Shear Stress Sensor Design

EML 4551C-Senior Design- Fall 2012

PRODUCT SPECIFICATION AND PROJECT PLAN

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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.

Desired Outcome

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.

Project Specifications

This project is based on an evaluation of a liquid crystal with properties that allow the measurement of shear stress. This material shows a relation between wavelengths reflections and shear stress applied. To achieve the requirements for the optical sensor product, some experimental specifications must be fulfilled for the initial apparatus:

-The sensor has to measure only shear stress, rather than pressure.

- A material layer thickness "t" must be specified in order to optimize the correspondence between the real stress applied and the received stress.

-A linear servo motor has to be used to apply a shear stress load of 1N, which will be measured by the load cell.

-The device should be capable of vary the angle of the light imposed and also the temperature range.

-A LED light must be applied and its reflection captured by a spectrometer, which is connected with a computer software. Different wavelengths have to be tested to see the material response.

Research

To build a shear stress sensor, first of all is important to know the properties of the material analyzed. There are a wide range of techniques for shear stress measurements. However, because of those properties, some of them are inappropriate for specific applications such as aquatic environments or high loads ranges. To come over these restrictions, in this project will be developed an optical sensor based on a cholesteric liquid crystal which demonstrate the phenomenon of selective reflection. In other words, shear stress is applied to this material its structure changes to adjust the wavelength of light. As a result, different wavelength of the reflected light is indicative of the shear stress experienced by the test surface.

The most important characteristic of device is that it has to be able to measure only shear stress, rather than pressure. To achieve this goal, the strain matrix should look like the matrix below:

$$\begin{pmatrix} \varepsilon_{xx} & \varepsilon_{xy} & \varepsilon_{xz} \\ \varepsilon_{yx} & \varepsilon_{yy} & \varepsilon_{yz} \\ \varepsilon_{zx} & \varepsilon_{zy} & \varepsilon_{zz} \end{pmatrix} = \begin{pmatrix} 0 & \varepsilon_{xy} & \varepsilon_{xz} \\ \varepsilon_{yx} & 0 & \varepsilon_{yz} \\ \varepsilon_{zx} & \varepsilon_{zy} & 0 \end{pmatrix}$$

$$\varepsilon_{xx} = \varepsilon_{yy} = \varepsilon_{zz} = 0$$

Considering the Hook's Law, and assuming $\varepsilon_{xx} = \varepsilon_{yy} = 0$,

$$\varepsilon_{zz} = \frac{1}{E}\left[\sigma_{zz} - \nu(\nu\left(\sigma_{yy} + \sigma_{zz}\right) + \sigma_{yy})\right]$$

Substituting the terms for σ_{xx} and σ_{yy} from the Hook's Law,

$$\varepsilon_{zz} = \frac{1}{E}\left[\sigma_{zz} - \nu\left[\left(\frac{\nu\sigma_{zz}}{(1-\nu)} + \sigma_{zz}\right) + \left(\frac{\nu\sigma_{zz}}{(1-\nu)}\right)\right]\right] = 0$$

The value of "ν" that solves the equation above is $\nu = 0.5$. As a conclusion, an optimum sensor for shear stress should be made from a material with the same poison ratio ν calculated, or close.

Budget

For the design of the shear stress sensor the sponsor has donated two thousand dollars to the project. Based on what knowledge the group currently has of the project the budget will be small because many of the parts that are needed are already acquired by our faculty advisor Dr. Oates. There is the possibility for experimenting in a solid plastic phase of the cholesteric which currently we do not know the cost of currently; if the polymer is very expensive the budget will have to be reformulated to maintain the donations from the sponsor. For the current time the budget will be low based on most of the components being in the laboratory already.

Gantt Chart

The figures below are Gantt charts of the schedules for the assignments of EML 4551C and for the design schedule of the project. The schedule is lenient in what is to be accomplished in for the design of the project, but for the assignments due in class there is a strict scheduling as to accomplish all of the goals in time for the reports to be turned into the professor/TA. The scale for the Gantt charts are weekly for the completion of assignments. For the assignments chart, the schedule is based on one semester because only the deadlines for fall assignments are known at this current point in time. The schedule for the design is set for both semesters because the steps needed to accomplish the experiments have been clearly set by Dr. Oates and his assistant.

Figure 1- Design Schedule

Figure 2- Assignment Schedule