A 3-LEVEL EXPERIMENT FOR TEACHING AUTOMATIC CONTROL

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Abstract : The object of this paper is to describe a procedure that can permit a student to understand both the theoretical and practical aspects of control. In order to accomplish this goal a laboratory exercise has been developed, which consists of three parts: Theoretical modeling, simulation of the real procedure and real time control. The procedure is a 1st order system for the control of the level of a filling tank.

Keywords: Educational aids, process control.

1.INTRODUCTION

Automatic control is an essential course that most of the engineering students are attending during their studies. Many of the students taking a first course in automatic control have difficulties with the theoretical aspects involved and also have difficulties to relate theory and practice. Laboratory exercises are essential so that the students can comprehend all the key aspects of control.
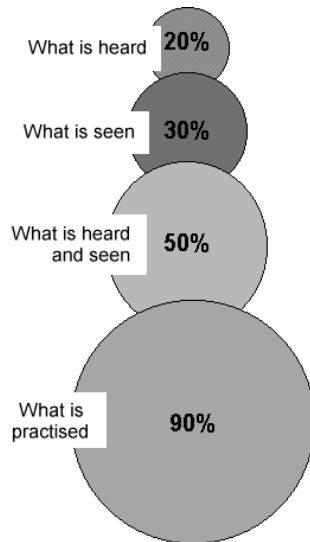

Fig 1. Presentation of the effect of different types of control education

Studies have shown that the human memory (ability to recall) is considerably better after active participation, compared to passive "consumption" of lectures. It has been discovered that only 20% of what is heard can be remembered; the recall ability is increased to 50% of what is heard and seen. However, maximum recall of 90%, is achieved by those who in addition, have performed practical exercises (Fig 1.) (Doitsidis 2000).

2. EXPERIMENT DESCRIPTION

The laboratory exercise, which has been developed, consists of three parts.

- Analysis through a linear ideal model, which approximates the experimental apparatus.
- Trial of the results in a modified more accurate simulated model of the system.
- Trial of the results of the model in the real system.

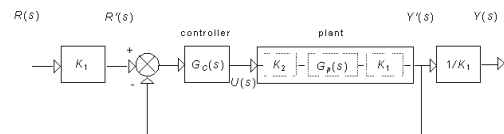Each of the three parts has a standard form (Fig 2.).

Fig 2. Standard form of the laboratory exercise.

For every step of the exercise the specific "plant" is replaced. The pre- and post-multipliers are essential so that the input and the output are expressed in natural units (i.e meters) and not in volts. The overall transfer function is not changing because,

$$\frac{Y'(s)}{R'(s)} = H(s) \qquad (1)$$

if we consider that, $R'(s)=K_1 R(s)$ and $Y(s)=(1/K_1)Y'(s)$ then

$$\frac{Y(s)}{R(s)} = H(s) \qquad (2)$$

3.PROCESS

3.1 Experimental apparatus

The experimental apparatus (Fig. 3) consists of a DC power supply, a power amplifier, a receptacle with pump, a filling tank, and a P/V converter. Lucas Nuelle manufactures the devices. The experimental apparatus is connected to a PC using the Lab-PC+ card, which is manufactured by National Instruments. The program that controls the devices is developed in LabVIEW.
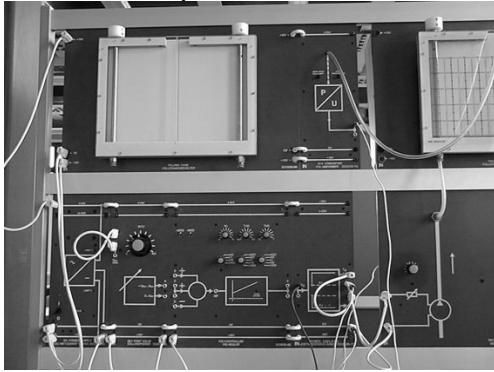

Fig 3. The experimental apparatus

3.2 Mathematical Modeling

In order to execute the experiment it's essential to derive the mathematical equations that describe the procedure.

The system, which is described, is a one input - one output system. The input is the desired level of the fluid inside the tank and the output is the real level of the fluid inside the tank (Fig 4.).
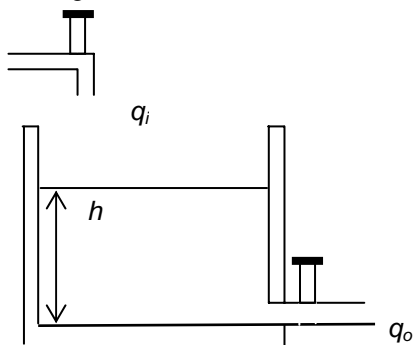

Fig 4. The filling tank

In order to approximate the procedure with a linear model the assumption that the flow is non-turbulent is made. The differential equation that describes the system is:

$$Cdh = (q_i - q_o)dt \qquad (3)$$

The relation of the resistance R with q_o and h is described from,

$$q_0 = \frac{h}{R} \qquad (4)$$

So the differential equation of the system becomes,

$$RC\frac{dh}{dt} + h = Rq_i \qquad (5)$$

The time constant of the system is RC. With the assumption that the initial conditions are zero, with Laplace transformation of (5) the following equation is derived,

$$(RCs+1)H(s) = RQ_i(s) \qquad (6)$$

Where,

$$H(s) = L[h] \qquad (7)$$
$$Q_i(s) = L[q_i] \qquad (8)$$

With the assumption that q_i is the input and h is the output the transfer function of the system becomes,

$$\frac{H(s)}{Q_i(s)} = \frac{R}{RCs+1} \qquad (9)$$

In order to extract the transfer function that describes the systems a program in LabVIEW has been developed. This program has as an output the voltage applied to the apparatus and as an input the voltage that corresponds to the level of the fluid in the tank given from the P/V converter.
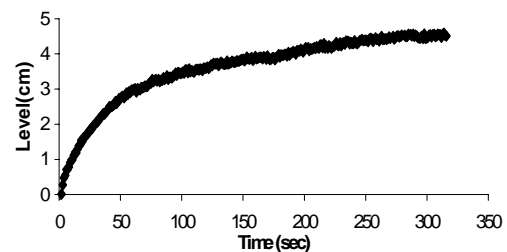

Fig 5. Graph Time-Level

Several experiments were made in order to find out in which voltage input the system reaches the steady state. For the specific voltage (3,3 Volts), after experimenting it was

calculated that the level in the tank was 4,5 cm (Fig .5).

The equation that represents the 1st order system is given from (9). In order to evaluate the exact form of the transfer function the determination of the time constant $\tau=RC$ is essential, where τ is the time, that the system takes to reach 63% of the value of the final response. In the specific system the time constant is 56 sec. Then (9) becomes,

$$\frac{Y(s)}{R(s)} = \frac{4.5}{56s+1} \quad (10)$$

which is the transfer function of the system.

3.3 Calculation of the parameters of the PI controller

In order to calculate the parameters of the PI controller, the design parameters where set as follows. The desired percentage overshot (M_p) was set at 15%, the settling time (t_s) at 30sec and the steady state error 0.5 at a band of $\pm 2\%$.

Using the analytical design (Sharian, et al., 1993) the parameters of the PID controller are, $K_P=26.65$, $K_I=50.54$.

3.4 Simulations

After calculating the parameters of the PI controller, the next step was to observe the behaviour of the system under the specific parameters. In order to do this the ideal model of the system and the real model of the system has been designed in Simulink. The block diagram of the real model is presented (Fig. 6).

With the control parameters that deriverd, the step response of the system is presented (Fig. 7) The desired level was set at 5 cm. The control signal of the ideal system is presented (Fig. 8).
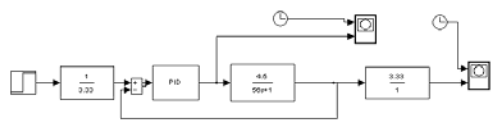

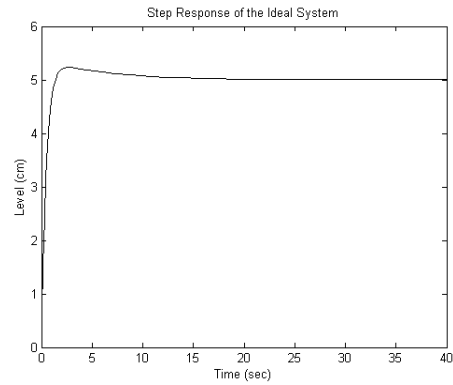Fig 6. Block diagram of the ideal system
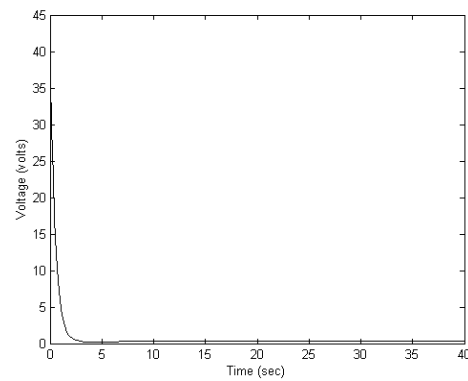

Fig 7. Step response of the ideal system

Fig 8. Control signal of the ideal model

Because the saturation of the amplifier is not a desired behaviour, with the method of trial and error we reduce the total gain of the system in order to avoid saturation by setting $K_P=1.84$ and $K_I=0.29$. With these parameters and with setpoint at 5 cm, the step response of the system is presented in the following diagram (Fig. 9). With the new parameters the saturation of the power amplifier is avoided (Fig. 10), but the designed requirements of the system are not met.
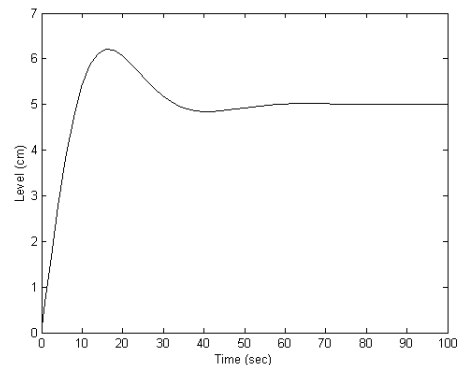

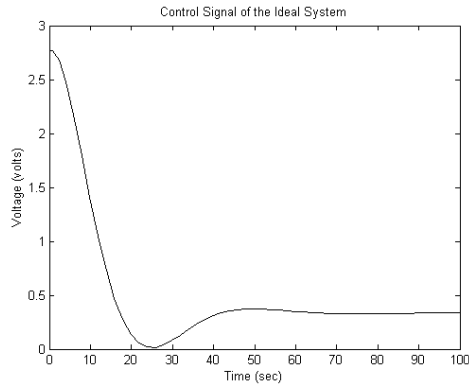Fig 9. Step response of the ideal system (without saturation)

Fig 10. Control signal of the ideal system
(without saturation)

After experimenting with the ideal system,
the behaviour of the real system was obseved
via simulations. The block diagram of the
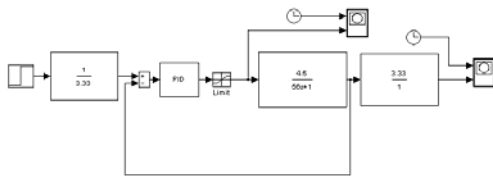simulated real system is presented (Fig. 10)

Fig 11. Block diagram of the simulated real
time system

For the same control parameters of the
system the step response (Fig. 12) and the
control signal (Fig. 13) are presented. The
amplifier is saturated again. In order to avoid
saturation the same control parameters that
have been used to avoid saturation in the real
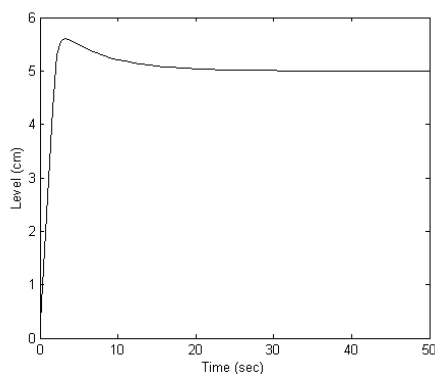model are applied again.

Fig. 12. Step response of the simulated real
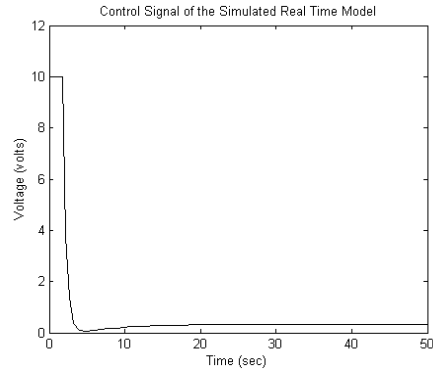time system

Fig. 13. Control signal of the simulated real
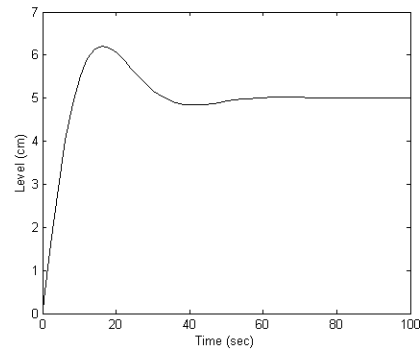time system

Fig 14. Step response of the simulated real
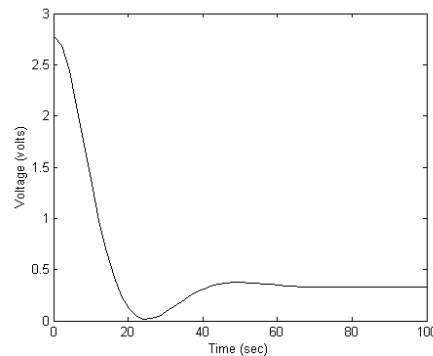time system (without saturation)

Fig. 15. Control signal of the simulated real
time system (without saturation)

3.5 Real time tests

After experimenting with the simulated
models the behavior of the real system has
been observed. In order to do so the
appropriate software has been designed in
LabVIEW environment. The control panel of
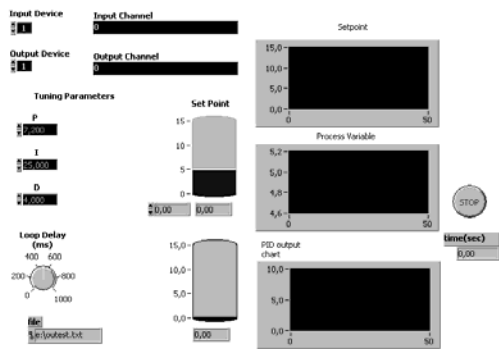the program is presented (Fig. 16).

Fig 16. The control panel of the PID controller

With the use of the program and for the same control parameters that have been used for the simulated models the following results have been obtained. The step response of the real system and the control signal of it are presented (Fig. 17, Fig. 18).
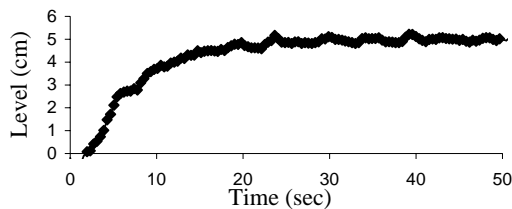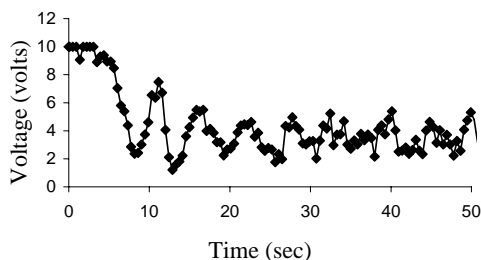

Fig 17. Step response of the real system

Fig 18. Control signal of the real system

It is observed from the figures concerning the real system that several differences exist between the real system and the simulated. The differences are the result of linearization, errors during the data acquisition from the real system and noise that cannot be modeled.

It's observed that the amplifier of the real system is saturated also. In order to avoid the saturation the parameters that have been used for the same purpose in the simulation are used also. The results are presented in the following figures (Fig 19, Fig. 20).
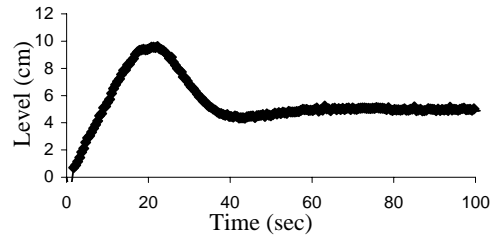

Fig 19. Step response of the real system
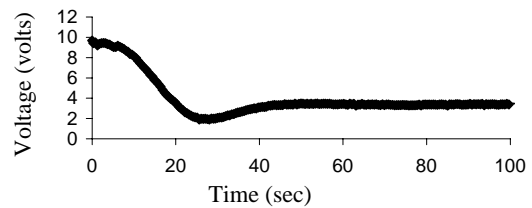(without saturation)

Fig 20. Control signal of the real system
(without saturation)

3.CONCLUSION

This paper attempts to present a full experiment that will help the students that are attending an introductory course in automatic control to understand both the theoretical and practical aspects. In order to achieve that goal a common experimental apparatus has been chosen.

In order to comprehend the theoretical aspects the student has to model the system and then make all the essential simulation in Simulink. Afterwards with the use of the program that controls the real system the behavior of the real system will be observed. Finally the student will make the comparison between the theoretical and the real results.

REFERENCES

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