The Research of Low-profile Load Cell Design Sensitivity

Ming-Hsiung Ho¹, Ping-Hui Lee² and Pinning Wang³

¹,²Department of Mechanical Engineering, Nanya Institute of Technology, 32054 Jhongli Taiwan, R.O.C.
³Department of Business Administration, Chien Hsin University of Science and Technology, 32097 Jhongli Taiwan, R.O.C.

* Corresponding author: a morris@nanya.edu.tw

Abstract. This low profile load cells are referred to the current injection molding machine manufacturers commonly used specifications. This study is about the low-profile load cell design by the finite element analysis and experimental strain measurement verification. In the study, two low-profile load cell were designed and analyzed. The A-type cross-section of the sensor is a generally designed cross-section and has sufficient reliability for commercial use. The B-type curve cross-section load cell from the previous study found that can carry a more significant load. In the study, compare the finite element analysis results with the actual strain measurements to verify the correctness of the analysis. In the experimental verification, the two type sections loadcells were calibrated. The load cells were loading from 0kN to 60kN to measure strain values. The strain values were recorded in experiment processes. When the two types of load cell under loading, the loading force, and strain values regression linearity was 99.99 %. The measured values of the A-type and B-type load cells at 60 kN were 298 με and 170 με, and the results matched finite element analysis strain values. It was shown that the setup of boundary conditions and loading method in finite element analysis were acceptable.

1. Introduction

Strain gauge technology has practically unlimited uses in the field. It can be used to test vehicles, ship hulls, dams, and oil drilling platforms. In many instances, new testing devices have to be designed and manufactured to match the required application. For example, measuring injection mold clamp force near a mold rig may require custom strain gauge technology to capture the subtle changes in stress distribution accurately.

There are several methods of measuring strain; the most common is with a strain gauge whose electrical resistance varies in proportion to the amount of strain in the load cell. The most widely used gauge, however, is the bonded metallic strain gauge. The metallic strain gauge consists of a fine wire or, more commonly, metallic foil arranged in a grid pattern.

The grid pattern maximizes the amount of metallic wire or foil subject to strain in the parallel direction. The cross-sectional area of the grid is minimized to reduce the effect of shear strain and Poisson strain. The grid is bonded to a thin backing, called the carrier, which is attached directly to the test specimen. Therefore, the strain experienced by the test specimen is transferred directly to the strain gauge, which responded with a linear change in electrical resistance. Strain gauges are available commercially with nominal resistance values from 30 to 3000 Ω, with 120, 350, and 1000 Ω being the most common values.
Joo and his coworker [1] described the design process and evaluation results of a compact six-component parallel plate structure (PPS) load cell for measuring three components of a force, a moment and a torque. They developed a new six-component load cell including a ring-type structure using a PPS as the essential sensing element. To minimize coupling errors, we determined the location of strain gauges using finite element analysis and then connected the strain gauges, calibrated tests were performed to evaluate sensitivities, coupling errors and nonlinearity errors.

Alam [2] Multi-objective optimization of the structural design of double end beam load cell had been performed using a genetic algorithm. Two design variables were used to minimize the structural mass, to maximize the structural strength, and to maximize the level of measurement accuracy. Based on the optimal results, the weight reduction of the structure was successfully achieved of about 8.6%. The design safety factor reached 24% larger than the yield failure criterion. Therefore, the structure would undoubtedly secure against the plastic deformation. The accuracy of measurement of the load cell was predicted to reach the category of high accuracy due to the amount of strain on the strain gauge cavity managed to exceed ± 1600 με.

Lee [3] In structural health monitoring, the safety of steel beam structures can be assessed by comparing the measured maximum stress and the allowable stress of the beam calculated by a design code. For the case of a steel beam subjected to variable lateral loadings, many difficulties exist in measuring the maximum stress in a beam with point sensors that can measure the strain only at a focal point of a beam since the location and magnitude of the maximum stress induced in a beam by the loading change. Although traditional strain sensors can measure the strain only at a focal point, a vibrating wire strain gauge (VWSG) that measures integrated strains over its gage length can consider the variation of strains due to variable loadings. This paper presents an estimation model to determine the maximum strains or stresses in a steel beam based on common strains measured using VWSGs. The model is derived by defining the relation between the common strains measured using VWSGs and the maximum strains of beams. The model is experimentally tested by comparing the maximum strain directly obtained from electrical strain gages and the estimated maximum strain based on the average strain from VWSGs.

Yao [4] a new type of highly stretchable strain sensor was developed to measure the significant deformation of a specimen subjected to dynamic loading. The sensor was based on the piezo-resistive response of carbon nanotube (CNT)/polydimethylsiloxane (PDMS) composite thin films. The piezo-resistive response of CNT composite gives the fast response in strain measurement, whereas the ultra-soft PDMS matrix provides high flexibility and ductility for large strain measurement. Experimental results showed that the CNT/PDMS sensor could measure large strains (up to 26%) with excellent linearity and ultrafast response (less than 30 μs). This stretchable strain sensor also exhibits much higher sensitivities, with a gauge factor of as high as 80, than the conventional foil strain gages. These strain sensing capabilities (large strain, ultra-fast response, high linearity, and high gauge factor) make the fabricated sensor suitable for high-rate dynamic loading test applications.

Ho [5] has studied the stress, strain and deformation distribution of the geometrical shape of the low-profile load cell and the stress and strain of the curved beams under the rated load and overload conditions. This study is focused on the strain analysis of the geometric design under compression load and discusses the correlation between finite element analysis results and load cell strain gage.

This low profile load cells are usually used to the current injection molding machine manufacturers commonly used specifications. The study procedures are 3D CAD design, production of the load cell, stress analysis, experimental verification.

2. Methods
The ways to observe the design results are the analytical method and experimental method.

The first step is to establish an analytical model that confirms that the designed structural stress is below the material's yielding stress and that the safety factor meets the requirements.

Then the second step is to stamp strain gage as the actual application state. The strain values of load cell were compared with experimentally measurements and analysis results.
The designed load cells would be loaded to 60kN, to observer stress, strain, deformation distribution.

2.1 Analysis models and material properties

Before FEA analysis, the load cell models were designed by using SolidWorks 3D CAD software, then transform models for FEA analysis. Establish an analysis model: According to the load cell requirements size and rated capacity requirements, the original dimensions of the two models were designed in SolidWorks software. The design of the bending beam types in the models was based on the current design A-type and new design B-type. The detailed dimensions of the load cell are as shown in Figure 1 and 2.

The analyses were focused on the models stresses concentration areas and the strain gage stamped position.

The setting of boundary conditions depends on the actual state of use. The position of the inner surface of the load cell bears the loading, and the position of the outer surface of the load cell restricts the displacement. This mode of loading is the type of bending beam. The model is shown in Figure 3.

The alloy steel material used in the analysis model is SNCM439, which is utilized in the screw, gear, shaft parts, vehicle parts and various high strength structural steel. The detailed material properties used in the analysis are shown in Table 1.
2.2 Experimental verification

The experimental verification was based on 2 kinds of design drawings to make load cells. The detailed dimensions are as shown in Figure 1 and 2.

Four strain gages were attached to the full bridge according to the strain gage attachment procedure, and strain values were measured. The position is shown in Figure 4. The stamped location is in the inner groove and is distributed at intervals of 90 degrees. Among them, two pieces are attached to the edge of the outer circle, and two pieces are attached to the edge of the inner circle. The gage length center of the strain gage is 5 mm from the edge.

Experimental equipment using MTS 810 100kN universal testing machine, Agilent digit multimeter 34401A and Agilent power supply E3460A. The specifications of strain gauges are 350 ohms, using Micro-Measurements company's single grid model J2A-XX-S033P-350. The Gage factor of strain gage is 2.135.

The measurement method is that the supply voltage of the full-bridge strain gauge is DC10V, starting from 0 loads and loading every 10kN until 60kN, recording the output voltage value in each phase.

3. Results and discussions

In the finite element analysis results, the first, assess the stress of the load cell when subjected to a load of 60 kN to confirm whether it is within the yielding stress. Afterward, the analyzed strain values are compared with the measured values.

3.1. Stress analysis

The stress distribution of A-type and B-type load cells are listed in Figure 5~8. The maximum von Mises stress of A-type load cell is 470.9 MPa. The maximum stress has appeared on inner hole surface. This is because the current model is a simple model and the hole position is not chamfered. In fact, the processing load cell holes, edges will be chamfered. The load cell maximum stress value is less than the yielding stress and compared with the ultimate stress, which is about 42.4% of the ultimate stress.

The B-type load cell which changed the groove from flat to circular is a new design. This design can increase load cell load capacity. For load cells, the load can be applied a wide calibration range. The stress analysis result of B-type load cell showed the maximum stress is 288 MPa at inner hole edge. The maximum stress is less than A-type load cell. If based on the maximum stress of the A-type load cell, the B-type load cell can carry loads of 60kN to 100kN. With the same geometry size, this
gives the load cell designer more flexibility and reduces too many load cell types. In Figure 7 and 8 are shown the R-curve position has greater stress at the intersection between the bending beam and the outer ring. The current design is R1. The sensitivity of the strain gauge can be controlled by designing the R-lead angle.

3.2 Experimental verification of strain values and finite element analysis results
On the experimental bench, according to the calibration procedure, starting from 0 kN, the load cell is pressed to the strain gauge numerical stability state after every 10 kN, and the recorded data are listed in Table 2.

At a load of 60 kN, the maximum strain value of the A-type load cell is 298 με, while the maximum strain value of the B-type load cell is 170 με.

A-type and B-type load cell load-strain relationship as shown in Figure 9. The linearity regression R-value of the strain gauge data and load are both 99.99%, showing the adhesion and measurement accuracy of the strain gauge.

In the comparison of the strain distribution and strain measurement of the finite element analysis, the results of the adjustment of the groove geometry ratio and the strain distribution diagram are shown in Figure 10 and 11. The strain at the position where the strain analysis result is displayed is close to 300 με in A-type and 170 με in B-type, which is quite close to the value of the actual measurement point. The results show that the analysis method is consistent with the measurement method.

Here, it can be proved that the boundary condition setting of the finite element simulation method is close to the actual application condition.

Table 2. Experiment measured strain values.

| Compression load (kN) | Strain (με)  |
|-----------------------|--------------|
|                       | A-type       | B-type       |
| 0                     | 0            | 0            |
| 10                    | -48          | -31          |
| 20                    | -96          | -60          |
| 30                    | -147         | -86          |
| 40                    | -198         | -114         |
| 50                    | -249         | -142         |
| 60                    | -298         | -170         |

Figure 9. Load cell strain and load relation.

Figure 10. The strain distribution of A-type load cell.
4. Conclusions
The results of this study for load cell under loading force can be summarized as follows:

1. After comparing the two load cell cross-section designs, the planar groove load cell has a higher stress and strain value than the arc section load cell. However, the sensitivity of the planar groove load cell is better than the arc section load cell.

2. The stress of the arc-shaped load cell with a 60 kN load can be relatively low. However, in the same size, it can provide a more extensive range of load 60kN~100kN, which is more flexible for load cell designers.

3. The measured values of the A-type and B-type load cells at 60 kN were 298 $\mu$E and 170 $\mu$E, and the linearity of the data was up to 99.99% of the standard as a sensor. Also, verify the effectiveness of the strain gauge stamped method and measurement methods.

4. The analysis results are similar to the experimental results. The assumptions of the verification analysis program are following the actual application state.

References
[1] J. W. Joo, K. S. Na, D. I. Kang, Measurement, 32, 125 (2002).
[2] H.S. Alam, Bahrudin, D. Soetraprawata, ICACOMIT, 10, 52 (2015).
[3] H.M. Lee, H.S. Park, Exper. Tech, 37, 23 (2013).
[4] S. Yao, X. Nie, X. Yu, B. Song, J. Blecke, IEEE Sensors Letters, 1, 1 (2017).
[5] M.H. Ho, P.N. Wang, J.P. Yeh, B.H. Wu, Adv. in Eng. Res., 121, 261 (2017).