Omnidirectional Force Sensor

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Abstract: For this project, we aimed to create a low-cost force plate that would allow further research into how small forces applied at a specific location can be measured with precision to determine their magnitude. The project included the conception, construction, and testing of a force plate that measures both the force applied, the direction, and the location of the force using measured strain values. Referring to previous research, we determined the best design and created a testable model using COMSOL. The prototype was constructed to leverage the simulation results for optimal strain measurement locations, and experimental validation compares well with finite element analyses.

Background:

The inspiration for this project was the lack of affordable and accurate pressure sensing tools. Our goal was to construct a force plate that is sensitive to the magnitude of force in an area of testing. Research into force plate designs indicated that a maltese cross design and strain gages would provide the basis to an accurate and low-cost force plate.

Placement of the Strain Gages:

Figure 1 shows a comparison between our analytical calculations and a finite element analysis on COMSOL of the length of one beam of the maltese cross. The data closely matches the analytical expression, with deviation towards the end due to the boundary condition. Both calculations and simulation indicate that the high region of strain is approximately 0.6415 in to 4.697 in from the center.

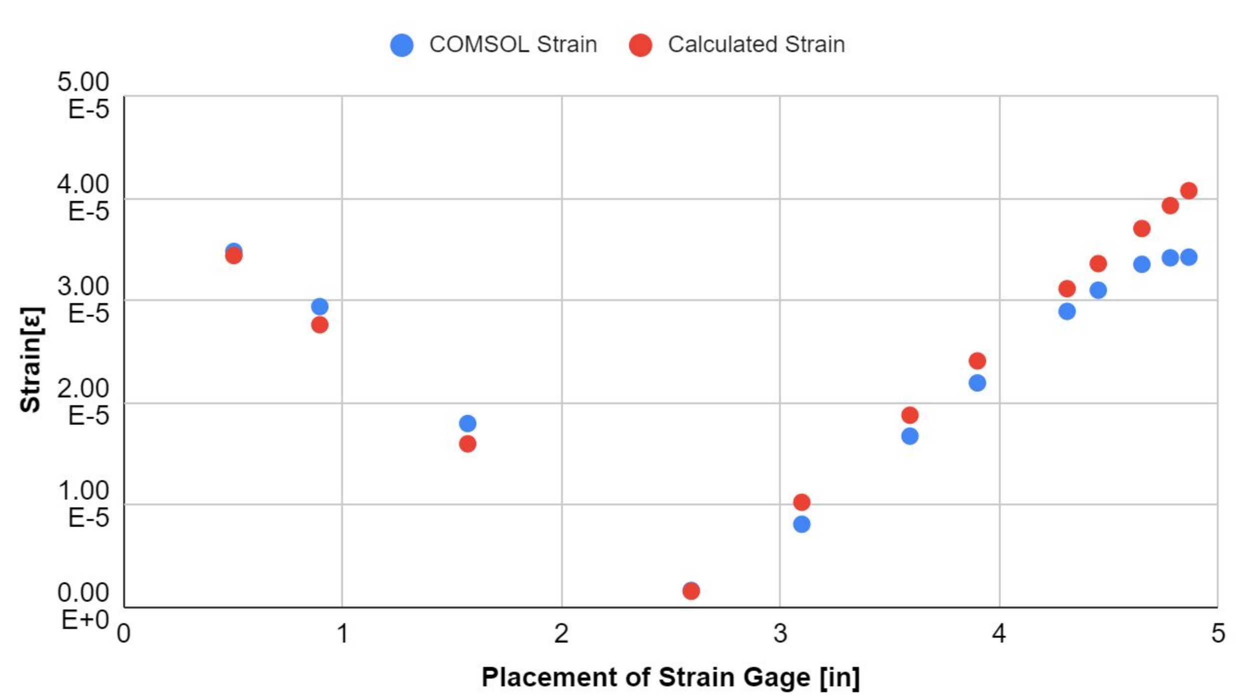

Fig. 1 Plot comparing measured vs simulated strain of 4N placed at the center of the cross.

Design Process

The maltese cross design was chosen since it lets us measure six degrees of freedom with ease and with minimal strain gages attached to the high regions of strain determined in Fig. 1. Aluminium 6061, strain gages, and wood were used to construct the force plate. A spring push pull force sensor of 5 N was used on the plate to calibrate it and check for symmetry around the center.

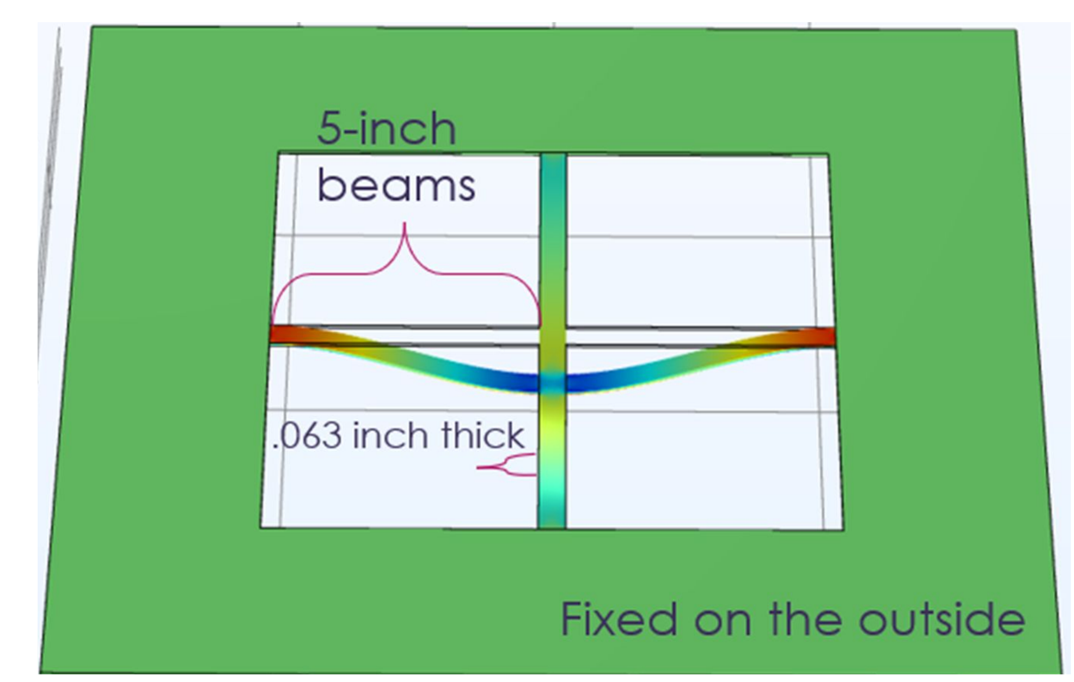

Fig. 2 The x direction of strain modeled on our final design in COMSOL with a force of 5N in the center. The red and blue show a high absolute value of strain.

Results:

In Fig. 3, different symbols correspond to the strain values for four different, but symmetric loading conditions of 5 N 2.5 in along each arm. We see that there is rotational symmetry where each gage measures similar values with deviations due to slight variation in the gage positioning. These results agree with the COMSOL simulation as well.

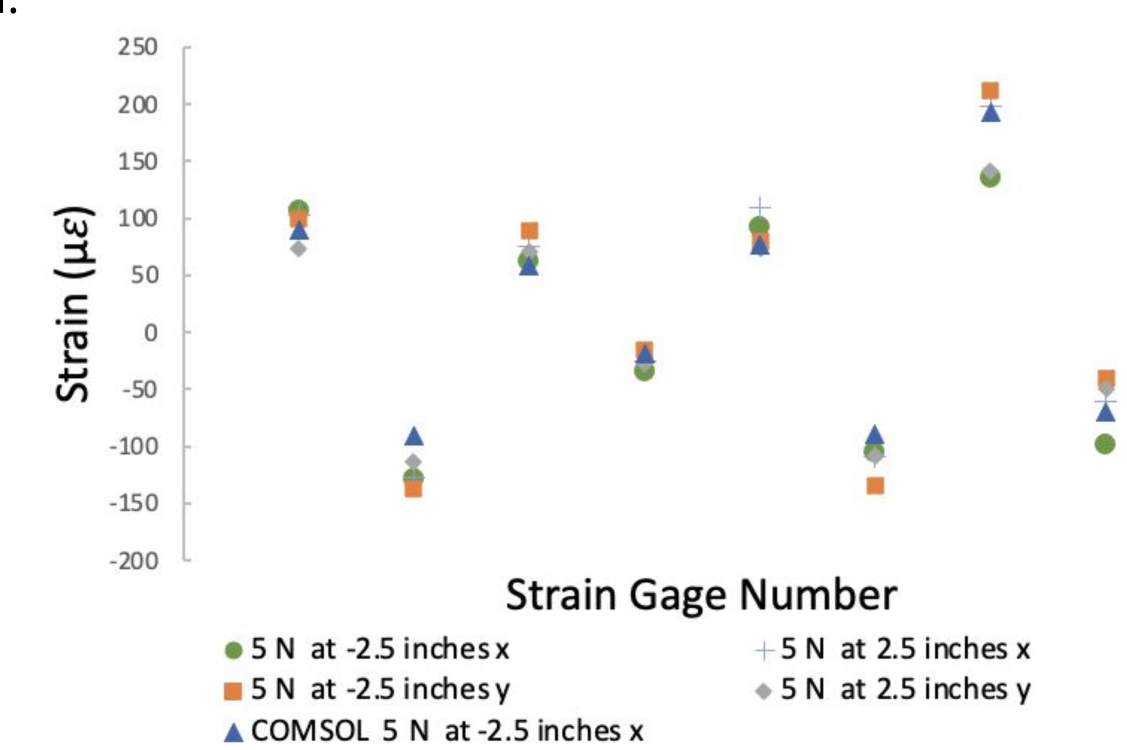

Fig. 3 Strain values for 5 N forces applied at symmetric locations along the different axes of the plate.

The strains for a 5 N force applied at the center of both beams are equivalent to the COMSOL values at the same locations. The different symbols in Fig. 4 correspond to both data sets.

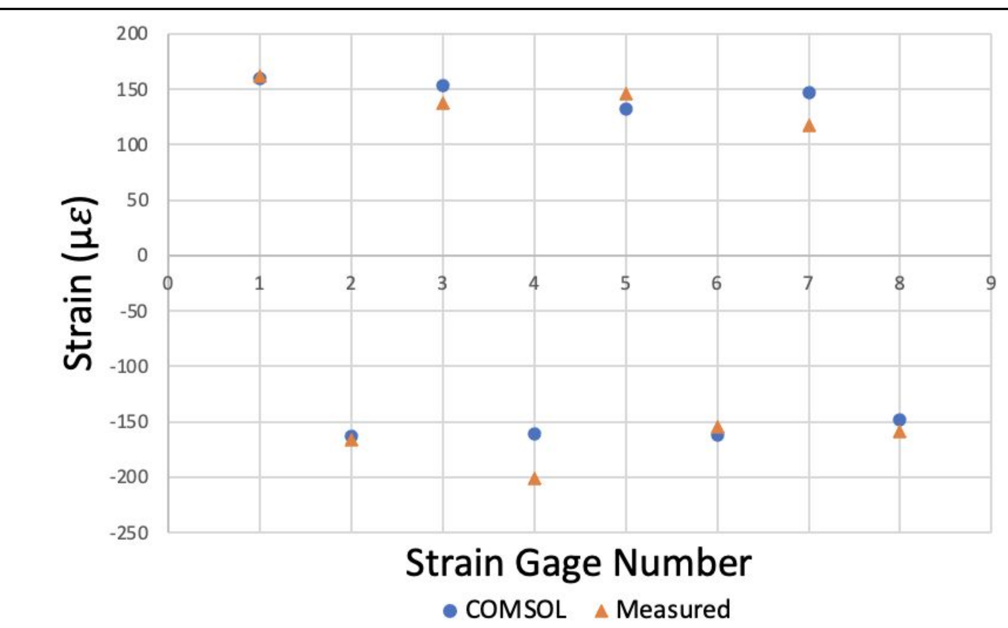

Fig. 4 Plot of measured and modeled strains for a 5 N force applied at the center.

The equation used to determine the magnitude of an unknown force applied at the center from any strain value, ε, is given by

$$F = \frac{\frac{1}{3}E\varepsilon b h^2}{L\left[0.25 - \frac{\left(\frac{L}{2}\right)-x}{L}\right]} \quad \text{(I)}$$

where E is the modulus of elasticity of the aluminum, $\frac{1}{6}bh^2$ is the moment of inertia of the beam, L is the length of the fixed beam, and x is the distance from the strain gage to the applied force.

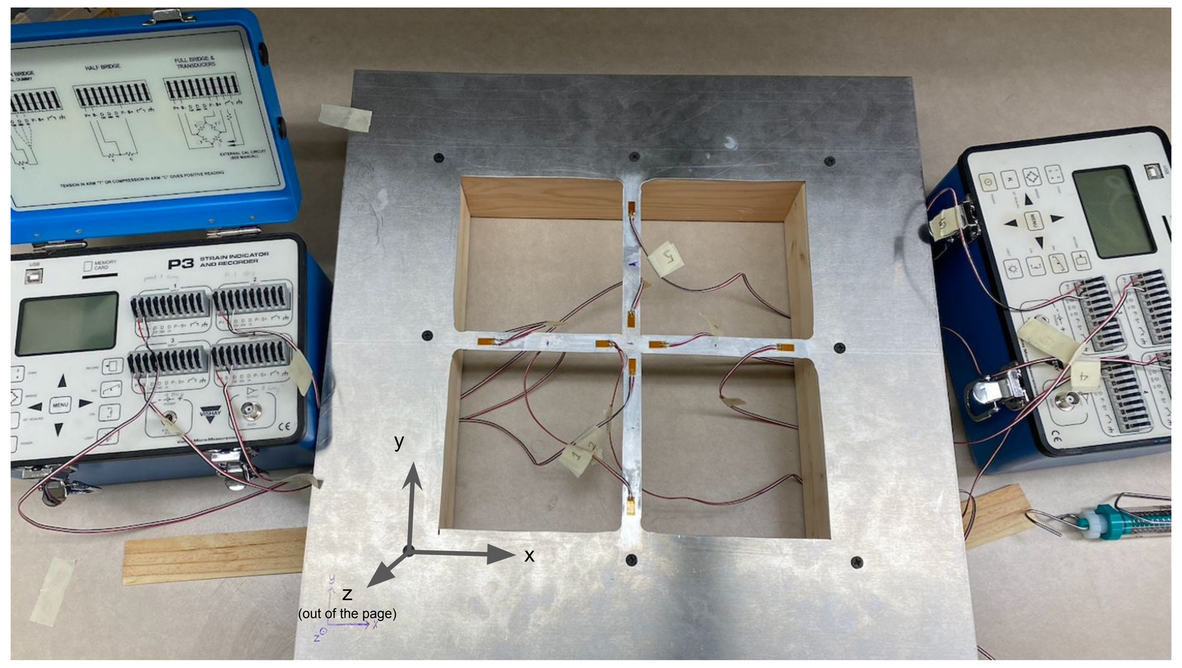

Fig. 5 The final force plate connected to the strain indicators.

Conclusion:

We set out to create a force plate that allows the user to find the value of an unknown applied force and its location on the plate. We built an aluminum symmetric force plate and a working COMSOL model. Using strain gages and the equation above, we were able to accurately back out a small, unknown force. This can be used as the basis for determining the angle of a force applied at the center to then find the magnitude and location of a force applied at different locations on a top plate attached at the center.

References:

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2. Kim, Gab-Soon, Dae-Im Kang, and Se-Hun Rhee. "Design and Fabrication of a Six-Component Force/Moment Sensor." *Sensors and Actuators* 77 (September 28, 1998): 209–20. http://www.elsevier.nlrlocatersna/.

Acknowledgments

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