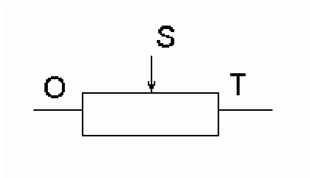
DC Circuit – Circuit Regulation

Circuit regulation means that we change the current / potential difference / electric power on certain elements of the circuit.

Basic knowledge: Current, voltage, potential, resistance, Ohm's Law. Serial and parallel connection, resultant of resistances. Power supplies, electromotive force, internal resistance, terminal voltage. Meters. Kirchhoff's Laws.

Potentiometer, helipot

A *potentiometer* is a resistor equipped with a third, sliding contact.
It can serve as a *variable resistor* or as a *voltage divider.*
In the circuit diagrams, a potentiometer is drawn as:

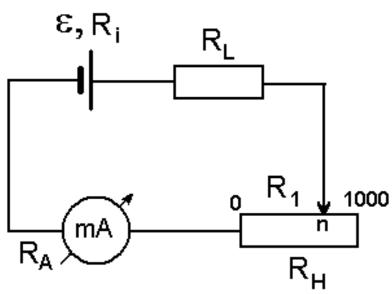


We will use helical potentiometers –*helipots*– where the wire is wound in the form of a helix. By moving the sliding contact S from left to right, the resistance R_{OS} between points O and S changes from zero to the maximum resistance of the potentiometer $R_{OT} = R_H$.
This is because R = (ρ/A) · ℓ, the resistance is proportional to the distance between the contacts (as in this case the resistivity and the cross-sectional area is constant).

The position of the sliding contact can be read from a scale.
The resistance R_{OS} is proportional to the scales read n: $R_{OS} = \frac{n}{1000} R_H$
where R_H is the resistance of the helipot (R_H is measured between points O and T),
and $0 \le n \le 1000$.
Below in the circuit diagrams R_{OS} will be denoted by R_1.

THEORY

1. Serial regulation



The current (or potential difference or power) on a certain element of a circuit – e.g. the load with resistance R_L– can be regulated using a variable resistor connected in series with the given element.

The loop current $$I = \frac{\varepsilon}{R_1 + R_L + R_A + R_i}$$

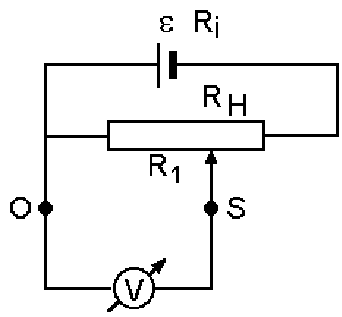
depends on the value of R_1, the variable resistance.

For n = 0 (i.e. $R_1 = 0$) we have maximum current: $I_{max} = \frac{\varepsilon}{R_L + R_A + R_i}$

and for n = 1000 (i.e. $R_1 = R_H$) the current is minimal: $I_{min} = \frac{\varepsilon}{R_H + R_L + R_A + R_i}$.

2a. The potentiometer as a voltage divider

Consider the following circuit containing a helipot, a source, and an ideal voltmeter:



Let us derive the formula for the voltage between the sliding contact S and the point O of the helipot in terms of R_{OS}!

The total resistance in the circuit is $R_t = R_i + R_H$,

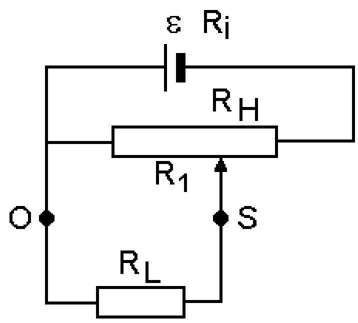
the current is $I = \frac{\varepsilon}{R_t} = \frac{\varepsilon}{R_i + R_H}$,

so the voltage across R_{OS} is $U_{OS} = \frac{\varepsilon}{R_i + R_H} R_{OS}$.

The voltage changes linearly from zero to $U_{max} = \frac{\varepsilon}{R_i + R_H} R_H = \frac{R_H}{R_i + R_H} \varepsilon$ as the sliding contact S moves from left to right.

2b. Potentiometric regulation of voltage when a loading resistor is applied

The *voltage divider* can be used to regulate the potential difference (or current or power) on an element. Above we have set up a variable-voltage source by means of a helipot, and now we apply this variable voltage to a device. This device "loads" the source by some resistance R_L.

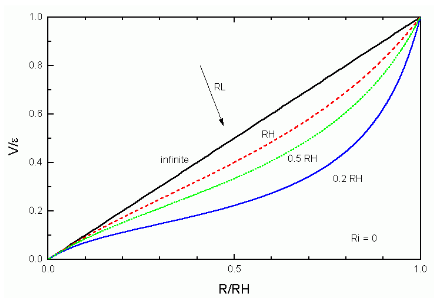


The potential difference U_{OS} across the given element (load) R_L

$$U_{OS}(R_1, R_L) = \varepsilon \cdot \frac{\frac{R_1 R_L}{R_1 + R_L}}{\frac{R_1 R_L}{R_1 + R_L} + (R_H - R_1) + R_i}$$

depends on the position of the sliding contact so that the regulation is

- monotonous (the greater R_1 the greater U_{OS});
- nearly linear in the vicinity of the two terminals of the potentiometer (n = 0 or 1000);
- nearly linear along the whole region if the load R_L goes to infinity.



The voltage supplied by the potentiometer as function of R_1/R_H at different ratios of the load to the total resistance of the helipot. (calculated curves for $R_i = 0$)

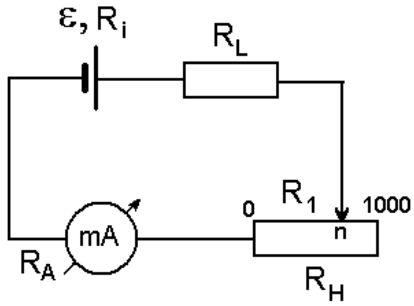
MEASUREMENTS

Tools: source, resistors, helipot, multimeter, connecting wires.

1. Serial regulation

Measure the resistance of the "load" R_L denoted by a <u>number</u>,
the total resistance R_H of the heliport R_H, and
the terminal voltage U_t of the voltage source.

Set up the following circuit:

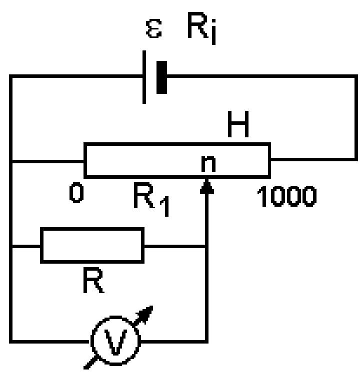


We measure current, by setting the universal meter to DC "A" function and connecting it in series with the resistors. Take care that you have to use the "mA" input.
Change the position of the sliding contact from 0 to 1000 scales in 100 scales steps. Measure the current at each scale setting. Collect the measurement data in the table.

2. Potentiometric regulation

Measure the resistance of the "load" R denoted by a <u>letter</u>.

Set up the following circuit:



The universal meter is connected now in parallel with the load. Use the "V" input. The internal resistance of the voltmeter is about 50 MΩ, high compared to R_H so it does not appreciably change the current flowing in the circuit.

Read the voltage at scale divisions as shown in the table.
Then disconnect the load and measure the voltage again at n = 300, 600 and 1000.

EVALUATION

1. Serial regulation

Taking the reciprocal of the current, it is $\frac{1}{I} = \frac{1}{\varepsilon} R_1 + \frac{R_L + R_A + R_i}{\varepsilon}$.

This is a linear relation between the variable resistance and the reciprocal current.

Plot 1/I *vs.* R_1.

Calculate the slope and the intercept of the line using the least squares method:
y = ax + b , where x = R_1 , y = 1/I , a = 1/ε , and b = (R_L+R_A+R_i) / ε .

Calculate the emf ε from the slope.

Determine the sum of the internal resistances from the intercept: $R_m = R_A + R_i$.

2. Potentiometric regulation

Plot U *vs.* R_1 for both cases, with and without the load. The latter should be a straight line:

$$U = \frac{\varepsilon}{R_i + R_H} R_1$$

Calculate the slope of the line using the least squares method.
y = ax , where x = R_1 , y = U , and a = ε / (R_i+R_H) .

From the slope calculate R_i, the internal resistance of the source.

Above in the serial regulation R_m, the sum of R_i+R_A was determined.
Calculate R_A, the internal resistance of the ammeter.