Shear Stress Sensor Design

EML 4551C-Senior Design- Fall 2012

MID-TERM I CONCEPTUAL DESIGN REVIEW

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Introduction

There currently isn't a small, inexpensive, and accurate method of measuring shear stress. The current methods aren't able to decouple the normal force from the shear force. It is hypothesized that normal and shear forces can be decoupled by measuring the light emitted from cholesteric crystals attached to a body undergoing a shear 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 a very important problem that needed to be solved and offered to finance our project. The current testing apparatus, created by Dr. Oates and his research assistant Matt Worden, is partially completed and needs to be completed before any testing can begin. Once we complete the apparatus we can begin research on whether cholesteric crystals can accurately measure shear stress better than the other methods existing today.

Project Scope:

Needs Assessment:

A testing apparatus for cholesteric crystals is required 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. The current methods unintentionally measure part of the normal component of pressure on the body as the shear stress. 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:

The liquid crystals are not a new item, but they have never been used to find shear stress. Dr. Dickinson from Eglin Air Force Base will be our sponsor providing us with the resources to fund the project. However our faculty advisor Dr. Oates will be providing most of the background information along with a lab and materials. The physical design will be to create a testing apparatus, but the data collected during experiments will be the bulk of our effort. The data collected will show how cholesteric crystals react to shear stress under various conditions. Eglin 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, robots, and other equipment. There are currently other shear stress sensors existing (MEMS shear sensors and oil films) 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 the cholesteric crystals in the form of a polymer.

Previous Technology:

In the past 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. In the upcoming section different methods for measuring shear stress will be presented 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 and quantitative fluctuating turbulence 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.

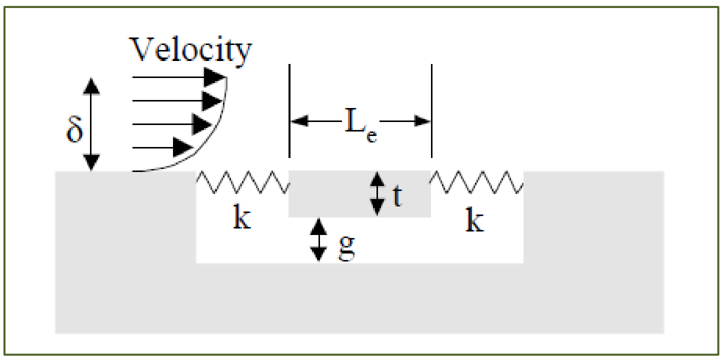

Figure 1- MEMS Direct Sensor (Naughton)

-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. After this, 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.

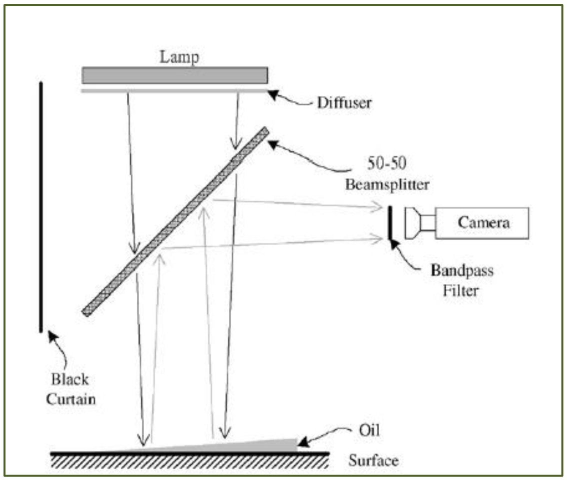

Figure 2- Schematic of image based oil film technique (Naughton)

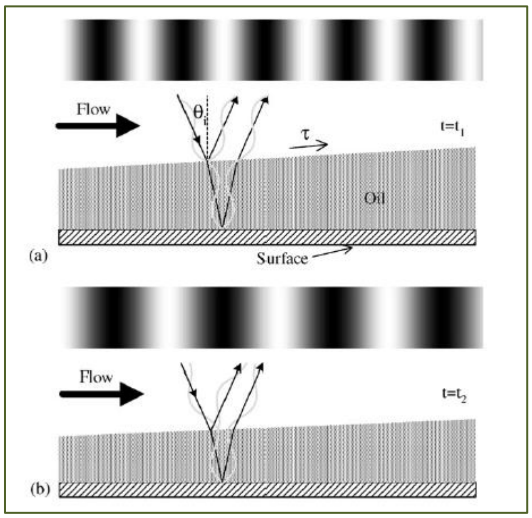

Figure 3-Interferometry finges (Naughton)

Single points, line, 1D and 2D techniques are examples 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 reflected from the liquid crystal layer. The major classifications are isotropic, nematic and chiral/cholesteric. From these, cholesteric is the material with more interesting properties.

One of the advantages is that, as it does not need electricity, it can be used in dirty environments. However, some limitations such as the color dependence on illumination and observation angles, as illustrated in the figure below, 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.

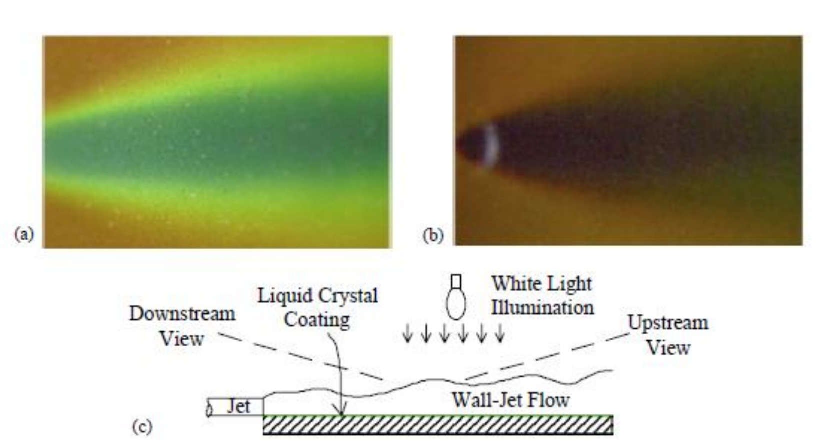

Figure 4- Viewed from different points, distinct change in color is observed (Naughton)

Devices for the measurement of light reflected from the crystal as the following have been developed. Figure 5 shows a patent scheme based on a laminate structure of a crystal polymer substrate attached to a test surface of an article.

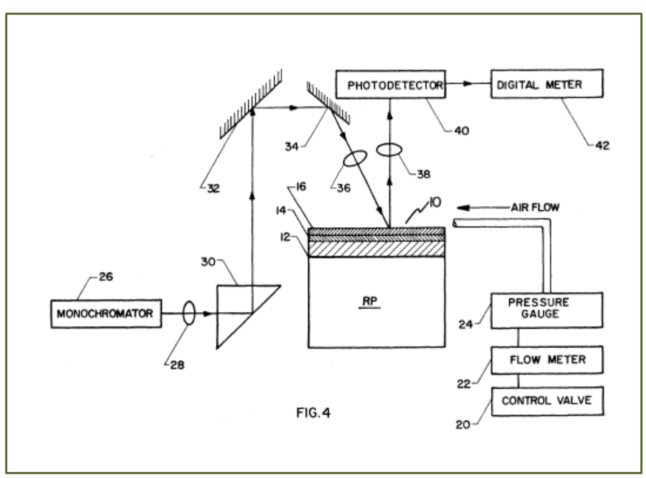

Figure 5- Patent 5223310 – Shear stress measurement apparatus(Singh)

Previous Design Work:

This project was started by another individual and then abandoned. We received the testing apparatus, as shown in figure 6, at the beginning of the semester and were told to proceed. In addition to the apparatus, we had 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 can't 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 and in between the glass slide and motor is where the load cell will be. With the baseplate already created and a clear plan of attack on how to mount the components that will be creating the load on the cholesteric crystals, only a few components need to be designed.

Figure 6- Previous design apparatus

Objectives to Improve on Previous Work:

The given apparatus, motor, and load cell have given the group a good starting direction but 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 only change was to the engineering drawings to give the motor block correct dimensions. The objectives made to improve on the previous design work were to create a 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 holder, a light sensor holder that would be able to vary the angle of observation from 0 to 90 degrees, and longer legs that would allow the light sensor to fit under the apparatus.

Goal:

We expect to have our testing apparatus built by the end of October. In the following months we will create a LabVIEW visual interface to control the experiments and record data. Once this phase is complete we will collect as much data as possible which will be the main product of this project. The phrase repeated by our sponsor was “good science”. Dr. Dickinson wants us to be impartial in collecting data on the cholesteric crystals as well as collect as much of it as possible. He doesn’t want us to make this method of measuring shear stress seem better than it actually is and accepts that this method may not be the best for measuring shear stress. Ideally we will find that the material doesn’t react to normal forces and our experiments can continue based on this finding. We then expect to determine how the material reacts under static and dynamic shear stress along with how the material reacts to different temperatures, light sources, and measurement angles. We also want to find the maximum and minimum shear values that the materials can record, if the material has an endurance limit, and the materials sensitivity to shear. Our group expects to answer all of these questions within this school year and present them to Dr. Oates and Dr. Dickinson in an impartial manner. With time permitting we will also test a solid form of the cholesteric crystals, indicate what type of applications the material is suited for, and design a “sensor package” that could be reproduced for future tests.

Design Criteria:

Some design constraints were imposed because of the fact that the testing apparatus was inherited. The first main constraint is space. The baseplate is 12” by 4.5” so nothing can go outside of that rectangle. 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 form any angle from 0 to 90 degrees. The light that is going to be used must be white so that it contains the highest wavelength distribution across the visible color spectrum. The light must also be kept stationary and in the same place for each experiment. 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 load applicable is 1N due to the given load cell.

The time available for the project development is a constraint. The first set of experiments should be completed by December 7th. When the first set of experiments is completed, a more expensive polymer form of the cholesteric crystals will be ordered. This polymer takes a good deal of time and money to create and the procurement of the polymer will only occur if the first set of experiments is done on time and if the budget is kept low. The project budget to conceptualize and build the device is $2000. 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.

Individual Tasks:

- Design a holder for the light source
- Design an apparatus for the fiber optic cable
- Devise a shear block that has the ability to apply heat to the specimen
- Create a support system for the shear block to reduce rotation from the motor
- Adjust legs of apparatus to fit the design criteria
- Submit purchase order for the materials needed

Concept 1:

Figure 7 below shows the design for concept one with the design of the light and sensor holder along with the shaft support. 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.

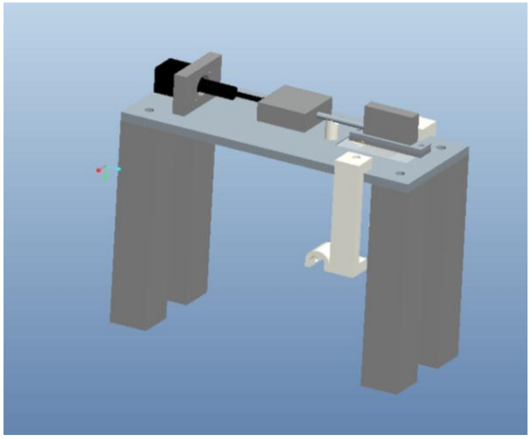

Figure 7- Concept 1- Dual Light Sensor Holder

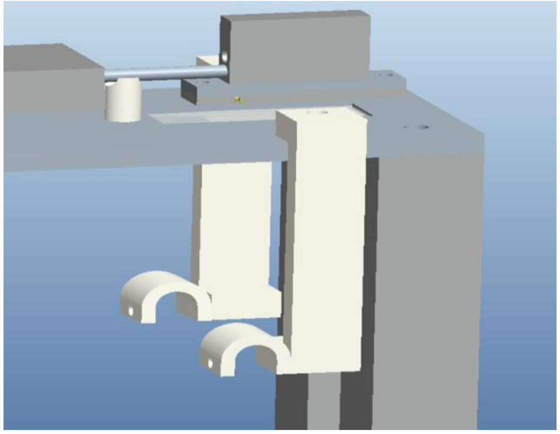

Figure 8- Close side view of holders and bracket to balance the shaft

Concept 2:

Shown in figure 9 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.

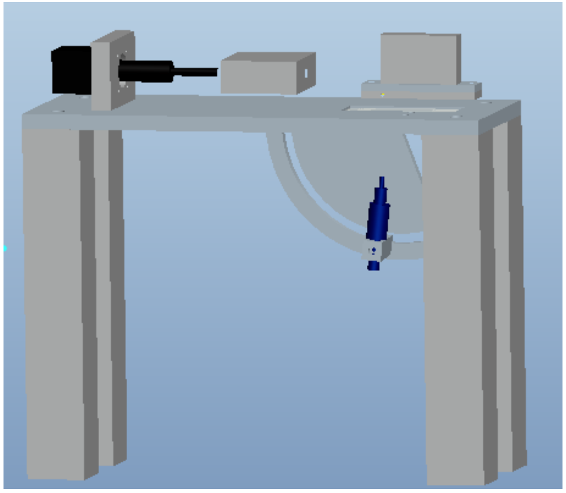

Figure 9- Adjustable sensor holder with degree indicating quarter disk

Concept 3:

Figure 10 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.

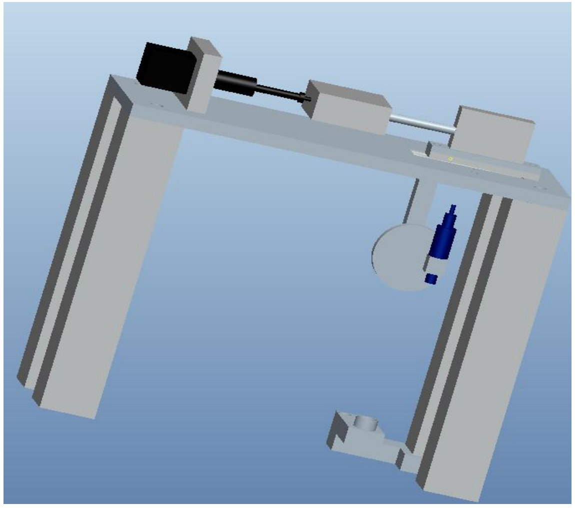

Figure 10- Concept 3- Wheel fiber optic sensor holder

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
Simplicity	0.20	2	0.40	4	0.80	4	0.80
Feasibility	0.20	3	0.60	5	1.00	4	0.80
Accuracy	0.40	2	0.80	4	1.60	1	0.40
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		2.35		3.85		2.65

Table 1-Decision Matrix of Design Concepts

Design Conclusion:

A decision matrix was used and along with the input from Dr. Oates and Matt Worden it was determined that it would be best to combine concepts one and two. Once 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, so placing the light holder at the base of the apparatus without being able to move was 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 if friction will be generated and 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. Still to be determined for the shaft support is if the support will be placed by the load cell or on the opposite side of the shear block due to how far the translation will be. If the support will have to be on the opposite side of the shear block then the base plate will need to be extended to accommodate for the support without interfering with the shear block motion.

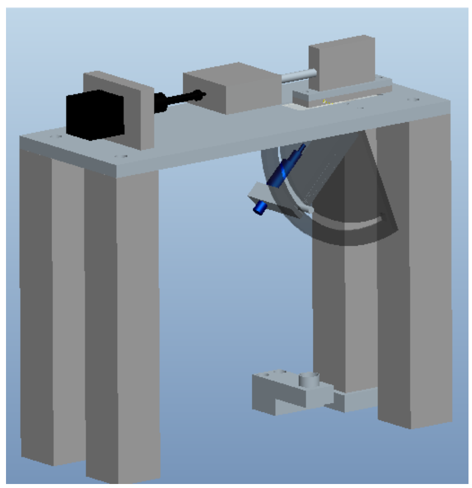

Figure 11- Final design concept after the recommendations from Matt W. and Dr. Oates

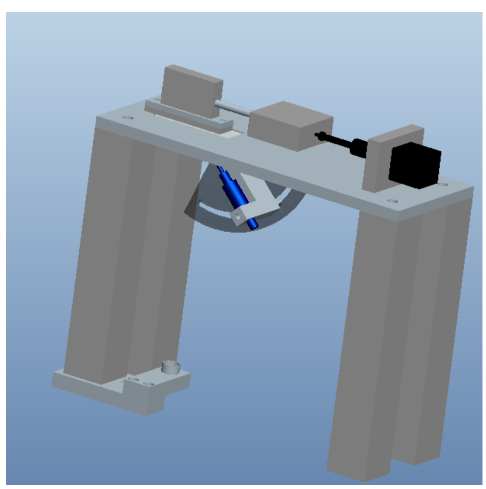

Figure 12- Angle of final design to show the light source holder

Shear Block Design:

The shear block was designed to house a heating pad and reduce a moment caused by the linear servo motor. The shear block is made out of three rectangular pieces of aluminum. The upper face of the bottom piece of the block that drags along the surface of the baseplate 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.

Light Source Selection

The light source for the apparatus is needed to be determined, so that the reflection off the specimen can be collected in determination of the data. There are many different ways of having a light source be a part of the experiment, in which the possibility of a light source having a pre-determined wavelength by applying a lens that only lets blue light pass through. After speaking with Dr. Oates and with Mr. Worden the light source for the experiment should be white light in which the specimen can reflect light the way that the liquid crystals would normally be affected by in real world environment. For placement of the light source it has been suggested to keep the light in a constant location as to reduce in error due to the variable of moving the light source. Once taking the advice the light source has been moved to directly below the specimen, this will affect the results because of how the wavelengths of the light reflect off the specimen.

Works Cited

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