Validation of Experimental Strain Measurement Technique and Development of Force Transducer

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Abstract - The accurate assessment of stress, strain and loads in components under working conditions are an essential requirement of successful engineering design. Experimental stress analysis over years has been playing an increasingly important role in aiding engineering product designers to produce not only efficient, economic designs but also in substantial reductions in weight and yet aid in easier manufacturing of the products. Electrical resistance strain gauges are a remarkable device which is small, lightweight, linear, precise and fairly inexpensive is used as a sensor in wide variety of applications. Load cell transducer is the most prevalent sensor which uses electrical strain gauges. In a load cell, the unknown, load is measured by sensing the strain developed in a mechanical member. Since the load is linearly related to the strain as long as the mechanical member remains elastic, the load cell can be calibrated so that the output signal is proportional to the load. The Thermal coefficient of expansion of unknown material may be determined with the strain gauges by mounting two half bridges resistances on the known material and unknown material respectively. Here, in this work, an attempt is made to develop a force transducer to find an unknown load using a cantilever beam. The Cantilever Beam (CLB) based transducer will be calibrated and validated using numerical approach, analytical approach and experimental measurements.

Index Terms- centilever beam, force transducer, strain gauge, wheatstone bridge.

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1 INTRODUCTION

The main techniques of experimental stress analysis which are in use today are brittle lacquers, strain gauges, photo-elasticity & photo-elastic coatings. Strain Gauges are popularly used in engineering measurement domains. Based on the principles used in the construction the strain gauges are classified into mechanical, optical, electrical and acoustical types. Of all, the electrical strain gauges have become so widely accepted that they now dominate the entire strain-gauge domain.

The discovery of the principle upon which the electrical resistance strain gage is based was made in 1856 by Lord Kelvin, who loaded copper and iron wires in tension and noted that their resistance increased with the strain applied to the wire. He then developed a Wheatstone bridge to measure the resistance change through which he further established three vital facts; first that resistance of the wire changes as a function of the strain, second, different materials has different sensitivities and three that Wheatstone bridge could be used to measure these changes accurately. Since then, extensive utilization of strain gages by industries and academic laboratories throughout the world has made bonded-strain-gages monitored by Wheatstone bridge as the most perfected measuring system.

1.1
1.2

Strain is the amount of deformation of a body due to an applied force. More specifically, strain (ε) is defined as the fractional change in length, as shown in the Fig. 1. Strain can be positive (tensile) or negative (compressive) and is dimensionless. In practice, the magnitude of measured strain is very small. Therefore, strain is often expressed as micro strain (με), which is ε x 10 -6 [1]

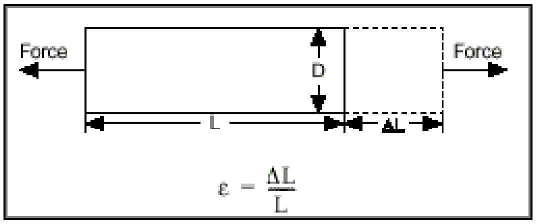

Fig.1 Definition of strain

Strain is the amount of deformation of a body due to an applied force. More specifically, strain (ε) is defined as the fractional change in length, as shown in the Fig. 1. Strain can be positive (tensile) or negative (compressive) and is dimensionless. In practice, the magnitude of measured strain is very small. Therefore, strain is often expressed as micro strain (με), which is ε x 10 -6 [1]

1.1 Principle of the strain Gage

The electrical resistance strain gauge is simply a length of wire or foil formed into the shape of a continuous grid, as shown above cemented to a non-conductive backing. The gauge is then bonded securely to the surface of the component under investigation so that any strain in the surface will be experienced by the gauge itself. Since the fundamental equation for the electrical resistance R of a length of wire is, R= ρL/A, It follows that any change in length, and hence sectional area, will result in a change of resistance. Thus measurement of this resistance change with suitably calibrated equipment enables a direct reading of linear strain to be obtained. This is made possible by the relationship which exists for a number of alloys over a considerable strain range between change of resistance and strain which may be expressed as follows:

$$\frac{\Delta R}{R} = K \times \frac{\Delta L}{L}$$

Gauge factor (GF) can be expressed as,

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$$\left[\frac{\Delta R/R}{\Delta L/L}\right]=\frac{\Delta R/R}{\varepsilon}$$

where, ε is the strain. The value of the gauge factor is always supplied by the manufacturer and can be checked using simple calibration procedures if required. Typical values of K for most conventional gauges lie in the region of 2 to 2.2, and most modern strain-gauge instruments allow the value of K to be set accordingly, thus enabling strain values to be recorded directly [2].

1.2 The Wheatstone Bridge- Working Principle

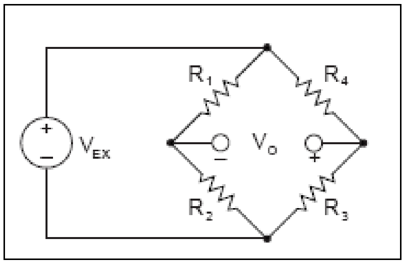

Fig.2 wheastone bridge circuit

The Wheatstone bridge circuit as shown in Fig. 2 for which condition of balance for this network being (i.e. the galvanometer reading zero when),

$$R_1 \times R_3 = R_2 \times R_4 .$$

In practice, the strain measurements rarely involve quantities larger than a few mill strains. Therefore, to measure the strain requires accurate measurement of very small changes in resistance*. The general Wheatstone bridge, illustrated, consists of four resistive arms with an excitation voltage, *Vex*. The output voltage of the bridge, V_0, will be,

$$Vo=\left[\frac{R3}{R3+R4}-\frac{R2}{R1+R2}\right]\bullet Vex$$

From this equation, it is apparent that when *R1/R2 = RG1/RG2*, the voltage output V_0 will be zero. Under these conditions, the bridge is said to be balanced. Any change in resistance in any arm of the bridge will result in a nonzero output voltage. Therefore, if we replace *R4* in Fig.2 with an active strain gauge, any changes in the strain gauge resistance will unbalance the bridge and produce a nonzero output voltage. If the nominal resistance of the strain gauge is designated as *RG*, then the strain-induced change in resistance, *ΔR*, can be expressed as *ΔR = RG × GF × ε*. Assuming that *R1 = R2* and *R3 = RG* [2,3].

Different bridge configuration are used for the assessment of strain among them a half bridge circuit is used by using two strain gauges in the bridge, the effect of temperature can be avoided. Fig. 3 illustrates a strain gauge configuration where one gauge is active *(RG + ΔR)*, and a second gauge is placed transverse to the applied strain. Therefore, the strain has little effect on the second gauge, called the dummy gauge. However, any changes in temperature will affect both gauges in the same way. Because the temperature changes are identical in the two gauges, the ratio of their resistance does not change, the voltage V_0 does not change, and the effects of the temperature change are minimized. Also the sensitivity of the bridge to strain is doubled by making both gauges active, although in different directions [2,4].

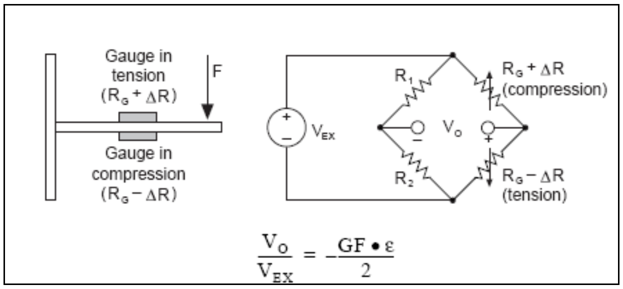

Fig.3 half bridge circuit

For example, A test specimen undergoes a substantial strain of 500 με. A strain gauge with a gauge factor GF = 2 will exhibit a change in electrical resistance of only 2 (500 ´ 10–6) = 0.1%. For a 120 W gauge, this is a change of only 0.12 W.

2 EXPERIMENTAL SETUP

A Cantilever beam made from aluminum alloy 6061-T6 as shown in the Fig.4 will be used for measuring bending strain with half bridge configuration. The Electrical resistance strain gauge as shown in Fig.5 is used with Vishay Micro measurement for Experimental measurement technique.

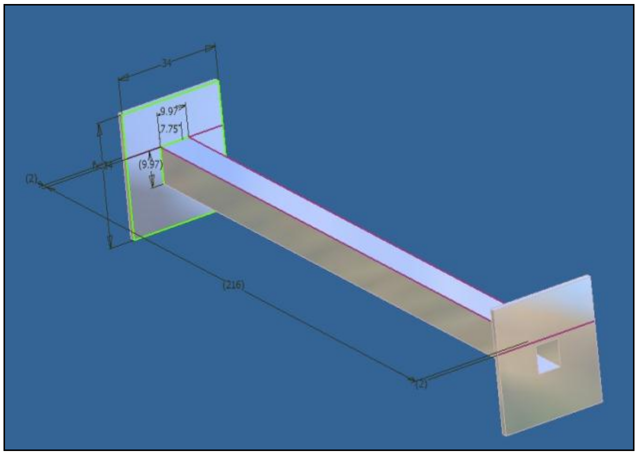

Fig.4. CAD Model of the beam

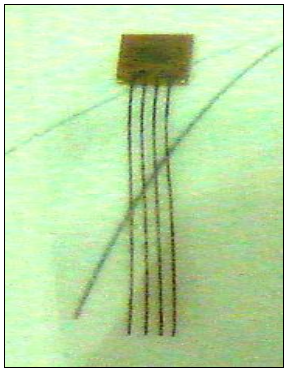

Fig.5 Electrical resistance strain gauge

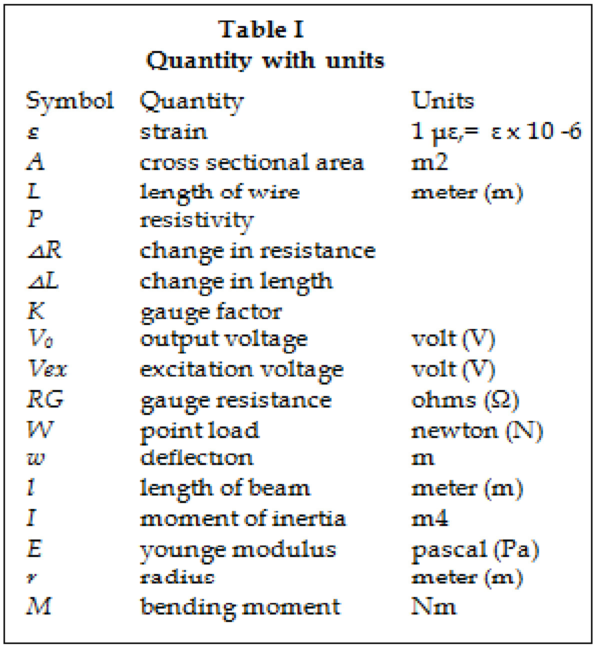

Table I
Quantity with units

Symbol	Quantity	Units
ε	strain	1 $\mu\varepsilon$= ε x 10 -6
A	cross sectional area	m2
L	length of wire	meter (m)
P	resistivity	
ΔR	change in resistance	
ΔL	change in length	
K	gauge factor	
V_0	output voltage	volt (V)
Vex	excitation voltage	volt (V)
RG	gauge resistance	ohms (Ω)
W	point load	newton (N)
w	deflection	m
l	length of beam	meter (m)
I	moment of inertia	m4
E	younge modulus	pascal (Pa)
r	radius	meter (m)
M	bending moment	Nm

Fixing of the gage to beam involves the sequential steps like Solvent Degreasing, Surface Abrading, Gage location Layout line, Surface Conditioning, Neutralizer, Locating the Strain gauge and Applying the bond to strain gauge by using the strain gauge accessories as shown in Fig.6 [5].

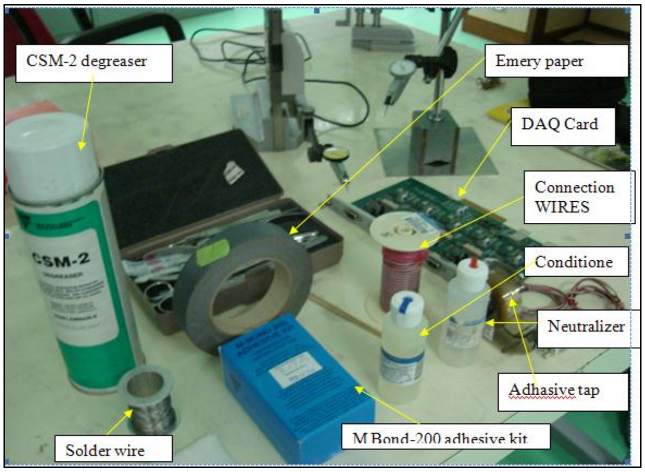

Fig.6. Strain gauge accessories

Model 5100 B Scanner (Make Vishay Micro Systems) is the type of the data acquisition system used for the measurement of the strain. Model 5100 B Scanners which provide fast static acquisition & digitization of 20 channels of various analog inputs. System flexibility allows for mixing type of input card within a scanner. Strain smart is the software which is provided within the data acquisition system. Fig.7 shows the details of half bridge circuit interconnection [5,6].

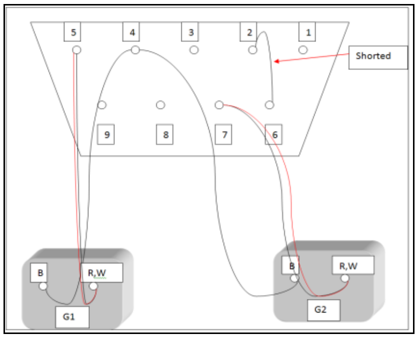

Fig.7 half bridge circuit interconnections details

3 EXPERIMENTAL PROCEDURE

A cantilever beam as shown in Fig.8 is subjected to a point load at the end of the beam. The strain gauges are attached on its top and bottom surfaces to measure strain produced at that location. Here the load is applied in steps of 0.25398 N. the strain gauges are attached to the data acquisition system with the help of multipin connectors which in turn is connected to the PC and data is read by the software. The software will produce the output in terms of micro strain and output voltage in the form of millivolt (*mV*). The data is taken for various load cases ranging from 0.25398N to 6.1 N and results are achieved.

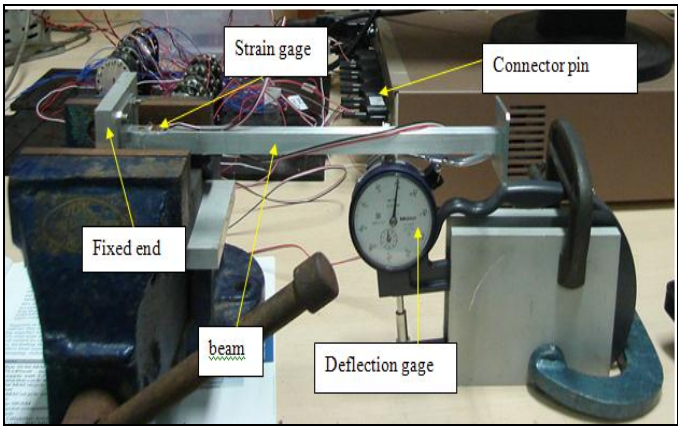

Fig.8. Experimental setup

4. VALIDATION

To validate experimental measured results two approaches are adopted, first classical mechanics theory is used to predict the displacements and strain, Second Finite Element Method by using the commercially available FEA software are used to compare the same. The results of these three approaches are compared and plotted in the graphs shown in figure 10.

From the pure bending theory, we have, A beam with a moment of inertia I and with Young's modulus E will have a bending stress σ at a distance "y" from the Neutral Axis and the NA will bend to a radius r in accordance with the following formula.

$$\frac{M}{I} = \frac{\sigma}{y} = \frac{E}{r}$$

By getting the value of the stress the theoretical strain can be found out by using the hook's law formula.

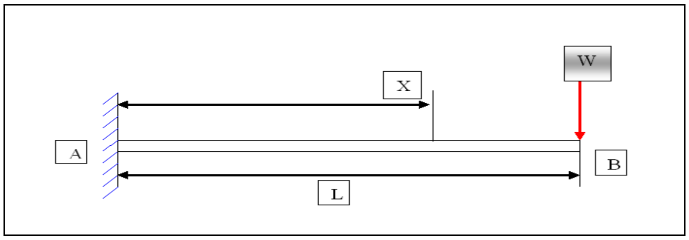

Fig.9 Cantilever beam with axial loading

As shown in Fig. 9, A cantilever beam is subjected to a point load at free end. Let M.I of the section of the cantilever at neutral axis be “I”. Consider any section of the cantilever at distance x from fixed end A. The bending moment at any section of the beam is given by

$$EI\,\frac{d^2y}{dx^2} = -w(l-x)$$

By Simplifying this equation we get deflection at A is zero at x=0. Now, downward deflection (Y) at free end, i.e. at x=L can be determine by

$$\frac{Wl^3}{3EI}$$

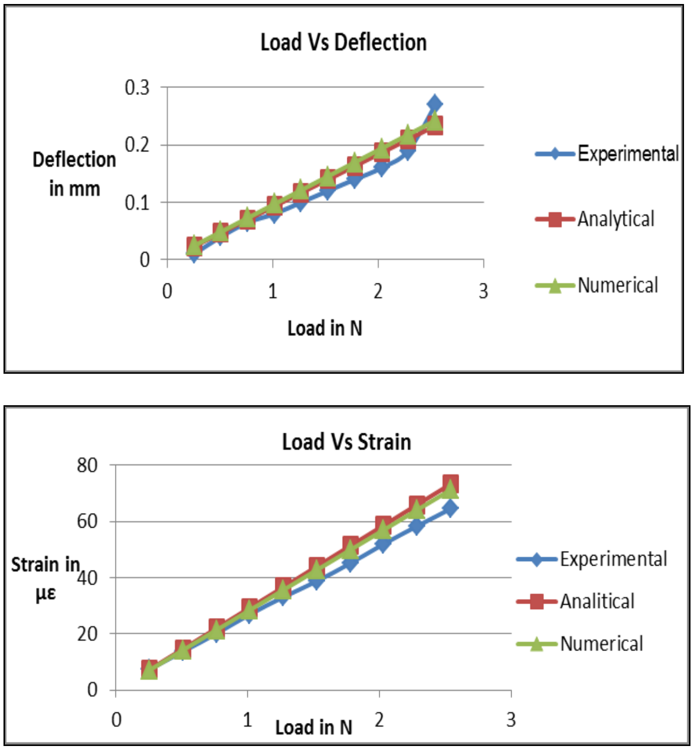

Fig. 10 A plot of comparison of strain/deflection results achieved by experimental, analytical and numerical approach

5 FORCE TRANSDUCER

The Bending beam developed earlier is used as a force transducer. From the load and deflection data generated for the cantilever beam, load characteristic curves are plotted. These loads curves are used to predict unknown loads and thereby using the CLB as a force transducer by measuring the corresponding strain indicated by the strain measurement setup created in the experimentation. To check the accuracies and ranges of the operation of the forced transducer some unknown loads are taken and loaded on the CLB. The corresponding strains/Voltages are plotted on the Strain V/s Load. The figure 11shows the unknown load dispersed on the strain v/s load characteristic curve [7,8].

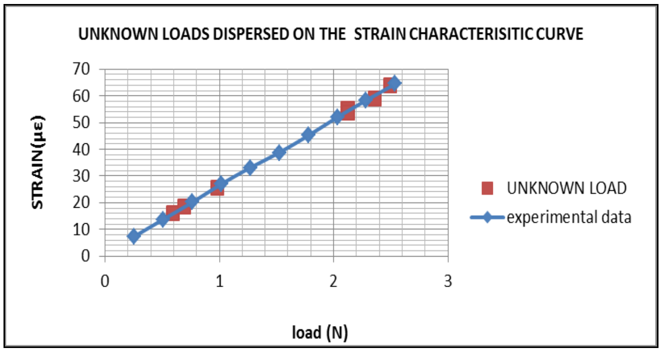

Fig. 11 A plot of comparison of strain charecteristics curves for the unknown load

6 CONCLUSION

An Experimented setup for the measurement of strain/stress has been successfully established using strain gauge measurement principle. The CLB is characterized for the plain bending using half bridge circuit and the behavior of CLB is validated using classical bending theory and FEM software. The characteristics curves for the load v/s strain, voltage are plotted for the CLB for the various loads, which results in development of force transducer. To check the behavior of the force transducer a sets of unknown load have been measured and the data have been dispend on the load characteristics curve. The fine method of dispend unknown load shows the accuracy of the load cell.

ACKNOWLEDGMENT

The authors are thankful to Space Application Center (SAC) for enabling them to work on the project. We deeply acknowledge the knowledge base bestowed on us by SAC official at various levels for generating the solutions proposed.

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