Laboratory Report

Introduction

Strain gauges can be used to measure the force that is applied to a cantilever beam. When a force is applied to the beam it causes the strain gauges that are attached to the beam to under go either compressive or tensile forces. The resistance within the strain gauges changes and this variation can be measured by a Wheatstone deflection bridge. It is possible to design and build a beam-type instrument to measure the force acting on a cantilever beam. A ready-made cantilever with two strain gauges attached called an Analogue Experimental Transducer provides an ideal basis for the design to be based upon.

A suitable measurement system is designed to measure the applied force on a steel cantilever beam. The system incorporates an operational amplifier and low pass filter to ensure that the optimum results are gathered.

Cantilever and Strain Gauge Properties

The geometrical dimensions of the steel cantilever can be ascertained by measuring the strain gauge and cantilever with a rule.

The strain produced at the strain gauges if a force is applied to the cantilever can be written in terms of the force, F.

EQUATION 1 *1*

EQUATION 2

Within this mechanical system two strain gauges are used, when a force is applied the cantilever beam bends. The strain gauge on the top surface of the cantilever is placed under a tensile strain, whereas the strain gauge on the bottom is placed under a compressive strain. With two active gauges used in this mechanical system the sensitivity is doubled from that of a single gauge.

The range of this force sensor will depend on several factors;

For calculations two assumptions are made; it is assumed that the gauges are situated at or near the beam supports and the maximum moment acts upon them.

It is known that the Young's modulus for the cantilever beam is 210GPa and the fatigue strength of the beam is 540MPa. Using equation 3, it is possible to calculate the strain that will be present in the stain gauge when the maximum loading force is applied.

EQUATION 3

Equation 2 then enables the maximum loading force, F, allowed for this system to be calculated.

Wheatstone Bridge Design

A Wheatstone bridge circuit is used to convert the change in resistance of the strain gauges to a voltage signal. In this design two identical strain gauges will be use to measure the strain in the steel cantilever when a loading force is applied. The two gauges have a nominal gauge resistance of 1k Ω, gauge factor G = 2.1 and a thermal induced change ±2μ strain/°C. Within the bridge circuit the power is supplied by a 9V battery.

Diagram 1, Appendix A shows the bridge circuit that is used within the force measurement sensor.

When the output voltage, V_o (equation 4) of the system is zero the bridge is balanced. At the time the bridge is balanced it is a lot easier to measure any small changes in the voltage, .

Figure 1 below shows the Wheatstone Bridge circuit, where, in this case the R_1 and R_2 are provided by the strain gauges.

From the circuit diagram it is feasible to treat the top and bottom parts of the bridge as individual voltage dividers giving;

The output voltage of the circuit is measured cross the terminals B and D so it is possible to calculate the total output of the circuit, V_O.

Therefore:

EQUATION 4

Equation four is able to be re-written in the form:

In this case the resistances of the strain gauges have a nominal resistance of 1kΩ and the two other resistors within the bridge circuit also have resistances of 1kΩ. As all the resistors and strain gauges within the circuit have identical resistances. The initial output voltage will be zero when $R_1R_3=R_2R_4$, in this case the circuit will be balanced when all the resistances within the circuit as equal.

There will although be variations in practice between the two strain gauges and therefore the resistances will be slightly different, but the assumption is made that they are identical to aid analysing the circuit. There will be resistances present in the wires, which will affect the balance condition.

The bridge output is related to the relative resistance change of the strain gauges. When a load is applied to the cantilever its causes the resistances in the strain gauges to change.

The strain gauge, gauge 1, on the top of the cantilever beam is put under a tensile strain so the resistance within it will increase.

The strain gauge, gauge 2, on the bottom of the cantilever beam is put under a compressive strain so the resistance within it will decrease.

With the change in resistances of the two strain gauges a change in the voltage output is produced. Equation 4 can be re-written as shown in equation 5

EQUATION 5

Since all the Resistances are of equal magnitude $R_1=R_3=R_2=R_4=R$ equation 5 can be written as follows:

EQUATION 6

Equation 6 shows the relationship between the change in the bridge output voltage and the change in the resistance when the cantilever has an applied force acted on it.

Amplifier Design

An amplifier is used to provide an appropriate voltage level which can be measured and in this case a 741 operational amplifier is utilised. The amplifier can be used as either an inverting or non-inverting amplifier. In this application it is appropriate to use a non-inverting amplifier as it has higher input impedance which reduces the amount of noise in the circuit.

The amplifier is designed to have a gain of 1001 which is provided by having resistors with values of R_1=100kΩ and R_2=100Ω.

With such a high gain used in this circuit there is significant noise present. The noise is also created by electromagnetic interference, for example, 50Hz noise as there is no screening protection present in the circuit.

Low-pass filter design

To overcome the problem of noise within the circuit a simple low pass filter is used, by connecting a capacitor across the feedback resistor. Figure 3 shows the low-pass filter.

It is required that the circuit have a time constant of 0.1 seconds. An appropriate capacitor is chosen to be connected in parallel with the 100kΩ feedback capacitor.

Force Sensor System Test

The system requires that it is zeroed before the force sensor system test is completed; this is accomplished by adjusting the balance potentiometer to zero when there is no load applied to the system. In addition when the test is completed all forces are removed from the system and it is checked that the output voltage returns to zero.

Table 1 shows the results of the addition of washers to the cantilever beam. The washers in this instance are used as 'standard weights' each with a mass of 0.25 grams, which is equivalent to 2.5×10^{-4}kg. The applied force, F, can them be calculated by the following method.

The graph of system output with varying applied loads, Appendix B, shows that there is a linear relationship between the two quantities. As the applied force increases so does the output voltage of the source and it is possible to add a regression line to the data plot to show this relationship.

The sensitivity, K, of the force sensor can be calculated by using equation 7.

EQUATION 7

It is also possible to determine the linear range of the measurements that were taken, and in this instance it is 0 to 3.68mN.

Digitalising results

The most useful format for the results to be in is a digital format; a data acquisition system with an analogue-to-digital card is used together with the Labview computer programme is utilised to change the data from analogue to digital.

Within the computer programme it is possible to vary the sample rate and the number of samples. The most appropriate sample rate in this case was on of 500 scans per second.

The dynamic behaviour of the cantilever can be investigated by varying the conditions to which it is subjected to. This can be done by tapping the cantilever beam and observing the waveform that is produced. Graph 3, Appendix C, shows that it takes the system 5.2 seconds for the system to stable after it has been disturbed.

The noise level present can be demonstrated by testing the circuit with and without the low pass filter. Removing the capacitor connected across the low pass filter demonstrates that the noise level is significantly higher than when the low-pass filter is added to the circuit. Graph 1, Appendix C, shows that the noise levels present without the low-pass filter makes it extremely problematic to interpret the data. Connecting a capacitor across the feedback resistor creates a low-pass filter, which reduces the amount of noise within the circuit. Graph 2, Appendix C, demonstrates the reduced amounts of noise compared to the waveform diagram when the capacitor is not present in the circuit.

The resonant frequency of the system was found to be 50ms.

Discussion and Conclusion

An equation for the overall output voltage against the loading force can be derived as there is a linear relationship present between the two factors and Graph 4 (Appendix B) shows this correlation. A regression line can be added to the data and an equation for this line derived from the equation of a straight line . The equation for the line is found to be .

This equation for the straight line corresponds to the relationship between the overall output voltage and the loading force and can be written in terms of these:

There are several factors which could effect the strain gauge measurements these include:

In this case the measurement system designed will not be affected by the ambient temperature and this is due to the fact that two identical strain gauges are used on the cantilever beam. This insensitivity of the system to the ambient temperature can be explained through the thermal expansion property of the material. The thermal expansion coefficient of the steel is given to be 11x10 *-6*/°C

EQUATION 8 *2*

where is the change in length

is the length at the reference temperature T *0*

is the thermal expansion coefficient

is the change in temperature)

As the two strain gauges are identical that are used in the circuit they will be affected the same way by the ambient temperature. There will although be variations in practice between the two strain gauges and therefore the resistances will be slightly different, but the assumption is made that they are identical to aid analysing the circuit.

Using equation 8 it is achievable to illustrate that if the ambient temperature of the steel increases the length will change. As the two strain gauges are taken to be identical they will be affected by the temperature change in exactly the same way. The change in the resistance caused by the compression or tension on the strain gauges will therefore be effected by the same factor.

When the temperature increases from T to ΔT the resistances of the two strain gauges, R *1* and R *2*, increase due to the increased change in resistance due to the temperature increase.

So the voltage output of the system, V *0*, will still be zero when no load is applied so the system will remain balanced if the ambient temperature is increased.

Including a low-pass filter to the design is an extremely beneficial as it significantly reduces the amount of noise within the circuit. This enables a better relationship to be derived between output voltage and applied load.

Recommendations

The system needs to be able to settle before any measurements of the output voltage are taken. For the system that has been designed the reading would have to be taken atleast 5.2 seconds after the force has been supplied. For example in the experiment when the washers were added the system was disturbed, this is similar to tapping the system. Graph 3 (Appendix C) shows that it requires 5.2 seconds for the system to settle. Allowing it to settle properly will ensure that the most accurate measurements for the output voltage are recorded and therefore a more precise equation for how the overall voltage output, V_o, is affected by the applied load, F, will be obtained.

A dampener could be added to the test rig to ensure that the strain gauges are not affected by any vibrations. Vibrations could be caused by many factors including knocking the test rig or leaning on the table that the analogue experimental transducer is being tested on. Vibrations would cause noise in the results and therefore will make them less accurate, a dampener would reduce the effect on vibrations on the results.

It could also be beneficial to increase the gauge factor of the strain gauges as this would increase the sensitivity of the measurement system.

To improve this measurement system it is possible to increase the number of strain gauges to four. This will increase the sensitivity to four times that of a single gauge. The arrangement with four gauges will also be insensitive to temperature changes along with tensile forces and torsion, which could all affect the results obtained. A configuration as shown in figure 6.9 (Appendix D) could be used on the cantilever to produce a forces measurement system when included with a Wheatstone bridge circuit.

References

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