Two Position Mode/ ON-OFF Controller

Aim of the work

Getting to know features of the ON-OFF controller, its applicability and how does it operate. Usage of the controller with thermal processes.

1 Equipment

Controller E5EN

- Controller type: ON/OFF;
- Output: reverse characteristics (for heating);
- Sensor: thermocouple type K;
- Alarms: max. deviation of the SP;
- Hysteresis: minimal H.

Controller input signal is a temperature (thermocouple type K voltage $0 \dots 50\ mV\ DC$).
Controller output is a switching contact (ON/OFF).
Controller parameters can be observed and set using settings menu.

Power supply and Object

See description of the Lab No. 1. "Control Objects".

DC supply

DC supply output range is $0 \dots 10\ mV$. It is used to simulate a thermocouple signal. Voltage can be turned (ON/OFF) and its value can be changed.

Signals recording

Provided by oscilloscope PCSU1000 (PCLab2000) and the amplifier.

Work flow

2 Acquaintance with a controller

- Output signals OUT and ALARM and their indication on the display.
- How to change the set point SV, what its limits are?

✓ Study the menu manual of the controller.

3 Thermocouple behaviour simulation

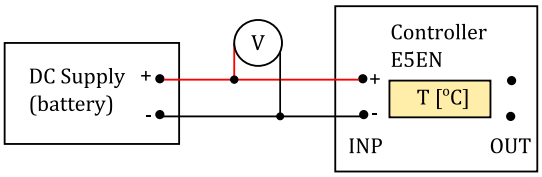

Figure 1: Thermocouple sensor simulation using DC power supply

✓ Simulate the thermocouple signal U_{tp} using DC supply output E.

Change voltage value on DC power supply, observe how temperature is changing.

✓ Measure voltage values E with voltmeter, read temperature values T from controller display.

To obtain a characteristics measure values at 3 points of reference inside the range, including voltage $E = 0\ mV$.

3.1 Calculate

✓ Calculate temperature value T corresponding to input voltage E readings.

✓ Compare results with temperature readings on controller display. Use the thermocouple rated transformation mapping tables (see Appendix Subsection 6.3).

3.2 Controller characteristics

Simulate the input signal of thermocouple E using the DC power source, observe the temperature readings PV and controller's outputs OUT and AL.

✓ Fix the set point value at $SV = 100\ °C$.

✓ Provide controller I/O characteristic OUT(T).

- Change temperature T reading PV in the neighborhood of the SV value by giving different input signal E.
- Observe the controller output (OUT) indicator.

✓ Provide alarm output characteristic AL(T).

- Make alarm signal appear at $120°C$, if $SV = 100°C$.

What type of alarm is used? Justify you answer!

4 Controller assembling

Caution! $U_m = 0 \ldots 250\ V$!

✓ Check if AC power source is turned off $U_m = 0\ V$.

✓ Make a circuit, see Fig. 2.

- Connect output of the object U_{tp} with controller input. Take the same object you used in Lab No. 1.
- Use controller's output to commutate the power supply voltage U_m.

  Power supply voltage value (amplitude U_m) can be changed.

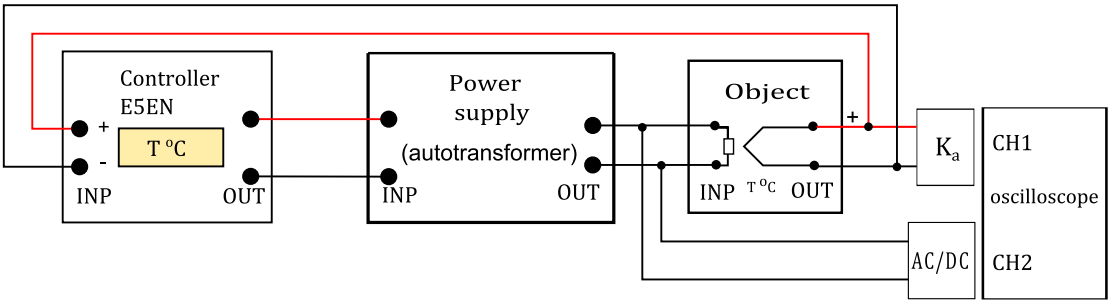

Figure 2: Controller + object

✓ Connect the output of the power supply U with the object input.

✓ Turn on the ventilator.

5 Controller operation

Observe the controller work in 4 operation modes. Try all combinations of SP, U_m.

- With two set points $SV_1 = 180\ °C$, $SV_2 = 220\ °C$ and;
- With two input voltages $U_{m_1} = 200\ V$, $U_{m_2} = 175\ V$.

In each mode observe the signals $U_{tp}(t)$ (output of the object) and $U(t)$ (input of the object) using oscilloscope (in **Single** mode).

✓ Start registration of the signals.

✓ Set the new value $\mathrm{SP} = \mathrm{SV}_1$, change voltage on power supply $U_{in} = U_{m_1}$.

✓ Then temperature is around 180 $°C$ for more precise observation of the process output signal U_{tp} do the following

Use oscilloscope **Transient Recorder** mode to record two signals 20 s/div.

In each mode observe the signals $U_{tp}(t)$ (output of the object) and $U(t)$ (input of the object) using oscilloscope (in **Single** mode).

- Output of the object Utp on CH1 (50 mV/div)
  - Shift signal to the bottom of the oscilloscope screen (first division) using the amplifier offset knob or Position sliders.
- Input of the object U $(0 \dots 240\ V)$ DC though the AC/DC on CH2 (2 V/div).
  - Shift CH2 to initial position using their Position sliders.

✓ Wait for the oscillation stabilization (2-3 oscillations);

✓ Read the minimal T_{min} and maximal T_{max} temperature values on the controller (PV);

✓ Change Mode of the control and continue registration. Repeat all above mentioned steps.

✓ Measure output signal period of oscillation T_i and input signal pulse width t_i, see Appendix Subsection 6.1, Fig. 3.

- Signal measurement markers may be used after the signal registration has finished.
- You can register several signals in one figure and consequently measure their parameters.

✓ At the end of registration add text to the figure (lab #, student name, operation modes, min/max temperature values, t_i and T_i), and save it.

5.1 Completion of the work

Set source voltage $U_{in} = 0\ V$. (**Caution!** $U_m = 0 \dots 250\ V$!)

✓ Disconnect the object, power source and controller.

✓ Disconnect the amplifier from PC USB port.

✓ Turn off the voltmeter.

5.2 Calculations

Provide the following parameters for one of the modes with $U_m = 200\ V$:

✓ Calculate temperature mean value T_0, temperature amplitude of oscillation $[°C]$, period T_i and frequency f;

✓ Calculate object input signal $U_0(t)$ mean value (1) , U_{rms} (2), and the amplitude of the first harmonics U_{h1} (3) from Subsection 6.1;

✓ Provide static characteristic equation $T = F_1(\Delta u)$ for new process: actuator + object, whereΔu is a controller output. /Use static characteristic from the Lab No. 1/.

✓ FOPDT model parameters of the process: actuator + object: process gain K_0, time constant τ and a delay θ, see Appendix Subsection 6.2.

6 Appendix

6.1 Square Wave signal

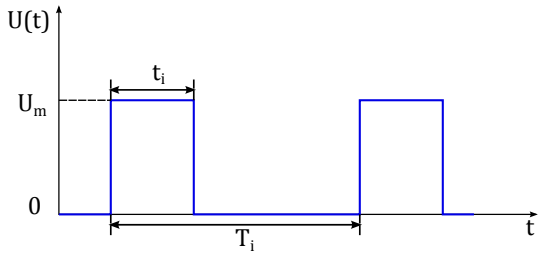

Figure 3: Square wave output

$$\max U(t) = U_m$$
$$\min U(t) = 0$$

$$U_0 = U_m \cdot t_i/T_i \tag{1}$$

$$U_{rms} = U_m\sqrt{(t_i/T_i)} \tag{2}$$

$$U(t) = U_0 + U_1 \cdot \sin(2\pi \cdot t/T_i) + U_2 \cdot \sin(2 \cdot 2\pi \cdot t/T_i) + \dots$$

$$U_{h1} = \frac{2 \cdot U_m \cdot \sin(\pi \cdot t_i/T_i)}{\pi} \tag{3}$$

6.2 Frequency response

Transfer function on the process "actuator + object" is a FOPDT function. Find parameters K_0, τ, θ for the transfer function.

$$W(s) = \frac{K}{1+\tau s} \cdot e^{-\theta s} \quad \text{or} \quad W(jw) = \frac{K}{1+\tau j\omega} e^{-j\omega\theta} \tag{4}$$

Delay does not have impact on magnitude of the signal, so $|W(j\omega)| = \left|e^{-j\omega\theta}\right| = 1$ and phase shift $\phi(\omega) = -\omega\theta$.

Aperiodic signal, see (4), has the following magnitude

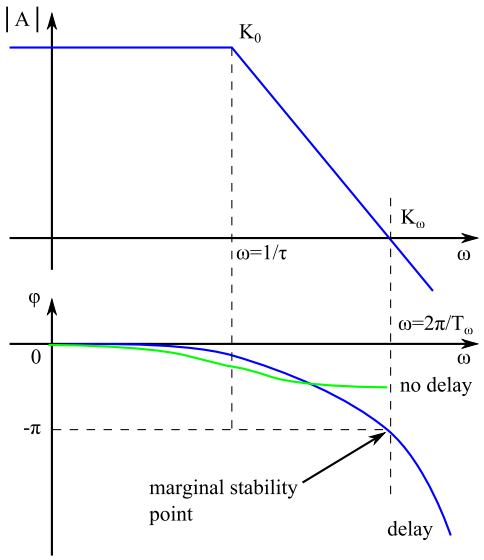

Figure 4: Magnitude and Phase characteristic of FOPDT model (Bode plot)

$$|A(j\omega)| = \frac{K_o}{\sqrt{1+(\omega\tau)^2}} \tag{5}$$

and $\phi(\omega) = -\arctan(\omega\tau)$.

For marginal stability we require that $|A(j\omega)|$ go precisely through the point $\phi = -180°$. Thus, phase angle for the whole system is

$$\phi(\omega) = -\pi = -\arctan(\omega\tau) - \omega\theta. \tag{6}$$

This fixes the frequency ω and the magnitude at that frequency K_ω.

If $\omega > 1/\tau$, then in (5) the unity term [+1] may be neglected. Eq. (5) can be simplified to the following form

$$K_\omega = \frac{K_o}{\omega\tau}, \tag{7}$$

so knowing the gains K_0 and K_ω, time constant τ can be found. Further, knowing the τ from (6) delay of the process θ can be found. Gain at fixed frequency depends on the output amplitude A $[°C]$ and first harmonics (amplitude) of the input signal U_{h_1}

$$K_\omega = \frac{A}{U_{h_1}}. \tag{8}$$

$$K_0 = \frac{\mathrm{d}T[^\circ C]}{\mathrm{d}u[\%]} = \frac{c \cdot U_m^2}{100}, \tag{9}$$

where K_0 is an initial gain for the system "actuator + object" $T[^\circ C] = f(u[\%])$ and u is controller output (Manipulated Value), see Lecture 9.

6.3 Thermocouple type K transform characteristic

Thermocouple type K rated characteristic $E(t, 0)$: thermoelectric voltage (mV) as a function of temperature readings T, if other parts of the thermocouple are at temperature 0 $^\circ C$.

Thermoelectric voltage $E(t, t_0)$ (if temperature values are t and t_0) can be found as $E(t, t_0) = E(t, 0) - E(t_0, 0)$ by using table of rated characteristics Table 1.

K°C

TABLE1 ***Type K Thermocouple*** *thermoelectric voltage as a function of temperature (°C); reference junctions at 0 °C*

°C	0	1	2	3	4	5	6	7	8	9	10	°C
						Thermoelectric Voltage in Millivolts						
-20	-0.778	-0.816	-0.854	-0.892	-0.930	-0.968	-1.006	-1.043	-1.081	-1.119	-1.156	-20
-10	-0.392	-0.431	-0.470	-0.508	-0.547	-0.586	-0.624	-0.663	-0.701	-0.739	-0.778	-10
0	0.000	-0.039	-0.079	-0.118	-0.157	-0.197	-0.236	-0.275	-0.314	-0.353	-0.392	0
0	0.000	0.039	0.079	0.119	0.158	0.198	0.238	0.277	0.317	0.357	0.397	0
10	0.397	0.437	0.477	0.517	0.557	0.597	0.637	0.677	0.718	0.758	0.798	10
20	0.798	0.838	0.879	0.919	0.960	1.000	1.041	1.081	1.122	1.163	1.203	20
30	1.203	1.244	1.285	1.326	1.366	1.407	1.448	1.489	1.530	1.571	1.612	30
40	1.612	1.653	1.694	1.735	1.776	1.817	1.858	1.899	1.941	1.982	2.023	40
50	2.023	2.064	2.106	2.147	2.188	2.230	2.271	2.312	2.354	2.395	2.436	50
60	2.436	2.478	2.519	2.561	2.602	2.644	2.685	2.727	2.768	2.810	2.851	60
70	2.851	2.893	2.934	2.976	3.017	3.059	3.100	3.142	3.184	3.225	3.267	70
80	3.267	3.308	3.350	3.391	3.433	3.474	3.516	3.557	3.599	3.640	3.682	80
90	3.682	3.723	3.765	3.806	3.848	3.889	3.931	3.972	4.013	4.055	4.096	90
100	4.096	4.138	4.179	4.220	4.262	4.303	4.344	4.385	4.427	4.468	4.509	100
110	4.509	4.550	4.591	4.633	4.674	4.715	4.756	4.797	4.838	4.879	4.920	110
120	4.920	4.961	5.002	5.043	5.084	5.124	5.165	5.206	5.247	5.288	5.328	120
130	5.328	5.369	5.410	5.450	5.491	5.532	5.572	5.613	5.653	5.694	5.735	130
140	5.735	5.775	5.815	5.856	5.896	5.937	5.977	6.017	6.058	6.098	6.138	140
150	6.138	6.179	6.219	6.259	6.299	6.339	6.380	6.420	6.460	6.500	6.540	150
160	6.540	6.580	6.620	6.660	6.701	6.741	6.781	6.821	6.861	6.901	6.941	160
170	6.941	6.981	7.021	7.060	7.100	7.140	7.180	7.220	7.260	7.300	7.340	170
180	7.340	7.380	7.420	7.460	7.500	7.540	7.579	7.619	7.659	7.699	7.739	180
190	7.739	7.779	7.819	7.859	7.899	7.939	7.979	8.019	8.059	8.099	8.138	190
200	8.138	8.178	8.218	8.258	8.298	8.338	8.378	8.418	8.458	8.499	8.539	200
210	8.539	8.579	8.619	8.659	8.699	8.739	8.779	8.819	8.860	8.900	8.940	210
220	8.940	8.980	9.020	9.061	9.101	9.141	9.181	9.222	9.262	9.302	9.343	220
230	9.343	9.383	9.423	9.464	9.504	9.545	9.585	9.626	9.666	9.707	9.747	230
240	9.747	9.788	9.828	9.869	9.909	9.950	9.991	10.031	10.072	10.113	10.153	240
250	10.153	10.194	10.235	10.276	10.316	10.357	10.398	10.439	10.480	10.520	10.561	250
260	10.561	10.602	10.643	10.684	10.725	10.766	10.807	10.848	10.889	10.930	10.971	260
270	10.971	11.012	11.053	11.094	11.135	11.176	11.217	11.259	11.300	11.341	11.382	270
280	11.382	11.423	11.465	11.506	11.547	11.588	11.630	11.671	11.712	11.753	11.795	280
290	11.795	11.836	11.877	11.919	11.960	12.001	12.043	12.084	12.126	12.167	12.209	290
300	12.209	12.250	12.291	12.333	12.374	12.416	12.457	12.499	12.540	12.582	12.624	300
310	12.624	12.665	12.707	12.748	12.790	12.831	12.873	12.915	12.956	12.998	13.040	310
320	13.040	13.081	13.123	13.165	13.206	13.248	13.290	13.331	13.373	13.415	13.457	320
330	13.457	13.498	13.540	13.582	13.624	13.665	13.707	13.749	13.791	13.833	13.874	330
340	13.874	13.916	13.958	14.000	14.042	14.084	14.126	14.167	14.209	14.251	14.293	340
350	14.293	14.335	14.377	14.419	14.461	14.503	14.545	14.587	14.629	14.671	14.713	350
360	14.713	14.755	14.797	14.839	14.881	14.923	14.965	15.007	15.049	15.091	15.133	360
370	15.133	15.175	15.217	15.259	15.301	15.343	15.385	15.427	15.469	15.511	15.554	370
380	15.554	15.596	15.638	15.680	15.722	15.764	15.806	15.849	15.891	15.933	15.975	380
390	15.975	16.017	16.059	16.102	16.144	16.186	16.228	16.270	16.313	16.355	16.397	390
400	16.397	16.439	16.482	16.524	16.566	16.608	16.651	16.693	16.735	16.778	16.820	400
410	16.820	16.862	16.904	16.947	16.989	17.031	17.074	17.116	17.158	17.201	17.243	410
420	17.243	17.285	17.328	17.370	17.413	17.455	17.497	17.540	17.582	17.624	17.667	420
430	17.667	17.709	17.752	17.794	17.837	17.879	17.921	17.964	18.006	18.049	18.091	430
440	18.091	18.134	18.176	18.218	18.261	18.303	18.346	18.388	18.431	18.473	18.516	440
450	18.516	18.558	18.601	18.643	18.686	18.728	18.771	18.813	18.856	18.898	18.941	450
460	18.941	18.983	19.026	19.068	19.111	19.154	19.196	19.239	19.281	19.324	19.366	460
470	19.366	19.409	19.451	19.494	19.537	19.579	19.622	19.664	19.707	19.750	19.792	470
480	19.792	19.835	19.877	19.920	19.962	20.005	20.048	20.090	20.133	20.175	20.218	480
490	20.218	20.261	20.303	20.346	20.389	20.431	20.474	20.516	20.559	20.602	20.644	490
500	20.644	20.687	20.730	20.772	20.815	20.857	20.900	20.943	20.985	21.028	21.071	500
°C	0	1	2	3	4	5	6	7	8	9	10	°C