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Fabrication and Testing of a Strain Gage Load Cell

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Abstract— In this work, a strain gage load cell was designed, constructed and subjected to experimental tests. The load cell consists of a square-section mild steel hollow tube, two electrical resistance strain gages and a digital strain meter. The two strain gages were bonded on opposite sides of the square section hollow tube with their longitudinal axes coinciding with the longitudinal axis of the tube. The two strain gages were connected to a digital strain meter in a half-bridge circuit configuration to measure the compressive strain resulting from the applied load. A universal testing machine was used to apply load on the load cell and the resulting compressive strain was read on the display unit of the digital strain meter. The test results indicate good agreement between the theoretical values of compressive strain and the measured values with an error of 3%.

Index Terms— compressive load, digital strain meter, half bridge configuration, load cell, strain measurement, Universal testing machine, Wheatstone bridge

1 Introduction

Measurement is defined as the process of experimentally determining values that can be credited to a quantity. It involves measuring a quantity value proportional to an unknown quantity [1]. Accordingly, electrical resistance strain gages are widely employed for the measurement of the strains developed in the mechanical parts subjected to external loads. Since strain is proportional to the applied load, it quantifies the applied load, as expressed by Hooke's law [2]:

$$\varepsilon = \sigma/E = F/AE \quad (1)$$

where,
ε: strain
σ: stress (Pa)
E: Modulus of elasticity (Pa)
F: applied load (N)
A: cross-sectional area (m^2)

The design of a strain gage load cell depends on the aforementioned principle. The length of the electric resitance wire in a bonded strain gage changes with the applied load which results in a change in its resistance. This change in resistance can be measured and correlated to the applied load. Since the change in wire resistance, due to applied load, is extremely small (in microstrains units), a Weatstone bridge is used to detect it. The bride produces an output voltage equivalent to the change in strain gage wire resistance [3].

Imran and Haneef [4] conducted an investigation to predict the bending stresses developed in curved beams. Three methods were employed for this purpose. The first method involves analytical evaluation of stress. The second method utilize finite element package ANSYS for determining the bending stresses in a curved beam. The third method involves experimental determination of the bending stresses by using strain gages. Comparison of the rsults of the three mrthods revealed that the analytical and the finite elements solutions were close. However, the discrepancy between the experimental test results and the other two methods was 20-25%.

Suryana and Muntini [5] developed a mass sensor using a strain gage with 120 ohm gage resistance cemented on a cantilever beam with a length, width and thickness of 2cm, 1cm and 20μm respectively. The deflection of the beam due to mass placed at one end of the beam is detected by the strain gage. The strain gage was connected to a Wheatstone bridge circuit which produces a voltage output equivalent to the strain gage output signal. A data acquisition system with PC interface was employed to store data. Test results indicated that the mass measuring device possesses very good linearity and high accuracy, with an error of only 1.06%.

Sulistyanto et al [6] designed a mass balance using a strain gage bonded on a cantilever beam made of brass. The strain gages has a resistance of 120 ohm. Since the output signal of the strain gage is very small (microstrains) a Wheatstone bridge circuit with an operational amplifier was used to obtain an equavelant voltage value. A microcontroller is used to process the data and an LCD screen is used to display the mass value. The experimental test results were satisfactory and justified the research objectives and the average error was 7%.

The objective of this work is to design, construct and test a strain gage load cell. For this purpose, two electrical resistance strain gages with a gage resistance of 120 ohm are cemented on opposite sides of a mild steel square hollow tube. The two strain gages are connected to a Wheatstone bridge circuit in a half bridge configuration. A digital strain meter is used to provide the excitation voltage and display the output signal of the Wheatstone brige ciruit. The load cell is subjected to experimental tests using a Universal Testing Machine. In order to verify the feasibility of this teqnique the experimental test results are compared with the theoretical values of strain.

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2 MATERIALS AND METHODS

The load cell designed and constructed in this work comprises a load tube, two strain gages and a strain meter. A mild steel square-section hollow tube was used. The tube has an outside diameter 12.7 mm and an inside diameter of 9.5 mm as shown in Fig.1.

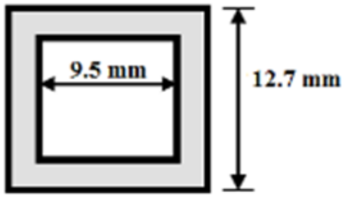

Fig.1 Cross-section of mild steel hollow tube.

The cross sectional area of the hollow tube in m² units is calculated as follows:

$$A = [(12.7)^2 - (9.5)^2] \times 10^{-6} \; = 71 \times 10^{-6} \qquad (2)$$

Two electrical resistance strain gages Type KFGS-6-120-C1-11 manufactured by Kyowa-Japan were used for measuring the compressive strain resulting from the load applied on the hollow tube. These strain gages have a resistance of 120 Ω and gage length of 10 mm. The strain gages were cemented on opposite sides of the square-section hollow tube with their longitudinal axes coinciding with the longitudinal axis of the tube as shown in Fig.2. The bonding area where the gages are cemented was prepared in accordance with procedure recommended by Perry and Lissner [7]. The bonding area was roughened with an abrasive paper grade 500 to increase the cement contact area. Then, it was cleaned using an alcohol solvent to remove any dirt, stains or grease from the surface. The cement used for bonding the strain gages on the mild steel tube was an instant-bond cyanoacrylate adhesive produced by UHU Company, Germany. One drop of the liquid adhesive was distributed evenly on the bonding area, and the gages were positioned using a transparent tape. Then, the gages were pressed firmly into position by the rolling motion of the thumb to squeeze out any excessive adhesive and trapped air. After installing the strain gages, the gage resistance was checked with an ohmmeter. Then, lead wires were used to connect the strain gages to Wheatstone bridge.

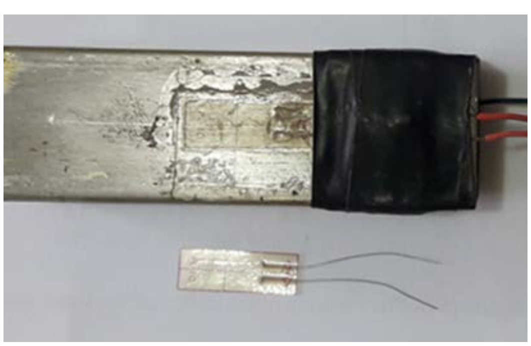

Fig.2. Strain gage cemented on hollow mild steel tube.

The modulus of elasticity of milld steel is 210 GPa [8]. If this value and the value of cross-sectional area of hollow tube calculated in (2) are substituted in (1), the theoretical value of compressive strain as a function of applied load can be obtained:

$$\varepsilon = 6.7 \times 10^{-8}\, F \qquad (3)$$

When the value of strain is expressed in microstrain units the relationship between the compressive applied force and the resulting strain becomes:

$$\varepsilon = 6.7 \times 10^{-2}\, F \qquad (4)$$

In this work, the two strain gauges are connected in a half bridge configuration as shown in Fig.3. The use of two active strain gages provides temperature compensation as well as doubling the output signal, thus, the measured strain expressed in (4) above becomes:

$$\varepsilon = 13.4 \times 10^{-2}\, F \qquad (5)$$

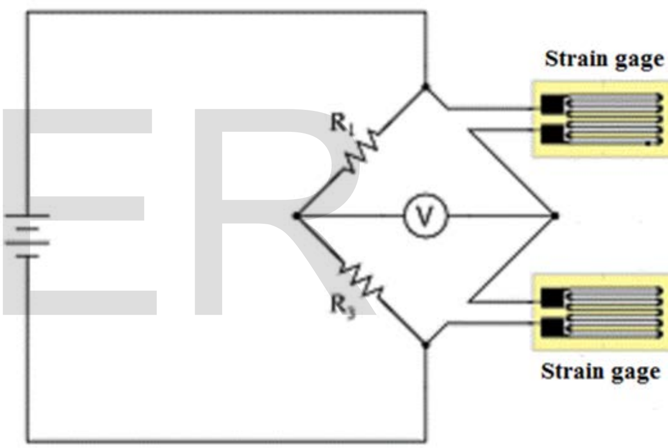

Fig.3: Connetion of two active strain gages in half bridge configuration.

The instrument used for measuring and displaying the output signal of the strain gages as well as supplying the strain gages with 5 V DC voltage supply is a digital strain meter shown in Fig.4. The input channel includes an amplifier with differential input and a fixed gain. The output of the amplifier is filtered and buffered to the LCD screen.

The load cell was subjected to experimental test in which the load was applied using a Universal Testing Machine (Fig.5) and the resulting strain was read on the strain meter display unit. Before load is applied, the zero shift is adjusted by the control switch of the strain meter to obtain zero strain at no load condition. Then, load is applied from zero to 500 N by an increment of 100 N, and the resulting strain was read on the the display unit of the strain meter.

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Fig.4. Digital strain meter

Fig.5. Univeral Testing Machine with load cell and strain meter.

3 RESULTS AND DISCUSSION

Fig.6 presents the experimental test results expressing the relation between the applied load and the resulting compressive strain measured by the strain gages.

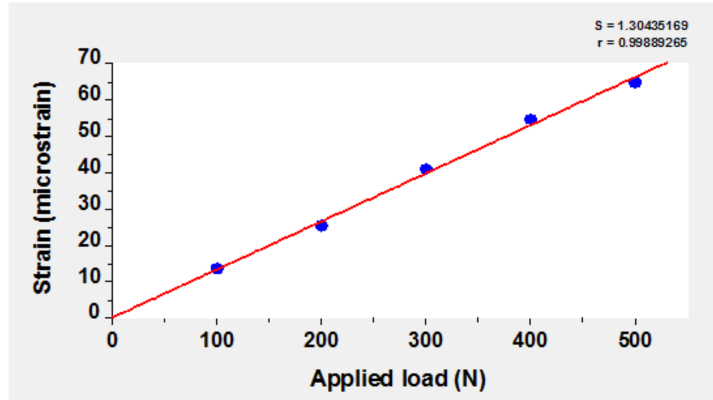

Fig.6. Aplied load vs compressive strain

As shown in figure the relationship between the applied load and the resulting compressive strain indicate very high linearity, with a high correlation coefficient of approximately 0.999. The measured compressive strain as obtained by linear least squares regression is expressed as:

$$\varepsilon = 0.333 + 0.1324\, F \qquad (6)$$

Comparison between the theoretical values of strain as calculated using (5) and the experimental results is presented in Fig.7. The error or deviation of test results from the theoretical relationship is found to be 3% which indicates good agreement between the theoretical and experimental results.

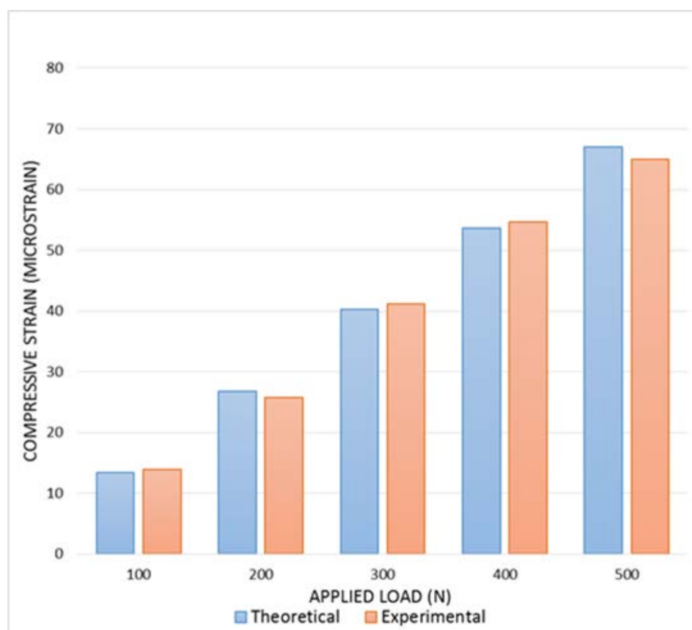

Fig.7. Comparison between theoretical and experimental results

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4 Conclusions

1- The experimental results have verified the validity of using strain gages for the measurement of compressive strain in load cells which satisfies the objectives of this experimental work.

2- The use of two strain gages in half bridge circuit doubles the output signal of the measured compressive strain and consequently the sensitivity of load cell which is desirable.

3- The experimental results indicate good agreement of the measured and theoretical values of compressive strain as indicated by the relatively good accuracy of (3%), and the relationship between the applied load and the measured compressive strain maintained good linearity.

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