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Experiment no.3
Control of Temperature System

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Objectives

In this experiment, the students will learn the basic operation of a temperature controlled system and will also learn the static and transient behaviour of the temperature process.

Following are the objectives of the experiment:

- Study the effect of flap, ventilator-motor, and input power over the temperature output.
- Evaluation of the "step response" of the temperature process.
- Find the transfer function of the temperature process.
- Design a suitable PID controller for the system.

Introduction:

The objective of any automation is to be able to efficiently and reliably control the behaviour of the process. Temperature systems are widely used in real life as in industrial applications, domestic domain (home, office), medical and biological process engineering. The basic operation of a temperature-controlled system is analyzed in this experiment.
Further, we should understand the system and determine the mathematical model of the process (Transfer function). This transfer function is used to design a PID controller that improves the performance of the system in closed loop.

Components and Equipments:

- Refererence variable generator 73402
- Power amplifier 73413
- Power Supply +/- 15 V 72686
- Temperature controlled system 73412
- Two position controller 73401
- P controller 73403
- I controller 73404
- D controller 73405
- CASSY-interface with Compute
- Set of bridging plug.
- Cassy lab software

Experiment Procedure:

A. Static Performance

Static test

Static test is performed to check the linearity of the equipment under test. If we want to test the "input power" we need to keep the ventilator-motor and flap at constant values and vary the input power scale.

Experiment:

- Connect the "Temperature Control System Block Diagram" (Figure 1) to the Power Supply unit and with the "Reference Variable generator".
- Set the output switch to 1V/10°C.
- Make sure that the temperature of the process settles at room temperature (Output voltage = the room temperature).

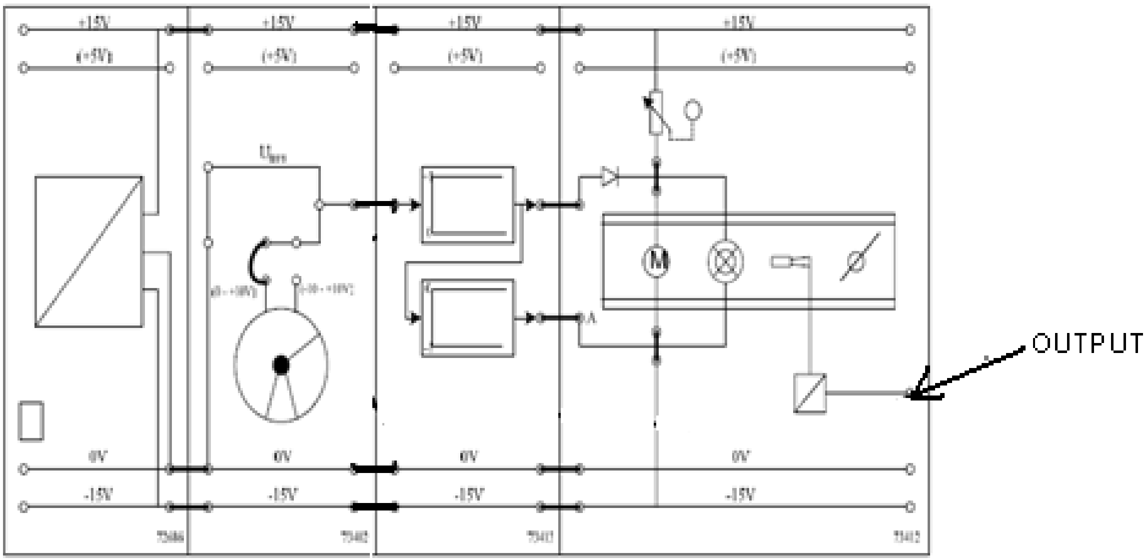


Figure 1 static test

- **Effect of "input power" over temperature**
  - Keep the flap at scale 2 and ventilator potentiometer at scale 3.
  - Record the temperature (using multimeter to reading the output voltage) of the system at inputs 0, 2, 4, 6, and 8 Volts.

Input Voltage (V)	0	2	4	6	8
Temperature (˚C)					

2. Evaluation

- Plot the temperature versus the input power.
- Label your scales very carefully.

B- System Identification.

The dynamic model of the temperature process can be described as first order linear transfer function:

$$G(s) = \frac{K}{1 + \tau s} e^{-Ls}$$

Where K is the DC gain defined as the ratio of output voltage to input voltage.

$$K = \frac{y(\infty)}{u(\infty)}$$

y (∞) = final (steady state) value of the output
u (∞) = input to the system
τ : time constant when the output reaches 63% of the final value.
L: velocity lag (time delay) pure time delay (dead time), The time required for the system to start responding to the input change. as shown in Figure2

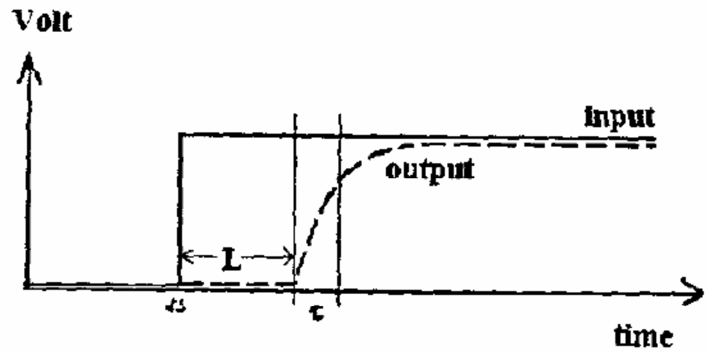


Figure 2 Representation of transient response

A linearized quantitative version of this model can be obtained with an open-loop experiment, by using the following procedure:

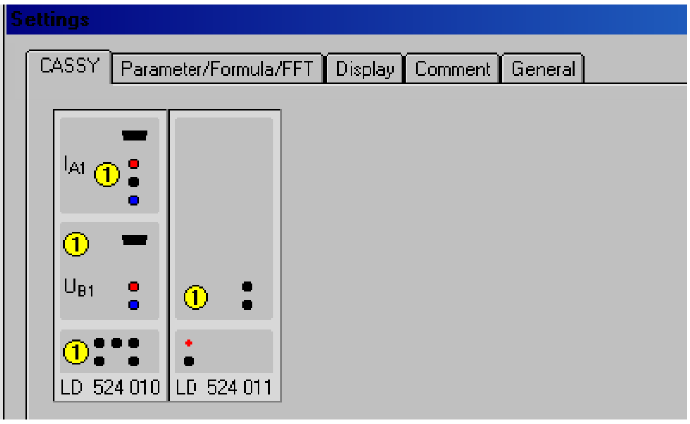
1. With the plant in open loop, take the plant manually to a normal operation point. Assume that the plant output settles at y (t) = y0 for a constant input 0 u (t) =u.
2. At an initial time 0 t, apply a step change to the plant input, from 0 u to u∞.
3. Record the plant output until it settles to the new operating point. Assume that you obtain the curve shown in figure 2. This curve is known the process reaction curve.
4. Compute the model parameters.

Experiment:

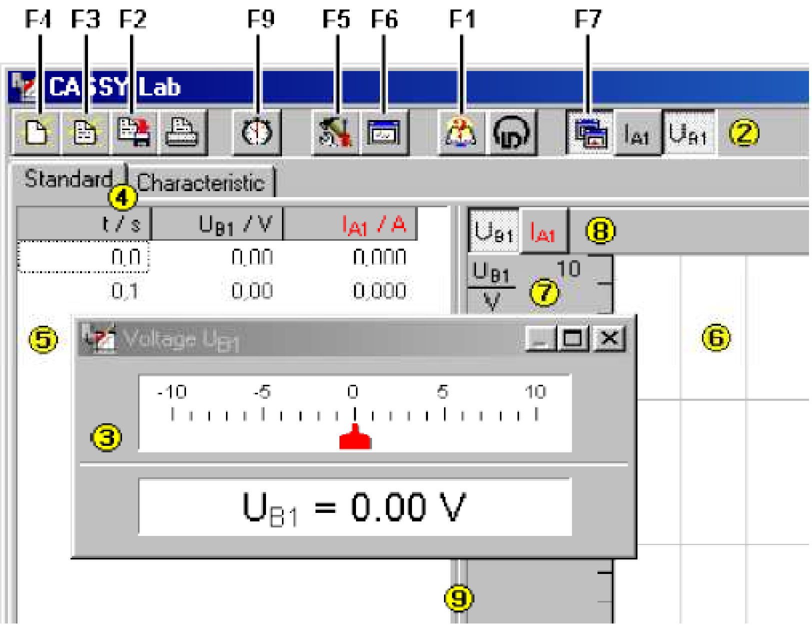
1- Connect the open loop Temperature control experiment as shown in the figure 3.
2- Connect the Temperature control system with the profi-cassy in order to plot the input and output signals
(Channel A: Output, channel B: input).
3- Open Cassy-lab software, Start => Programs => Cassy lab.

First measurements

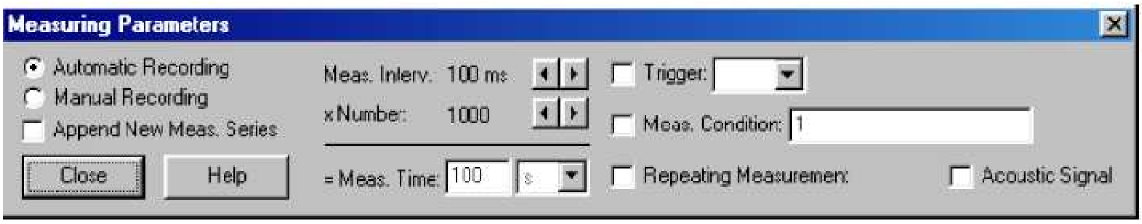
When the software detects one or more CASSY devices, the CASSY tab of the setup dialog (F5) displays the current configuration (including any attached sensor boxes). To conduct a measurement, **just click** on the corresponding input or output (1)



The channel initially appears automatically in the table (5) and in the diagram (6).



And will appear the box allows you to change the settings of measuring parameters which control the actual measurement.



Put the Meas. Time to 200 s.

When you want to start measurement just press to  **F9**, Starts and stops a new measurement. You can use the right mouse button to open the table display menu in the table and the evaluation menu in the diagram.

4- Using Cassy lab software, Record the transient behaviour for the following case:
(Step input):
   - Cool down the system at room temperature (remove the input power from the temperature system open flap to 4 and increase the potentiometer to 10 to increase speed of motor until the output voltage equal the room temperature).
   - After cooling the system restore the input power, set the flap at scale 2 and ventilator potentiometer at scale 3.
   - Start with Reference voltage = 6 V until you reach a steady state.
   - Record the time required to achieve this state, name it T.

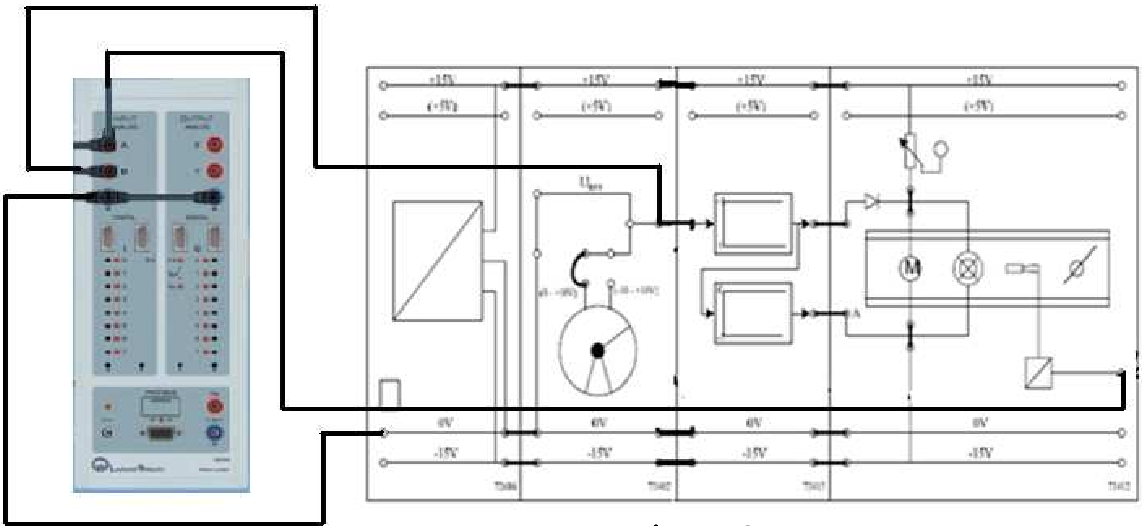


Figure 3

5- From the transient responses in above case, deduce the open loop transfer function of the temperature process (identify the parameters K, τ and L from the obtained response).

6- Comment on all of your results.

C. Open-Loop Two-Position Control

The main targets of the previous parts were to have an understanding of modelling concepts in terms of static and transient performance. The temperature process was used in its open-loop form. This Part will introduce the idea of open and closed-loop control. Following are the objectives of this Part:

- Study the two-position (discontinuous) controller.
- Examine the effect of hysteresis on the temperature process.
- Maintaining output temperature close to a reference (set point) value.

There are many controllers that could be used to perform the task. They differ in simplicity and configuration. In this part, the two-position controller is introduced as the regulator. This controller will recognize only two states and will have only two actions: On or OFF.
Figure 4 shows a block diagram of the circuit under study:

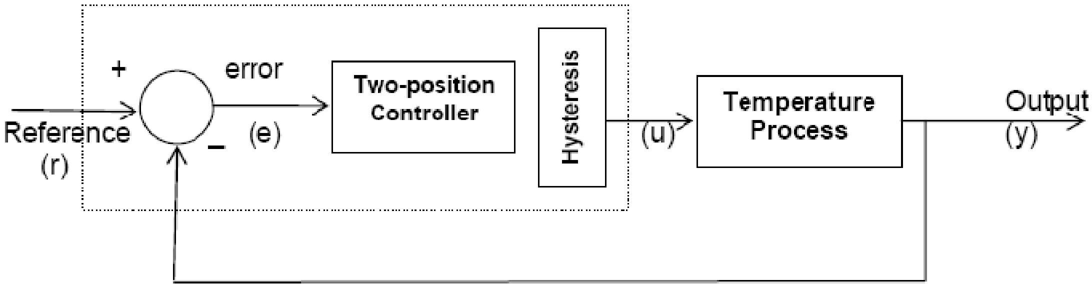


Figure 4: Block diagram of a closed loop two-position controller.

The controller that we will study can have hysteresis effects, by examining the block diagram, we can easily deduce that:

$e(t) = r(t) - y(t)$

If there is no switching hysteresis (h = 0), the two states of the controller are:

$$\begin{cases} e > 0 \Rightarrow u : \text{ON} \\ e < 0 \Rightarrow u : \text{OFF} \end{cases}$$

However, if there is switching hysteresis h, the two states:

$$\begin{cases} e > h \Rightarrow u : \text{ON} \\ e < h \Rightarrow u : \text{OFF} \end{cases}$$

Experiment:

1- Cool down the system at room temperature (remove the input power from the temperature system open flap to 4 and increase the potentiometer to 10 to increase speed of motor until the output voltage equal the room temperature).
2- Set up the experimental arrangement as shown in the block diagram of Figure 5.

3- Keep the same settings as before (switch off).
4- Disconnect the feedback path from the output to the input of the controller.
5- Setting fan potentiometer to 3-scale division and the flap to 2-scale.
6- Set the reference to 6 V.
7- Set the switching hysteresis to 0 V and plot the reference and the output on the same graph.

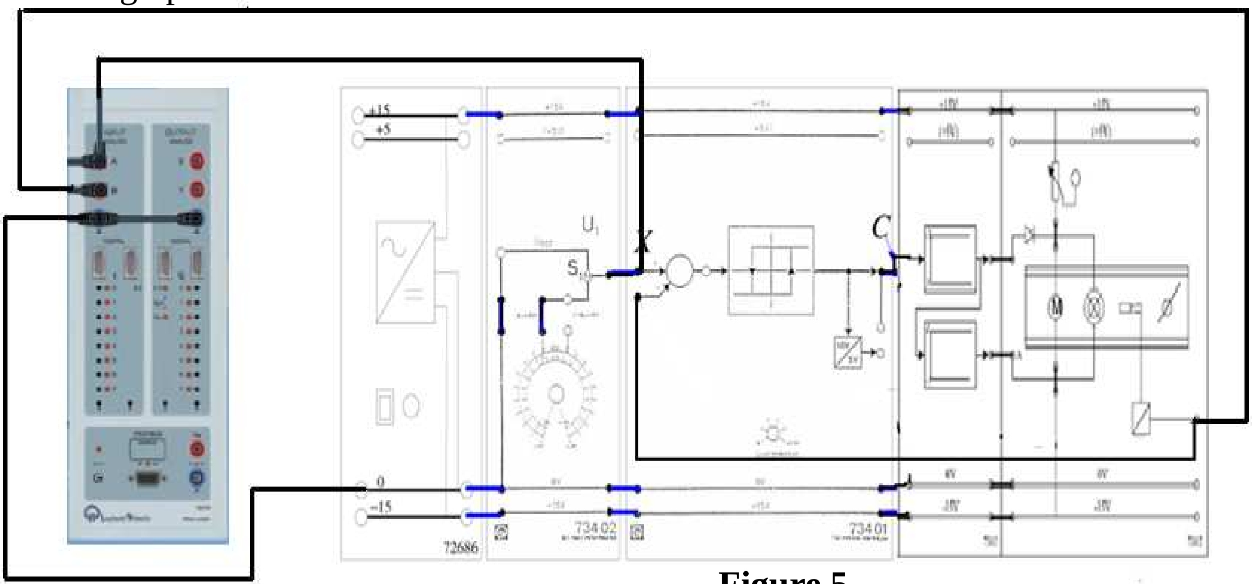


Figure 5

D. Closed-Loop Two-Position Control

Experiment:

1- Cool down the system at room temperature (remove the input power from the temperature system open flap to 4 and increase the potentiometer to 10 to increase speed of motor until the output voltage equal the room temperature).
2- Set up the experimental arrangement as shown in the block diagram of Figure 5.
3- Set the fan potentiometer to 3-scale division and the flap to 2-scale.
4- Set the reference to 6 V.
5- Plot the output and control signal for the following values of hysteresis:
   1) h = 0 V 2) h = ± 0.5 V
   Observe the behaviour of the lamp!, Deduce the frequency of the control signal.
6- Discuss the difference between the open-loop and the closed-loop two-position controller.
7- Discuss the effects of the hysteresis on the output and control signal.

E. PID-Controller:

So far, a simple control technique has been evaluated: the two-position control. This part will introduce another type of controller; which is called PID (Proportional, Integral and Derivative). This control approach is one of the oldest and most popular techniques used in the industry, because it is simple and effective.

Figure 6 shows a block diagram of this control.

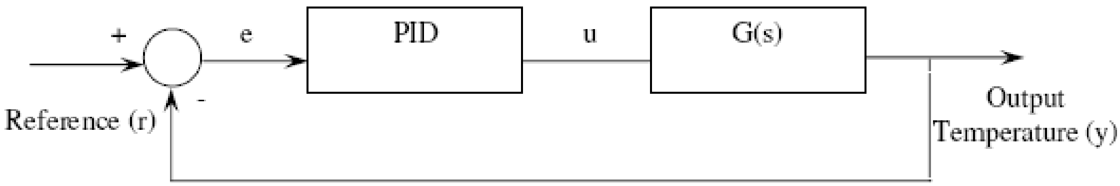


Figure 6

- **Cohen and Coon method.**

The model obtained (transfer function) can be used to derive various tuning methods for PID controllers. Cohen and Coon proposed one of these methods. The suggested parameters are shown in table 1.

Table 1

	Kp	Tr	Td
P	$\frac{\tau}{K L}\left(1+\frac{L}{3\tau}\right)$		
PI	$\frac{\tau}{K L}\left(0.9+\frac{L}{12\tau}\right)$	$L\left(\frac{30\tau+3L}{9\tau+20L}\right)$	
PID	$\frac{\tau}{K L}\left(\frac{4}{3}+\frac{L}{4\tau}\right)$	$L\left(\frac{32\tau+6L}{13\tau+8L}\right)$	$\left(\frac{4\tau L}{11\tau+2L}\right)$

The PID controller is given by:

$$u_{PID}=K_p\, e(t)+\frac{K_p}{T_r}\int e(s)\,ds+K_p\, T_d\,\frac{de(t)}{dt}$$

Experiment:

The connection for this experiment is given below in Figure 7:

1. Cool down the system at room temperature (remove the input power from the temperature system open flab to 4 and increase the potentiometer to 10 to increase speed of motor until the output voltage equal the room temperature).
2. Set the fan potentiometer to 3-scale division, the flap to 2-scale and power supply to 6 V.

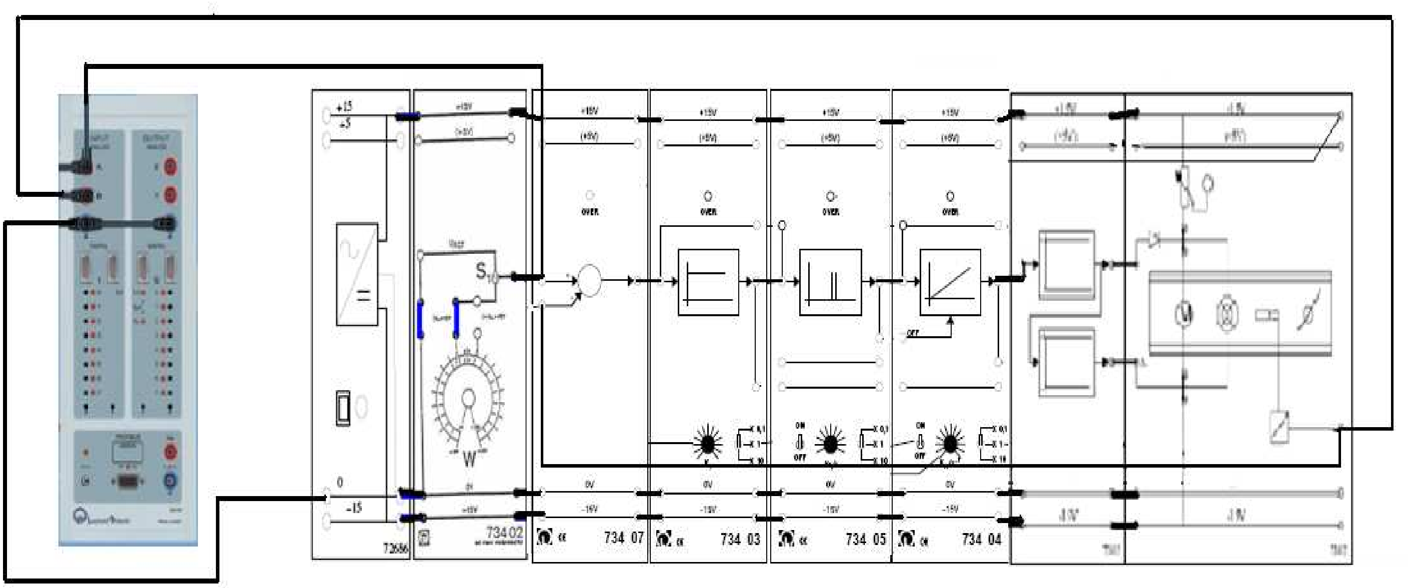


Figure 7

A. Effect of KP, KI, and KD :

A proportional controller (Kp) will have the effect of reducing the rise time and will reduce, but never eliminate, the steady-state error.

An integral control (Ki) will have the effect of eliminating the steady-state error, but it may make the transient response worse.

A derivative control (Kd) will have the effect of increasing the stability of the system, reducing the overshoot, and improving the transient response.

- Study the Effects of change each of controllers Kp, Kd, and Ki on a closed- loop system and summarized it in table shown next:

CL RESPONSE	RISE TIME	OVERSHOOT	SETTLING TIME	S-S ERROR
K_P		Increase	Small Change	
K_I	Decrease			Eliminate
K_D				

B. General tips for designing the PID controller:

When you are designing a PID controller for a given system, follow the steps shown below to obtain a desired response:

1. Obtain an open-loop response and determine what needs to be improved.
2. Add a proportional control to improve the rise time (Kp = 10, 50).
3. Add a derivative control to improve the overshoot.
4. Add an integral control to eliminate the steady state error.
5. Adjust each of the KP, KD and KI until you obtain a desired overall response.