Visualizing Stress Fields With Photoelasticity Under Multiaxial Loading

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***Abstract*— The stress developed in a component due to external loading is one of the most important criteria for engineers to understand as stress governs material failure. However, the internal stress distribution/field is often difficult to visualize. In order to impart a better understanding of stress to students and visualize these distributions for research purposes, Dr. Sinko has requested the design of a multiaxial loading device that uses photoelasticity to visualize stress fields developed in transparent samples via a polariscope. This device should show the stress field of any clear sample subject to compressive, tensile, torsional, and/or bending loads. In this work, a loading frame is designed that holds a transparent sample and applies all loading conditions through the use of a linear actuator and two stepper motors. Further, a control system is developed that allows for user input from a command-line interface for specification of loads and displacements.**

Keywords-Photoelasticity; stress; distributions

I. Introduction – Photoelasticity

Students enrolled in mechanical engineering programs must take mechanics of materials classes as part of their core curriculum. In this class, students learn about the stresses and strains that form within materials under load. While the stresses and strains are understood through equations and definitions, it can still be difficult to fully understand these concepts without being able to visualize how these quantities varying internally within the materials.

One method of visualizing stress is through the use of photoelastic behavior of transparent materials. The photoelastic effect is the rotation of the polarized light by the stress field in the material generates a pattern displaying contours of equal stress [3]. In other words, as the stress distribution in the material changes, the visual patterns observed when looking through the sample will also change and can be used to show the stress distributions.

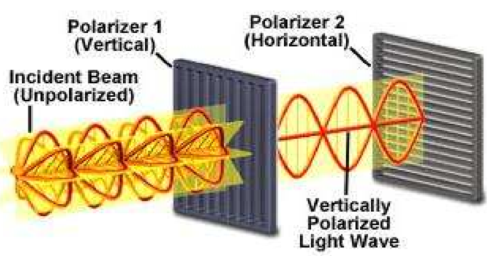

Figure 1: Polarization of Light Waves [1]

As shown in Figure 1, photoelasticity uses special filters to polarize light that will shine though the transparent material. Normal light occurs as waves that will disperse within a clear object and no patterns will be seen. When light is polarized, however, the waves that make up the light are restricted to a single plane [2]. The light in the photoelasticity device is provided by an array of LEDs. The light shines through a polarization filter, the demonstration sample, then another polarized filter rotated 90º from the first filter. This orientation allows the light to display the stress distributions for demonstration.

If the light shining through a clear object is polarized, the light will change based on the stresses that are distributed within the clear object due to a change in the refractive index of the material predicted by the photoelastic effect. Put more simply, different values of internal stress correspond to the different colors of visible light as the stressed areas will act similarly to a prism and separate the colors. As shown in Figure 2, this provides a mechanism for visualizing stress distributions and point of stress concentration in the material.

Figure 2: Photoelastic Beam no loading (left) and under combined loading (right) [2]

II. Design Requirements

The objective for the project was to create a loading device that can view the stress fields in test sample using photoelasticity. The project needed to be able to apply up to 3 types of loading at a single time with loads ranging from 0 Newtons to 100 Newtons. The user should be able to control the applied forces by giving the system the forces or the desired strain on the sample and some size and material properties of the sample. The device also needed to be able to be moved easily so that it can go in and out of classrooms without extra equipment to move it.

III. Structural Design

To demonstrate how stress fields change under different loading conditions, a structural frame was developed that was capable of supporting the sample and provides three primary types of loading: torsion, axial loading (tension and compression), and bending. The overall design of the device is pictured in Figure 3.

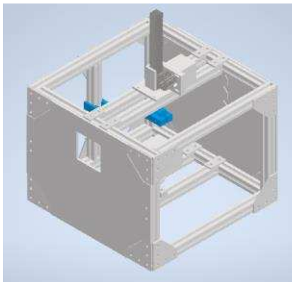

Figure 3: Isometric view of Photoelasticity device

A. *Torsion*

To apply torsional loading (i.e. twisting) to the sample, the top clamp is held fixed while the bottom clamp is rotated. This is accomplished by mounting the bottom clamp to a gear that rotates on a pin and is clipped into place. The gear is turned by using a stepper motor and another gear to produce the required torsional load. This configuration allows the motor to be positioned away from any axial loading that can be applied concurrently.

B. *Axial Loading (Tension/Compression)*

Tensile and compressive loading of the sample fall under the same system where the sample will either be stretched or compressed. Axial loading is accomplished through a rack and pinion system driven by a stepper motor. This is the selected method over a discrete linear actuator as it is more rigid and can better withstand forces from other axes. The discrete motion of the stepper motor provides an accurate representation of the amount of displacement caused in the specimens, allowing the load to be more closely controlled.

C. *Bending Moment*

Bending of the sample is accomplished by applying a transverse point load which causes a bending moment to develop throughout the sample. The point force is applied using a linear actuator. It is mounted so that it can be moved up and down the frame to set the position at which the force can be applied and thereby change the bending characteristics of the beam.

IV. Control System

Software running on a Raspberry Pi controls the loading mechanism's actuators through the Raspberry Pi's general-purpose input/output interface. The loads applied to the specimens are user-specified. The values are entered through a typical keyboard and monitor interface. Once a load has been specified, the actuators remain active until the specified load has been applied. The system will hold the loading state until the user specifies that the system should reset, then all loads on the specimen will revert back to default (zero).
Since this system does not rely on sensor feedback, the actual applied load is approximate with regards to the user-specified load. The software calculates the necessary displacement for a specified load in the case of torsional and axial loading. However, a specific load can be applied with the linear actuator by supplying specific currents. A logic diagram for

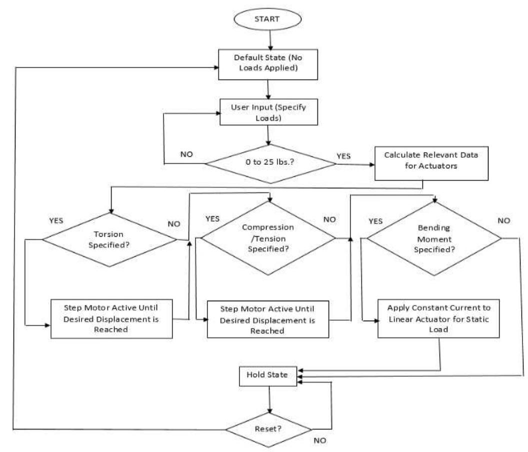

Figure 4: Logic Diagram for the Control System

the developed software if shown in Figure 4.

V. Discussion

Understanding stress is vital to any mechanical engineering student. We were able to successfully create a prototype to display stress for students to benefit from in their studies.

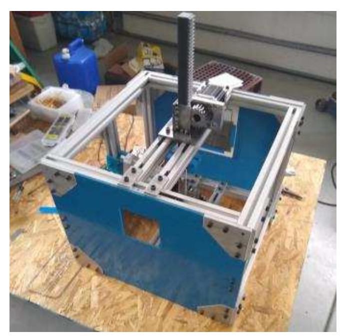

Figure 5: Prototype Photoelasticity device

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