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Experimental and Analytical Study for Uncertainty in Strain Measurement

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***Abstract*— There are various methods available for measurement of physical strain on material using strain gauges incurred uncertainty in measurement due to several factors. The aim of this study is to determine uncertainty in strain measurement due to bridge configuration. For determining uncertainty in measurement the setup of cantilever beam with quarter bridge, half bridge and full bridge is developed. Using classical and finite element analysis strains are calculated for different loads. The actual strain measurement is carried out using NI LabVIEW for different loads with quarter bridge, half bridge and full bridge configurations. The uncertainty analysis is carried out and found that quarter bridge has more uncertainty than half bridge and full bridge configuration.**

***Index Terms*— ANSYS13.0®, LabVIEW, Strain gauges, Wheatstone bridge, Uncertainty Analysis.**

I. INTRODUCTION

Historically, the development of strain gauges has followed many different approaches, and gauges have been developed based on mechanical, optical, electrical, acoustical and even pneumatic principles. Electrical resistance strain gauge nearly satisfies all of the optimum requirements for a strain gauge therefore it is widely employed in stress analysis and as the sensing element in many other applications. Wheatstone bridge is commonly employed to convert the resistance change to an output voltage. The quarter, half and full bridge configuration of strain gauge based circuits are considered to illustrate the analysis [6]. Although the strain gauge is inexpensive and relatively easy to use.

II. ANALYTICAL AND NUMERICAL WORK

A. *Theoretical Analysis*

1. Analysis using classical method

Let us suppose cantilever beam is of dimension 200 mm ×38 mm ×3 mm. A load of range 0.005N to 0.05N is applied on free end. 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. By getting the value of the strain the theoretical strain can be found out by classical method using the hook's law formula [2].

B. *Analysis using Analytical / Finite Element Analysis method using ANSYS® 13.0*

Finite Element Method by using the commercially available FEA software is used to compare the same [2]. The results of these approaches are compared and plotted in the graphs.

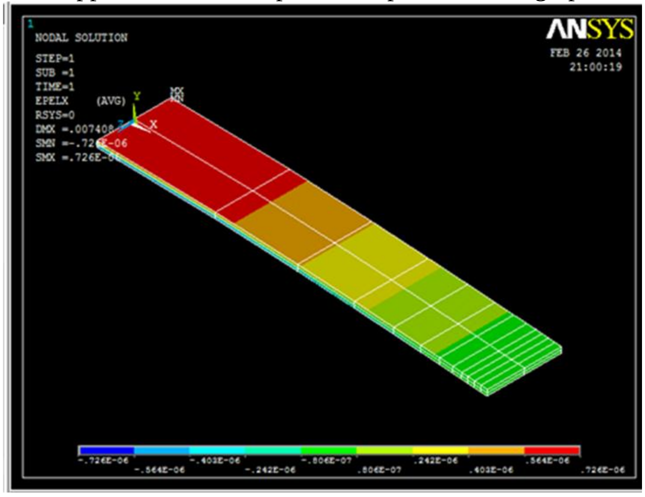

Fig.1 Analysis of Strain by ANSYS® 13.0

III. EXPERIMENTATION

I. *Experiment setup*

It consists of a base made up of cast iron. On the base plate two square blocks of acrylic material are placed to support and fix cantilever beam made up of stainless steel. These acrylic blocks are fastened using screw to base vertically and other horizontally to the beam. Three numbers of beams with 200 mm × 38 mm × 3 mm size made of steel 304 have been used in experiment for full bridge, half bridge and quarter bridge. One end of the beam is fixed to the acrylic block by screws and other end kept free therefore getting the maximum strain near to the fixed end of the beam. So strain gauges are bonded near to the fixed end of the beam to measure maximum strain in the beam [11]. In this experiment to measure bending strain we have used electrical foil type resistance strain gauges. Total length of strain gauge is 10 mm with active length 5 mm. The Gauge factor of strain gauge is 2.13 and resistance at zero load 120 Ω. Standard procedure of mounting strain gauge was adopted and using "Bondable Terminal Pad" lead wire connected to the strain gauge.

II. Bridge Configurations

The following figure 2 shows position of strain gauge resistors in a bending configuration for the full-bridge.

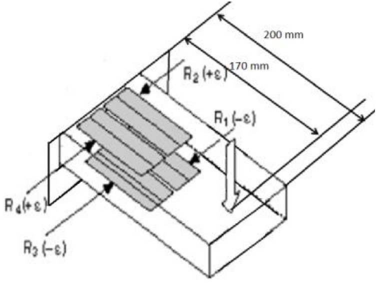

Fig. 2 Full-Bridge Schematic Diagram

Four active strain gauge elements, two mounted in the direction of bending strain on the top side of the strain specimen and the other two mounted in the direction of bending strain on the bottom side [6].

The following figure shows how to position strain gauge resistors in a bending configuration for the half-bridge.

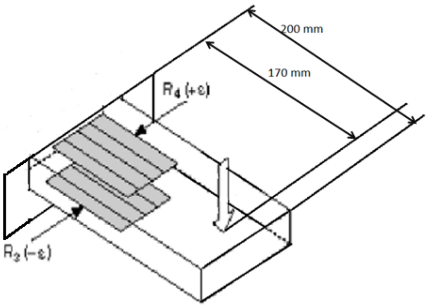

Fig.3 Half-bridge Schematic Diagram

Half-bridge strain gauge configurations have the following characteristics: Two active strain gauge elements, one mounted in the direction of axial strain on the top side of the strain specimen and the other mounted in the direction of axial strain on the bottom side. Two passive half-bridge completion resistors, known as a dummy resistor are used to completion of wheatstone bridge circuit [6].

The following figure shows how to position a strain gauge resistor in a bending configuration for the quarter-bridge.

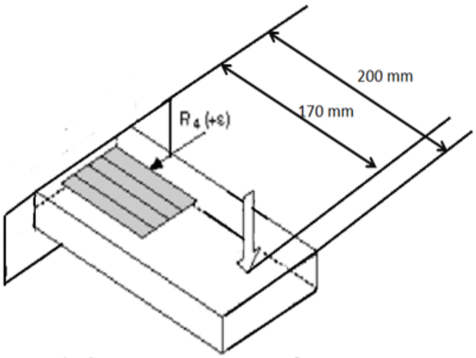

Fig. 4 Quarter-bridge Schematic Diagram

A single active strain gauge element mounted in the principle direction of axial or bending strain. Three passive quarter-bridge completion resistor, known as a dummy resistor are used to completion of wheatstone bridge circuit [6].

III. Strain Measurement Using Virtual Instrumentation

The software that has been used in this project for virtual instrumentation is LabVIEW software by National instruments [3].

LabVIEW: LabVIEW is a graphical programming environment used by millions of engineers and scientists to develop sophisticated measurement, test, and control systems using intuitive graphical icons and wires that resemble a flowchart.

National Instrumentation 9219: Ni 9219 is 4 analog input channels with 24bits Delta-sigma (with analog profiteering) ADC resolution having Simultaneous Sampling mode

Connecting the NI 9219: Connect the positive signal of the signal source to the positive input signal terminal (HI) and the negative signal of the signal source to the negative input signal terminal (LO). Use the excitation terminals if the sensor requires a separate excitation connection. Refer to the NI 9219 Circuitry section for information about connections in each mode.

Fig. 5 NI 9219 [21]

Connecting Wires to the Spring-Terminal Connectors: Use a flathead screwdriver with a blade smaller than 2.3 × 1.0 mm (0.09 × 0.04 in.) to connect wires to the detachable spring-terminal Connectors. Insert the screwdriver into a spring clamp activation slot and press a wire into the corresponding connector terminal, then remove the screwdriver to clamp the wire into the terminal.

National Instrumentation cDAQ9172: The NI cDAQ-9172 is an eight-slot NI Compact DAQ chassis that can hold up to eight C Series I/O modules as shown in figure 6

Fig. 6 NI cDAQ9172 [21]

The measurements of strains are carried out by varying the loads at free end from 0 to 0.05 N at room temperature using 2.5 excitation voltage, for each load with different bridge configurations 5000 samples are acquired at the rate of 500 Hz.

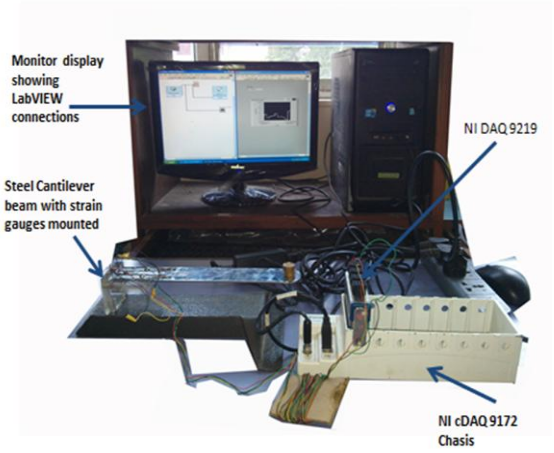

Fig. 7 Experimental Setup For Strain Measurement

The fractional changes in resistance with respect to deflection of the cantilever were stored in the data files [3]. Using National Instruments LabVIEW version 9.0, V.I. block diagram was created with DAQ assistant, Numeric indicator, write to measurement file to store date in spread sheet and wave form chart as shown in figure 8.

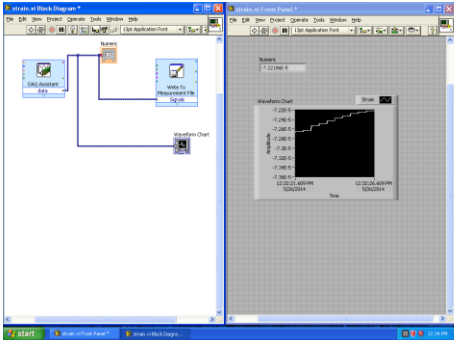

Fig. 8 Block Diagram and Front Panel

IV. UNCERTAINTY ANALYSIS

When a set of several repeated measured samples of X has been taken, the mean $\bar{X}$ and estimated standard deviation Sx, can be calculated for the set.

$$\bar{X} = \frac{\sum_{i=1}^{N} X}{N} \tag{1}$$

$$S_X = \left(\frac{1}{N-1}\sum_{i=1}^{N}(X-\bar{X})^2\right)^{\frac{1}{2}} \tag{2}$$

From these, the estimated standard uncertainty u, of the mean is calculated from

$$u = \frac{S_X}{\sqrt{N}} \tag{3}$$

Where N is the number of samples in the set [1]. The standard uncertainty of the mean has historically also been called the standard deviation of the mean, or the standard error of the mean.

Combining standard uncertainties:

Individual standard uncertainties calculated by evaluations can be combined validly by ‘summation in quadrature’ (also known as ‘root sum of the squares’). The result of this is called the combined standard uncertainty[1,6].

$$\text{Combined Uncertainty} = \sqrt{a^2 + b^2 + c^2 + \cdots etc} \tag{4}$$

V. RESULTS & DISCUSSION

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

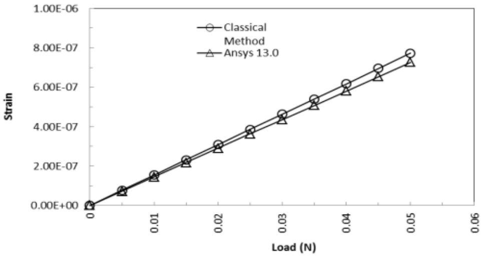

Fig. 9 Showing comparison of strain calculated by classical method and ANSYS® 13.0

For experimental purpose Stainless Steel beam was fabricated. Using data of fabricated beam the strain for plain bending classical method were validated using ANSYS® 13.0 software. Results are tabulated as following and comparison of strain is shown graphically.

Strain Measurement: The calibration of Wheatstone bridge was carried out. For Wheatstone bridge, calibration was done by putting weights on cantilever beam and observing the corresponding output of the strain gauge. A regression equation was fitted corresponding to the observed values. By finding relation between measured strain and calculated strain, calculated strain is calibrated in terms of measured strain. The readings for calibration as shown in figure.10, figure.11, figure.12 for Full bridge, Half bridge, Quarter bridge respectively.

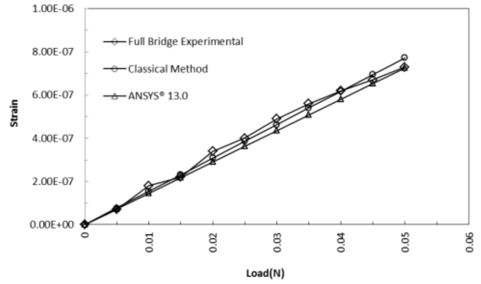

Fig. 10 A plot of comparison of strain results achieved by experimental, analytical and numerical approach for Full Bridge.

Figure 10 shows that full bridge experimental strain measurement results. The obtained results are matching with classical and finite element analysis method and getting approximately linear curve.

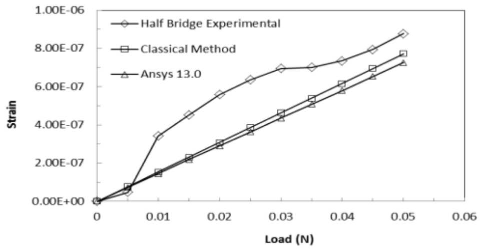

Fig. 11 A plot of comparison of strain results achieved by experimental, analytical and numerical approach for Half Bridge.

From the fig. 11 it is very clear that the number of active gauges are two, it incurred a errors in measurement.

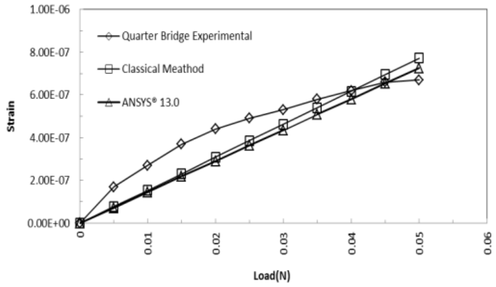

Fig. 12 A plot of comparison of strain results achieved by experimental, analytical and numerical approach for Quarter Bridge.

Figure 12 shows that quarter bridge experimental strain measurement results comparison with classical and finite element analysis method. It seen that for larger load error in measurement is reduced compare to lower weight.

Using the concepts and procedures in the ISO Guide to the Expression of Uncertainty in Measurement, a standard uncertainty (u) is defined as an estimate of the standard deviation of the parent population from which a particular elemental error originates. Then combined uncertainty is found from the combination of all of the elemental standard uncertainties

TABLE 1 UNCERTAINTY OF STRAIN MEASURING CIRCUITS

Measuring circuit		**Quarter bridge**	**Half bridge**	**Full bridge**
Input Parameters Load(N)	0	2.21E-09	2.51E-09	2.38E-10
	0.005	9.06E-10	1.36E-10	2.10E-10
	0.01	9.46E-10	1.69E-10	2.06E-10
	0.015	9.21E-10	1.96E-10	2.43E-10
	0.02	3.29E-10	2.01E-10	1.79E-10
	0.025	3.45E-10	1.85E-10	1.54E-10
	0.03	2.99E-10	1.97E-10	1.55E-10
	0.035	4.27E-10	2.35E-10	1.89E-10
	0.04	4.29E-10	2.31E-10	2.05E-10
	0.045	2.10E-10	1.65E-10	2.26E-10
	0.05	5.09E-10	1.51E-10	1.63E-10
Combined Uncertainty		2.90741E-09	2.58418E-09	0.661296E-09

VI. CONCLUSION

The experimental setup for three bridge configuration has been developed successfully. The measured strain value and strain found by classical and FEA method is in good agreement. The uncertainty analysis is carried out for strain values obtained by experiments with different bridge configurations. The result of uncertainty analysis shows uncertainty value is more in case of quarter bridge as this bridge configuration use only one active strain gauge. Thus this study concludes that more number of active gauges increases error affecting of strain gauges cancelling each other.

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