Strain gauges

The strain gauge sensor converts the strain to the change in electrical resistance. It is formed by a conductor of length *l*, cross-section area of *S* and resistivity *ρ.* If we start to deform such a conductor all of the mentioned parameters are going to change and thus the electrical resistance of the conductor is changed too. This is called the piezoresistive effect. For the resistance of a conductor we can write:

$$R = \rho \frac{l}{S}$$

Mainly the longitudinal deformation is used where following relation applies:

$$\frac{R}{R} = K \frac{l}{l}$$

where *K* is called a gauge factor and it is dependent on the material. According to the used material it is possible to divide the strain gauges into metal and semiconductor ones. It is necessary to use materials where the resistance is weakly dependent on temperature. The semiconductor strain gauges have typically greater values of *K* and thus are more sensitive but their change in resistance with deformation is nonlinear. Strain gauges are also used in many other sensors for measurement of pressure, force, mass and deformations.

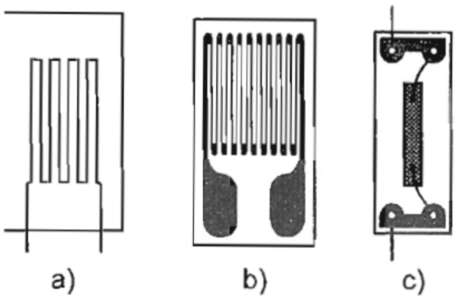


Fig.1 Examples of strain gauges design

Connection of resistance sensors in Wheatstone bridge:

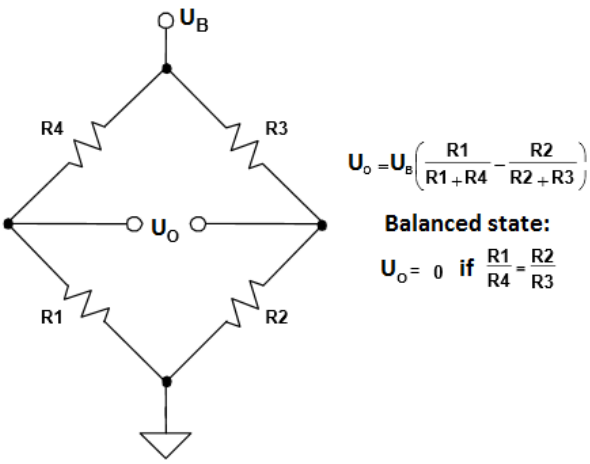
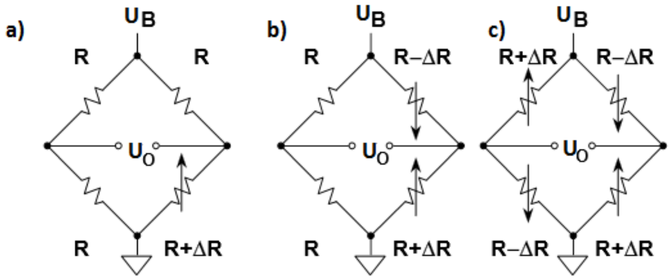


Fig.2 Wheatstone bridge

The changes in resistance of strain gauges are very small and often difficult to measure. Sometimes there is need to connect them to a Wheatstone bridge circuit. The basic diagram of Wheatstone bridge can be seen in Fig.2. It is composed of four resistors (R1, R2, R3 and R4) it is supplied by a source of constant voltage U_B. The output voltage of the bridge is denoted as U_O. If the bridge is in balanced state (such that R1=R4 and R2=R3) then the output voltage $U_O=0$. If we replace either one or all of the resistors by a resistive sensor (for example a strain gauge) the output voltage U_O will depend on measured quantity (Fig.3). Possible configurations of Wheatstone bridge are: quarter-bridge (Fig.3a), half-bridge (Fig.3b) or full-bridge (Fig.3c). Legs of bridge without a sensor are formed by resistors R with same values as the initial resistance of sensor. The change in sensor resistance is denoted as ΔR.



	a)	b)	c)
Constant voltage U_B	U_O: $\frac{U_B}{4}\left[\frac{\Delta R}{R+\frac{\Delta R}{2}}\right]$	$\frac{U_B}{2}\left[\frac{\Delta R}{R}\right]$	$U_B\left[\frac{\Delta R}{R}\right]$
Constant current I_B	U_O: $\frac{I_B R}{4}\left[\frac{\Delta R}{R+\frac{\Delta R}{4}}\right]$	$\frac{I_B}{2}\left[\Delta R\right]$	$I_B\left[\Delta R\right]$

Fig.3 Wheatstone bridge configurations

Sometimes the constant current source is used as bridge supply rather than constant voltage. The advantage of using a constant current source is that the resistance of the bridge supply leads has no longer effect on the output voltage reading. Moreover the nonlinearity of the output voltage when changing the resistance of one sensor in bridge is decreased.

Capacitive sensor:

Principle is based on the change of capacity *C* caused by measured quantity. We can change the capacity of a capacitor by changing the distance *d* between electrodes, changing surface area of electrodes *S* or by changing the permittivity *ε* of medium in which the electric field of capacitor is created.

$$C = \varepsilon \frac{S}{d}$$

In our experiments the sensor based on change of the electrode distance is being used. This type of sensor is called a gap capacitive sensor.

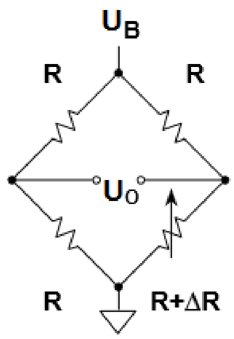
Exercises:

1. Get familiar with exercise measurement set for strain gauges and capacitive sensor
2. Check the functionality of particular strain gauges in set
3. Measure the dependence between output voltage and deformation when using quarter-bridge configuration of strain gauges with constant voltage and constant current source as a bridge supply. Compare the linearity of both cases of supply sources.
4. Measure the dependence between output voltage and deformation when using full-bridge configuration of strain gauges with constant voltage and constant current source as a bridge supply. Compare the linearity of both cases of supply sources.

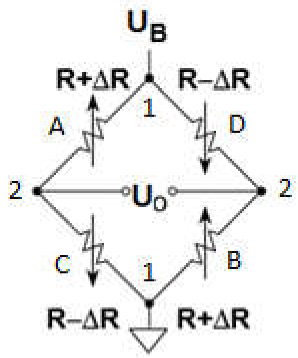
5. Measure the dependence between capacity and flexing arm position of capacitive sensor.

Measurement guide:

1. Measurement set utilizes a flexing arm. At each side of the flexing arm there are 2 semiconductor strain gauges of type WDH111 with initial resistance 120Ω. They are marked using letters A, B, C, and D in exactly the same way as corresponding connection terminals. The bending of flexing arm is done using a small screw located on the right side. The level of flexing arm deformation can be measured dimensionless using scale under the flexing arm. Capacitive sensor is created using two electrodes, one of which is made by flexing arm itself and the second one using a secured metal plate. By bending the flexing arm the capacity of sensor is changed approximately in the range of 4pF to 12pF.
2. Using ohmmeter check the functionality of particular strain gauges mounted on flexing arm. Connect ohmmeter to terminals of the strain gauge marked D and bend the flexing arm using hand. Notice the direction of resistance change. Using the same method, continue checking strain gauges C, B and A. How is the change in resistance related to the mounting positions of particular strain gauges on flexing arm? Choose one of the strain gauges (take note on which one) and measure the dependence between its resistance and flexing arm position for at least 10 positions. Change the position of flexing arm using a screw and read the position using small paper scale.
3. Now connect the same one strain gauge into quarter-bridge configuration (as seen on figure). Use the bread board and three ordinary 120Ω resistors to build the bridge. Measure the bridge output voltage U_O using multimeter. Use laboratory supply unit as a constant voltage source of 1.2V for U_B. Fully unscrew the flexing arm screw. Why is there a non-zero voltage output of the bridge while the flexing arm is not bended and in default position? Measure the dependence between U_O and flexing arm position for at least 10 positions. Change the power supply to a constant current source of 10mA and repeat the last measurement.



4. Connect the strain gauges to the full-bridge configuration (as seen on figure) and measure the dependence between U_O and flexing arm position. Notice how the strain gauges are connected in the bridge according to resistance change direction. Use 1.2V constant voltage source as a supply for bridge. Would the linearity of the measured dependence get changed if you use a constant current source instead?



5. Disconnect wires from the bridge and connect the LCR meter to CAP terminals of capacitive sensor. Now measure the dependence between capacity and the position of flexing arm. Try to put your hand nearby the capacitive sensor. What does it do and why?

Plot the measured dependencies and compare the linearity of the output voltages for particular types of bridge supply sources.