Force measurment system based on strain gauges engineering essay

In this part there will be a use of a strain gauge device which experiences a change of electric resistance when it is strained. Design, build and test a force sensor using strain gauges are provided, as well as development of the appropriate combination of strain gauges with other electrical components to obtain an electric voltage or current representing tensile, compressive or bending strain, together with means of displaying and/or recording its value, is a strain gauge system.

Tasks

Design and build a strain gauge based force sensor based on a cantilever design or otherwise.

Build an appropriate VI that can be used to carry out all tests on the sensor.

Experimentally evaluation of the output/force transfer functions of the sensor. Include linearity, hysteresis, sensitivity, accuracy and repeatability in the evaluation.

Calculation the expected theoretical output values of the sensor and compression them with the experimental results obtained above.

Investigate the effect of temperature on the accuracy of the sensor. Based on this investigation suggest a temperature compensation scheme to improve the performance of the sensor.

Build an appropriate VI that takes the output of the sensor and display the result in appropriate units.

Part I

“ Explain how the AC Power (wattmeter) measurement is carried out at NPL. Draw a block diagram of the measurement system used. You should include the sources of uncertainties in your discussion.”

Volts, Amps, Watts, VARs and Power Factor are essential fundamental quantities which must be measured accurately in order to optimize the control and delivery of electric power.

Definition of electrical power

At a given moment, when a current i travels from generator G to receiver Rin the direction defined by the voltage v delivered by the generator (figure 1), the instantaneous power supplied to the receiver R is equal to product v. i.

Figure Generator & Receiver

If the voltage and current are DC, the mean power V. I is equal to the instantaneous power V. I. If the voltage and current are sinusoidal AC, there is generally a phase shift Ï† between the voltage and the current (figure 2).

The instantaneous values of voltage v and current (I) have the form:

v = Vmax cos Ï‰t

i = Imax cos (Ï‰t – Ï†)

Where Ï‰, the pulse, is proportional to the frequency F (Ï‰ = 2Ï€F).

Figure phase shift between the voltage and the current

The instantaneous power has a value of: Vmax . Imax . cos Ï‰ . cos (Ï‰t – Ï†). You must take the average value of this product during a period to obtain the expression of the power provided by generator G to receiver R. This power is called the active power and is expressed by the formula:

The wattmeter provide the expression of this product, either by causing a deviation of the pointer in the case of a device with an electrodynamics moving coil, or by supplying a DC current or a voltage proportional to the product in the case of electronic wattcmeters; this current or this voltage is then applied to an analogue or digital display.

The existence of a phase shift Ï• between the current and the voltage leads, for AC currents, to the introduction of 3 additional quantities:

â- The apparent power S = Veff . Ieff, in VA (volt-amperes), defining the voltage Veff not to be exceeded (insulator breakdown, increase in core loss) and the intensity Ieff circulating in the receivers.

â- The power factor:

When the current and voltage are sinusoidal quantities:

â- The reactive power Q = Veff . Ieff . sin Ï•, in rva (reactive volt-amperes).

The latter may be directly measured by a wattmeter if for voltage Vmax . cos Ï‰t we substitute a phase-shifted voltage of Ï€/2, i. e. Vmax x cos (Ï‰t – Ï€/2).

The mean product measured will be Vmax . Imax . cos (Ï‰t – Ï€/2) x cos (Ï‰t – Ï•) which is expressed by:

Vmax. Imax Q = cos (Ï€/2 – Ï•) = Veff . Ieff . âˆš sin Ï• 2

Knowing P and Q, we can calculate the apparent power and the power factor:

Apparent power: S = âˆšP2+Q2

Power factor: PF = P/S = P/âˆšP2+Q2

Knowing the parameters defined above: active power, reactive power, apparent power, power factor, is fundamental in electrical engineering and enables accurate calculation of the characteristics of the equipment used: yield, load, cos Ï•, utilization limits. The wattcmeters used for these measurements are classified in three major families: electrodynamics and electronic.

Digital Sampling Watt Meter

In NPL the digital sampling AC wattcmeters, which are used for calibration work, each require the generation of sample timing pulses suitably locked to the frequency of the AC which is to be measured. Repetitive waveforms representing the instantaneous test voltage and test current are digitised at equal intervals of time harmonically related to the period of the waveforms. A new NPL standard wattmeter calibrator incorporates improved sample timing generation. It uses a crystal digital oscillator to govern both the sample timing and the AC source frequency. This avoids reliance on timing interpolation uniformity within an input period; only digital frequency dividers are needed. Alternatively, commercial frequency synthesizers can be used, with a common master frequency, to give sampling and signal frequencies. Either alternative allows digital phase control, and reduces the use of special-purpose precision analogue electronics.

AC power wattmeter and voltmeters:

Figure AC Power Measurement by sampling

Power measuring at NPL is based on a digital sampling technique. This works by using a pair of analogue to digital converter (ADC) to take instantaneous samples of the respective voltage and current waveforms involved in measuring by multiplying the specimen pairs, the instantaneous power can be established and by averaging instantaneous over a defined interval the average power of that interval can be arranged.

Figure Sampling Wattmeter

This technique relies on the execution of the ADC in terms of its exactness and its ability to take samples at well-defined instant in time. To meet these requirements NPL has developed an ADC system based on the fastest shape of ADC, known as a blaze converter. Unfortunately, these devices are of circumscribed resolution and to overcome this limitation they are included in configuration that uses a Digital to Analogue Converter (ADC). This organized whole makes employ the repetitive properties of the waveforms of attention where single round is extremely like to the following round.

Figure Phantom Power

The computer takes a conjecture at the signal level at a stated moment on the waveform. This digital guess is accurately converted to voltage using the DAC. The guess can then be compared to the incoming signal at the required dot in time and the “ mistake voltage is converted using the blaze converter and passed back to the computer. Because the waveforms are assumed to be repetitive the computer can improve its conjecture for the next round of the waveform using the mistake knowledge from the former round. In this manner the computers conjecture converges on digital reproduction of the input waveform. This reproduction can then be used for AC voltage, current measuring.

Figure NPL ADC Schematic

Two of these ADC systems are used for single-phase measuring. They are used in conjecture with transducers that change unlike levels of voltage and current to the working signal levels of the ADCs. In organization to present traceability all of these components require single calibration and characterisation.

Uncertainty Contribution

Any estimation of uncertainties must start by identifying all significant contributions. There may be several sources of error in a measurement where the magnitude of the error could be quantified. Where these can be identified, they should be corrected such that only the residual unknown component contributes to the uncertainty of the measurement. Using the importation of DC voltage from a higher level laboratory as an example, there will be the following uncertainty components:

Calibration Uncertainty

Transportation

Stability with Time

Stability with Temperature

Noise

Usually the measurement techniques used will ensure well defined conditions and minimize loading effects such that the main contributions listed above will be the only significant ones.

Calibration Uncertainty

Calibration uncertainty is a significant contribution and is usually reported on the certificate of calibration issued by another organization i. e. the national laboratory. Quite reasonably, the national laboratory is beyond the control of other commercial organizations and there is little that can be done by the " customer" to evaluate the uncertainty reported as a single ± value on the certificate. For this reason the calibration uncertainty is usually treated as a type B contribution. The reported uncertainty may vary slightly for each calibration and will usually be at a 95% minimum confidence level.

Part II

Force measurement system based on strain gauges

Introduction

A small product based of strain gauge is designed in this part of the assignment, force measurement based on strain gauge. Two strain gauges connected properly on each side of a steel cantilever; these two strain gauges are a part of a resistance combination called Wheatstone bridge supplied by 5V. The output of this circuit connected to data acquisition card through an amplification circuit. A Low pass filter circuit provided. The circuit has been designed and calculated then built on a PCB supplied by power supply device. Moreover the circuit has been tested and practically operated using suitable weights (UK 1 penny to 10 pence); ten coins have been used. Data acquisition card used to pass the results to the computer. LabVIEW software was the tool used for monitoring the results.

Strain gauge:

As an external forces applied to an object, this will produce a stress and strain. That means the metal object will be compressed and the resistance of the metal will increase, while the resistance will decrease if the metal stretched. By using this feature of a specific metal; force measurement sensor bas been built. This called strain gauge. The design of a force measurement system was based on strain gauges because as the name implies they are used for measurement of strain. The strain gauge is attached to the object by a suitable adhesive, such as superglue as shown below:

Strain gauge mounted on component under test

Figure strain gauge glued on cantilever[1]

Strain gauge operation:

Generally electrical resistance (R) of a metal wire is proportional to the length (L) and inversely proportional to the area (A) as given by (where Ï) is the resistivity).

The change in resistance in a strain gauge of resistance R is nearly proportional to the applied strain. [ref9] Hence:

K is constant known as the gauge factor which is the sensitivity to strain.

Strain; . The gauges used in this report have K= 210±0. 02

Figure (2) shows loaded cantilever Beam

SG 1

SG 2

L

F

X

Figure stain gauge block diagram[2]

The gauges are glued at a distance (L-X) from the load, a load of mass m and weight mg is suspended from the cantilever beam. The beam has thickness t and width w and is made from stainless steel with a young modulus. The calculated strain due to the suspended mass is. Therefore the relative change in the resistance of the strain gauge is given by:

•

Wheatstone Bridge

The change of the resistance of the strain gauges is very small; so the strain gauges have to be connected in a Wheatstone bridge shown in figure (6). The gauge glued on top of the beam is in tension, the gauge glued underneath the beam is in compression, hence strain causes equal and opposite resistance changes in the gauges. By using two gauges the effects of temperature variations on the gauge resistance are cancelled.

The bottom end of the bridge circuit is connected to the ground, the circuit is powered by the bridge excitation voltage VEX applied to the top side of the bridge.

Figure Wheatstone bridge[3]

If the strain increases the resistance of Gauge One from R to R + then the resistance of Gauge Two is decreased from R to R – . Hence the voltage VG is given by:

To balance the Wheatstone bridge the Zero Adjust resistor is adjusted to produce a voltage of VADJ . [ref11] Therefore the output voltage V0 of the Wheatstone bridge is given by:

Substituting

Then:

Circuit design details:

Figure Circuit design

This circuit is designed and built by a team of three students; and it’s a number of stages as shown in the block diagram below:

Two strain gauges connected on a Wheatstone bridge.

Amplification circuit

Low pass filter circuit (RC circuit).

Data acquisition

LabVIEW software based on Computer

Strain Gauges

Wheatstone bridge

Amplification Circuit

Filter (RC)

D. AQ

Computer Screen

Figure circuit block diagram

Stage one

Pre-circuit has been designed and built; which is consists of two strain gauges of resistance of 120â„¦ of each glued on the cantilever. Wheatstone bridge provided with R1, R2 of 1k â„¦ of each and powered by 5v. The figure below show the circuit diagram of first stage.

Figure First stage circuit connection

The circuit above is a half bridge; while the output voltage will be as:

and the object that are used to be measured by the strain gauge sensor is the UK pennies as shown in figure and the mass for it is 3. 5 gram.

Calculations bridge output voltage

L = 140mm,

x = 50mm

w = 8mm

t = 0. 5mm

E = 210Gpa

G = 2

The maximum loading force that the Cantilever can handle is:

Where “” is the Fatigue strength for steel?

Since,

Then,

Kg

m = 204 gram

So the maximum mass that courses the max force is 204gram

Since:

G= 2

Vs= 5V

So:

Then:

0. 219485 mV

0. 43897 mV

0. 658455 mV

0. 87794 mV

1. 097425 mV

1. 31691 mV

1. 536395 mV

1. 75588 mV

1. 975365 mV

2. 19485 mV

The following table shows the calculated values:

Calculated values

No of coins

Mass (gram)

0

0

1

3. 5

2

7

3

10. 5

4

14

5

17. 5

6

21

7

24. 5

8

28

9

31. 5

10

35

The figure shows the relation between the mass of the coins and the calculated output voltage of the bridge circuit.

Chart 1. The relation between the mass and O/p voltages

Second Stage:

In this stage an amplification circuit is needed in order to increase the output voltage to a range of 0 10 v as an input to the data acquisition, INA126 OP AMP has been used with a gain resistance of around 80 ohms to get a 1000 amplification ratio, the following figure show the op amp circuit diagram:

Figure Op amp circuit diagram

According to the data sheet, and from the table shown above the gain of the circuit can be adjusted by varying the Gain Resistor “ RG”. The gain 1000 needed could be done by using or adjusting the gain resistance RG to be 80. 4 â„¦ (variable resistor has been used).

And the following calculations proves the value of the Gain Resistor “ RG”

Since;

So;

Third stage:

Figure Low pass filter circuitAs show in circuit diagram, an RC filter with a components of C= 22uF and R = 10 k ohms. The calculation below shows that this filter values is above the maximum frequency of the expected values from the dc components and to guarantee to get rid of the voltage spikes.

The frequency value is about 1 Hz.

Measuring the Bridge output voltage

As the circuit has been connected, start measuring the output of the Bridge circuit for each number of coins.

Measurement values

No of coins

Mass (gram)

0

0

1

3. 5

2

7

3

10. 5

4

14

5

17. 5

6

21

7

24. 5

8

28

9

31. 5

10

35

And the chart bellow shows the relation between the mass of the pennies and the measured output voltage of the bridge circuit.

Chart 2. The relation between the mass and O/p voltages

The chart above shows the relation between the mass of the coin with the output voltage values, it can be clearly seen that there is a non-linearity with the chart and this caused by the non accurate measures. The red line is the trend-line which used to simulate the real linearity for the chart.

The following table shows the results of the output of the amplification circuit

Measurement

No of coins

Mass (gram)

Output of the Bridge in (mV)

0

0

0

1

3. 5

0. 20

2

7

0. 41

3

10. 5

0. 62

4

14

0. 83

5

17. 5

1. 12

6

21

1. 42

7

24. 5

1. 57

8

28

1. 78

9

31. 5

1. 93

10

35

2. 21

Experimental procedures

Procedures:

Connecting and implementing the circuit as shown in the circuit connection

Testing the circuit if it's working

Make sure of the output of the bridge is set to 0V.

Put the coins (penny) on the beam and observe the output of the circuit, if the circuit it works, go to next step.

The bellow picture shows the penny which has been used as the weights to be measured in the experiments. The weight of this penny is 3. 5. That should be taken into account in the calculations.

Figure UK Penny

Data acquisition:

Lab View has been used to simulate the operation of the circuit. Lab view is a measurement application which uses a variety of data acquisition hardware. The following Figure shows the block diagram consisting of the DAQ assistant and some numerical representation of the number of coins and weight in grams with the ability to adjust the offset.

The bellow pictures showing how the practical work had been carried and what stage we did carry to finish this piece of work:

Integrating all the circuits had been justified and connecting the output to the LabVIEW by the data acquisition. LabVIEW screen shots below show the real practical results of the circuit:

Figure LabVIEW simulation

Output values with no load on cantilever

Figure output value with on load

Screen shots for some values:

When taken the results another test has been done by exchange the cantilever upside down and negative results found. And the following

LabVIEW screen shot result show the output voltage with 10 coins on, with both negative and positive results:

Figure output of 10 coins (negative and positive)

Results and Analysis

No

of coins

Test 1

Test 2

Test 3

Test 4

Test 5

Test 6

Test 7

Test 8

Test 9

Test 10

Mean (Average)

Standard Deviation

1

0. 20

0. 24

0. 23

0. 21

0. 22

0. 23

0. 24

0. 25

0. 26

0. 20

0. 228

0. 02044

2

0. 41

0. 47

0. 43

0. 42

0. 39

0. 38

0. 41

0. 44

0. 49

0. 42

0. 426

0. 03373

3

0. 62

0. 71

0. 69

0. 64

0. 63

0. 62

0. 65

0. 64

0. 63

0. 61

0. 644

0. 03204

4

0. 83

0. 78

0. 81

0. 83

0. 83

0. 82

0. 79

0. 72

0. 75

0. 82

0. 798

0. 03795

5

1. 12

1. 21

1. 18

1. 19

1. 09

1. 05

1. 17

1. 16

1. 15

1. 11

1. 143

0. 04968

6

1. 42

1. 37

1. 34

1. 25

1. 23

1. 22

1. 28

1. 18

1. 21

1. 41

1. 291

0. 08749

7

1. 57

1. 81

1. 79

1. 71

1. 64

1. 62

1. 67

1. 66

1. 61

1. 56

1. 664

0. 08462

8

1. 80

1. 79

1. 81

1. 77

1. 69

1. 67

1. 69

1. 63

1. 67

1. 81

1. 733

0. 06929

9

1. 93

1. 99

2. 01

2. 05

1. 99

1. 99

1. 89

1. 93

1. 97

1. 92

1. 967

0. 04855

10

2. 21

2. 29

2. 32

2. 28

2. 20

2. 26

2. 16

2. 26

2. 10

2. 21

2. 229

0. 06624

Maximum Experimental Error

The maximum experimental error in the expected value of Vo using the formula

The error in our application was acceptable and it’s expected, many factors may affect the results especially temperature affect as the strain gauge based on resistance variation of the metal which affected by temperature.

Self evaluation

During working on this mini project I have learn a lot according to sensors application specially strain gauges application, and how we could make use of the sensors and how to design a circuit by choose the suitable components as well as improving the output results of the circuit. With the help from the tutor Dr Ahmed we succeed to design and built the circuit.

The team which I was involved to do the work with was very good as very accomplish to finish the work as soon as possible. Working on teams has so many advantages as the work would be split to save the time. The designing and the building for the circuit didn't take much time, by the time we finished the design we started to take the measuring and the readings for the outputs.

Working on new software like the LABVIEW was very challenge because it's the first time for me to get use to this software and a very hard work has been taken to carry some tutorials and know how the software is work. As this software is very wide in use and has everything that the engineer can have the benefit from the use of such amazing software.

Conclusion

A mini project has been designed and built based on strain gauge trying to perform what it is regarded as basic function like measuring the weight. Stain gauges are quite simple in design. The circuit diagram of the design was designed in the MULTISIM electronic workbench software.

All components were calculated to get suitable values as well as a typical calculation has been done for the results. The measurement values compared with the calculated values and a very small different was provided as this is expected and acceptable.

Lapview tool was the best software to simulate the output of the circuit where the output can be clearly achieved as well as we could multiply, divide and/or add factors to the output results value.