

## Lab Fil

### Measurement of the weight of a load cell. Amplification, filtering and calibration of measurement signals.

## 1 .1 Preparatory Information

### Introduction

In industry, different kinds of sensors are used for measuring variables.

The most common is to measure a voltage corresponding to a second quantity, such as temperature, or - as in this exercise - weight.

### Calibration

The simplest way of translating the measured voltage of the desired variable is with a linear approximation - in our case, the measurement of voltage  $x$  and weight  $y$ .

To determine the slope of the line, we need two measuring points. We assume two known weights 0 g och 400 g and measure the two corresponding voltages. With these measurements, we can *calibrate* our scale. The result of the calibration shows that the scale is correct at 0 g and 400 g.

The calibration can then be checked by weighing a third known weight, for example 200 g. The principle of the calibration is shown in Fig. 1.

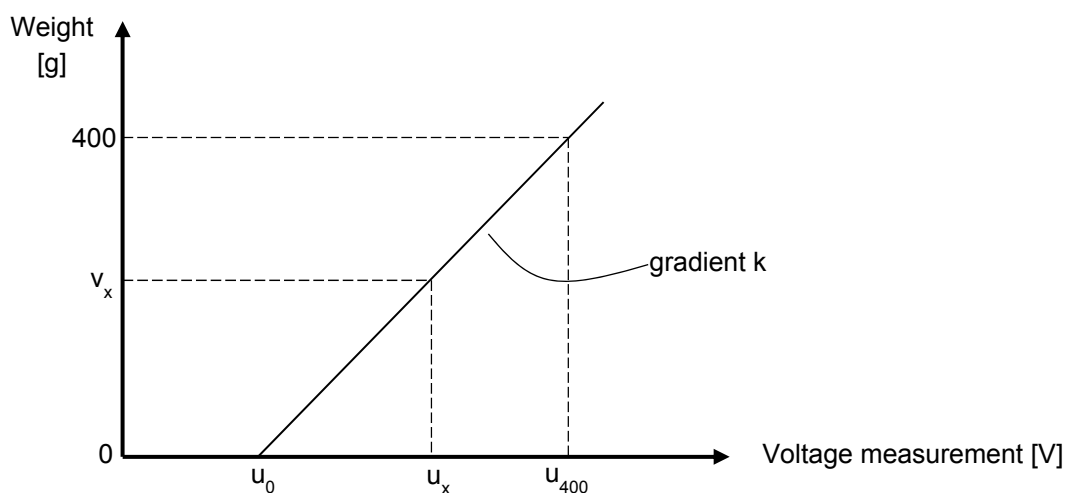


Fig. 1 Weight as a function of voltage measurement,  $v_x = k \cdot u_x + m$

Starting from these figures, we can generate a formula for calculating the weight  $v_x$  at the input voltage  $u_x$ .  $u_0$  and  $u_{400}$  are measured voltages and can be used to calculate  $k$  and  $m$ .

$v_x =$

## Strain gauges

In this experiment, we will convert weight to voltage with the help of a *strain gauge*.

The resistance of a metal wire is given by the formula:  $R = \frac{\rho L}{A}$  where  $\rho$  is the resistivity of the metal,  $L$  is the length of the wire, and  $A$  the cross sectional area of the wire.

Stretching the wire (putting strain on it in a longitudinal direction) will increase its resistance. The cross sectional area is also reduced, but for simplicity we will assume here that  $A$  is constant.

The reverse is also true - the resistance decreases if the wire is compressed.

Calculate the resistance of a 1 m long copper wire ( $\rho_{Cu} = 1,72 \cdot 10^{-8} \Omega m = 1,72 \cdot 10^{-2} \Omega \frac{mm^2}{m}$ ) with an area of  $0,172 mm^2$ :

R :..... m $\Omega$

If the wire is stretched to 1.005 m, calculate the new resistance:

R :..... m $\Omega$

If a strain gauge is attached to, for example, the spar of an aircraft wing, one can measure the load that the wing is exposed to and the deflection of the wing.

In practice, the strain gauge comprises of a metallic foil on a flexible film. The metal foil forms a pattern that shows the maximum resistance change of the strain / compression in one direction, but not in other directions, therefore it is important that the sensor is properly positioned. Below is an example of what the foil pattern may look like.

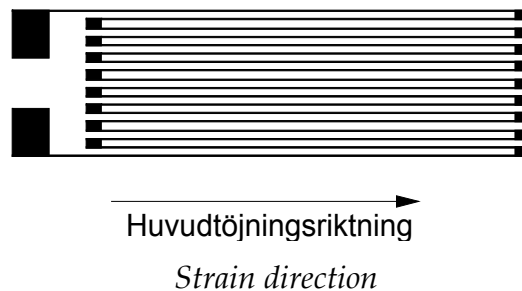


Fig. 2 Strain gauge

It is difficult - and thus expensive - to measure the small resistance changes that a strain gauge can provide. The sensors are therefore arranged in a bridge circuit, so that they instead measure a voltage change, which is much easier.

The bridge consists of four identical strain gauges  $R_1$ - $R_4$ , symbolised by the variable resistors in Fig. 3. A voltage  $U_E$  - known as the *excitation voltage* - feeds the bridge and  $U_S$  is measured to determine the strain.

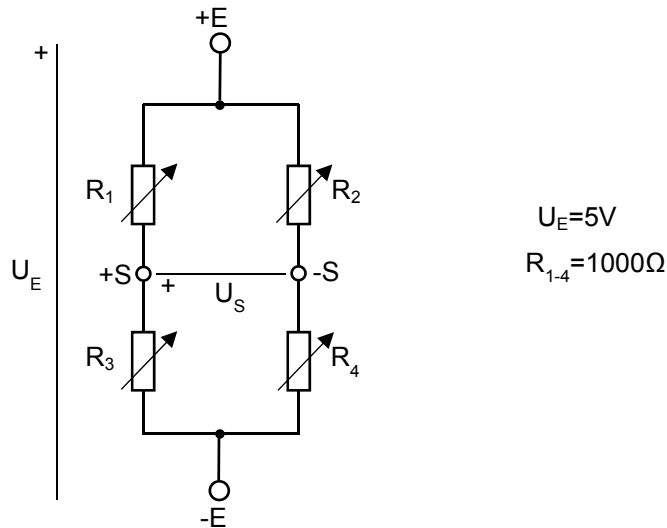


Fig. 3 Bridge connection using strain gauges

$U_E$  is 5 V in our example.

Calculate the voltage  $U_S$  if all the resistors are unstrained and 1000  $\Omega$  each.

$U_S$ : .....

Now suppose that  $R_2$  and  $R_3$  are stretched to the resistance 1001  $\Omega$ , and that  $R_1$  and  $R_4$  are compressed to 999  $\Omega$ , and calculate  $U_S$  for this case.

$U_S$ : .....

Obviously here the voltages are very small, but with an amplifier they can be scaled up to a more manageable magnitude, which you will have the chance to do in the lab.

In the lab, we will measure the weight by indirectly measuring the deflection of a beam using strain gauges. This kind of sensor arrangement, designed to measure force, is known as a *loadcell*. The strain gauges are attached to the beam as shown in the diagram below.

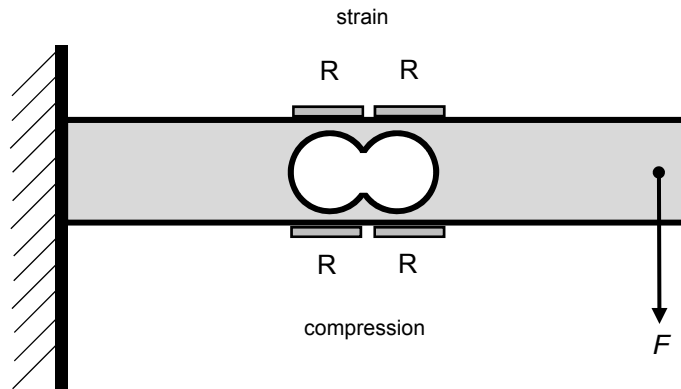


Fig. 4 Loadcell - beam with strain gauges

Start from the bridge connection shown in Fig. 3 and **write in** the indices for resistors 1 to 4 in Fig. 4 above, so that the maximum measured voltage is obtained when the beam bends.

The strain gauge is coupled to the amplifier as shown in Fig. 5. It has two outputs - a voltage output  $U_{ut}$  with the span 0-5 V, and a current-loop output  $I_{ut}$ , which will be described later.

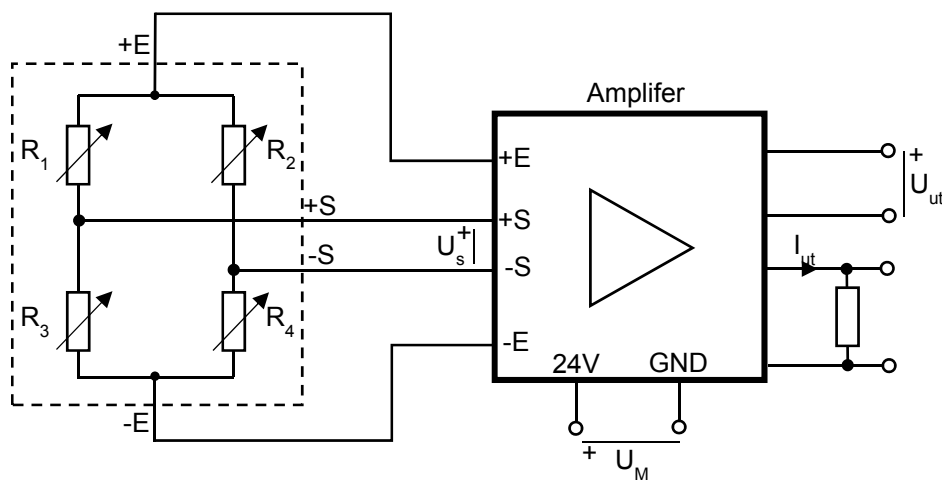


Fig. 5 Circuit diagram for the bridge and amplifiers

## Current Loops

In industry, sensors are often connected to the measuring and control device by long cables, which can pick up interference from electrical equipment, and other nearby cables. To get round this, you can use a current loop, which is less sensitive to disturbances, to transfer the sensor readings.

The current in the loop is converted to a voltage in the measuring equipment through a resistor, as shown in the simplified diagram below.

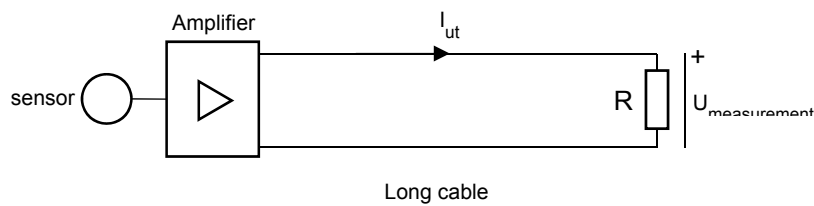


Fig. 6 Current loop

The magnitude of the current is standardised to an approximate range of 4-20 mA, where 4 mA corresponds to the smallest value and 20 mA the largest.

The reason for not using 0 mA as the minimum measurement value is that the measuring device could mistakenly identify a current of 0 as a cable break.

If the measuring device has a range of 0 to 5 V, what value should the resistor be to not exceed 5 V at 20 mA?

$R_{\text{measurement}}$  :.....

## Lab Equipment pick list

Quantity	Equipment
1	Loadcell set with amplifier
1	10-terminal box
1	Universal multimeter.
1	Resistor 390 $\Omega$
2	Resistor 1 k $\Omega$
1	Resistor 3 k $\Omega$
6	Red wire
4	Black wire
4	Yellow wire
1	500 g weight (5 x 100 g)
1	100 g weight with hook
1	Spring

## 2.1 Voltage measurement with a loadcell

**Note! The beam in the loadcell is designed for a 1 kg load, so ensure the burden is not more than that to avoid damage.**

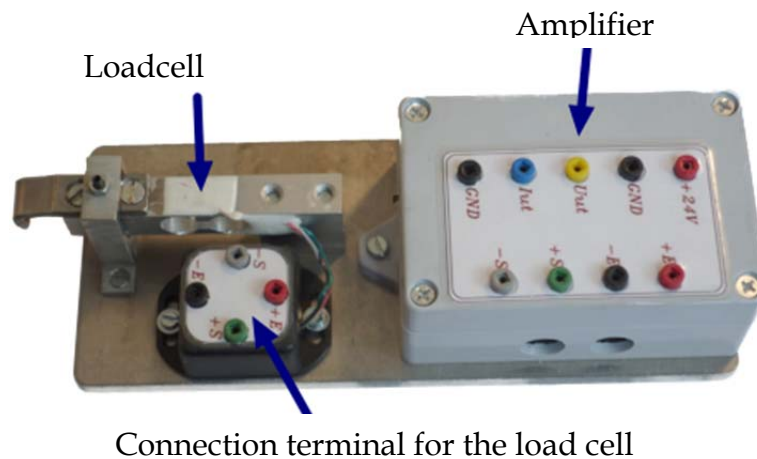


Fig. 7 Loadcell panel

Connect the 24V supply voltage to the amplifier on the load cell panel.

Then connect the excitation voltage from the amplifier +E and -E to the load cell connection terminals +E and -E .

Measure the voltage  $U_S$  mellan +S and -S from the load cell with the multimeter, without weights. Measurement value: :.....

Add a load of 400 g. Does the weight generate a measurement voltage on the multimeter.

Answer: .....

Remove the weight and unplug the multimeter. Connect bridge outputs + S and -S to the amplifier.

Measure the output voltage of the amplifier without weight.

Measurement value: .....

Add a load of 400 g. Measurement value: :.....

Calculate the output voltage you should get if the weight is 200 g.  $U_{ut}$  :.....

Now check the measurement to see if this is true.  $U_{ut\ measurement}$  :.....

When there is no load on the loadcell, the instruments probably did not show a reading of 0V. What are the likely reasons for this?

.....  
 .....

Present your results to the lab assistant. **Assistant's signature:** \_\_\_\_\_

### 3.1 Measurements with LabVIEW

The LabVIEW-program is known as a virtual instrument (or VI) since it can imitate the function and display of a traditional physical instrument such as an oscilloscope, multimeter or speedometer. In LabVIEW there are many tools for collecting, analysing, presenting and storing data.

A LabVIEW-program, "VI", consists of two parts, the front panel and the block diagram. The front panel comprises of user interface of buttons, potentiometers and other so-called "controls" and "indicators", such as LEDs and graphs. In the block diagram, the functionalities is built by the user. The items at the front panel shows up in the block diagram and the controls appears as inputs and the indicators as outputs.

You will now use a prepared VI, called "fil.vi", which is available on the course homepage (use course MF1016). Download this to your desktop and double click the icon to start LabVIEW.

Connect U<sub>ut</sub> and GND from the amplifier to AI0 and AIGND connection box for the measurement card in the computer controlled by LabVIEW. Remove the weight from the load cell and start the measurement.

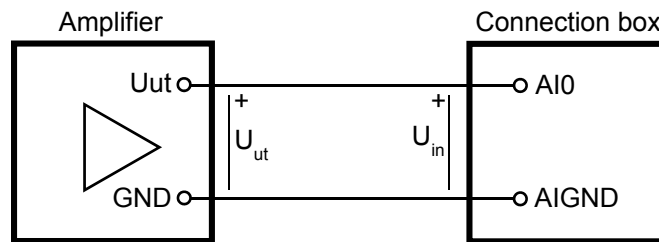


Fig. 8 Connecting the amplifier to the connection box

U<sub>in</sub> at the terminal box corresponds to U<sub>ut</sub> at the amplifier.

Is the value shown for *uin* in LabVIEW stable? :.....

Probably the signal is "noisy", but the VI program has a low pass filter that suppresses noise of a certain frequency, called the *cut-off frequency*. Other names for this include, *bandwidth*, and *break frequency*.

The filtered signal is called *uin-fil* in the front panel. Adjust the cut-off frequency until *uin-fil* becomes sufficiently stable.

Which cut-off frequency is needed to get a satisfactory weight measurement? :..... [Hz]



Both of the front panel's instrument displays show weight as a function of the voltage measurement. The left one uses  $u_{in}$  directly, whilst the right instead uses the filtered value  $u_{in-fil}$ . If you have chosen a good value for the cut-off frequency, the right needle should be less "floppy" than the left.

To convert the voltage measurement to a display of weight, the instrument display must be calibrated. Measure  $u_{in-fil}$  at two points and fill in the table below:

Vikt [g]	$u_{in-fil}$ [V]
0	$u_0 =$
400	$u_{400} =$

From these measurements, you can calculate  $k$  and  $m$ , in accordance with the preparation task given in section 1 of these notes.

$k$  : .....

$m$  : .....

Enter  $k$  and  $m$  in the front panel, and check with a few different weights to ensure your measurements match.

Weight	Value shown
0 g	
200 g	
500 g	

What you have done is a **calibration** of the measurement system. In the past, this was often done by hand using hardware, but nowadays it is almost exclusively done with software, and the measurements are digitally processed.

You have also **filtered** the measurement signal to reduce the effect of external interference, in order to get a measurement that can be used.

Present your results to the lab assistant. **Assistant's signature:** \_\_\_\_\_

## 4 .1 Determining the spring rate

Often, the measurement quantity itself is not of direct interest. A measurement quantity can be used to calculate another quantity indirectly. In this example, we measure time to determine a spring stiffness constant.

Use a spring to hang a weight of 100 g on the load cell. Do this carefully to avoid swinging. The graph window in the front panel shows how the voltage from the load cell varies sinusoidally.

Note the time period for the oscillation from the graph.  $T$  :.....

Calculate  $\omega_0$  and use  $\omega_0 = \sqrt{\frac{k}{m}}$ , where  $k$  is the spring rate and  $m$  the mass, in order to calculate the spring rate  $k$  :.....

Present your results to the lab assistant. **Assistant's signature:** \_\_\_\_\_

## 5 Measuring the current loop with a load cell

When measuring the current loop, you must choose a suitable resistor value so that the voltage across the resistor is matched to the input voltage range of the measuring equipment.

Use the 10-terminal to connect a 1000  $\Omega$  resistor to the amplifier's current loop  $I_{ut}$ .

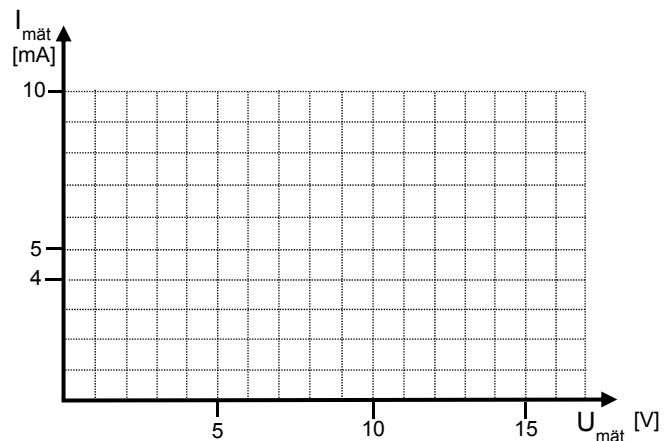
On the instrument display, measure the voltage across the resistor when there is no load on the load cell. Measurement value: :.....

Is this consistent with the loop current's specification?

We will examine how different resistors affect current loop measurement.

With 500 g weight on the load cell, use resistors of 390  $\Omega$ , 1000  $\Omega$ , 2000  $\Omega$  and 3000  $\Omega$  successively and measure the voltage across the resistors, calculating the corresponding measurements for the current. Plot the values in the chart below.

$R_{mät}$ [ $\Omega$ ]	$U_{mät}$ [V]	$I_{mät}$ [mA]
390		
1000		
2000		
3000		



As the value of the resistor increases, the current measured seems to "bend". What could this be due to?

Present your results to the lab assistant. **Assistant's signature:** \_\_\_\_\_