PID controller with analog output

Aim of the work

Getting to know features of the PID controller, thyristor (Y13) and theirs applications. Open-loop step response of the controller various modes.

1 Equipment

Controller E5CN or E5CN-H

- Controller type: PID;
- Sensor: temperature (thermocouple type K voltage $0 \ldots 50\ mV\ DC$);
- Output signals: current with range $4 \ldots 20\ mA$.

Controller parameters can be observed and set using settings menu.

DC Power supply

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

Thyristor (Y13)

Thyristor controls the output voltage U, so that that power $P \equiv U^2$ given to load (thermal object), is proportional to the input signal i, thus $U \equiv \sqrt{i}$. This enables to compensate the nonlinear behavior of the thermal object temperature $T(°C)$ with respect to input voltage U.

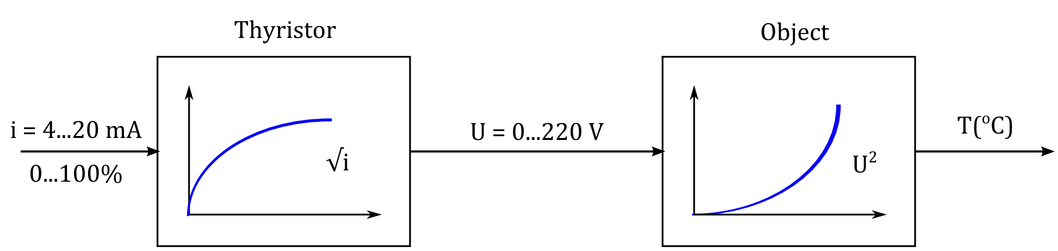

Figure 1: Linearization of the controlled process using tyristor

Voltmeter

Multimeter for controller output measurement $OUT = 4 \ldots 20\ mA$.

Signals recording

- Software oscilloscope Velleman PCSU1000 (PCLab2000).
- Tektronix TDS 2001C with signal power divider (1:100).

Work flow

Check settings of the controller, assemble the circuit, read and calculate parameters.

2 Controller mode

Use simplified menu and check the next controller parameters:

- Is thermocouple type K-1 (*in-t 6*)?
- Is controller mode PID (*Cntl PID*)?
- Is characteristic reverse (*õrEV õr-r*)?
- What are the units of **P,I,D** parameters?
- What is the range of setpoint **SV** (SL-H, SL-L)?

3 Assembling

✓ For the first test assemble a circuit Fig. 2-(1).

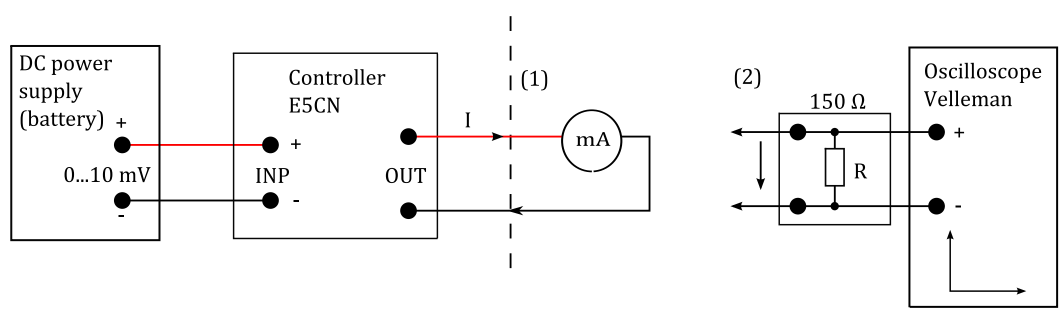

Figure 2: Studies of PID controller reaction on error: (1)-measuring output, (2)-recording output signal

4 Controller modes

The next parameters should be used during all tests

✓ Set the setpoint $SV = 40\ ^\circ C$;

✓ Set the proportional band $PB = 50\ ^\circ C$.

4.1 P-mode controller

✓ Set reset and derivative time $T_i = 0, T_d = 0$, respectively.

Static characteristics of the controller

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

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

✓ Measure controller output values $i[mA]$ with multimeter, read temperature values $T[^\circ C]$ from controller display.

To obtain a characteristics measure values at 3 points *inside* the Proportional Band. Consider cases where PV is outside the range.

Calculations

1. For the measured values convert controller output units$i[mA]$ into $OUT[\%]$.

2. Provide static characteristics $OUT(\%) = f(PV(^\circ C))$.

Step response registration

Study of P controller reaction on error of the control: recording of the controller output.

✓ Disconnect a voltmeter and assemble a circuit Fig. 2-(2).

✓ In **Transient recorder** mode set oscilloscope parameters (0.5 V/div, DC, 20 s/div). Turn off CH2.

✓ Set input signal $PV = 40\ ^\circ C$ using DC power supply. In that case $PV = SV \ \Rightarrow$ error $e = 0$.

✓ Shift signal to the bottom of the screen. Start recoding using oscilloscope **Single** mode.

✓ Create error on the input of the controller:

If DC power supply has switch “Short Output / Normal Output”, change mode to “Short Output”.

In all other cases use switch “Power On / Off” and turn off the power supply.

✓ Read the obtained temperature value T, calculate e.

Input step change is $PV = SV \quad \rightarrow \quad PV = T_0$.

✓ Record the step response signal, observe the precess (also see Lecture 6: Continuous controllers, Sec. 1.1), when signal doesn't change eliminate input error.

If DC power supply has switch "Short Output / Normal Output", change mode to "Normal Output".

In all other cases use switch "Power On / Off" and turn on the power supply.

✓ Continue registration in the same figure, start the next test.

4.2 PD-mode controller

✓ Add the derivative component $T_d = 7\ s$ to the controller parameters.

✓ Observe a process, also see Lecture 6: Continuous controllers, Sec. 1.4.

✓ When signal doesn't change eliminate input error (see description above).

4.3 PI-mode controller

✓ Check if signal is on initial level, otherwise see "Wind up" avoidance in the following section.

✓ Change tuning parameters: $T_i = 50\ s, T_d = 0\ s$.

✓ Observe a process, also see Lecture 6: Continuous controllers, Sec. 1.3.

✓ When signal doesn't change stop registration. Measure all needed parameters, see Calculations 4.4.

✓ Save figure with the next information: Lab. #., Student names, Date.

✓ Eliminate input error (see description above).

4.4 PID-mode controller

✓ To avoid "Wind up" situation and to reset the controller's output value do the following

1. Put controller to the **STOP** mode. See indication on the controller's display.
2. Set the **RUN** mode again.
3. Signal drops on the initial level and if $PV = SV \Rightarrow OUT = 0\%$.

✓ Change the tuning parameters: $T_i = 50\ s, T_d = 7\ s$.

✓ Observe a process. Save figure.

Calculations

Open *Lecture 6*: Continuous controllers: PID. Found out how to obtain settings of the controller from output characteristics.

Calculate:

1. P controller gain K_c and PB from both test in Section 4.1;
2. PD controller real transfer function $W_c(s) = K_c \left(1 + \frac{T_d \cdot s}{1 + T_p \cdot s}\right)$ and parameter T_p;
3. PI controller real parameters.

5 Thyristor Y13

✓ Assemble test object.

NB! For controller's output measurement multimeter should be connected in series with a thyristor.

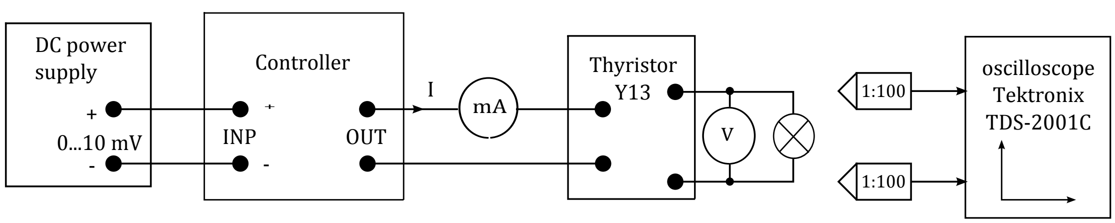

Figure 3: Schematic diagram for thyristor output studies

✓ Set controller into P-mode.

✓ Erase value from the output: use **STOP** mode.

✓ Plug lamp to the thyristor.

The right working mode of the thyristor can be provided with a load.

5.1 Thyristor

✓ Measure controller output values $i[mA]$ with multimeter, and output values of the thyristor $U[V]$.

To obtain a characteristics measure values at 3 points inside the Proportional Band. Consider cases where PV is outside the range.

Oscilloscope TDS2001C

✓ Connect analog oscilloscope with a voltmeter (pointer gauge) using signal power divider (1:100).

Check if:

1. Scale is right

   Push **AutoRange** button, which activates the autoranging function. Choose both: horizontal and vertical scaling.

2. Coupling AC

3. CH1 - CH2 (the channel 2 waveform is subtracted from the channel 1 waveform)

   Push the **Math** button to display waveform math operations.

4. Probe Voltage 100X

   Push **1** → **Probe** → **Current** → **Scale** and select an appropriate value.

Cursors

This method allows you to take measurements by moving the cursors. There are two types of cursors: Amplitude and Time. To use cursors use **Cursor** button. Use **Time Cursors** in order to measure the thyristor firing angle α and period T.

Measure

Push the **Measure** button to access automatic measurements. Use one of the next measurements types: $P_k - P_k$, RMS, Max or Min in order to obtain U_m value.

5.2 Calculations

1. Provide characteristic $U[V] = f(i[\%])$ as a table and equation, see Fig. 1.

2. Provide output signal $u(t)$ for one of the input values, figure from Tektronix oscilloscope.

3. Calculate the (Y13+object) characteristic $T(°C) = F(i[\%])$. (How temperature of the object depends on thyristor Y13 input signal.) Use data obtained during test at Lab No 1 (Thermal object).

4. Provide parameters for equation (1): how thyristor RMS $U(U_m, \alpha)$ depends on sinusoidal signal amplitude U_m and thyristor firing angle α.

$$U_{RMS} = \sqrt{\frac{1}{T}\int_{\alpha}^{T} {U_m}^2 \sin^2(\omega t)\mathrm{d}t}, \tag{1}$$

   where T is a period of oscillation.