EXPERIMENT KW5: SENSORS AND INSTRUMENTATION SYSTEM

Related course: KIE3010 (Instrumentation)

OBJECTIVES:

1. To assess the performance of strain gauges for measurement of linear displacement
2. To understand the use of strain gauges in a potential divider, quarter, half and full bridge configurations and the relative sensitivities in each case
3. To assess the sources of error in using strain gauges to measure displacement

EQUIPMENT:
Strain gauges

INSTRUCTIONS:

1. Record all your results and observations in a log book or on a piece of paper
2. Follow the demonstrator's instructions throughout the experiment

REFERENCE(S):
Refer to the main references of KIE3010

TESTS:
PART A: Strain Gauge
PART B: Linear and Rotary Potentiometer

PART A: Strain Gauge

INTRODUCTION:

Strain gauges are devices designed and constructed so that their resistance changes when they are strained: that is their physical dimension increases or decreases. This is usually arranged to happen when the body which they are bonded (stuck) changes and so the strain gauges resistance may be used to measure the amount of strain the body is experiencing.

To maximise this effect, there are two main considerations to take into account when using strain gauges. The first is to design strain gauges so that their resistance changes appreciably with strain and secondly, they are attached to a system such that they are affected by strain. Other considerations are made to minimise any changes in resistance caused by any effect other than strain: the main one is temperature.

In the experiment, four strain gauges, nominal resistance of 120 Ω, are mounted on a flexible beam. This provides an exaggerated amount of movement at its free end when the Linear Assembly is moved but relatively little at the clamped end at which the strain gauges are fixed. Two strain gauges are mounted on each side of the beam such that when the beam deflects to the left, two of the gauges are in tension (increase in their resistance) and the other two in compression (decrease in their resistance). Deflecting the beam to the right reverses this effect.

Part A1: The Strain Gauge Potential Divider

This circuit as shown in Figure A1 is a simple potential divider with a strain gauge (tension) R_{sg}, connected in series with a fixed matching resistor R and a power supply V_{in} connected across both. The output voltage V_{out} of this circuit parameters is governed by the ratio of the strain gauge resistance R_{sg}, to the total resistance $R_{sg} + R$, where

$$V_{out} = \left(\frac{R_{sg}}{R_{sg} + R}\right) V_{in}$$

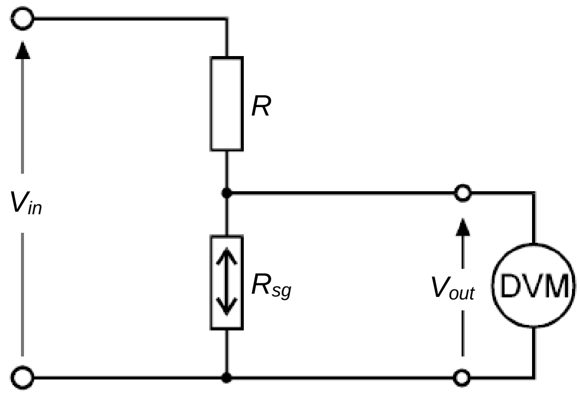

Figure A1. Strain gauge potential divider

The objective of this experiment is to determine the performance of the strain gauge potential divider. Use the patching leads to connect the circuit as shown in Figure A1.

Move the Linear Assembly to the right by rotating the rotary scale clockwise until it reaches the end stop. Carefully adjust the dial until the zero aligns with the edge of the moulding. Observe the initial value of meter reading and record it here.

Meter reading = ____________ V

AQ1: Was this value expected? Use the potential divider equation given previously to support your answer.

The equation predicts that a change in the resistance of the strain gauge should produce a change in the output voltage. Manually rotate the rotary scale anticlockwise to move the Linear Assembly over the whole range of movement and observe the change in the indicated voltage. Return the Linear Assembly to the start position once you have completed this exercise.

You should see that the indicated meter reading changes very little.

AQ2: Why could this be if we know that the strain gauge resistance has to have changed with the amount of displacement caused?

Modify the circuit to include the Differential Amplifier between the output and the voltmeter as shown in Figure A2. Set the gains of the amplifier, k1 and k2, to maximum and adjust the setting of Ref_1 to make the indicated meter value as small as possible (less than 5 V to be within the range of the 'set zero' control). Now zero the reading with the 'set zero' control.
Note: Set rotary scale to min scale = 0 before set 'set zero' control.

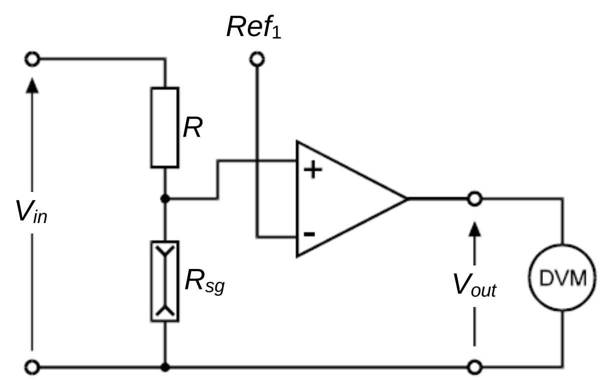

Figure A2. Strain gauge potential divider with differential amplifier

The output signal is now the amplified difference between the two inputs signals, the potentiometer value Ref_1. The changes in the output are caused by the changes in potential divider ratio due the changes in R_{sg}.

In steps of 1 mm (one complete revolution of the rotary scale), move the Linear Assembly to the left over its full range of travel and record corresponding meter readings to complete Table 1 (Output (V) Left). Repeat step in opposite direction and record corresponding meter reading to complete Output (V) Right. Be careful to adjust the control in one direction only for each set of readings.

Table A1. Results for gauge in tension

Displacement (mm)	**Output (V) Left**	**Output (V) Right**
0		
1.5		
2.5		
3.5		
4.5		
5.5		
6.5		
7.5		
8		

AQ3: From Table A1, plot a graph of Output Left and Output Right vs. Displacement in one graph. Determine the sensitivity of the measurement system from the slope of both graphs and the intercept point with y-axis.

AQ4: Comment on the linearity, hysteresis, scatter and repeatability of the measurements obtained.

Repeat the above procedure with one of the compression gauges replacing the tension gauge and over the same range of displacements to complete Table A2.

Table A2. Results for gauge in compression

Displacement (mm)	**Output (V) Left**	**Output (V) Right**
0		
1.5		
2.5		
3.5		
4.5		
5.5		
6.5		
7.5		
8		

AQ5: From Table A2, plot a graph of Output Left and Output Right vs. Displacement in one graph and compare them with those obtained with the tension gauge (Table A1).

Part A2: The Quarter Strain Gauge Bridge (or Quarter-Bridge)

The quarter strain bridge is a conventional bridge circuit and an example of a Wheatstone bridge. One arm is formed by a strain gauge in series with a fixed resistor (R_1 + R_2) and the other by two fixed resistors (R_3 + R_4). The quarter strain gauge bridge is shown schematically in Figure A3.

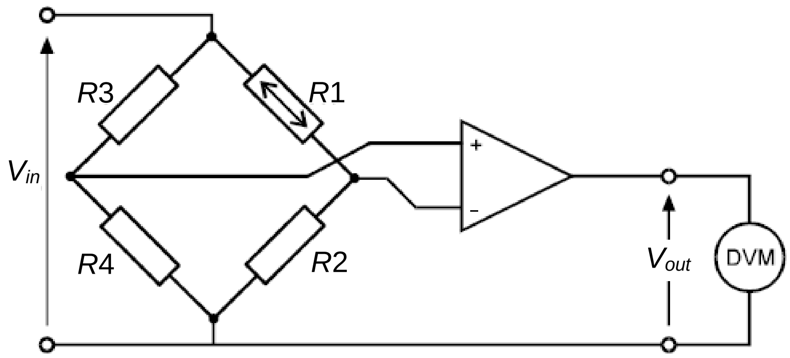

Figure A3. Quarter strain gauge bridge with differential amplifier

The strain gauge arm produces a change in output with change in strain while the resistor arm produces a fixed voltage to replace that produced previously with the additional, variable, supply (Ref_1). Effectively, the performance should be the same as for the potential divider circuit in Part A1 but at a lower cost. The objective of this experiment is to determine the performance of the quarter bridge and compare it with the results of the potential divider.

Connect the quarter bridge strain gauge circuit as shown in Figure A3. Repeat the procedure of Part A1 to complete Table A3.

Table A3. Results for quarter strain gauge bridge

Displacement (mm)	Output (V) Left	Output (V) Right
0		
1.5		
2.5		
3.5		
4.5		
5.5		
6.5		
7.5		
8		

AQ6: From Table A3, plot a graph of Output Left and Output Right vs. Displacement in one graph. Determine the sensitivity of the measurement system from the slope of the graph and the intercept point with the y-axis.

AQ7: Compare these results with Part A1 for the potential divider circuit.

Part A3: The Half Strain Gauge Bridge (or Half-Bridge)

The half-bridge is a further enhancement to the basic Wheatstone bridge. One arm is now formed by two strain gauges (R_1 and R_2), one positioned to experience increasing tension and the other increasing compression when the Linear Assembly moves in one direction.

Figure A4 is a circuit of the half strain gauge bridge. The variation in the output is affected by the change in resistance of both strain gauges. The fixed resistor arm (R_3 and R_4) produces a fixed reference voltage to compare the variable output of the strain gauge arm.

Connect the circuit as shown in Figure A4. Repeat the previous procedure to fill in Table A4.

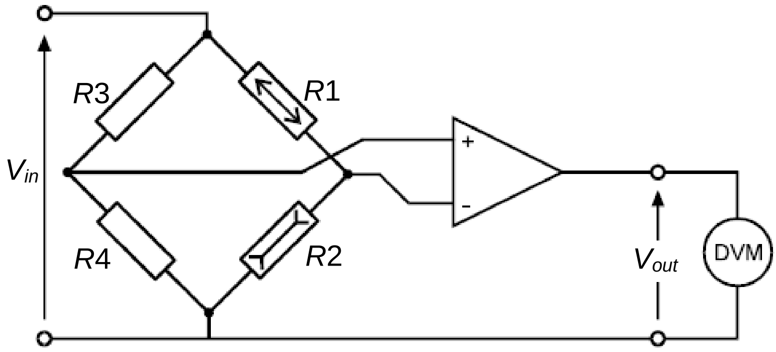

Figure A4. Half Strain Gauge Bridge with differential amplifier

Table A4. Results for the half strain gauge bridge

Displacement (mm)	Output (V) Left	Output (V) Right
0		
1.5		
2.5		
3.5		
4.5		
5.5		
6.5		
7.5		
8		

AQ8: From Table A4, plot a graph of Output Left and Output Right vs. Displacement in one graph. Determine the sensitivity of the measurement system from the slope of the graph and the intercept point with the y-axis.

AQ9: Compare these results with those obtained for the potential divider and quarter-bridges in Parts A1 and A2.

<u>Part A4: The Full Strain Gauge Bridge (Full-Bridge)</u>

The final development to the Wheatstone bridge circuit is to replace all fixed resistors with strain gauges, two tension and two compression. They are arranged so that when the Linear Assembly is moved, the output voltage from one arm increases (becomes more positive) while the other reduces (becomes less positive). The difference between these two signals, as supplied to the amplifier, is to increase the overall measured signal amplitude at the output. Figure A5 shows the full strain gauge bridge circuit. Connect the circuit as shown in Figure A5. Repeat the previous procedure to fill in Table A5.

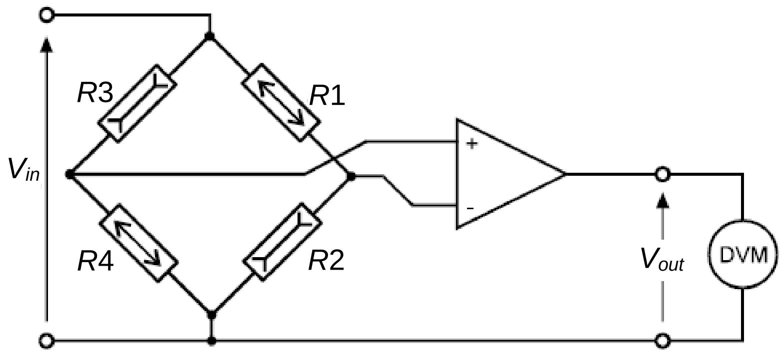

Figure A5. Full bridge strain gauge with differential amplifier

Table A5. Results for the full bridge strain gauge

Displacement (mm)	Output (V) Left	Output (V) Right
0		
1.5		
2.5		
3.5		
4.5		
5.5		
6.5		
7.5		
8		

AQ10: From Table A5, plot a graph of Output Left and Output Right vs. Displacement in one graph. Determine the sensitivity of the measurement system from the slope of the graph and the intercept point with y-axis.

AQ11: Compare these results with the potential divider, quarter-bridge and half-bridge in Parts A1, A2 and A3.

Additional Questions:

AAQ1. What is the smallest movement of the Linear Assembly detectable by a change in the meter reading?

AAQ2. What would be the effect of reversing the polarity of the supply to the potential divider?

AAQ3. What would be the effect of reducing the voltage supplied to the potential divider?

AAQ4. Is there a deadzone in the measurement system and if so what is its cause?

AAQ5. What are the main parameters that affect the quality of the measurement system?

AAQ6. What was the effect of replacing the tension gauge with the compression gauge in Part A1?

AAQ7. For the potential divider circuit in Part A1, what is the smallest movement of the Linear Assembly detectable by a change in the meter reading?

AAQ8. What would be effect on the results of swapping the strain gauge and the resistor of the Quarter Bridge?

AAQ9. What would be the effect on your results of reversing the connections to the differential amplifier?

AAQ10. What would be the effect on your results if the measurement is started with the Linear Assembly zeroed at the far left and moved to the right?

AAQ11. Describe how you could modify this experiment, circuit and procedures, to be able to measure temperature using bridge techniques.

DISCUSSION:

Use the results, observations made and the answers given to each of the question in this experiment to write a discussion on the use of strain gauges for measuring linear displacement.

Include any theory to support the discussion and conclusions given. Suggest any changes to the experiment that could improve the quality of the results and that could widen the scope of the experiment.

Part B: Linear and Rotary Potentiometer

OBJECTIVES:

- To understand how linear and rotary potentiometers are attached to a system to measure displacement
- To make judgements on characteristics of potentiometers

INTRODUCTION:

The potentiometer is an electrical device comprising a resistor with a sliding third contact, often termed a wiper, which allows the voltage to be varied depending upon where the slider is positioned along the length of the resistor.

Potentiometers are found in many electrical and electronic applications and in many different forms, sizes and power ratings. For instance, in a high power application, a wire wound potentiometer may be used to provide a variable DC or AC power supply delivering many amperes at some voltage less than the supply voltage. In an electronic system, a low power rated carbon track potentiometer may be used to preset the voltage on a circuit board to achieve the desired level of response.

Manual adjustment of the wiper along the length of the fixed resistance produces a variable voltage at the wiper. The magnitude of this output voltage is directly proportional to its relative position along the length of the resistor.

If the potentiometer wiper is connected to a moving system, any movement in that system will cause the wiper to move and change the output voltage. This signal provides a direct measurement of position or change in position. Hence, although a potentiometer, it is used as a sensor for measuring linear displacement. A potentiometer circuit is shown in Figure B1.

The output voltage is governed by the position of the wiper (C) which lies between the two ends, A and B, of the resistance. The output voltage is given by $V_{out} = V_{in}$(CB/AB), where CB is the linear distance (or angular rotation) from B to C and AB is the maximum linear distance (or angular rotation) from B to A.

Hence when the potentiometer wiper is in position B, the output voltage will be zero and when in position A, the voltage is maximum (V_{in}). In any intermediate position, the voltage at the wiper will be between 0 and V_{in}. If the resistance is linear throughout its length, the output voltage will also be linear and directly proportional to the wiper position along the length of the resistance. In this system, the wipers of both linear and rotary potentiometers are connected to the Linear Assembly such that any movement of the assembly causes the output voltage to change in direct proportion.

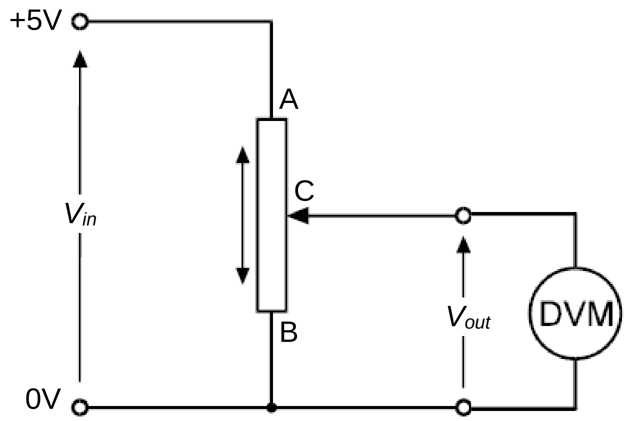

Figure B1. Potentiometer circuit

Part B1: Linear Potentiometer

1. Use the patching leads to connect the circuit in Figure B1.
2. Move the Linear Assembly to the right by rotating the manual control clockwise until it reaches the end stop. Adjust the dial until the zero aligns with the edge of the moulding.
3. In steps of 1 mm, (one complete rotation of the rotary scale), move the Linear Assembly to the left over its full range of travel and record corresponding meter readings to complete Table B1 (linear potentiometer column Figure B1). Be careful to adjust the control in one direction only throughout the procedure.

Table B1. Results for linear potentiometer

Displacement (mm)	**Output (V) for linear potentiometer (Figure B1)**	**Output (V) for linear potentiometer with bipolar supply (Figure B2)**	**Output (V) for linear potentiometer with differential amplifier (Figure B3)**
0			
1.5			
2.5			
3.5			
4.5			
5.5			
6.5			
7.5			
8			

4. An alternative supply to the potentiometer is from a bipolar supply, as shown in Figure B2. Use the patching leads to connect the equipment as shown in Figure B2.

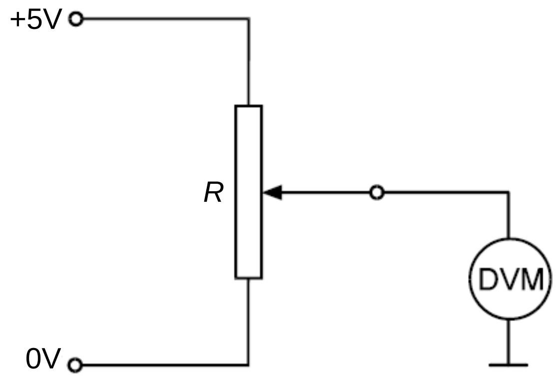

Figure B2. Linear potentiometer with bipolar supply

5. Repeat the previous procedure to move the Linear Assembly from the right to the left and record corresponding values of displacement and meter reading to complete Table B1 (linear potentiometer with bipolar supply column Figure B2).
6. The circuit in Figure B3 shows the output from the potentiometer connected to the input (+) of a differential amplifier with an external reference voltage, Ref_2, connected to the other input (−). The objective is to use the reference voltage to remove any offset in the output signal when the Linear Assembly is in the starting position.
7. Use the patching leads to connect the equipment as shown in Figure B3. With the amplifier gain set to unity, adjust Ref_2 to zero the meter reading at the starting position. Repeat the previous procedure to complete Table B1 (linear potentiometer with differential amplifier Figure B3).

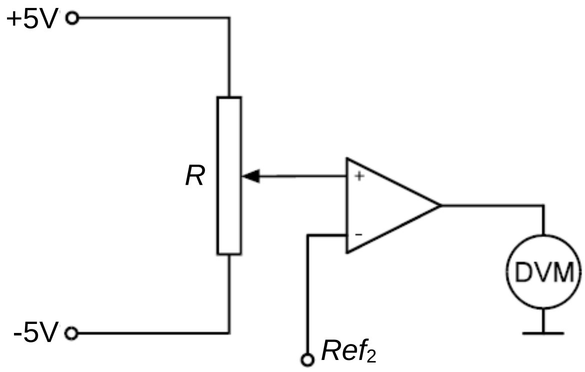

Figure B3. Linear potentiometer with differential amplifier

BQ1. From Table B1, for each of the linear potentiometer,
- **a) Plot a graph of Output vs. Displacement separately.**
- **b) Comment on the shape of every graph.**
- **c) Measure the slope and intercept point with y-axis of every graph.**
- **d) Write the equation governing every measurement system.**

Part B2: The Rotary Potentiometer

In terms of operating principles, the rotary potentiometer is the same as the linear potentiometer. The wiper moves over a fixed resistance to provide a varying output signal proportional to the movement. The difference is in the design so that the resistance forms into an arc and that the wiper rotates about a central pivot.

The rotary potentiometer illustrates the conversion of linear motion into rotary motion by the use of a worm and wheel arrangement (any similar arrangement producing the same effect could also be used). In addition, although the shaft rotates by the movement of the Linear Assembly, the final motion delivered to the potentiometer is rotary.

1. While moving the Linear Assembly over its full range of movement, visually inspect the effect it has on the shaft of the rotary potentiometer in terms of the angle moved through. Also, observe any relative movement between the worm and wheel arrangement, which would cause errors in measurement.
2. Use the patching leads to connect the equipment as shown in Figure B3 (use rotary potentiometer). Repeat the previous procedure to complete Table B2.

Table B2. Results for rotary potentiometer with differential amplifier

Displacement (mm)	Output (V)
0	
1.5	
2.5	
3.5	
4.5	
5.5	
6.5	
7.5	
8	

BQ2: From Table B2, plot a graph of Output vs. Displacement. Comment on the shape of the graph. Measure its slope and intercept point with y-axis. Write the equation governing this measurement system.

END OF EXPERIMENT