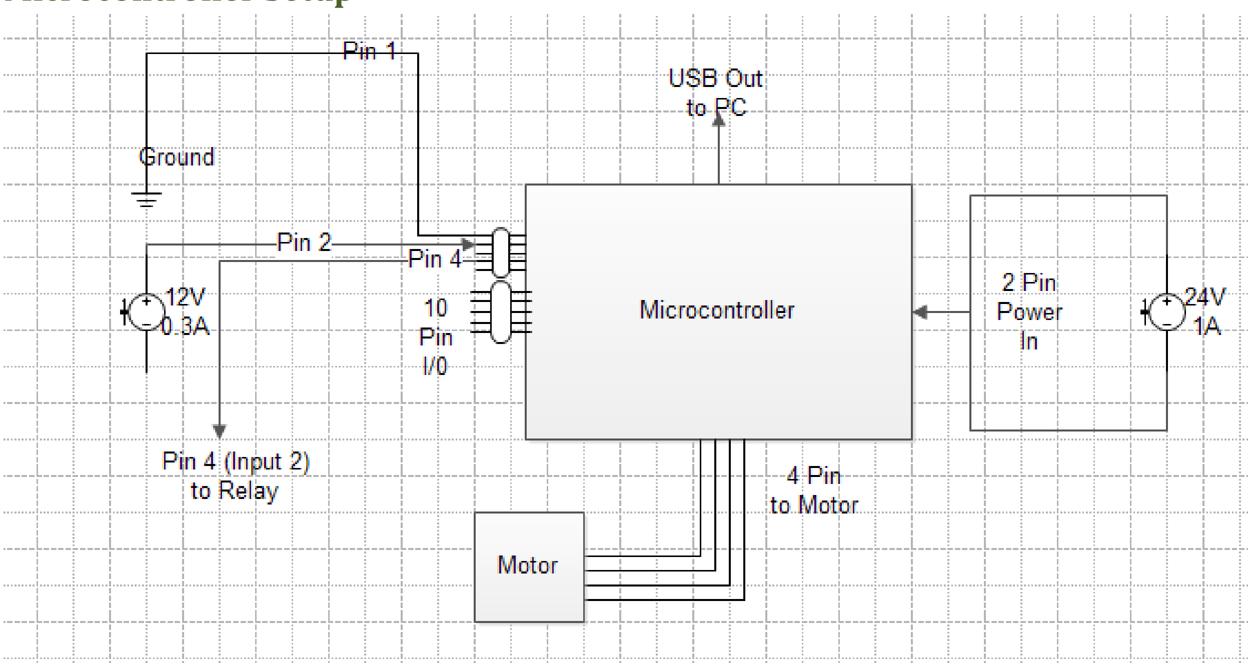

Figure 42- Microcontroller Wiring Diagram

- Connect the USB connector to the microcontroller and the PC. Ex. Figure 43
- Attach the 2-pin, 4-pin, and 10-pin connectors to the microcontroller. Ex. Figure 43
- Connect the 2 wires from the 2-pin connector to a power supply with 1A and 24V. Ex. Figure 43
- Connect the 4-pin connector to the servo motor. Ex. Figure 43
- Attach pin 1 and 2 to a power supply with 0.3A and 12V. Ex. Figure 43

PIN POSITION	DESCRIPTION
PIN 1	GROUND I/O SUPPLY
PIN 2	+ I/O SUPPLY
PIN 3	INPUT 1
PIN 4	INPUT 2
PIN 5	INPUT 3
PIN 6	INPUT 4
PIN 7	OUTPUT 1
PIN 8	OUTPUT 2
PIN 9	OUTPUT 3
PIN 10	OUTPUT 4

Figure 43- 10-Pin Assignments

- Attach pin 4 to the input of the relay on the bread board.

Automatic Shutoff Setup

The load cell used in the experimental setup has a 10N limit. The load cell is rated up to 10 times its capacity. However to be safe and not risk damaging a $500 load cell, an automatic shutoff was created using LabVIEW and the motor microcontroller. The main issue with creating the shutoff was that the microcontroller documentation was limited resulting in the assumption that the inputs needed a voltage when they in fact need to be grounded to be triggered.

The automatic shutoff works by measuring the voltage coming from the load cell in LabVIEW and determining if that voltage corresponds to a load over 10N. If the load is over 10N LabVIEW outputs a signal from the DAQ board attached to the computer which travels to a bread board. Attached to the bread board is a relay. Attached to the relay's input is the input to the motor microcontroller. Attached to the relay's output is a grounded wire. The relays switch terminals are attached to the DAQ board that triggers the relay. When the relay is triggered, the microcontroller's input is grounded triggering an interrupt in the motor's programming. The interrupt goes straight to a stop function in the programming which stops the motor. All of the aforementioned steps happen instantaneously resulting in the motor being protected from a load over its capacity.

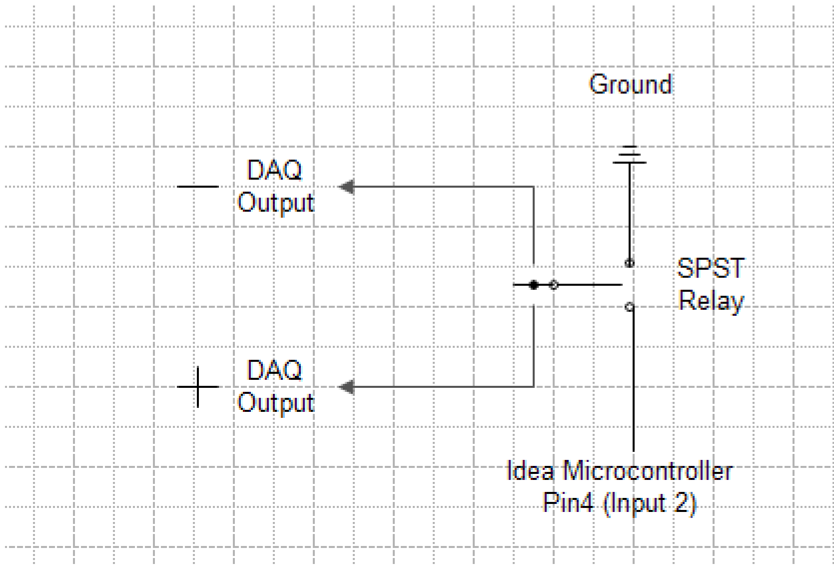

Figure 44- Relay Wiring Diagram

- Make sure the wire attached to pin 4 is also attached to the relays input. Ex. Figure 44
- Ground the output of the relay. Ex. Figure 44
- Attach the DAQ cables to the gate of the relay. Ex. Figure 44

Final Setup

- Plug in the amplifier and turn on the power supply(s).

Programming

LabVIEW

For data collection, the program, LabVIEW was selected because it is compatible with a wide range of data acquisition devices and methods. The components used in the LabVIEW program are the data acquisition board (load cell) and the spectrometer. The first program that LabVIEW runs is a program that stores the reference spectrum of the liquid cholesteric crystals (the interface can be seen in Figure 47). A reference spectrum is a spectrum taken with the shear block in place but no liquid crystals on the block. This spectrum is the spectrum of the light source, which also appears when the liquid crystals are tested. During the analysis phase, the reference spectrum is subtracted from the test spectrum to give a clearer image of the liquid crystals. The deference in the liquid crystals observed spectrum with and without the subtraction of the reference spectrum can be seen in Figure 46 and Figure 45, respectively. For experiments on the liquid cholesteric crystals a continuously running operation is required; a do-while loop is designed with a storage action for the load cell and spectrometer data (block diagram of LabVIEW program is Figure 73). The rate of data collection can vary depending on the hold in the do-while loop and the efficiency in which the program was designed. A decrease in the hold time increases the sampling rate if the computer has the resources to do so. The initial LabVIEW program created was able to sample at a maximum speed of 40ms. Analysis of the data at this sampling rate showed that the color change was occurring too quickly and a faster sampling rate was deemed necessary. Storing the large amounts of data while LabVIEW was also acquiring data was the result of the slow sampling rate and a new method of storing the data was sought out. A solution was found after several iterations of different LabVIEW programs using various methods for storing data were created. The hold is currently set at 5 milliseconds and LabVIEW on average samples at a rate of 6ms with this hold. Analysis confirmed that the sampling rate of 6ms has the ability to accurately record the crystals color change, even when the shear block is moved at high speeds. Once the experiment has completed the data collected from the spectrometer and load cell are written to files as raw data samples. For the polymer testing, the liquid crystal reference spectrum program is used to take data. During the tests the angles of the light source and spectrometer are changed in five degree increments (i.e. 40, 45, 50…). The reason for using the same program as the liquid crystals is because the polymer testing is currently only for angle dependency and not with any motion or force. In the future when the polymer is to be tested with force applied, the 6 millisecond hold program will be required. Also in the LabVIEW interface, there are text boxes, as can be seen in Figure 48, in which the conditions of the experiments can be recorded (i.e. distance traveled, velocity, acceleration, light angle…), and then written to the same file as the raw data.

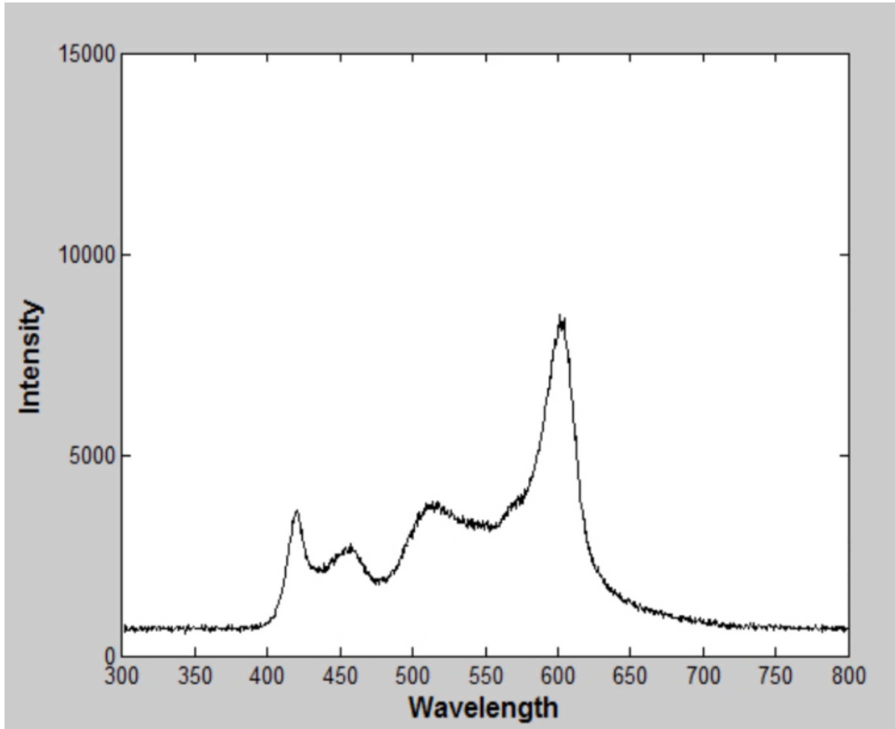

Figure 45- Red Liquid Crystals without the Subtraction of a Reference Spectrum

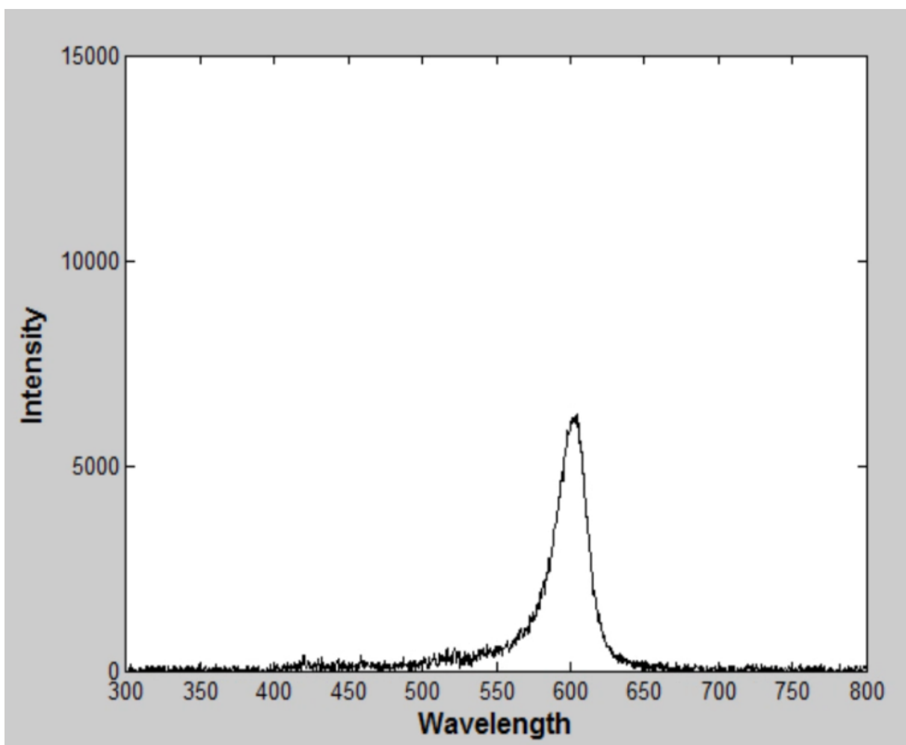

Figure 46- Red Liquid Crystals with the Subtraction of a Reference Spectrum

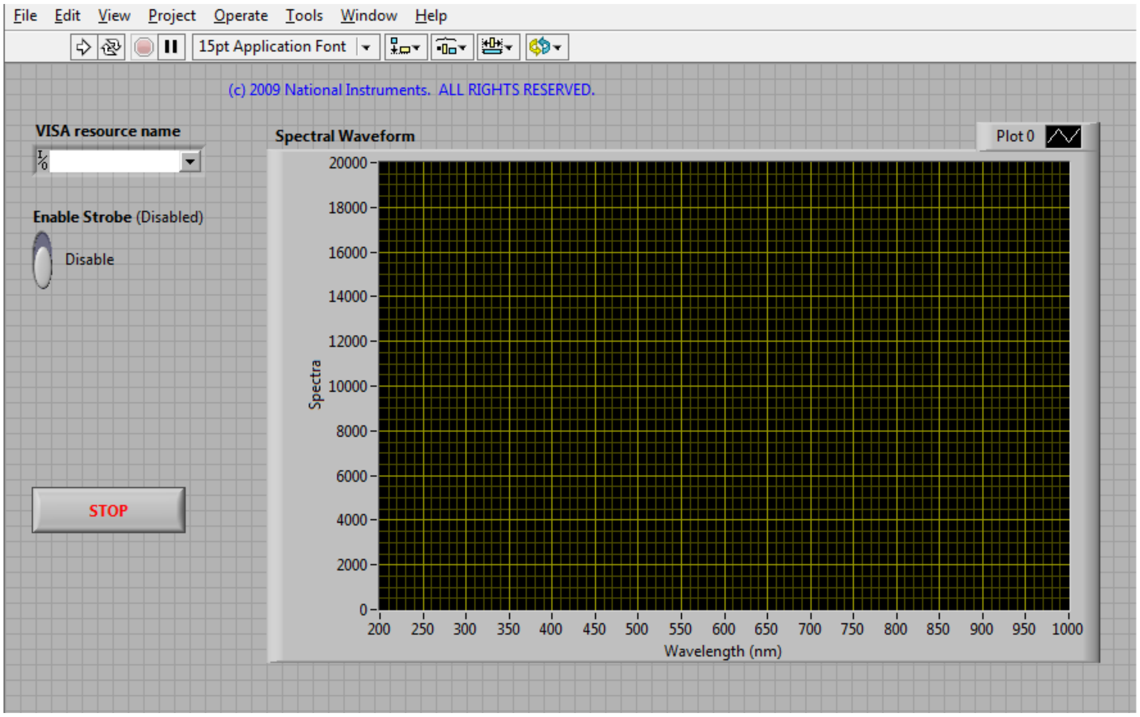

Figure 47- LabVIEW Reference Spectrum Interface

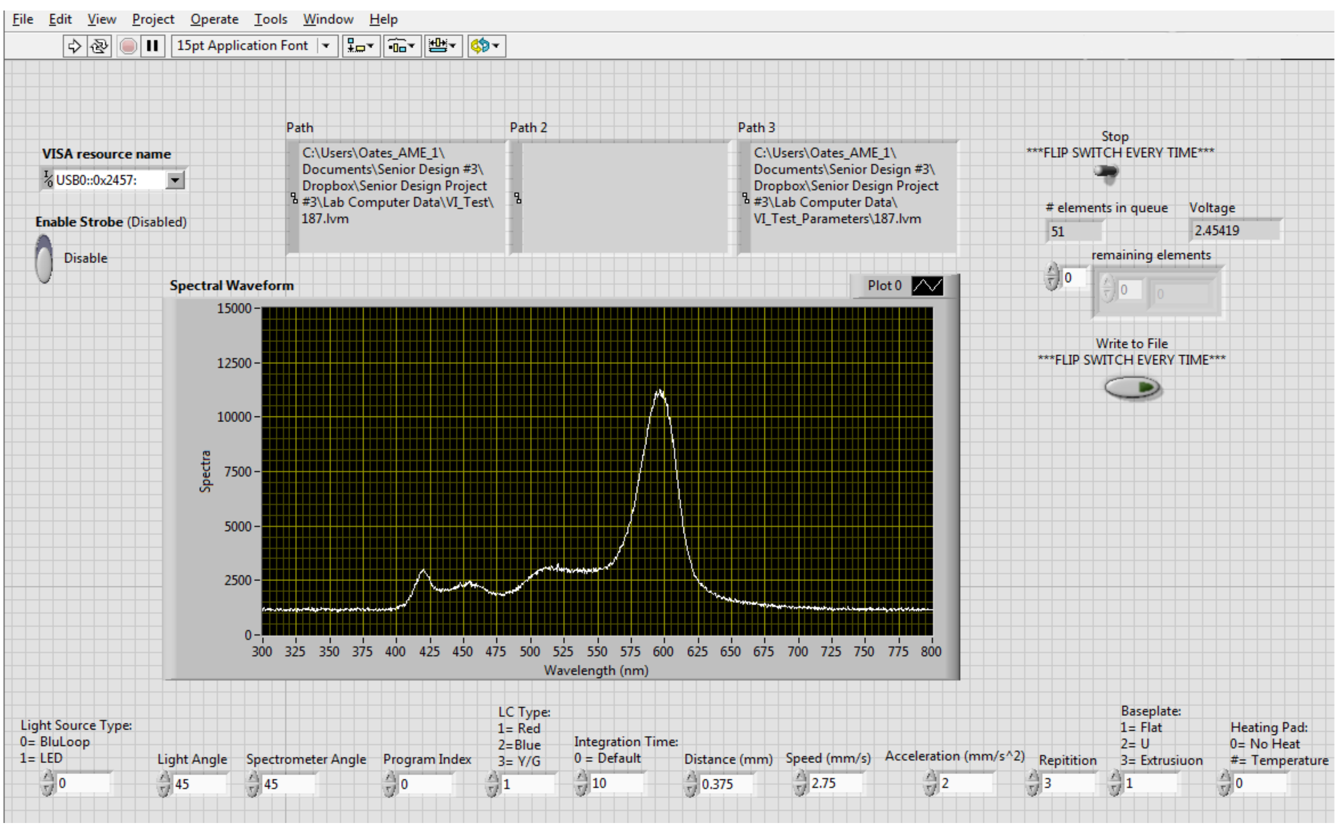

Figure 48-LabVIEW Testing Interface

MATLAB

Once the experiments are completed, MATLAB is used to calculate values for intensities of the spectrums collected. The MATLAB program has the capability to organize and assign the raw data from the LabVIEW files. For the MATLAB program implemented, the data is taken out of the columns set by LabVIEW and organized by what the values correspond to in the experiment (i.e. Wavelength, Time, and Voltage). Once all of the data has been organized, the reference spectrum intensities are then subtracted from the corresponding wavelength intensities of the experiment. Subtracting the reference spectrum from the experiment intensities isolates the cholesteric crystal wavelengths and nullifies the light wavelengths. To relate all of the experiments (after the subtraction of the reference spectrum), the intensities are normalized where the intensities all keep the same ratios, but the highest intensity becomes a value of one. The spectrums are normalized because the intensity values are arbitrary, but the ratios of wavelength intensities are important.

MATLAB is then to display figures that will show multiple sets of data, including wavelength versus time, wavelength peak versus time, load versus time, and difference in polymer angle intensities versus angle. By using the plot function in MATLAB the data points are selectable for viewing and recording values. For the liquid crystal testing, a “movie” function has been created to plot the spctrum and see it change over time, so the actual motion of the spectrum shift can be viewed. This program works by plotting each spectrum very quickly in series like frames of a movie. This allows the user a second look at the raw data that was obtained. An additional program was created to analyze multiple test runs to decrease the time spent on analyzing each experiment one a time and minimize human input.

Organizing the polymer data is a little different than the liquid crystal data. Since the liquid crystal data collected a full spectrum every ~6 milliseconds the file contains multiple samples; the polymer experiments only have one spectrum per angle. The MATLAB program then takes the polymer data and subtracts the consecutive angles throughout the experimented angles (i.e. 45-40, 50-45) to assist in displaying the change of intensities.

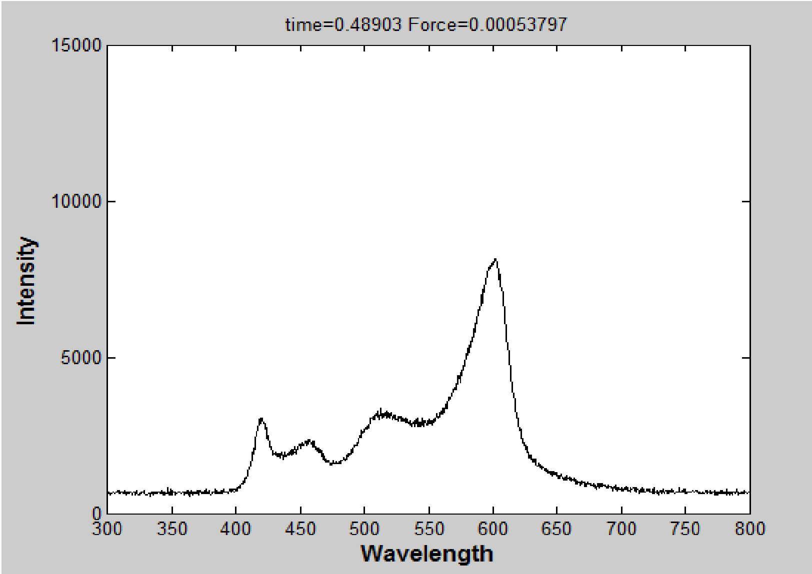

Figure 49-MATLAB Liquid Plot-Full Spectrum (~0 Force)

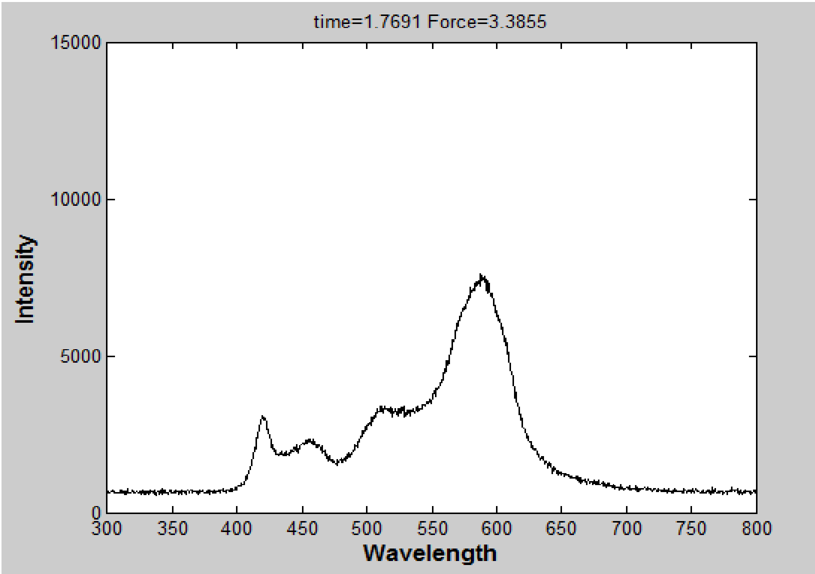

Figure 50-MATLAB Liquid Plot-Full Spectrum (3.4 N Force)

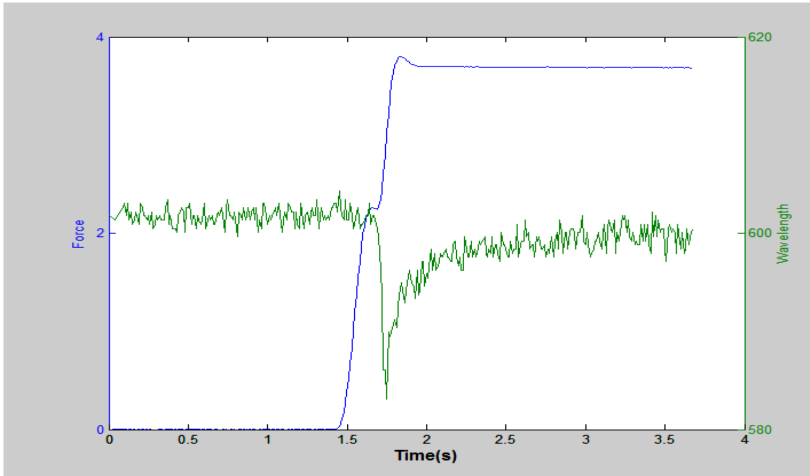

Figure 51- MATLAB Liquid Plot-Peak Wavelength and Load versus Time

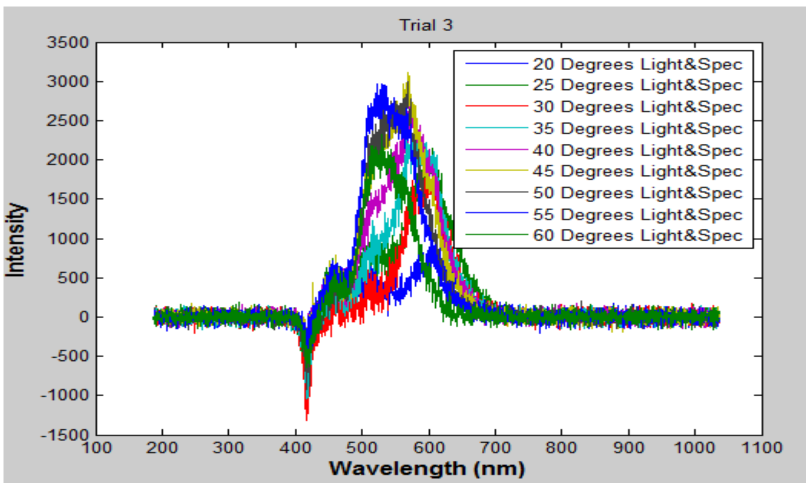

Figure 52- MATLAB Polymer Plot- Intensity versus Wavelength- Full Spectrum (20-60 degrees)

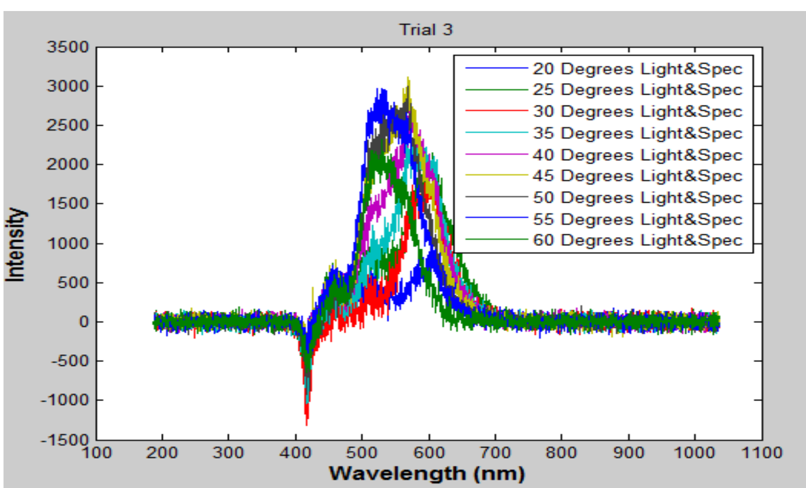

Figure 53-MATLAB Polymer Plot- Intensity versus Wavelength- Angle =40 degrees (3 trials)

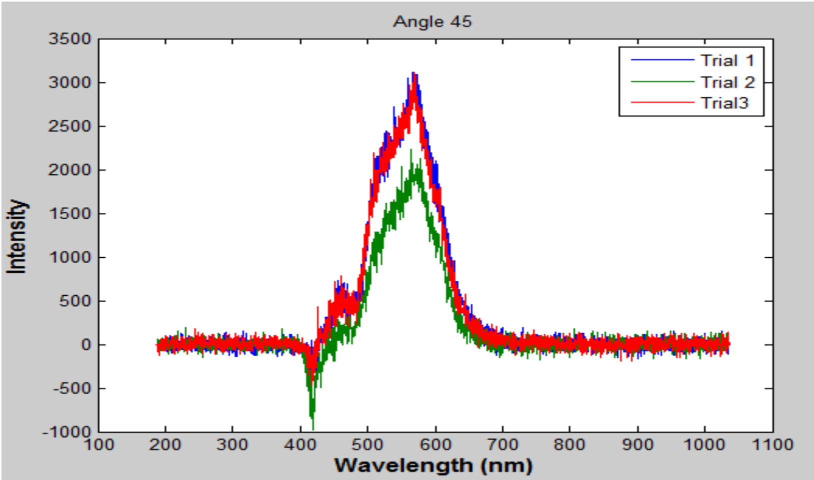

Figure 54- MATLAB Polymer Plot- Intensity versus Wavelength- Angle =45 degrees (3 trials)

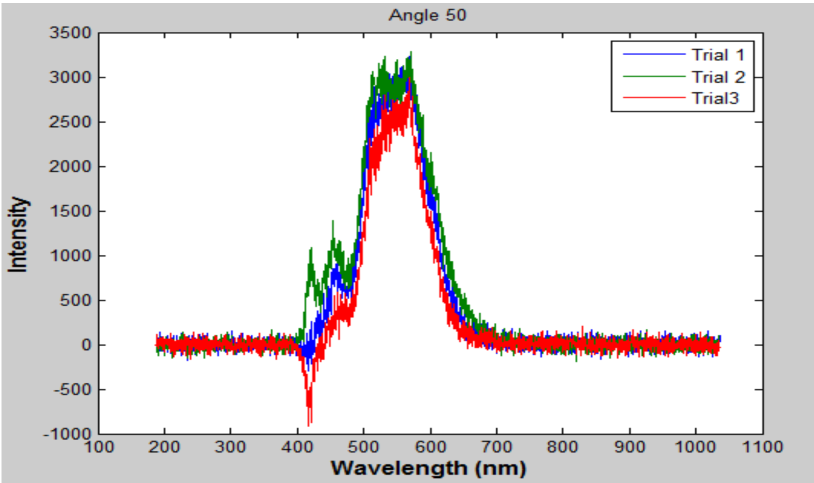

Figure 55-MATLAB Polymer Plot- Intensity versus Wavelength- Angle =50 degrees (3 trials)

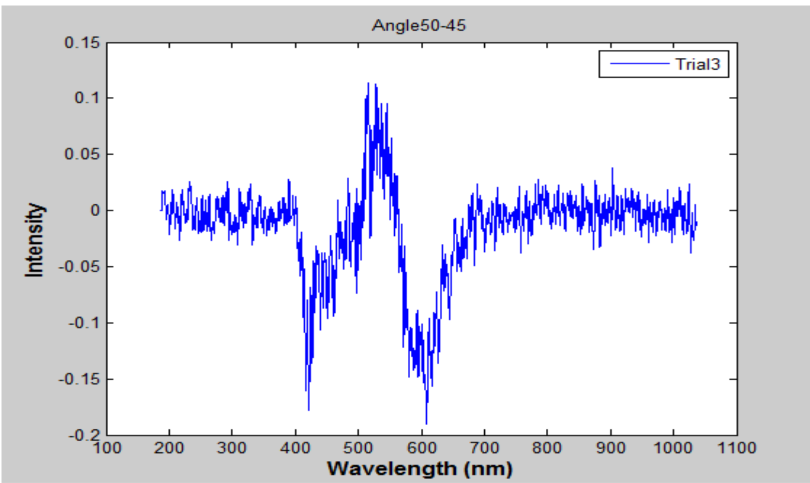

Figure 56-MATLAB Polymer Plot- Intensity versus Wavelength (Normalized)- Difference in Intensities of 45 to 50 degrees

Obstacles

Programming in MATLAB came fairly easy during the initial steps; the main issues were with the LabVIEW program because of the lack of experience with LabVIEW. Over the course of experiments issues arose with how the LabVIEW was writing the data into files and the sampling rate. As previously stated in the report, the hold in the data time is important to collecting the continuous data of the liquid crystals. During testing the sampling rate was too slow for the data to be acquired correctly, so the sampling rate had to be altered to accommodate for the poor results. By decreasing the sampling time errors started to occur in the programming, this was because data was continuously writing to the file while the computer was trying to take in results. To fix this issue there was much trial and error in writing programs that would assemble the data correctly and sustain an acceptable sampling time. For example, programs were written to form a "junction" of the data to assign to a matrix, which was then later to be separated into arrays that were written into data files. In another case ,the data was filled into a matrix and then the matrix was stored in the random access memory (RAM) of the computer, while the experiment was running, and then the data was written to a file. Other programs were written, but the success was short lived once the specifications for the processing time or sampling time were viewed. Finally, the proper LabVIEW program file was arraigned to where a queue stored the data in the RAM; while slowly writing data as to decrease CPU usage, and then once the experiment was complete the queue would release all of the data to be written to a file.

Each attempt at a new type of LabVIEW program required the building of a new MATLAB program to analyze the results once the files appeared to be writing correctly to a file. Writing a new MATLAB program for each new LabVIEW wasn't difficult but was time consuming and necessary to analyze the newly acquired data and make sure it was being collected properly. In one case, the sampling rate was acceptable and the data was properly stored to a file; so a MATLAB program was developed. When viewing the data in MATLAB, it was immediately apparent that there was a multiple second delay before the data started to write to a file and the color shift, according to the MATLAB graphs, was happening seconds before the force was applied.

Operation Instructions

Before testing can begin liquid crystals must be made from the powder cholesteric crystals. To make the liquid crystals follow the instruction given by Pressure Chemical Company in which the ratios of cholesteric crystals are given. Once all of the samples have been measured turn on a hot plate, and place a large beaker on the hot plate half filled with water. Once the temperature of the water reaches 180 degrees Fahrenheit place a small beaker in the water, and then add the samples of powder cholesteric crystals. Wait for the cholesteric crystals to start melting, and then occasionally stir the crystals to break up the smaller pieces. After the cholesteric crystals have completely melted take the small beaker out of the water and place to the side for cooling. If other types of liquid crystals are desired repeat the same steps and follow the Pressure Chemical Company instructions for the ratios.

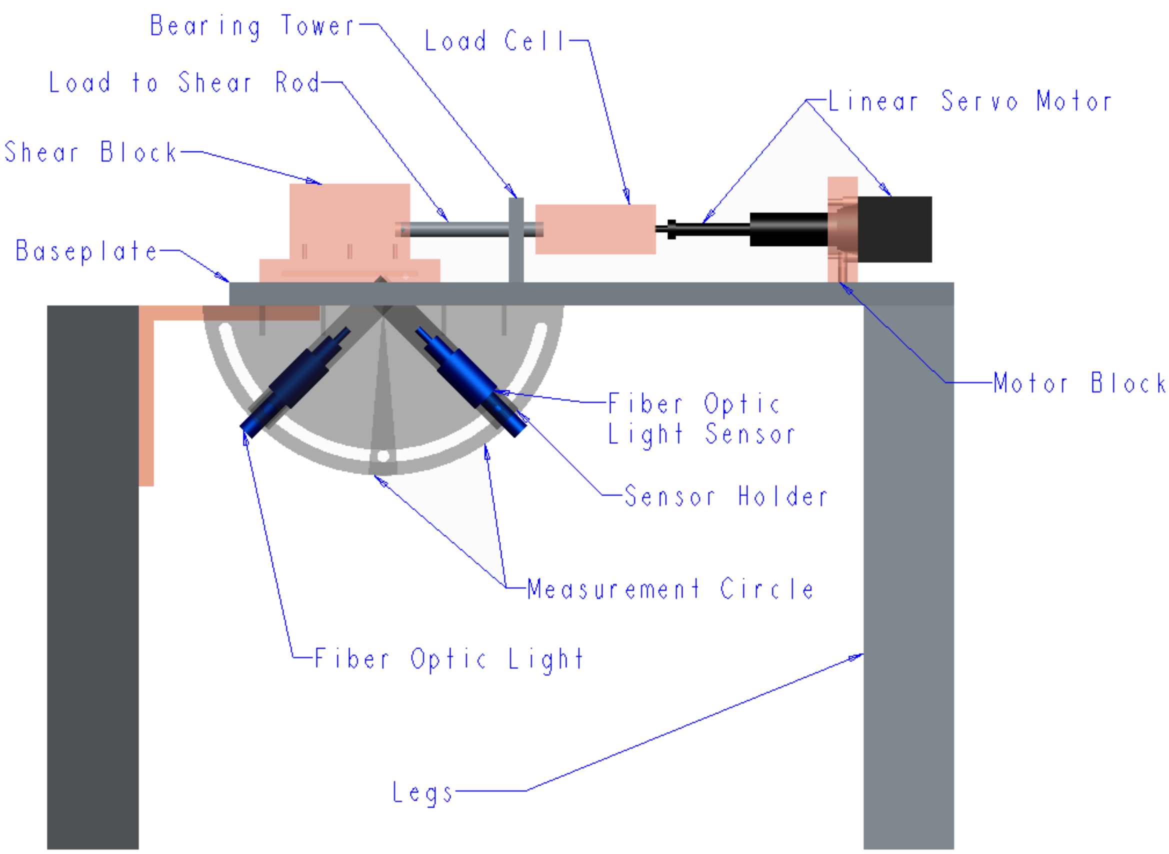

Figure 57- Apparatus Part Names and Locations

The apparatus needs to be completely assembled before the testing can begin. Make sure that the linear servo motor is connected to the motor block, the load cell is screwed in to the servo motor, and the connecting rod is attached to the load cell. Select which shear block base is going to be tested, and place the liquid crystals in the correct location on the apparatus. Place the liquid crystals on a glass slide or on the base of the shear block depending on the type of shear block base being used. Also be sure to spread the liquid crystals evenly as to have a consistent thickness and to increase the area in which the spectrometer can detect. Once the liquid crystals have been applied to the shear block, attach the shear block to the connecting rod by tightening the set screw. Also be sure to check that the shear block is over the glass slide slot in which the liquid crystals are placed. Set the location of the spectrometer and fiber optic cable to the angles desired as marked on the measurement circles. Then turn on the BluLoop light source for the apparatus to be ready for testing. The final pre-testing step is to turn on the power source:

- For the side connected to the 10-pin I/O of the microcontroller select a voltage of 12.0V±0.01V and 0.3A±0.01A.
- For the side connected to the 2-pin of the micro controller select a voltage of 24.0V±0.01V and 1.0A±0.01A

To begin the testing open the programs *LabVIEW*, *MATLAB*, and *Idea Software*. In the *LabVIEW* software run the Reference Spectrum 2.0 and Spectrum 2.1 Overload files, which controls the information from the spectrometer. In the Spectrum 2.1 Overload interface, input all of the values that correspond to the experiment that is being run (i.e. light source=1 [BluLoop]). In MATLAB open the file Experiment_02_1, keep this file in the background because it will be used at the end of the testing to determine the outcomes. In *Idea Software* select the file "Stop Forwd", this file commands the linear servo motor on its movements.

Once all of the programs are open on the desktop, go to the Reference Spectrum 2.0 interface and select the "Run" icon. While looking at the graph being displayed on the interface adjust the Spectrometer and BluLoop Fiber optic cables for the desired intensities. When the desired intensities are found, press the "Stop" button to take a snapshot of the spectrum to assign the image as the reference. (Note the file number that the reference spectrum has been saved to because it will be needed for the MATLAB file)

After the Reference Spectrum has been determined open the *Idea Software* window and select the "Communication" tab. From the communication tab choose the option "Single" and press ok; there will be a pop-up that appears to select which communication port the micro controller is connected to (ex. Comm4), select the port then press "Ok". Select the program that is wanted to run, to select the program press the "Program" tab. If a new program is to be written, write the operations wanted in the experiment to the table. For example:

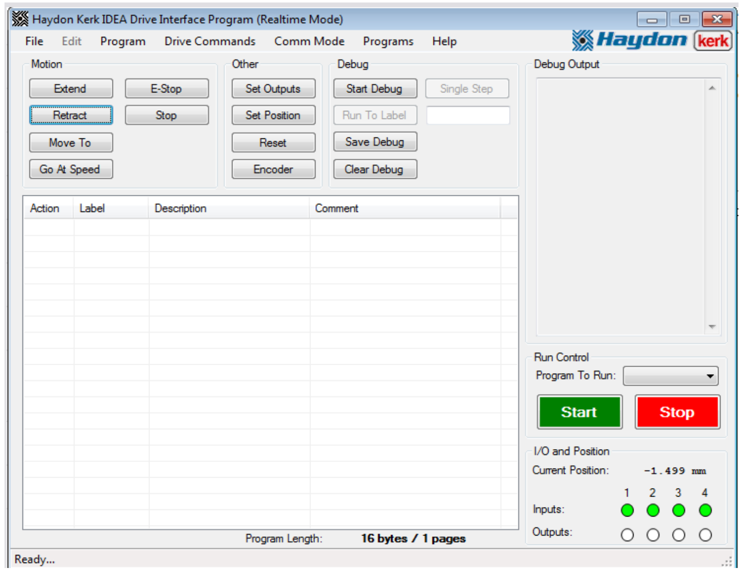

Figure 58-Idea Software Real Time Interface

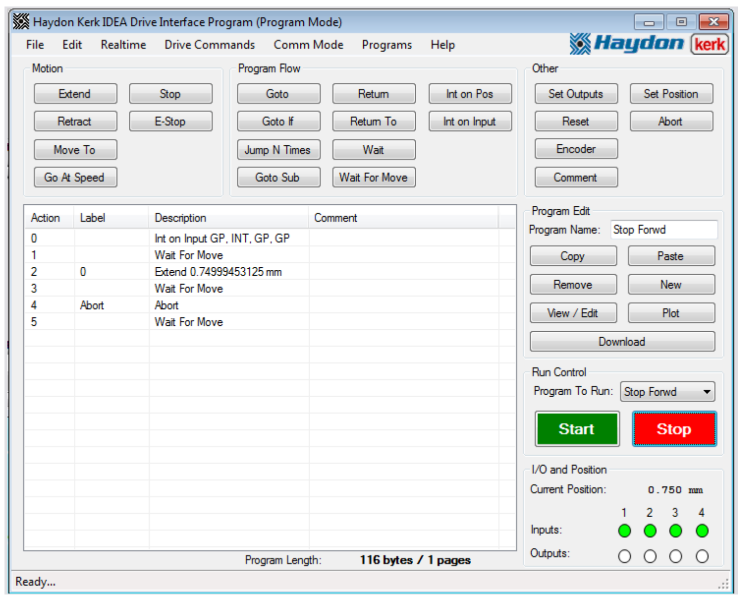

Figure 59- Idea Software Program Interface

Extend and Retract both have options in which the distance, velocity, and acceleration can all be chosen by double clicking the line of code. This is also where adjustments can be made to the experiment in how the servo motor will operate. Once programming is complete name the program in the "Name" box, and then select the "Download" icon. A pop-up will appear with the option of overriding the current servo motor program (select "Yes"). After the program has been downloaded to the micro controller select "Real Time" tab, and another pop-up will appear asking is to save the program (select "No"). When the *Idea Software* steps have all been completed move the window to the right half of the screen, as to easily select the "Start" button.

Select the Spectrum 2.1 Overload interface, and place the interface on the left half of the screen. Click the "Run" icon to start recording the spectrum data. Once "Run" is selected, go to the *Idea Software* window and press "Start" to initiate the servo motor. Go back to the Spectrum 2.1 Overload interface and wait for the servo motor to complete movement(s). After the servo motor has stopped running press the "Stop" icon. (Note the file number of the spectrum for the MATLAB file)

Go to the MATLAB Command Window, and run the file Experiment_02_1. Once the program is running, it will ask for "file number:?" and "Reference Spectrum number:?" (ex. file number=28, Reference Spectrum number= 11). The "file number:?" is the file from the Spectrum 2.1 Overload, which was noted by the previous steps. And the "Reference Spectrum number" is the file noted in the Reference Spectrum program. After the files have been chosen, the program will run and display figures representing the wavelength, intensity, load, and time. Some of the figures will display *Wavelength vs. Time, Intensity and Wavelength* vs. Time, and *Load vs. Time*. On each of the figures that will appear points can be selected on the lines to show the actual data values collected during the experiment.

In a lab notebook, note all of the variables (i.e. distance, velocity, acceleration, etc.) and all of the important features of the figures (such as the max. and min. wavelengths, load, and any unusual values). If another experiment is going to be run make sure that the servo motor is retracted back to the original placement before running the next test. When all testing is complete or changing of liquid crystals/bases return the servo motor to the original start position.

After all testing is completed; close all software programs without saving any changes to the program files. Also turn off the power supply to the relay and micro controller. Then loosen the set screw to the shear block, and slide off the shear block from the apparatus. Clean off all of the components that have liquid crystals on them, which include the shear block, apparatus, and glass slides, with a paper towel and rubbing alcohol. The paper towel is allowed to be put in the garbage can per the Safety Manual.

Results

Two materials have been considered as possible alternatives to correlate shear force with color change. The first one is polymer cholesteric crystal, and the second is liquid cholesteric crystals. This section will present the results obtained when the angle is changed on the polymer, as well as when a force is applied to the liquid crystals.

Polymer Cholesteric Crystal

The first tests have been conducted as angle dependency with the polymer cholesteric crystal. Due to the fragile nature of polymer cholesteric crystals, a force was not applied to the specimen because the specimen would break without any results. Angle dependency for the polymer is calculated by adjusting the angles of the light source and spectrometer as to determine the spectrum intensities. The following figures show data collected during testing:

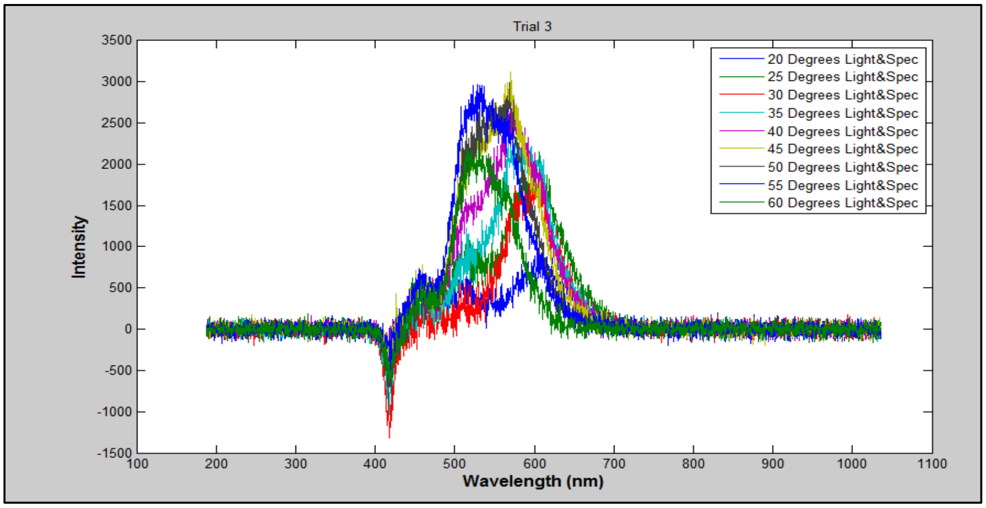

Figure 60- Full spectrum with respect to angles

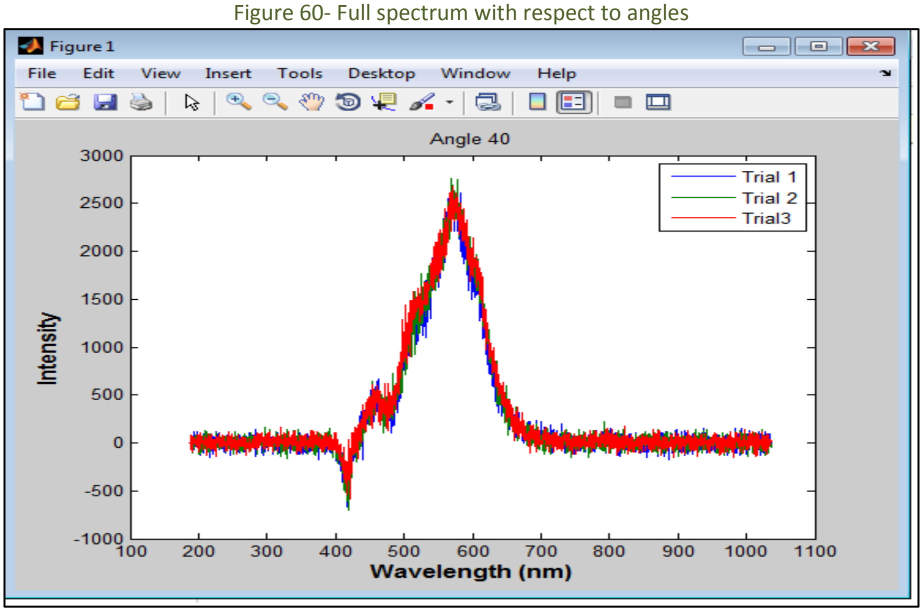

Figure 61- Spectrum at 40 degrees (light source and spectrometer)

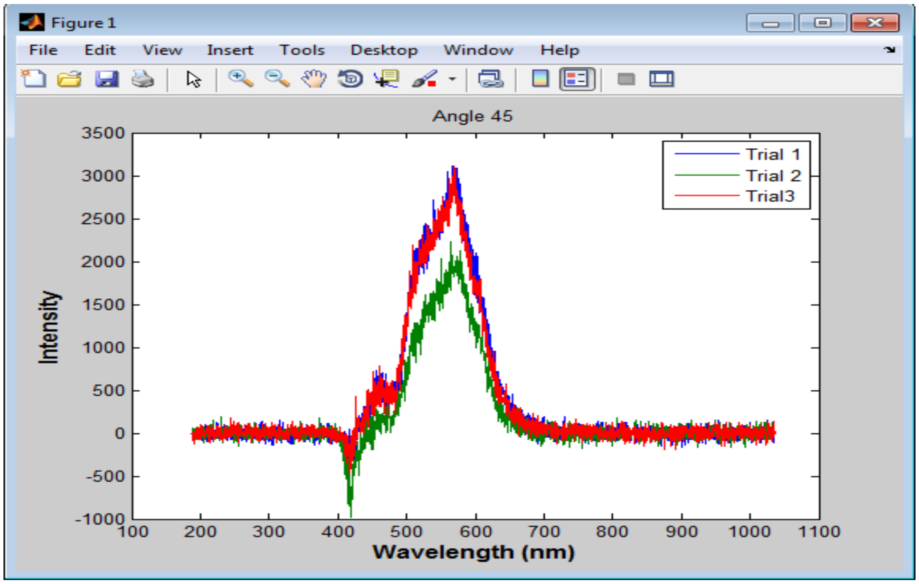

Figure 62- Spectrum at 45 degrees (light source and spectrometer)

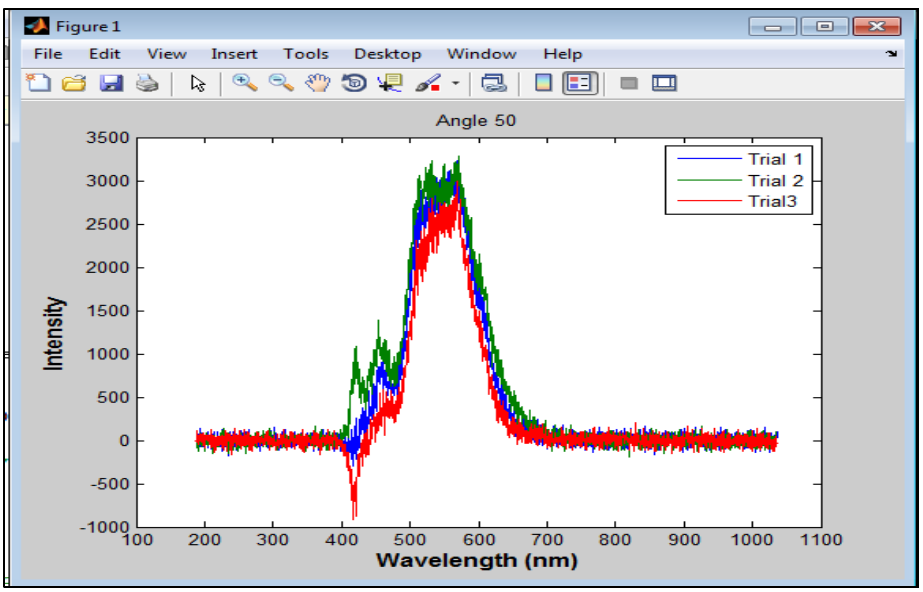

Figure 63-Spectrum at 50 degrees (light source and spectrometer)

Figure 60 shows the full spectrum for all angle data collected during one of the trials of polymer testing. Since the spectrums are difficult to see each angle is separated into figures that contain all three trials for the specific angles. From the above angle specific figures, a change in intensities for each wavelength does change with the change in angle of the light source and spectrometer, thus proving angle dependence. To better illustrate the intensity changes from one angle to the previous the normalized intensities have been subtracted:

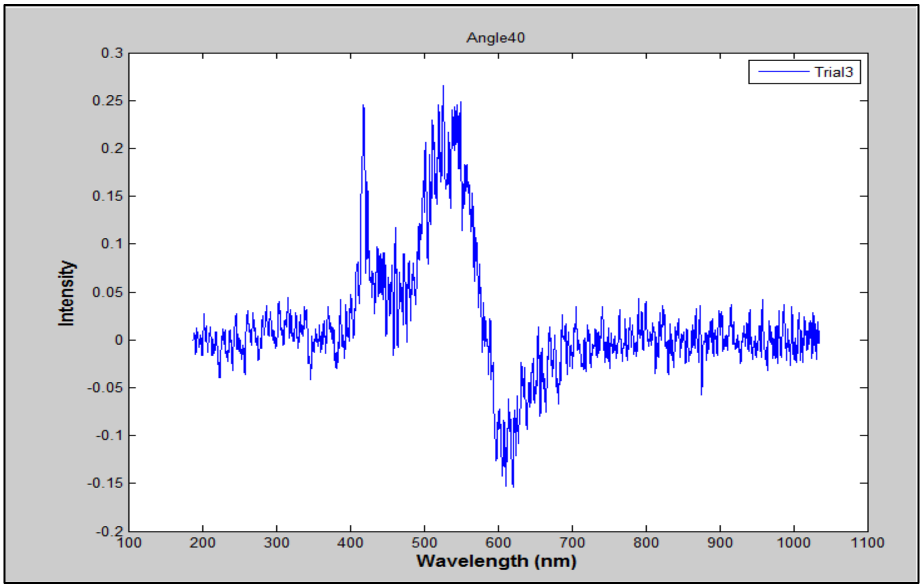

Figure 64- Difference between spectrums (40-35 degrees)

In Figure 64, the spectrum at an angle of 40 degrees is subtracted from the previous angle (35 degrees), to show how the intensities of the wavelengths differ. To get a proper subtraction of intensities between the two spectrums a normalized spectrum is required; the normalized spectrum is the ratio of wavelengths intensity to the maximum intensity because intensity is arbitrary when accounting for wavelengths. At the ~600nm wavelength a negative intensity is represented, then the ~550nm wavelength has a positive intensity; these values show how the peak wavelength from one angle to the next shifts. The negative intensity represents the previous angles peaks, and the positive represents where the current peak is located.

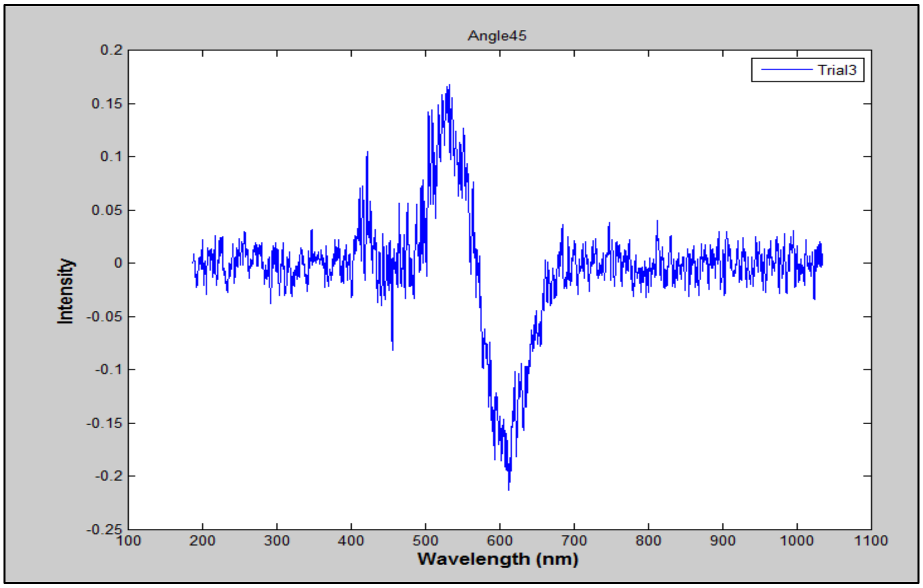

Figure 65- Difference between spectrums (45-40 degrees)

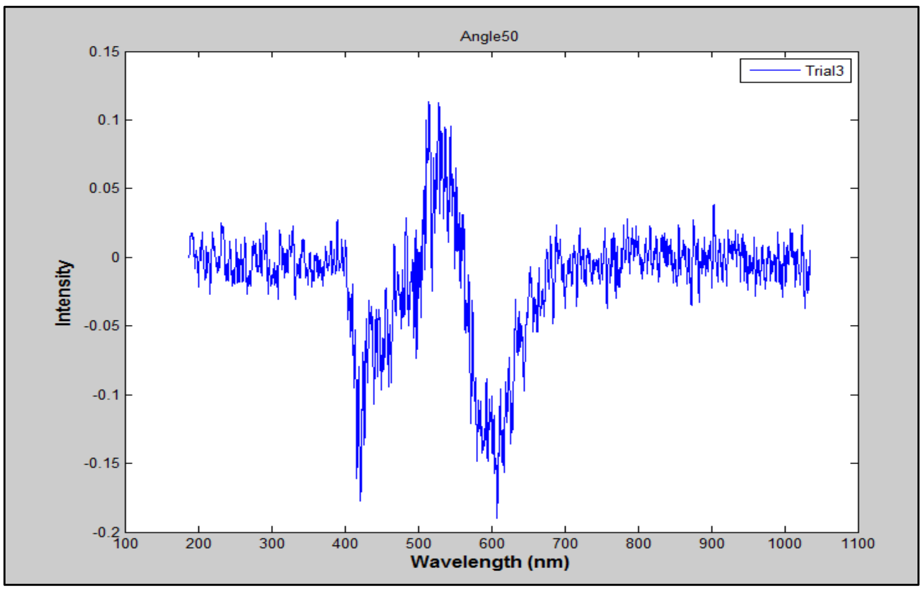

Figure 66- Difference between spectrums (50-45 degrees)

Figure 65 and Figure 66 show the same results as Figure 64, in that the change in the angle of the light source and spectrometer will change the intensities of the wavelengths.

For the beginning stages of testing, only the greatest intensity wavelengths are being determined. From these highest intensity wavelengths Figure 67 reveals a slight linear correlation for Trial 3 of the 3 experiments conducted. This correlation may prove to be accurate in depicting the wavelengths of the polymer reflection due to the angle of rotation, but more testing will need to be executed.

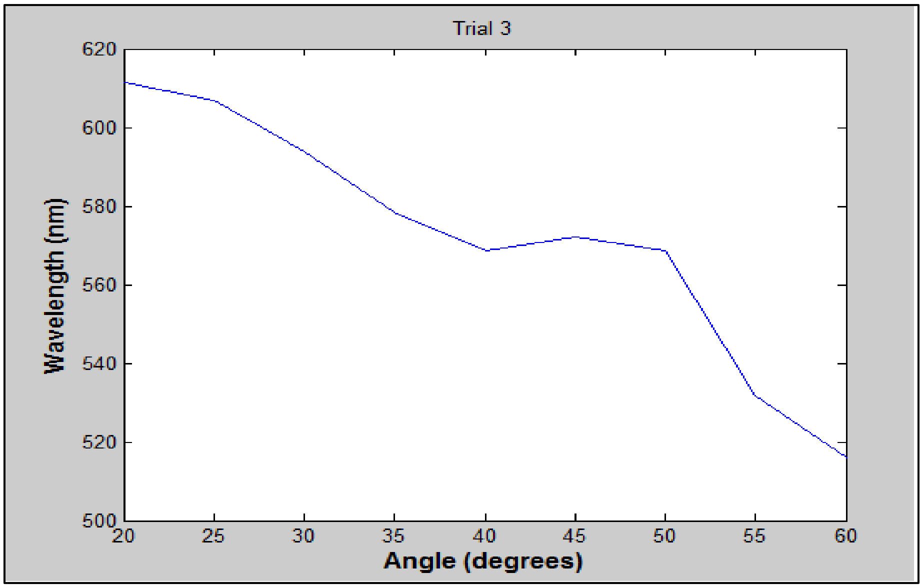

Figure 67- Peak Wavelength per Angle

To ensure repeatability of the results three trials were performed and a strong correlation between the three trials is apparent. For further figures of experiments see Appendix.

Cholesteric Liquid Crystal

The second batch of tests has been conducted with the cholesteric liquid crystal. In this case, instead of angle dependency, force dependency was studied in the wavelength.

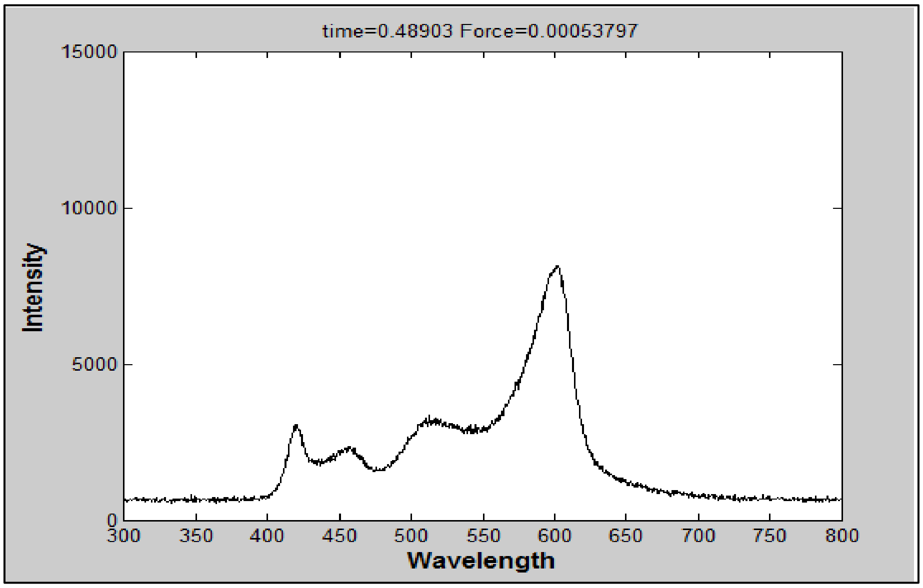

Figure 68- Liquid crystal spectrum (~0 N Force)

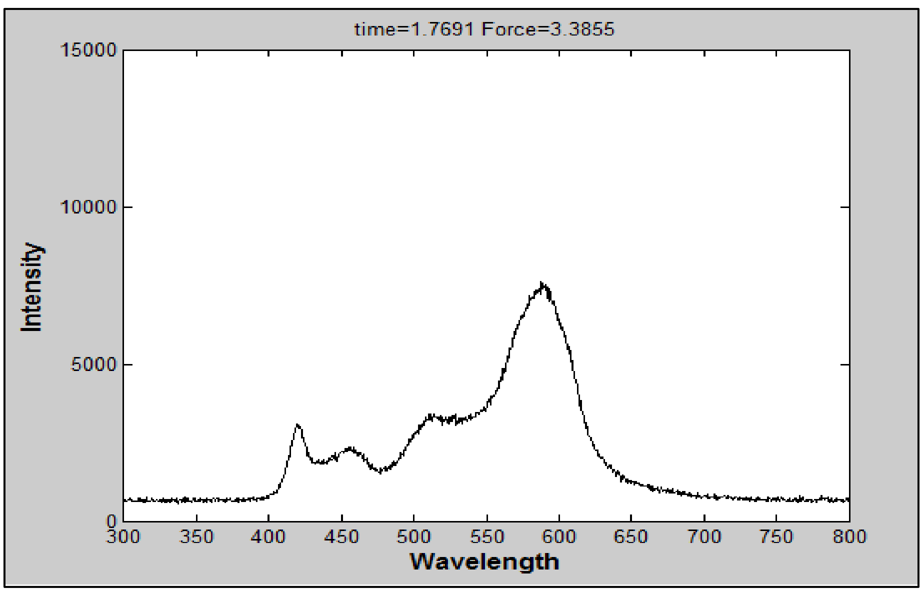

Figure 69- Liquid crystal spectrum (~3.39 N Force)

Figure 68 and Figure 69 display how the liquid crystal spectrum changes with respect to a force being applied to the liquid cholesteric crystals. Even though the change in shape of the spectrum is difficult to see the highest peak can be seen to change shape.

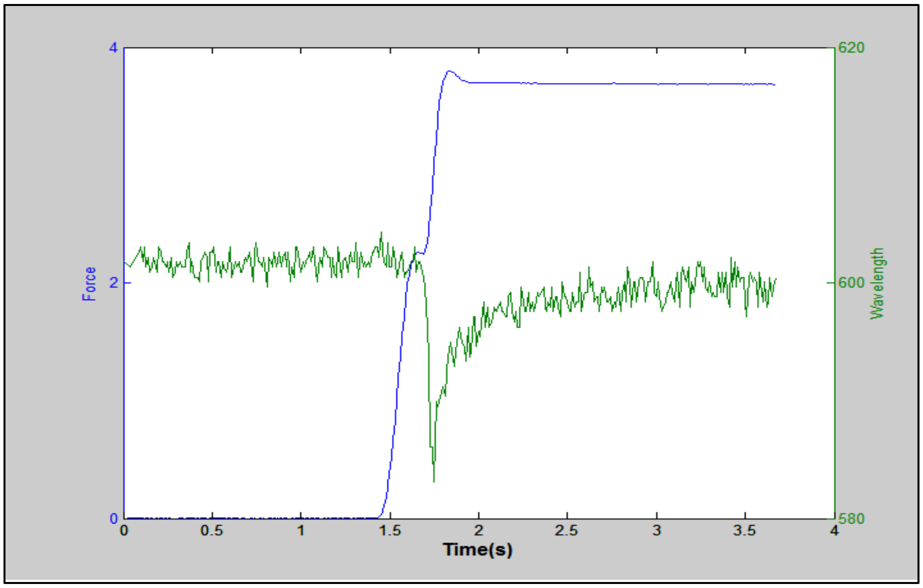

Figure 70- Force and Wavelength versus Time

Because of the difficulties in determining the maximum wavelength change in the previous figures, Figure 70 shows the plot of maximum wavelength intensity and load versus time. To determine the change in wavelength intensity a reference spectrum is taken, so that the reference spectrum can be subtracted from the experiments spectrum over the elapsed time of the experiment. Also seen in Figure 70 is the force applied to the liquid cholesteric crystals, the force helps in determining a correlation to which wavelength intensity will be the largest. From the experiments, an analysis of the force applied to the wavelength change correlation can be applied.

Variables that Affect Liquid Crystal Test Results

Cholesteric liquid crystals are extremely sensitive and it's necessary to minimize every possible variable to get repeatability. The most important variable is the angle of the spectrometer and light on the crystals. The crystals are angle dependent and therefore have a different spectrum depending on the angle of the light source and spectrometer. The measurement circles with angle indices were created to keep the spectrometer and light source at the same angle and mitigate the variation in setting an angle and switching between angles. The color of the light source will change the spectrum observed and experiments should only be compared when the same light source is used. If two glass slides are used (only with the flat bottom shear block) during testing, the crystals can seep between the two slides causing the spectrum to not shift properly when a shear force is applied. The solution to this problem is to use the extrude or "u" shaped shear block which only requires one glass slide or periodically clean off the crystals that seep between the two glass slides. The distance that the light source and spectrometer are from the liquid crystals affects the intensities seen by the spectrometer. A change in these distances can be accounted for by subtracting a reference spectrum from the spectrum of crystals and normalizing the spectrum. The amount of liquid crystal on the shear block and glass slide affects the spectrum shape. The best way to get a good spectrum is to start off with a small amount of crystals on the shear block and add more crystals until the color of the liquid crystals becomes the dominant wavelength in the wavelength distribution. Too many crystals have been added if the peak wavelength shift doesn't occur or if a smaller peak shifts instead of the peak corresponding to the color of the crystals. After each run the shear block needs to be returned to its starting position. When the shear block moves most of the crystals say attached to the shear block and move with it. This results in the testing of a new spot on the shear block if it isn't returned to its original position. The time between each test is another very important factor. Based on the spectrum distribution it appears that the liquid crystals settle seconds after the movement of the shear block takes place but in fact it takes minutes for them to fully settle. When tests are performed in quick succession the peak wavelength shift is less dramatic than when the crystals have time to settle in between each experiment. The best way to deal with the settling problem is to perform the tests at specific timed intervals. This yields more repeatable data than when the testing intervals are random. The following testing parameters will affect the experiments but are independent variables that should only be altered one at a time to determine their impact on the crystals: crystal color, baseplate type, distance traveled, speed, and acceleration.

Velocity Tests				
Distance (mm)	Velocity (mm/s)	Acceleration (mm/s^2)	Peak Wavelength (nm)	Force (N)
0.375	5	2	573.88	4.07
0.375	15	2	574.13	4.03
0.375	20	2	574.30	4.04
0.375	25	2	574.90	4.08

Acceleration Tests				
Distance (mm)	Velocity (mm/s)	Acceleration (mm/s^2)	Peak Wavelength (nm)	Force (N)
0.375	5	5	569.86	4.17
0.375	5	10	569.20	4.21
0.375	5	20	569.03	4.21
0.375	10	10	570.05	4.24

Unit Cells

Unit cells are small packaged cholesteric crystals both polymer and liquid to determine viable options for manufacturing of a sensor. For the polymer cholesteric crystal, unit cells are adopted to a column matrix that has the properties of cantilever beams with polymer attached to the top. This design contributes to the decoupling, as when a shear is applied a deflection angle can be correlated to the change in wavelength. Figure 71 shows the top and side views of VHB tape with this concept. The color change would be viewed by a sensor normal to the surface of the VHB and pointed at the crystals. This would allow the sensor to see a color change when the beam moves just like the angle dependent tests. The color change is dependent on the properties of the beam.

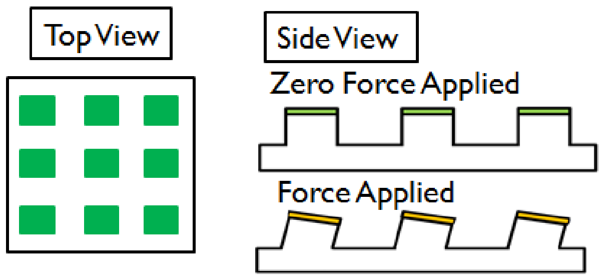

Figure 71- Unit Cell of polymer crystals using VHB tape

For manufacturing a unit cell for liquid crystals, a material can be used to where liquid crystals can be injected in vertical columns in the material. Since the cholesteric crystals are in liquid form, attaching them to the top of a beam will not be viable. Injecting the crystals into a material and then sealing the holes will contain the crystals but still allow the crystals to change color when the material that they are in deforms. This means that the properties of the material selected must be known to calculate the shear forces applied. After the material properties are known the wavelengths that correspond to the shear forces can be determined, and be used as a sensor for shear forces.

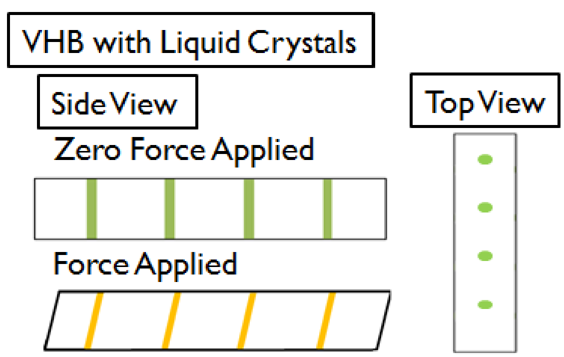

Figure 72- Unit Cell liquid crystals using VHB tape

Environmental and Safety Issues

The current project contains only a limited amount of materials including a load cell, linear servo motor, spectrometer, aluminum apparatus, glass slides, and cholesteric liquid crystals. The cholesteric crystals are the only of the aforementioned components that pose a threat to the environment or its handlers. There do not appear to be any environmental hazards posed by the crystals. The material safety data sheet shown in the appendix only indicates to dispose of the crystals according to state guidelines. The safety sheet also indicates that the crystals may cause irritation if they come in contact with the skin or eyes and irritation if they are ingested or inhaled. The solution for contact with the skin and eyes is to flush with water. If inhaled and irritation occurs, medical attention is advised. Medical attention is also advised if ingested. When combusted, the crystals will emit the toxic fumes carbon monoxide, carbon dioxide, and hydrogen chloride. The crystals aren't carcinogenic and aren't considered hazardous by any of the government agencies listed in the material safety data sheet. The materials that make up the cholesteric crystals are cholesterol, oleycarbonate, cholesterol nonanoate, cholesterol chloride, cholesterol dichlorobenzoate, cholesterol benzoate, and cholesterol propionate. All of these chemicals are used in cosmetics as for color and aren't considered hazardous.

Cost

Eglin Air Force Research Laboratory has donated $2000 to the design of the shear stress sensor using liquid crystals. After purchasing materials and parts from McMaster-Carr, LED Supply and Pressure Chemical Company the project has come to a total of $869.29, which is well under budget and the cost for travel per the FAMU & FSU College of Engineering mileage reimbursement of $170 ($.44/mile traveled) the project is still under the budget set by Eglin AFRL. There are components that are being used by the senior design group in the Optics Lab of the Aero-Propulsion, Mechatronics and Energy Center (AME), if the components in the lab were to be purchased the budget would be exceeded. For the pricing and listing of the components used in the Optics Lab Table 4 in the Appendix displays all of the information. Also a polymer cholesteric crystal will be supplied for more testing as to see how the angle and force affect the specimens. The polymer form will not be from the budget set by Eglin AFRL, but graciously by Dr. Oates the faculty advisor on the project.

Part	Unit Price	Quantity	Price
Teflon Bearing	$3.11	1	$ 3.11
Insulation	$9.03	1	$9.03
Heat sheet	$38.90	1	$38.90
Fasteners	- -	- -	$21.84
LEDs	$23.74	3	$71.22
Liquid Crystals	$75.00	3	$225.00
Load Cell- 10N	$485.00	1	$485.00
Thermocouples	$19.00	2	$38.00
VHB	$18.44	1	$18.44
	Total		$369.10

Table 3- Purchased Parts

Conclusion

The conclusive evidence of the senior design shows both the polymer and liquid cholesteric crystals have an ability to change relative intensities due to the angle of reflection. Through experimentation results show how a correlation of peak wavelength to force applied may possibly be obtained. More experimentation will need to be performed to have a better understanding of how the wavelengths correlate to a force applied to the cholesteric, but from current data the continued experimentation looks optimistic for a correlation. Also the sampling rate will become essential in the analyzing of data, because of how quickly the intensity shift occurs when a force is applied to the liquid crystals. Since there are many components recording data at high sampling rates, the LabVIEW program is required to have a high frequency to obtain accurate results. Currently 6 milliseconds is being used as the sampling time and is providing enough resolution.

The outlook of the project does look promising for finding a causation of the color change of cholesteric crystals and future research is recommended. The analysis might have to be re-examined; due to the possibility of the single largest peak value may not contain all of the details needed to determine the stresses applied. All of the experiments are saved to files, so while the analysis is being conducted there will not be the needed to restart all of the testing.

Polymer forms of the cholesteric crystals have angle dependence, this correlation will be important when the manufacturing comes in the process. Manufacturing of the polymer form is difficult currently, but with more processing the cost should decrease. The polymers ability to change wavelengths due to angle changes is how a shear sensor could be designed. Currently the theoretical design is for a polymer to be attached to a structure (column) that can bend under shear force and withstand large compressive/tensile forces. The compressive/tensile force will not affect the angles of polymer in relation to a spectrometer, but the bending forces displacing the column should change the peak wavelength. This change in peak wavelength can determine displacement of the column by knowing how bending stresses affect the structure. Thus the bending stress will be implemented as a shear stress on the columns.

Specials Thanks

We would like to thank the FSU-FAMU College of Engineering for providing us the opportunity to work on this senior design project. In addition, we thank Dr. Oates, our academic advisor, for the support during each weekly meeting and for keeping us on track. We’d also like to thank Dr. Dickinson and Dr. House, our project sponsors, who motivated us on our trip to Eglin Air Force Base, showing the engineering applications that our project was tied to. Thank you Matt Worden, our graduate assistant, who taught and helped us with the experimental and simulation studies. Finally, we would like to thank Dana Edmunds, Jeremy Phillips, Marshall Lewis, and Keith Larson from the machine shop for manufacturing the components for our apparatus.

Appendix

Environmental and Safety

MATERIAL SAFETY DATA SHEET

PRESSURE CHEMICAL CO.

Pressure Chemical Co.

Item Number: LC Kit
Chemical Name: Pressure Chemical LC Kit

••

1. Chemical Product and Company Identification

CHEMICAL NAME: **This MSDS is for a combination of Liquid Crystal (LC) products. These products include the following:**

Chemical Name	Synonym	CAS Number	PCC Item No.
Cholesterol oleylcarbonate	None	17110-51-9	L193
Cholesterol nonanoate	Cholesterol Pelargonate	1182-66-7	L170
Cholesterol chloride	3-Chloro-Cholest-5-ene	910-31-6	L050
Cholesterol 2,4-dichlorobenzoate	None	32832-01-2	L078
Cholesterol benzoate	None	604-32-0	L010
Cholesterol propionate	None	633-31-8	L230

MANUFACTURER:
Pressure Chemical Co.
3419 Smallman St.
Pittsburgh, PA 15201
412-682-5882
FAX 412-682-5864
email: service@presschem.com

EMERGENCY TELEPHONE NUMBERS:
For Chemical Emergency, Spill, Leak, Fire, Exposure, or Accident Call
CHEMTREC - Day or Night 800-424-9300
or 703-527-3887 outside USA

Pressure Chemical 24 Hour Emergency Number: 412-565-1190

2. Composition / Information on Ingredients

HAZARDOUS INGREDIENTS

None of the components in this kit are considered as hazardous under the OSHA Hazard Communication Standard.

3. Hazards Identification:

POTENTIAL HEALTH EFFECTS:

ROUTE(S) OF ENTRY:
Inhalation: X
Skin/Eyes: X
Ingestion: X

EFFECTS AND SYMPTOMS OF OVEREXPOSURE:
May be harmful if swallowed, inhaled or absorbed through skin. Symptoms of exposure may include irritation.

EFFECTS OF INHALATION:
May cause irritation.

EFFECTS OF SKIN CONTACT:
May cause irritation.

EFFECTS OF EYE CONTACT:
May cause irritation.

EFFECTS OF INGESTION:
May cause irritation.

CARCINOGENICITY, as determined by:

NTP: Not Listed
IARC: Not Listed
OSHA: Not Listed

MEDICAL CONDITIONS AGGRAVATED BY EXPOSURE:
None Known.

4. First Aid Measures:

FIRST AID FOR EYES:
In case of contact, immediately flush eyes with large quantities of water for at least 30 minutes. Assure adequate flushing of the eyes by separating the eyelids with fingers. Call a physician if irritation persists.

FIRST AID FOR SKIN:
In case of contact, immediately wash skin with plenty of soap and water for at least 15 minutes. Remove contaminated clothing and wash before reuse.

FIRST AID FOR INHALATION:
If irritation of the upper respiratory tract occurs, remove to fresh air at once. If not breathing, give artificial respiration. If breathing is difficult, administer oxygen. Seek medical attention immediately.

FIRST AID FOR INGESTION:
Seek proper medical attention.

NOTE TO PHYSICIAN:
None

5. Fire Fighting Measures:

FLASH POINT: Flash point only available for Cholesterol Oleylcarbonate FP: 113 deg C
METHOD USED: Closed Cup

FLAMMABLE / EXPLOSIVE LIMITS: Explosive Limits Not Determined

EXTINGUISHING MEDIA: Water spray, dry chemical, foam or carbon dioxide.

SPECIAL FIRE FIGHTING EQUIPMENT / PROCEDURES:
Use water to cool fire-exposed containers. Wear self-contained breathing apparatus and protective clothing to prevent contact with skin and eyes.

UNUSUAL FIRE / EXPLOSION HAZARDS:
Emits toxic fumes under fire conditions.

COMBUSTION PRODUCTS:
Carbon monoxide, carbon dioxide, hydrogen chloride.

6. Accidental Release Measures:

Absorb on sand, vermiculite, or clay and/or sweep up and place in closed containers for disposal.

7. Handling and Storage:

HANDLING AND STORAGE PRECAUTIONS:

Keep containers tightly closed.
Keep away from heat.

8. Exposure Controls / Personal Protection:

Respiratory Protection: If significant quantities of dust are generated, wear appropriate NIOSH/MSHA approved respiratory protection to eliminate inhalation exposure. Respiratory protection is not typically required under normal conditions of use.

Skin/Hand Protection: Wear chemical-resistant gloves and chemical resistant clothing.

Eye Protection: Wear safety goggles.

Avoid all exposure to eyes, skin and clothing. Avoid prolonged or repeated exposure. Wash thoroughly after handling.

VENTILATION REQUIREMENTS:
Use good industrial ventilation and local exhaust hoods if inhalation risk exists in use.

EXPOSURE LIMITS:
No exposure limits have been established.

9. Physical and Chemical Properties:

	Cholesterol oleylcarbonate	Cholesterol nonanoate	Cholesterol chloride	Cholesterol 2,4-dichlorobenzoate	Cholesterol benzoate	Cholesterol propionate
APPEARANCE	Opalescent Fluid or Solid	White Crystalline Solid	White to off-white Crystalline Solid	White to off-white Crystalline Powder	White to off-white Crystalline Powder	White to off-white Waxy Solid
ODOR	Negligible	Coconut	Negligible	Negligible	Negligible	Negligible
MOLECULAR FORMULA	$C_{46}H_{80}O_3$	$C_{36}H_{62}O_2$	$C_{27}H_{45}Cl$	$C_{34}H_{48}O_2Cl_2$	$C_{34}H_{50}O_2$	$C_{30}H_{50}O_2$
BOILING POINT	Unknown	Unknown	Unknown	Unknown	Unknown	Unknown
MELT POINT	10 °C	74 – 77 °C	92 – 93 °C	125 – 127 °C	149 – 151 °C	114 °C
SOLUBILITY IN WATER	Insoluble	Insoluble	Insoluble	Insoluble	Insoluble	Insoluble
SPECIFIC GRAVITY	Unknown	Unknown	Unknown	Unknown	Unknown	Unknown
VAPOR PRESSURE	Unknown	Unknown	Unknown	Unknown	Unknown	Unknown
VAPOR DENSITY	Unknown	Unknown	Unknown	Unknown	Unknown	Unknown
EVAPORATION RATE	Unknown	Unknown	Unknown	Unknown	Unknown	Unknown

10. Reactivity:

STABILITY: Stable

HAZARDOUS POLYMERIZATION: Not expected to occur.

INCOMPATIBILITIES: Strong acids, bases, oxidizing agents and reducing agents

HAZARDOUS DECOMPOSITION PRODUCTS: Fire may release carbon monoxide and carbon dioxide, and hydrogen chloride.

11. Toxicological Information:

No toxicological information is available.

12. Ecological Information:

No ecological information is available for this chemical.

13. Disposal Considerations:

Observe all applicable local, state, and federal environmental regulations.

14. Transportation Information:

US DOT SHIPPING NAME: DOT NOT REGULATED

15. Regulatory Information:

OSHA HAZARDOUS: NO

TSCA LISTED: Yes

SARA TITLE III:

SECT. 302 EXTREMELY HAZARDOUS SUBST. TPQ (Lbs): N/A

REPORTABLE QUANTITY (RQ)(Lbs): N/A

SECTION 313 LISTED: No
LISTED MATERIAL/COMPOUND:

SECTION 311/312 HAZARD CATEGORIES:

Pressure:	N
Fire:	N
Reactivity:	N
Acute Health:	N
Chronic Health	N

STATE / INTERNATIONAL REGULATORY INFORMATION:

PENNSYLVANIA RIGHT TO KNOW.	**LISTED:** No
NEW JERSEY RIGHT TO KNOW:	**LISTED:** No
CALIFORNIA PROP 65.	**LISTED:** No
CANADA DOMESTIC SUBST. LIST	**LISTED:** No
EINECS	**LISTED:** No

16. Other Information:

REASON FOR ISSUE	: New MSDS
REVISION DATE	: November 20, 2006
SUPERSEDES DATE	: Not Applicable

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Cost

Part	Quantity	Price
Aluminum	- -	$64
BluLoop Light Source	1	$1575
Fiber Optic Spectrometer	1	$2771
Linear Servo Motor	1	$230
Software	--	$2669
Multimeter	1	$15
DAQ Board	1	$369
Amplifier-SGA Power Signal Converter	1	$345
Motor Driver	1	$396
Power Supply	1	$130
Total		$8,413

Table 4- Supplied Parts from Optics Lab

Operation Instructions: Step by Step

Pre-Testing

- Create the liquid crystal specimens based on the instruction from Pressure Chemical Company.
    - Measure liquid crystal sample masses by the ratios given
    - Turn on hot plate for melting liquid crystals, with a large beaker half way filled with water then place a smaller beaker in the water
    - Place the liquid crystals in the smaller beaker that is on the hot plate
    - Periodically stir (preferably with a stirring rod) the liquid crystals to assist in the melting of the solid
    - Once the liquid crystal is completely liquid then take the smaller beaker out of the larger beaker
    - Place the smaller beaker to the side to cool off
    - Repeat all steps for any other liquid crystals desired
- Make sure the apparatus is assembled
    - The linear servo motor is screwed to the motor block
    - The load cell is screwed to the servo motor
    - The connecting rod is screwed in to the load cell and through the bearing tower
    - Attach the correct bottom plate to the shear block
    - Place the liquid crystal in the desired location(i.e. on a glass slide or on the shear block)
    - The shear block is attached to the connecting rod with the set screw tightened
    - Also the shear block is over the liquid crystal location (above glass slide)
    - Align the light and sensor holder to the correct angle as indicated by the degree markers
    - Turn on the BluLoop light source
- Turn the Power supply on.
    - For the side connected to the 10-pin I/O of the microcontroller select a voltage of 12.0V±0.01V and 0.3A±0.01A.
    - For the side connected to the 2-pin of the micro controller select a voltage of 24.0V±0.01V and 1.0A±0.01A

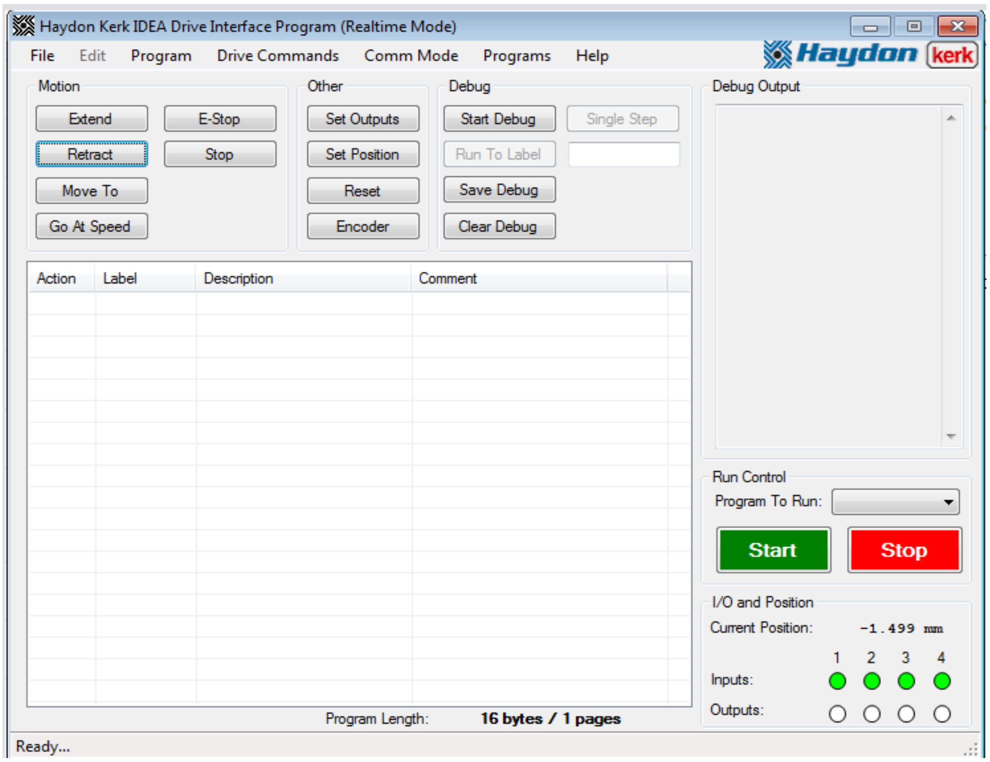
Testing

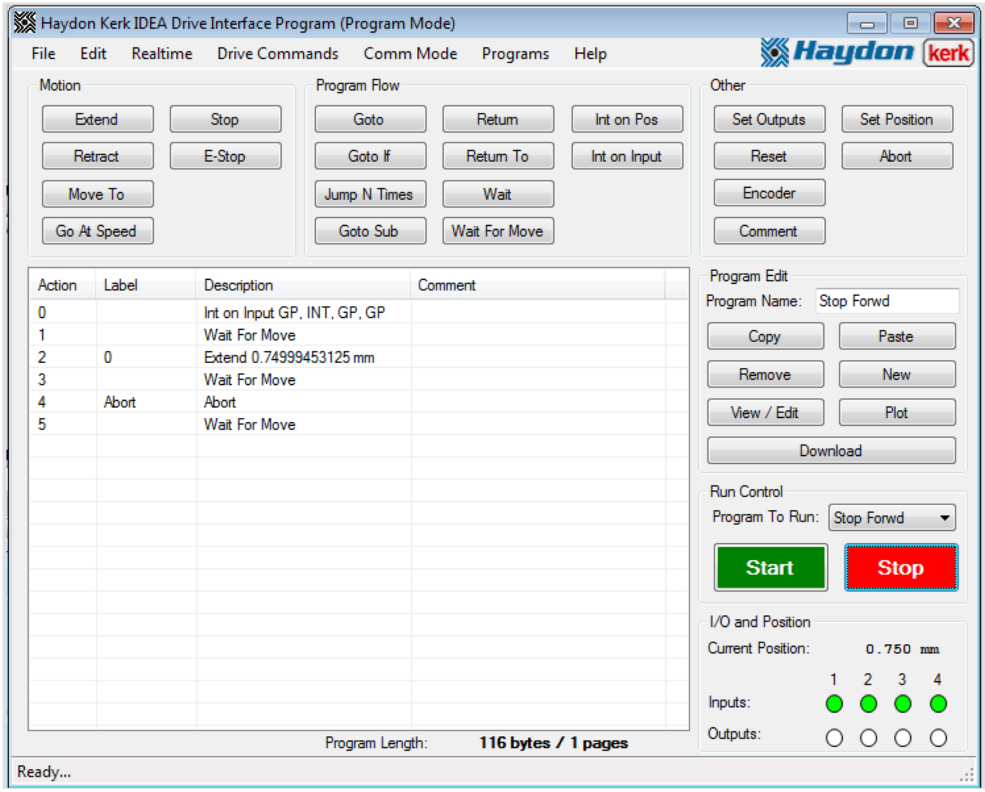
- Launch the software on the computer
    - Open *LabVIEW* and open the program file Reference Spectrum 2.0 and file Spectrum 2.1 Overload
    - Open MATLAB and open the program file Experiment_02_1
    - Open *Idea Software* and open the program file "Stop Forwd"

- LabVIEW
    - Go to the Reference Spectrum 2.0 Front Interface and select the run icon.
    - Adjust the Spectrometer and BluLoop fiber optic cables for the desired intensities by the graph on the Interface

- Once the desired spectrum intensity is desired hit the “Stop” icon.
- Note the file number that the reference spectrum has been saved as

- Idea Software
    - Click the Communication tab
    - Select the option “Single” and press ok
    - Once the pop up appears select the correct communication port (ex. Comm 4), then click Ok
    - Click the Program tab
    - Input the operations that are wanted for the experiment if another program is desired.
        - Example:





  - In the Extend or Retract command, the distance traveled, velocity, and acceleration can all be defined.
- Name the program that was created and press the Download icon.
  - Press Yes to replace current program on controller
- Select the Real Time tab (Same location as Program was located)
  - Press Yes to save the program file
- Place the *Idea Software* window to the right half of the screen

- LabVIEW
  - Select the Spectrum 2.1 Overload interface
  - Place the interface to the left half of the screen
  - Click the “Run” icon to start recording spectrum data
    - Once Run is selected on the interface go to the *Idea Software* window and press “Start”
  - After the servo has stopped running click the “Stop” icon on the Spectrum 2.1 Overload Interface
  - Note the file number that the spectrum has been saved
- MATLAB
  - Run the MATLAB file Experiment_02_1
    - The program will ask for “file number:?”. This is the file spectrum number

        - Then the program will ask for "Reference Spectrum number:?". This is the reference spectrum that was noted previously.
    - The program will then run and display figures representing the wavelength, intensity, time, and load
        - Figures can be altered to display the variables in certain axes
            - For Example:
                - Wavelength vs. Time
                - Intensity and Wavelength vs. Time
                - Load vs. Time
    - From the figures all of the data points can be selected from the plot, so finite values can be determined.
- Record variables in lab notebook. (i.e. distance, velocity, acceleration, wavelength, etc.)
- If another test is going to be run, press the "Retract" button on the *Idea Software* to return to initial starting position
- When testing is complete return servo motor to original start position

Post-Testing

- Close all software programs without saving any changes to the program files.
- Turn off the power source
- Loosen the set screw on the shear block and slide off the shear block from the apparatus
- Clean off the bottom of the shear block, glass slides, and apparatus with rubbing alcohol and paper towels
    - Dispose of paper towels in garbage can due to safety manual allowing disposal in garbage can

Trouble Shooting

Problem: Idea software won't detect the servo motor.

Solutions:

- Make sure the power supply is attached to the microcontroller and that it's powered on.
- Make sure "com 4" is selected as the communication port in the Idea software.
- Close the Idea software & power cycle the power supply.

Problem: Servo Motor is stuck in the retracted position.

Solutions:

- Close the Idea software & power cycle the power supply.
- Move the servo motor back a small increment.
- Disconnect the servo motor from the apparatus.

Problem: Spectrum has more than one peak.

Solutions:

- Make sure the light and sensor are at 45°.
- Add more Liquid crystal.

Problem: Spectrum is too small.

Solutions:

- Make sure the BluLoop is on.
- Make sure the light and sensor are at 45°.
- Increase light and sensor distance from glass slide.

Problem: Emergency shutoff not working.

Solutions:

- Ground the input and check the Idea software to see if the input changes from green to white. If no change occurs the input isn't properly grounded.
- Make sure the gate power for you relay is high enough (above0.25W).

- Make sure the input is being grounded and isn’t supplied a voltage.

Problem: Load cell is outputting uncharacteristic data.

Solutions:

- Make sure amplifier is on and is set for the proper mV/V conversion.
- Disconnect the load cell and allow the cell to discharge.

Problem: MATLAB spectrum graph is nonexistent in the center of the spectrum.

Solutions:

- Wrong reference spectrum was used.
- If correct reference spectrum was used take another and repeat the experiment.

Problem: LabVIEW spectrum graph in the user interface displays uncharacteristic data or axis.

Solutions:

- Stop the program from running and then start the program running.

LabVIEW Block Diagram

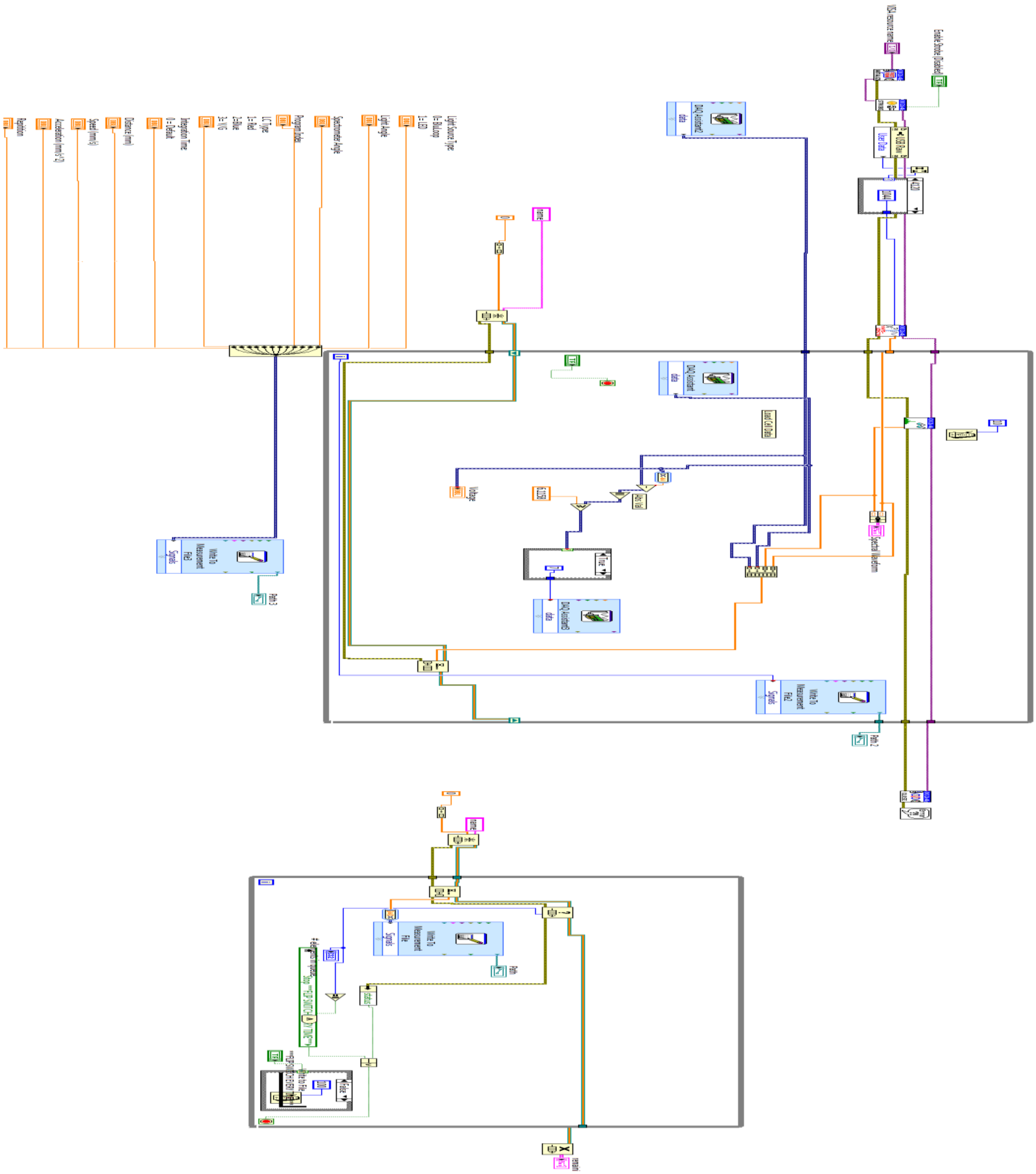


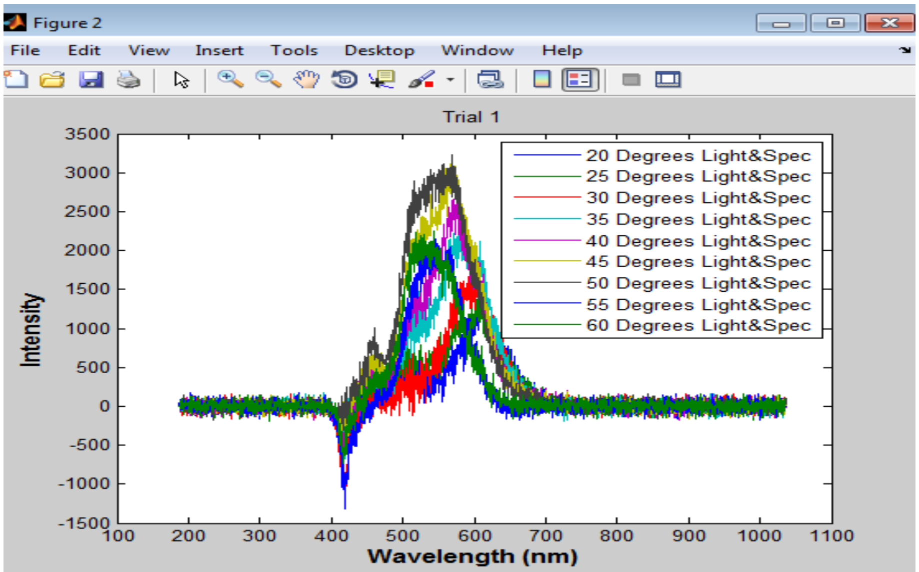
Figure 73- LabVIEW Block Diagram

MATLAB Figures

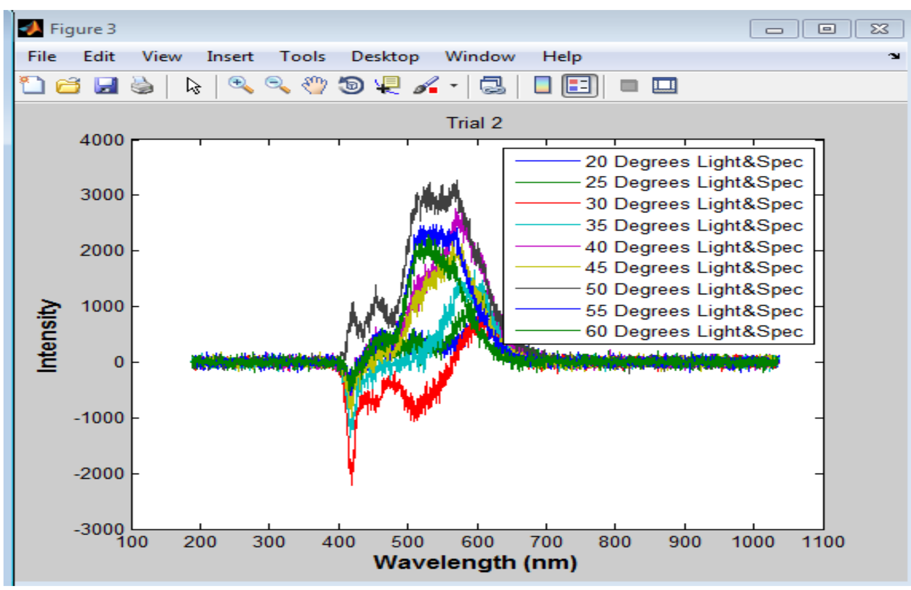
Polymer- Three Trials of Angle Dependency

Full Spectrum

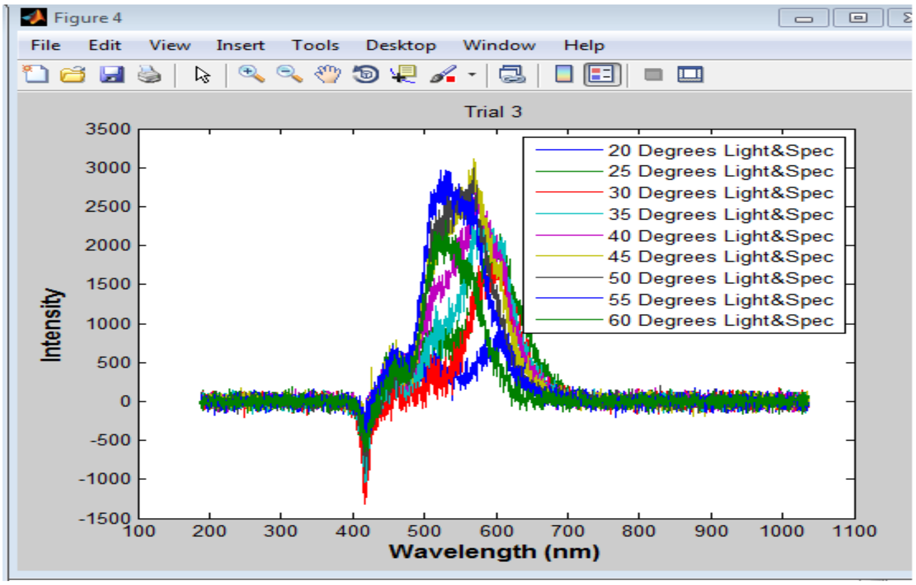
Trial 1



Trial 2

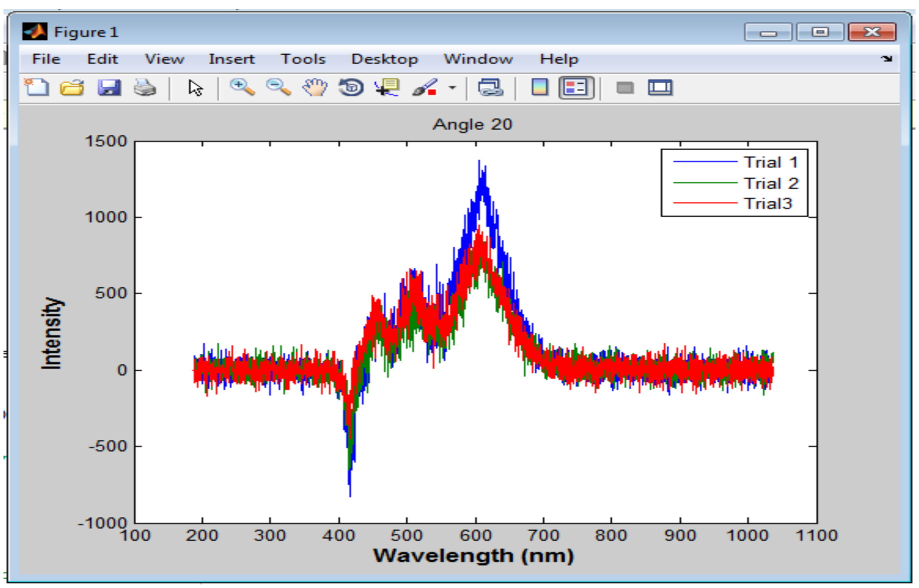


Trial 3

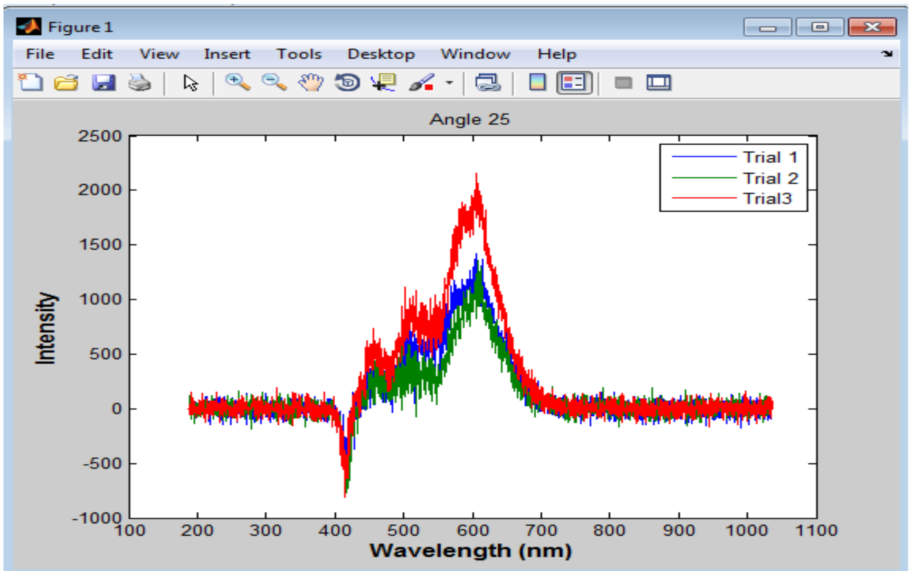


Separated Angles

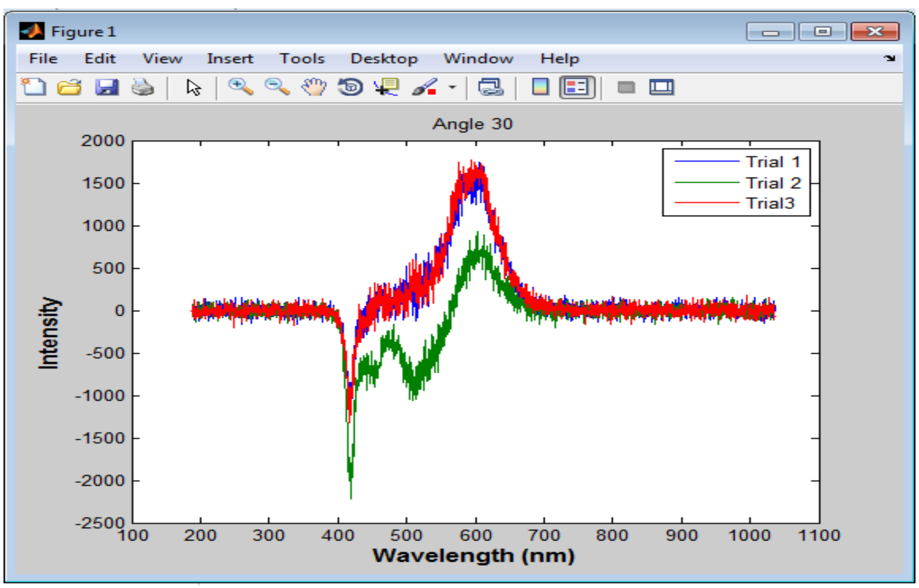
Angle= 20 degrees



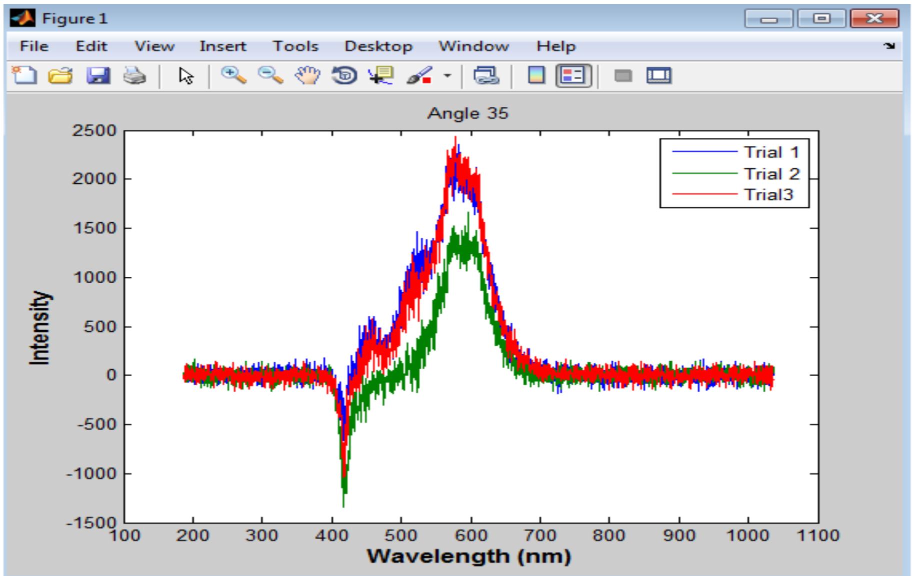
Angle= 25 degrees



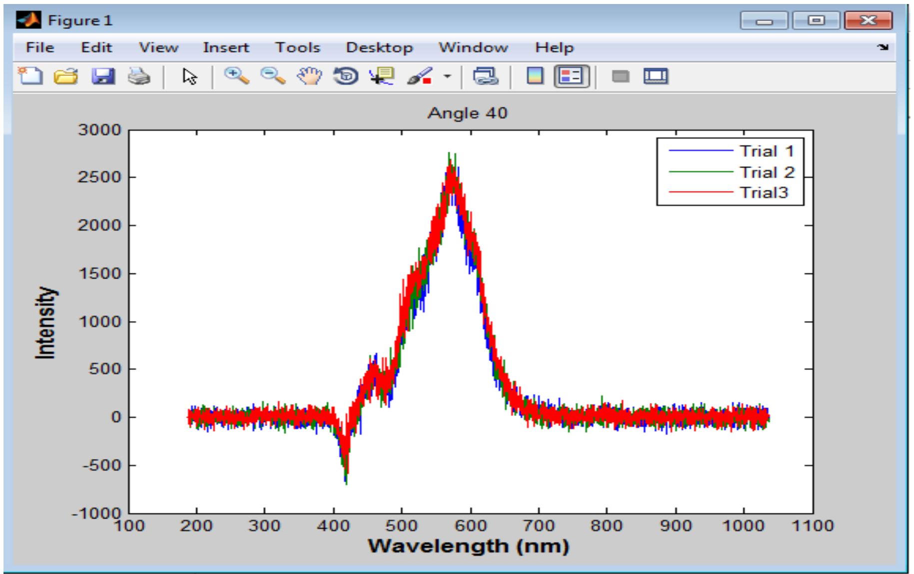
Angle= 30 degrees



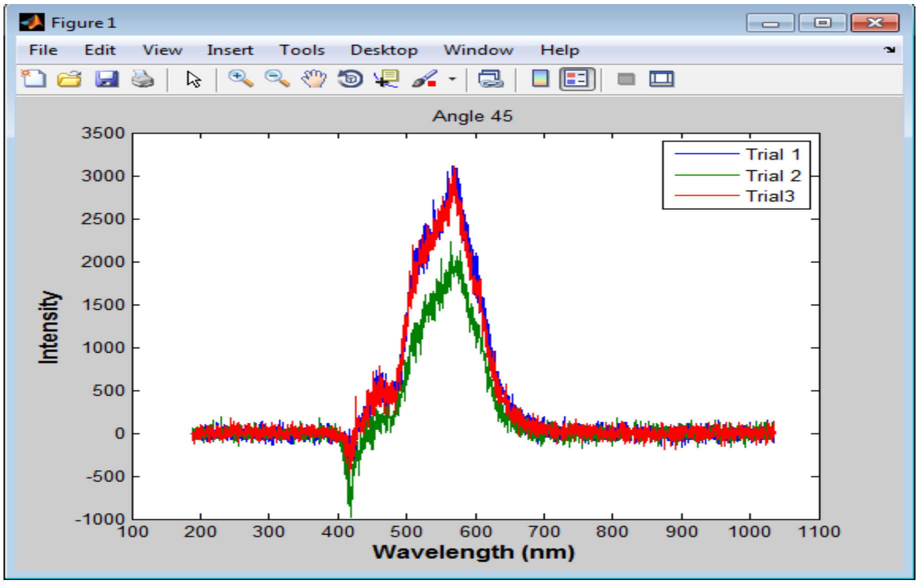
Angle= 35 degrees



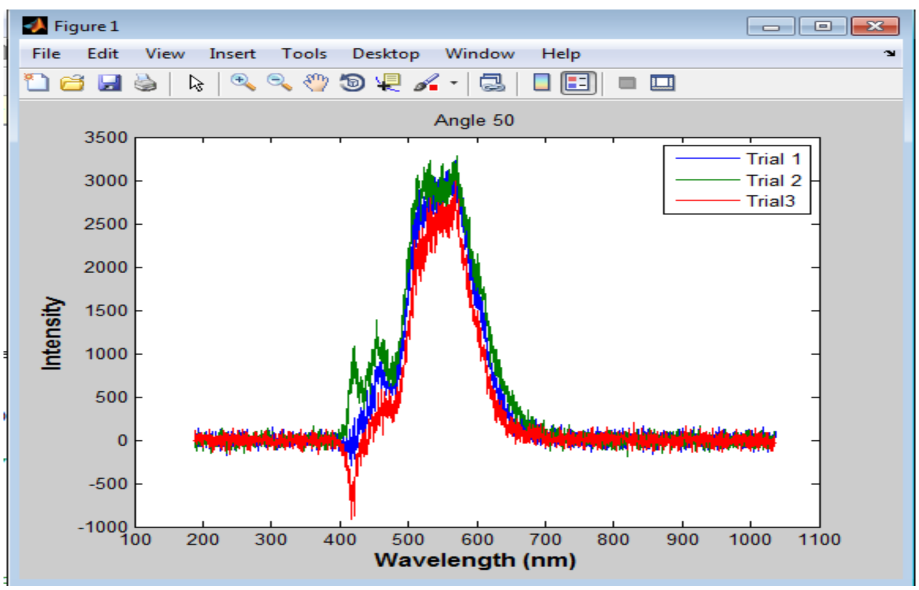
Angle= 40 degrees



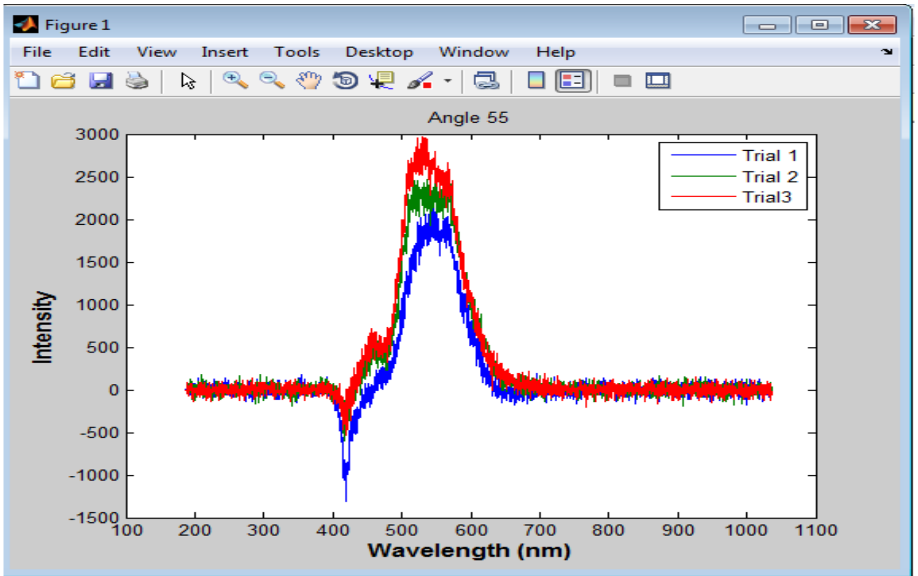
Angle= 45 degrees



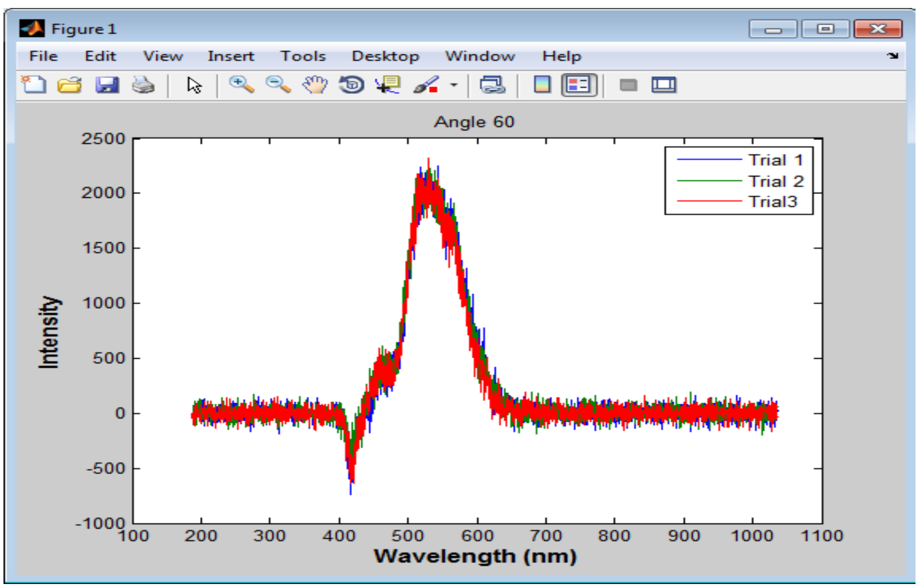
Angle= 50 degrees



Angle= 55 degrees

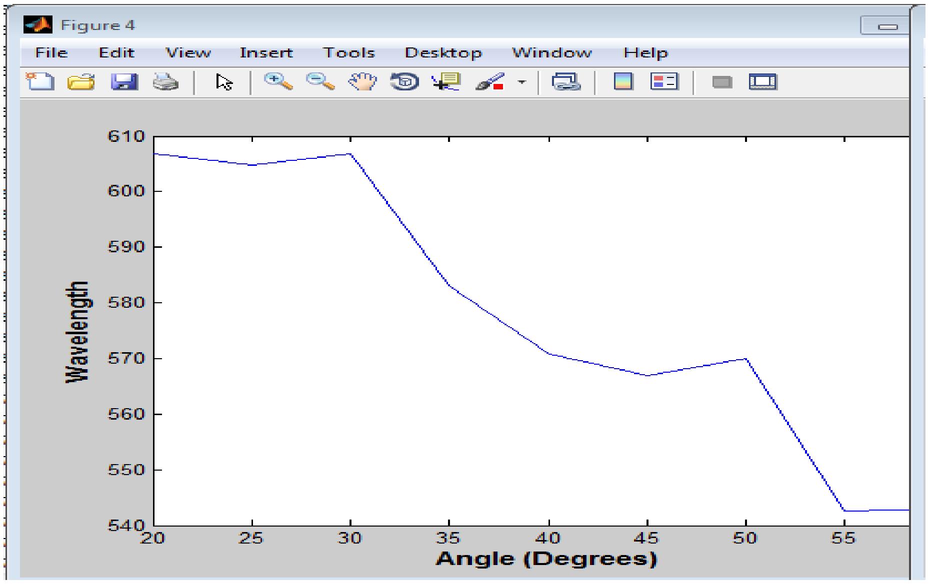


Angle= 60 degrees

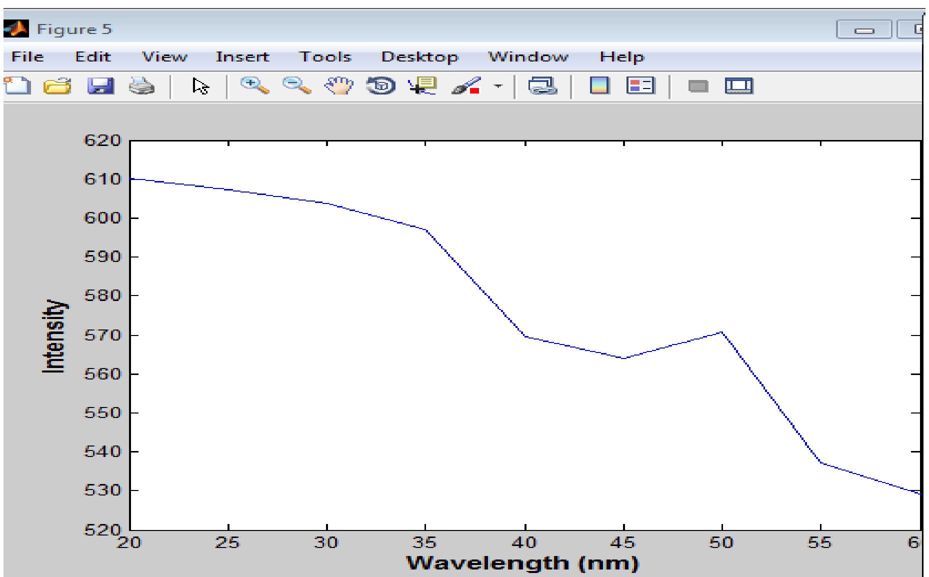


Peak Wavelength per Angle

Trial 1



Trial 2



Trial 3

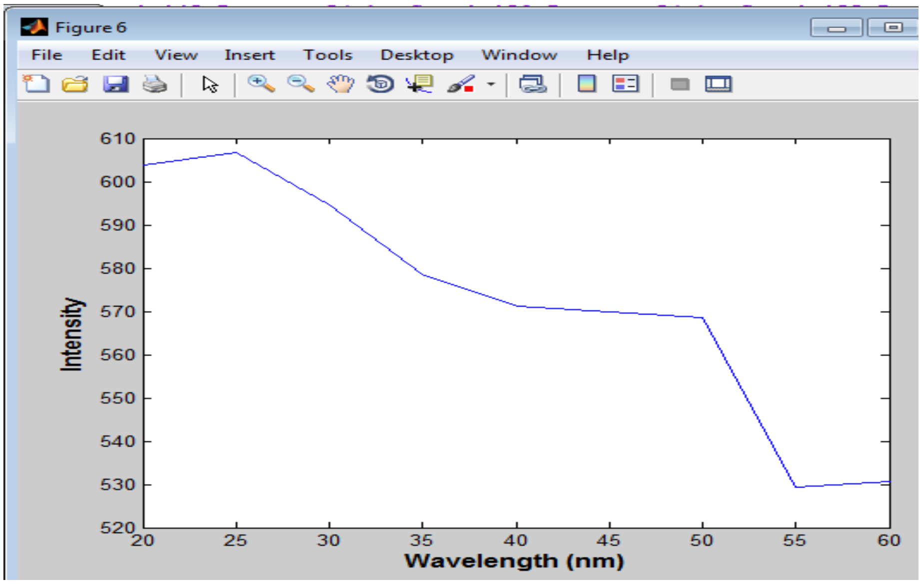


Figure 6
File
Edit
View
Insert
Tools
Desktop
Window
Help
Intensity
610
600
590
580
570
560
550
540
530
520
20
25
30
35
40
45
50
55
60
Wavelength (nm)

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