Load Cell Design Using COMSOL Multiphysics

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Abstract

COMSOL Multiphysics was used to design the spring element of a binocular load cell. The model predicted the location of four high strain regions and their amplitudes for loads from 0-2.5 kg. The load cell was fabricated from 6061 aluminum and four strain gages were installed at the high strain regions. Absolute mean model-predicted strain was 1.41% of measured strain. The load cell transducer was highly linear.

Introduction

Load cells are commonly used force transducers that convert an applied mechanical load into a voltage. Load cells comprise spring elements that deform with load, strain gages that vary their resistance with deformation of the spring element, and a Wheatstone bridge circuit that produces voltage proportional to strain. The popular “binocular” design uses a beam with two holes and a web of beam material removed as the transducer spring element. Since the complexity of this geometry prevents prediction of strain via simple calculation, a COMSOL model was used to guide load cell design.

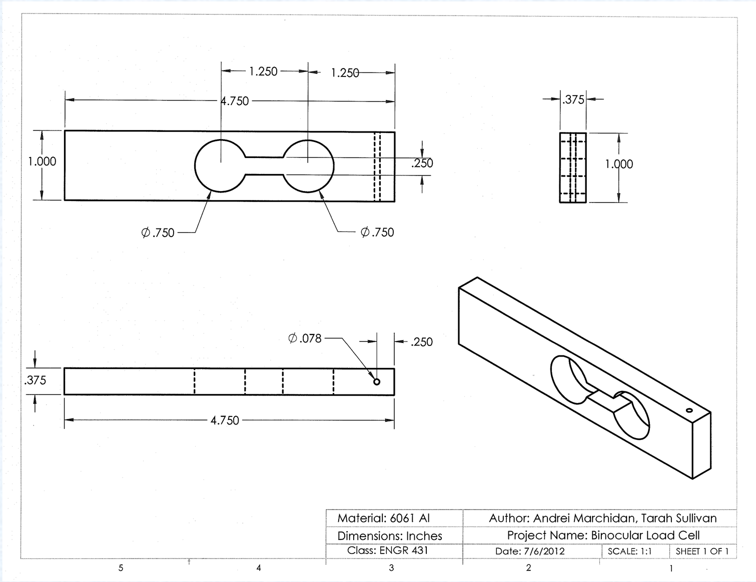

Fig. 1: Imported SolidWorks CAD drawing.

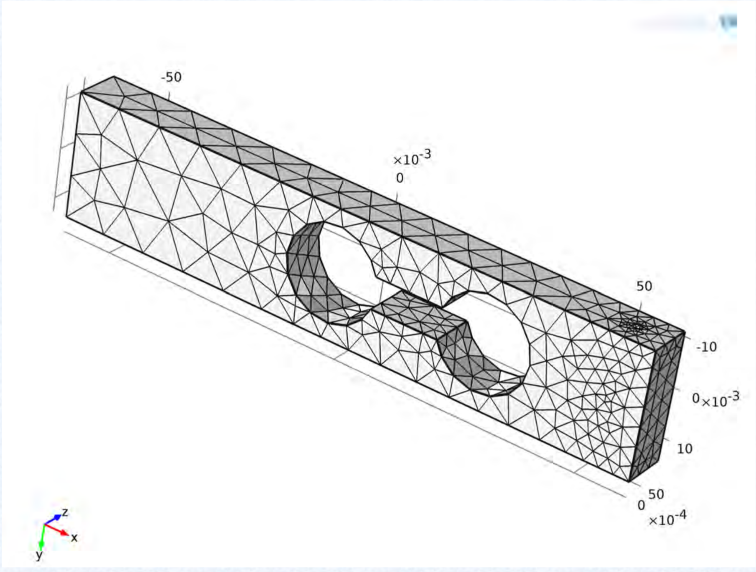

Fig. 2: COMSOL generated fine mesh.

COMSOL Multiphysics Model

A 3-dimensional solid mechanics model was built, with geometry imported from SolidWorks (Fig. 1). The spring element was modeled as homogeneous, linearly elastic 6061 aluminum. The left-hand end of this beam was defined as a fixed constraint boundary. Loads were applied to the right-hand end of the beam as a point load in the y direction. A fine physics-controlled mesh was generated (Fig. 2) and a stationary analysis was performed, using default solver settings. Model geometry parameters were varied until the sum of strains in all four high strain regions (Fig. 3) provided several hundred micro-strain (1e-6) over the desired load range of 0-2.5 kg. After the geometry was established, strain gage locations T1, C1, T2 and C2 were defined as point probes and the load was varied as a parameter sweep analysis.

Model Verification

The load cell spring element was milled from 6061 aluminum bar stock and strain gages were mounted at the four high strain regions. Strain gages were general purpose (Vishay Micro-Measurements CEA-13-240UZ-120) and installed using standard techniques [4]. Gages were wired with 27 AWG polyurethane insulated solid copper wire and gage lead wires were of uniform length to prevent unwanted lead resistance differences. The four gages were wired as a full active bridge (Fig. 4) using four conductor shielded cable and a Vishay P3 Strain Indicator and Recorder [5].

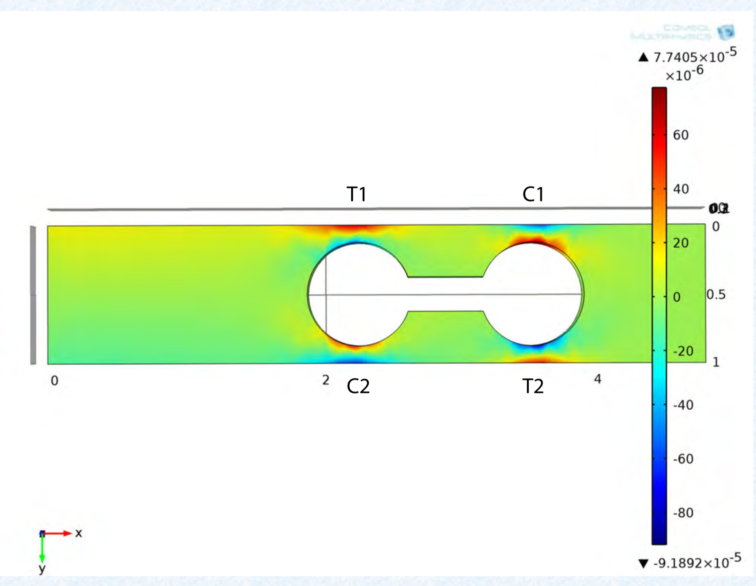

Fig. 3: High strain regions T1, C1, T2, and C2.

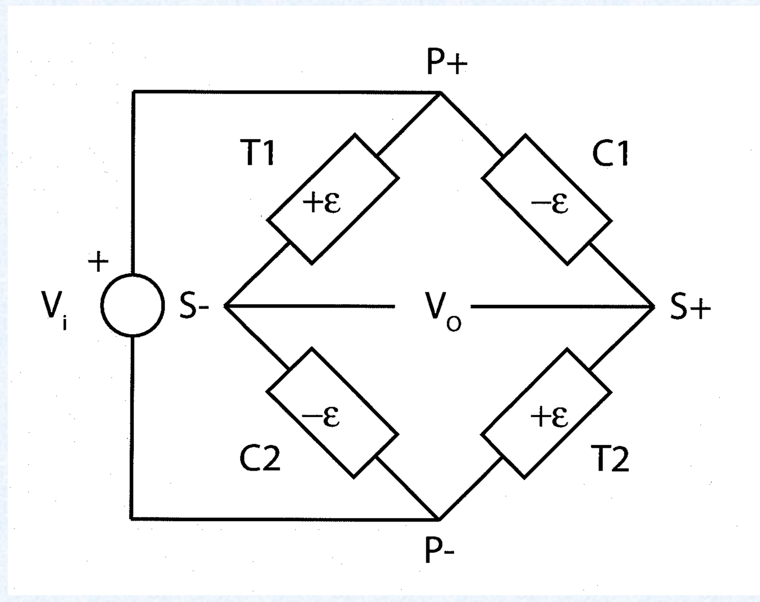

Fig. 4: Full bridge transducer.

$$\epsilon_{\text{total}} = \epsilon_{\text{T1}} - \epsilon_{\text{C1}} + \epsilon_{\text{T2}} - \epsilon_{\text{C2}}$$

Results

Fig. 5 shows bending strain arising from an applied load of 1 kg. The highly scaled deformation image shows how the four high strain regions correspond to simultaneous tension in the T1 and T2 regions and compression in the C1 and C2 regions. Table 1 lists strain corresponding to locations T1, C1, T2 and C2, total COMSOL model strain, and measured total strain. Model predictions closely agreed with measurements.

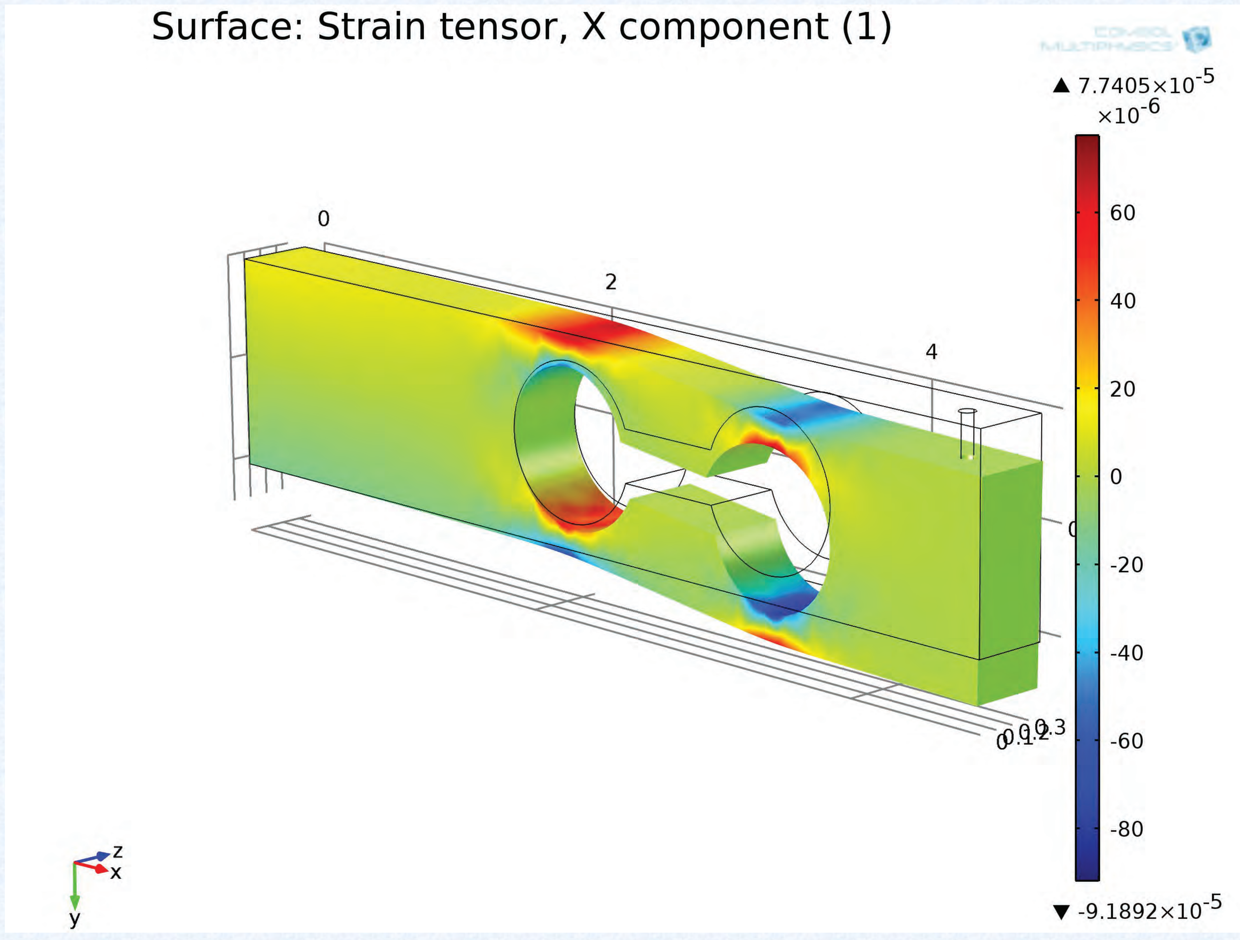

Fig 5: Strain and deformation for 1 kg load.

Table 1: Comparison of model and experimental strain measurements.

Mass [g]	T1 [ϵ]	C1 [ϵ]	T2 [ϵ]	C2 [ϵ]	COMSOL [$\mu\epsilon$]	Measured [$\mu\epsilon$]	Difference [%]
500	3.24E-05	-2.71E-05	2.69E-05	-3.26E-05	119	120	0.840
600	3.89E-05	-3.25E-05	3.23E-05	-3.92E-05	143	144	0.770
700	4.54E-05	-3.80E-05	3.76E-05	-4.57E-05	167	167	0.180
800	5.19E-05	-4.34E-05	4.30E-05	-5.22E-05	191	190	-0.262
900	5.84E-05	-4.88E-05	4.84E-05	-5.88E-05	214	214	-0.187
1,000	6.49E-05	-5.42E-05	5.38E-05	-6.53E-05	238	233	-2.183
1,100	7.14E-05	-5.96E-05	5.92E-05	-7.18E-05	262	257	-1.908
1,200	7.78E-05	-6.51E-05	6.45E-05	-7.83E-05	286	280	-1.995
1,300	8.43E-05	-7.05E-05	6.99E-05	-8.49E-05	310	304	-1.809
1,400	9.08E-05	-7.59E-05	7.53E-05	-9.14E-05	333	327	-1.920
1,500	9.73E-05	-8.13E-05	8.07E-05	-9.79E-05	357	350	-2.016
1,600	1.04E-04	-8.68E-05	8.60E-05	-1.04E-04	381	373	-2.048
1,700	1.10E-04	-9.22E-05	9.14E-05	-1.11E-04	405	397	-1.878
1,800	1.17E-04	-9.76E-05	9.68E-05	-1.18E-04	429	420	-2.189
1,900	1.23E-04	-1.03E-04	1.02E-04	-1.24E-04	452	445	-1.549
2,000	1.30E-04	-1.08E-04	1.08E-04	-1.31E-04	477	468	-1.887
2,100	1.36E-04	-1.14E-04	1.13E-04	-1.37E-04	500	491	-1.800
2,200	1.43E-04	-1.19E-04	1.18E-04	-1.44E-04	524	514	-1.908
2,300	1.49E-04	-1.25E-04	1.24E-04	-1.50E-04	548	537	-2.007
2,400	1.56E-04	-1.30E-04	1.29E-04	-1.57E-04	572	561	-1.923
2,500	1.62E-04	-1.36E-04	1.34E-04	-1.63E-04	595	584	-1.849
					Absolute Mean % Difference		1.41

COMSOL Model Equations

$$\nabla \cdot \boldsymbol{\sigma} + \boldsymbol{F_v} = \boldsymbol{\rho}\, \ddot{\mathbf{u}}$$

$$\boldsymbol{\sigma} - \boldsymbol{\sigma_0} = \boldsymbol{C} : (\boldsymbol{\epsilon} - \boldsymbol{\epsilon_0} - \boldsymbol{\epsilon_{\text{inel}}})$$

$$\boldsymbol{\epsilon} = \frac{1}{2}\left[\nabla \boldsymbol{u} + (\nabla \boldsymbol{u})^T\right]$$

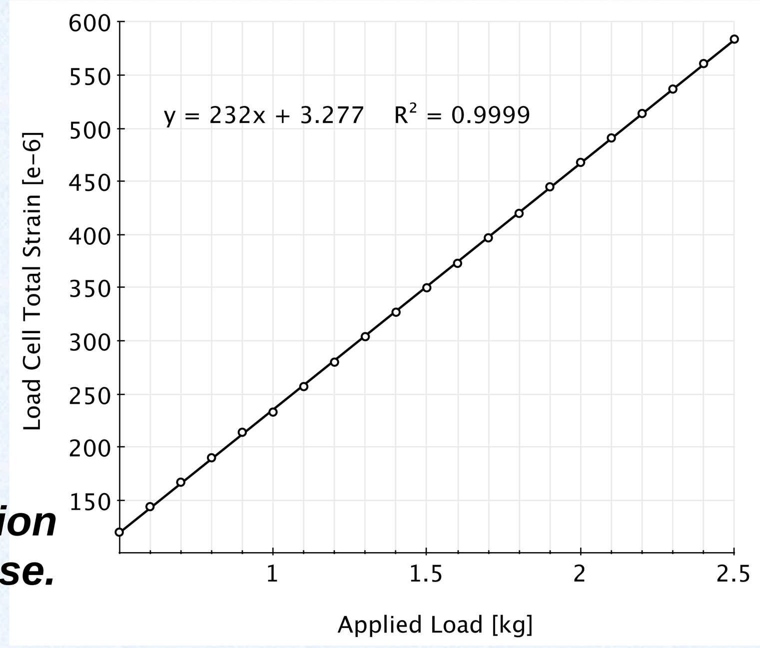

Fig. 6: Final load cell output as a function of applied load, showing linear response.

Conclusions

Load cell design is challenging due to the complex geometry of spring elements. COMSOL solid models are useful for predicting strain in these designs, for locating strain gage mounting positions, and especially for optimizing maximum strain for the desired load range. Model predictions were validated by measurements performed with the completed load cell, and model and experiment agreed with absolute mean percent difference of 1.41% (Table 1). Measured strains also showed that this transducer is linear over the entire load range (Fig. 6).

References

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