Feedback, Control, and Photoelasticity Measurement System

Senior Design Team 46
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***Abstract*—This document gives a brief overview of the prototypes completed by the 2021-2022 senior design team 46. Which include a portable table-top machine and a material testing housing unit. Both devices exploit the photoelastic effect and demonstrate optical stress distributions within specimens,**

I. INTRODUCTION

Traditionally, stress-strain data for a material is collected by subjecting a material specimen to a tensile test. During these tests, load cells and strain gauges affixed to the specimen collect data that can be used to quantify the material deformation. While this type of test provides valuable data about the material's mechanical properties, it does not provide a means to determine the stress distribution/field within the specimen. To address this shortcoming, a device that can collect stress-strain data while simultaneously allowing for the visualization of stress distributions is desirable.

The visualization of stress distributions within a material can be achieved by using the concept of photoelasticity. Photoelasticity, or the photoelastic effect, is a phenomenon related to changes in the optical properties of a material subjected to mechanical deformation. Changes in these properties can be visualized using a process that filters out all coordinate light waves into a single coordinate direction. To achieve this effect, white light is shined through two polarized lenses rotated 90 degrees relative to each other. Once the material is deformed and undergoes stress, the wavelengths are refracted inside the specimen. These stresses are then viewed with the photoelastic effect where the user can analyze the stress distributions.

For the stress distributions to be visualized properly, the specimen used must be a transparent material. The tabletop unit uses 1/8" thick plexiglass, while the MTS test uses research specific materials.

The goal for this project was to design and fabricate two devices that incorporate the photoelastic effect:

1. A portable device that is capable to load a specimen and visually demonstrate the photoelastic effect during tensile and compression tests for students in undergraduate mechanics courses. (Tabletop Unit)
2. A prototype that could attach to an industrial tensile test machine and be used to record photoelastic behavior during tensile tests (MTS Housing)

II. TABLETOP UNIT

Demonstration of hands-on optical stress distribution is at the forefront of the goal for this device. This prototype will allow professors to bring the machine into a classroom and demonstrate to students how to analyze materials based on their optical properties. The tabletop unit is an improvement from a previous design team. These improvements include precise loading, real-time imaging, data storing, adequate force application, and a graphical user interface. This device performs a tensile test while also capturing the photoelastic effect while the test is being conducted. The previous design used a stepper motor along with a gear and rack arraignment to apply the force to the specimen. Upon verification, conclusions were made that the 0.869 lbf produced was not capable of exerting an acceptable amount of force to adequately display stress concentrations. For this reason, the updated design utilizes a pneumatic system. This system includes an air compressor, pressure regulator, solenoid valve, and a piston-cylinder to apply force to the specimen. The air compressor will provide a max pressure of 100psi, while the mechanical pressure regulator will allow the user to adjust how much pressure the system undergoes. The solenoid valve will allow the air flow to change directions within the piston-cylinder. With this design, the system can produce a maximum force of 124 lbf to visually display the stress concentrations within the specimen. To exert the force onto the specimen, the clamping arrangement in Figure 1 uses a vice to clamp the bottom of the specimen while using a machined aluminum clamping system to hold the top of the specimen. This clamping system also includes a load cell (orange wire) that presents the load to the user in real-time.

Preliminary tests were conducted using 1/8" plexiglass specimens. These test specimens were designed to include preloaded stress within the specimen using holes of various geometry and were cut using a laser cutter.

The prototype testing showed very promising results regarding showing the optical stresses induced by a tensile test. The concluding results are shown in Figur*e 2* .

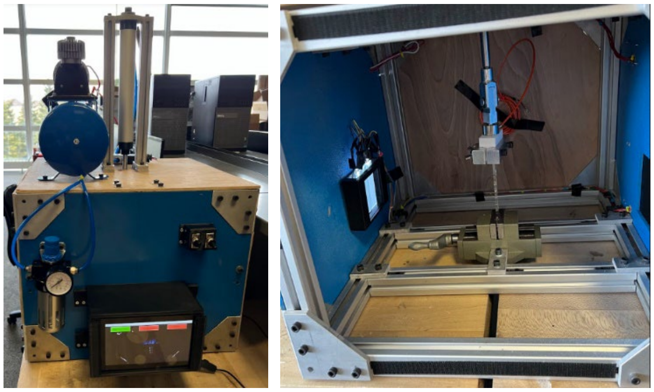

Figure 1 – Exterior & interior of Table-top Unit

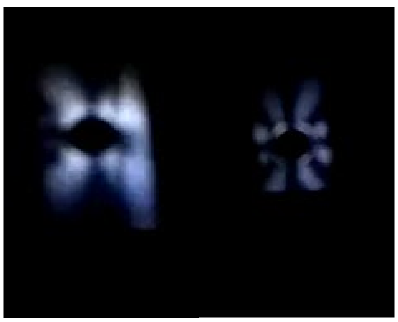

Figure 2 - Table-top compression & tension test with a circular hole

III. MTS Housing

The MTS housing device is attached to an industrial material testing machine. This machine can produce much higher forces than the tabletop machine. This device will be primarily used to conduct research testing. The device shares much of the same functionality as the tabletop machine such as real-time imaging and data storing. The MTS housing device was designed to be compatible with an MTS (Material Testing System) 810, the entire frame of the device was 3D printed out of Black PLA. This design includes all the materials to obtain the photoelastic effect, a camera, digital display, and raspberry pi. The materials used to obtain the photoelastic effect include white LEDs, polarized film, and transparent material (plexiglass). The camera will be used for capturing images and videos. The digital display will be used for viewing the data in real time along with allowing the user to control the system. The Raspberry Pi is the computer that will be controlling the whole system and storing data. The image in Figure 4 shows the device fastened to the MTS 810 and fully functional. The functionality will allow researchers to save images and videos from the test to include in their research documentation. For prototype testing purposes, a specimen of quarter-inch plexiglass was stressed under tension. A ¼” diameter hole was drilled in the middle of the specimen to create a stress concentration to be easily visualized. The internal stress concentration surrounding the hole is illuminated via the photoelastic effect and is depicted in Figure .

Figure 3 - MTS Device

Figure 4 – Photoelastic effect of MTS ¼” plexiglass test

IV. Conclusion

Both prototypes from this design group achieved 100% functionality and are ready to be used for their intended purposes. Successful optical stress distribution in both devices will aid in educational and research progression. There were some short comings during this project such as short circuiting a Raspberry Pi and not creating an easy access to changing specimens in the MTS device. The MTS device could be modified such that it allows the user to easily load specimens into the testing area. Simply cutting a hole on the side of the device while also fabricating a cover for this hole would easily fix this problem. For the table-top machine, the weight of the machine is unfortunately quite heavy. Which could be a challenge for professors transporting the device from classroom to classroom.

Acknowledgment

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