

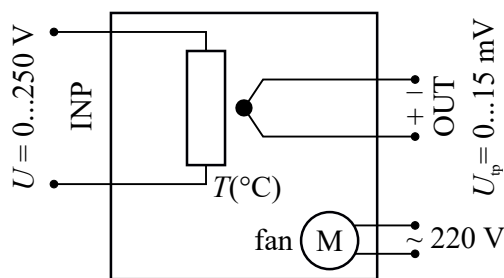
## Control Objects

### Aim of the work

The purpose of this work is to obtain models of the thermal process using step response identification techniques. Static and dynamic (FOPDT - First Order Plus Dead Time) characteristics should be found.

## 1 Equipment

### Object



Thermal object contains a heater  $u = 0 \dots 250 \text{ V}$  and sensor (type K thermocouple with output voltage  $0 \dots 15 \text{ mV DC}$ ) which measures the heating temperature  $T$ . Object may contain a ventilator (motor power supply with a separate connector  $220 \text{ V AC}$ ).

Difference between the Object temperature  $T$  and temperature  $T_0$  of the environment causes output voltage  $U_{tp}$ ,

$$\Delta T \text{ (}^\circ\text{C)} = a \cdot U_{tp} \text{ (mV)}, \quad (1)$$

where gain  $a$  depends on the type of the object.

This equation has an accuracy of  $\pm 1 \text{ }^\circ\text{C}$  within temp. range of  $0 \text{ }^\circ\text{C} \dots 300 \text{ }^\circ\text{C}$ . A wider temperature region has a nonlinear characteristic.

### Power Supply

Object's voltage source is powered up by a switch "Power". The output signal of the AC power supply has 50 Hz frequency and voltage RMS value, voltage can be changed between  $0 \dots 250 \text{ V}$ . To obtain voltage on the output of the device terminals "Inputs" should be short-circuited (in this work, a short cord, in other works it will be a controller output).

### Controller

Thermocouple converts  $U_{tp}$  signal into a temperature  $T$  with units  $^\circ\text{C}$ . For an input signal the controller is set as thermocouple type K. In case of input signal absence short-circuit the input,

otherwise controller detects the input rupture and gives an error message. If input signal is zero controller shows its own temperature.

### Voltmeter

Measures the output of the object's thermocouple  $U_{tp}$  (mV DC).

## Work flow

Assemble a test object, measure its static characteristic, register step response of the object in order to obtain dynamic characteristic.

## 2 Assembling

✓ Before assembling check/set power supply  $U = 0$  V

1. set knob to the leftmost position.

✓ Connect object with power source and voltmeter.

**ATTENTION!** All (dis)connections to voltage source must be done at the state ("Power: Off"). During the process, do not touch the object and its cables! **It is dangerous! 220 V.**

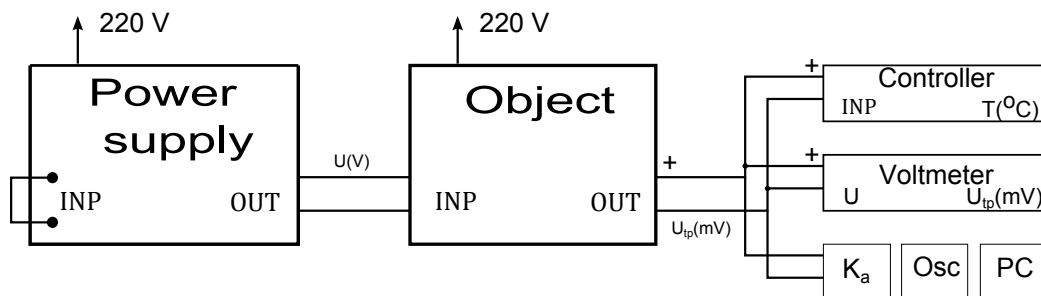


Figure 1: Test object assembly

To record a signal use the amplifier ( $K_a$ ), oscilloscope (Osc), and computer (PC).

### Oscilloscope PCS1000

- ✓ Connect oscilloscope to the PC's USB port.
- ✓ Run the PCLab2000SE.
  - Choose PCSU1000 device with USB connection.
- ✓ Select **Transient Recorder** Mode (displayed above).

Registration of the signal begins and ends with click on button "Run" or "Single". "Run" starts a cycle: at the end of the screen it erases the previous and starts the new one, "Single" - single recording at the end of the screen recording stops. Use Single Mode during the experiment.

**NB! During the recording registration speed cannot be changed.**

Recorded signal can be measured, printed, saved. Use an accessory amplifier (gain  $K_a \approx 122$ ) because oscilloscope has low sensitivity and a wide band.

- ✓ Connect amplifier to PC via USB.
- ✓ Connect output of the Object  $U_{tp}$  through the amplifier to oscilloscope (use CH1).

Observe the polarity!

Oscilloscope receives  $U_{os} = 122 \cdot U_{tp}$  signal.

### 3 Statical characteristic of the object

Find the dependance of the object's temperature  $T$  and thermocouple's voltage  $U_{tp}$  on the input voltage  $U$ : change the input voltage  $U$ , wait until the output stabilizes, read the values of  $T$  and  $U_{tp}$ .

- ✓ Test object on the next input signals 0, 75, 100, 125, 150 V.
- ✓ Put data into the **Excel Table**.

Table 1: Statics of the Object

$U(V)$	$T(^{\circ}C)$	$U_{tp}$
0		
75		
100		
125		
150		

**Equipment tuning**

While power source voltage  $U = 0\text{ V}$

- ✓ Check if object's ventilator is working
- ✓ Set voltmeter to measure the DC voltage ( $mV \text{ --- } \text{ )}$
- ✓ Turn off CH2 (it is not in use).
- ✓ Select CH1 of the oscilloscope, set next parameter:  $0,2\text{ V/div}$ .
- ✓ Shift initial level of the channel CH1 to the bottom using "Position" slider.  
You can check it on the high registration speed  $1s/div$
- ✓ Set right registration speed  $100\text{ s/div}$ .
- ✓ Start recording: press "**Single**".

Start first test with  $U = 0\text{ V}$ . Wait until step response outputs are stabilized (do not change)(it takes about 7 min). Read obtained values of  $T$  and  $U_{tp}$ .

- ✓ Fill in the table.
- ✓ Change input signal  $U$  of the power supply to the next value.

Repeat previous procedure. Do the values of the output signals increase? Can you see it on oscilloscope screen?

Repeat the test with the next voltage values  $U$ .

Then you finished a final test

- ✓ Object active **voltage remains**  $150\text{ V}$ .
- ✓ Stop recording the signal on oscilloscope.
- ✓ Add Text to the figure (right button click on the figure)

1. Lab #
2. Object #
3. Who did (your names)
4. Date

- ✓ Save figure

In menu *File - Save*.

### Calculate

Assuming that the temperature rise is proportional to the power or  $U^2$  (object's resistance  $R$  is independent of temperature), find the static characteristic equation  $T = F_1(U)$  in three different ways

1. Using Excel diagram (see Appendix 5)
  2. Using two-test measurement data ( $U = 0 V$  and  $U = 150 V$ )
  3. Using all the data to minimize the root mean square error (see MATLAB Appendix 5)
- ✓ Provide the static characteristic and its equations  $T(U)$ .
  - ✓ Calculate the gain of the process  
from the test data

$$K_p = \frac{\Delta T(t \rightarrow \infty)}{\Delta U(t \rightarrow \infty)} \quad (2)$$

- ✓ Fill in the table additional column with calculated  $K_p$  values.
- ✓ Evaluate results.

### 4 Step response $T(t)$

The process is subjected to a step change of the input voltage  $U$  and the output variable  $U_{tp}$  response is recorded over time. Oscilloscope traces the amplifier output signal  $U_{os} = K_a \cdot U_{tp}$ .

#### Preparations

- ✓ Read the initial temperature value  $T_1$  ( $U = 150 V$ ).
- ✓ Set the recording speed  $50 s/div$ .

#### Test

- ✓ Change the power supply voltage by step  $U \rightarrow 0 V$  (POWER OFF). At the same time start to record signal on oscilloscope (use **Single** button).
- ✓ Wait until output reaches the steady-state value. Read the final temperature value  $T_2$  ( $U = 0 V$ ).

### Calculations

- ✓ Estimate the parameters ( $K_p$ —process gain,  $\tau$ —time constant,  $\theta$ —time delay) for the first-order process using:
  1. Maximum Slope Method
  2. Tangent line and 63% Method
  3. Two-point Method ( $t_{28}, t_{63}$ )
- ✓ Choose the best method. Provide a transfer function  $W_p$  which describes the dynamics of the process.

See Lecture 4, Sec. 2.5 Experimental estimation of the FOPDT model parameters.

### Data processing

In order to measure signals we need to use markers. In the menu *View-Markers* choose markers  $dV$  &  $dt$ .

- ✓ Add text to the figure: lab, who did, input change, temperature values  $T_1, T_2$
- ✓ Measure the 100% span  $\Delta U_{os}$  of changed output signal  $U_{os}$ .
  - Put one horizontal marker on the initial value ( $\max U_{os}$ ) and the second one on the final value ( $\min U_{os}$ ) of the signal. Read value between markers  $\Delta U_{os}$  ( $mV$ ) in the left bottom corner.
- ✓ Calculate the 63.2% of the whole span  $\Delta U_{os}$ .
  - Shift minimal value (bottom) marker to the point there signal changed on 63.2% of the total span  $\Delta U_{os}$ .
  - Put the second vertical marker (time marker) on the point of intersection of the graph and horizontal marker.
- ✓ Read the time interval  $t_{63}$ .
  - Add value to the text in the figure.
- ✓ Find the  $t_{28}$  same way.
  - Add value to the text in the figure.

Save the figure. Save the figure with faster recording speed ( $20 s/div$ ). Save Excel file with table and diagrams.

**Completion of the work**

- ✓ Shut down the power supply, put voltage value  $U = 0 V$ .
- ✓ Disconnect the amplifier from PC USB port.
- ✓ Disassemble the object's input, output and ventilator.
- ✓ Turn off the controller.

Everyone should submit a report consisting of graphs, diagrams, calculations and result evaluations.

## 5 Appendix

### Excel diagram

1. Draw up a diagram of  $T(U)$ 
  - choose diagram type **XYscatter**
  - if diagram already has 3 points, provide a line equation  $T(U)$ 
    - right click on the line
      - add *Trendline—Polynomial (order 2)*
      - *Display equation on chart*
  - format the diagram (put axes labels, etc.)
2. Analogically draw up the next diagram of  $U_{tp}(T)$ , find the line equation—it is **linear!**

### MATLAB functions

We are looking for the input-output relationship between the voltage  $U$  and temperature  $T$  using  $T = T_0 + c \cdot U^2$ .

Linear regression between  $T$  and  $U^2$  in **MATLAB** gives us  $T = [1 \ U^2] \cdot [T_0 \ c]' = \phi' \cdot \theta$ .

✓ Add the next code to the MATLAB workspace

```
U = [0 75 ... 150]';           % add input voltage values from your Excel table
T= [T0 ... Tn]';           % add temperature values
phi=[ones(size(T)), U.* U];
x=inv(phi'* phi)* phi'* T     % calculates elements T0, c
```