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Level Control in a System of Tanks in Interacting Mode Using Xcos Software

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Abstract

The main objective of this project is to control the level of liquid in a systems of tanks in interacting mode using Xcos software for the process of learning of the course of process control. Initially, mathematical modeling in each tank was carried out by means of mass balances. After, it was identified the controlled and disturbance variables. Finally, the control system was simulated using Xcos software as didactic tool for the understanding of the study of strategies of control. Simulation of level control of tank 1 using integral proportional controller (PID) reached steady state faster than proportional (P) and proportional integral (PI) controllers. Also, it is observed that error and steady state time decrease with increasing the value of proportional gain for simulation using proportional controller. While, the number of oscillations and its overshoot increase with increasing the value of proportional gain. Also, the PID controller reacted to the step change in the set point of level with a good performance. Likewise, the PID controller acted very well against a step change in the output flow of the pump.

Keywords: Interacting tanks, mathematical model, closed loop, tuning, PID

1 Introduction

The control systems in the industry are justified due to the automatic control of variables in the processes to improve product quality, maintain safety and reduce environmental pollution. This is enabled by the measurement and control of variables such as flow rate, pressure, temperature, and concentration [1], which leads to lower production costs [2]. Since customers also judge a company by the quality of their products and services, process control helps ensure that companies maintain a loyal customer base. Therefore, an integral learning process in the automatic control area is important and where the students are prepared for the real world outside academia, to apply their knowledge, experience, and practical skills to improve the abilities in process control area and this valuable knowledge can be applied to the real world situations. In practice, the process variables, such as pressure, level, temperature and flow are generally controlled by an automatic controller. The parameter fitting of controller cannot directly be made on the process, so before application, the sufficient debug and test must be held on the simulation platform or plant in pilot scale [3]. One of the systems most commonly used in industrial processes is tank systems that allow the distribution, storage and processing of a wide variety of products in different states such as liquids, gases and solids. Tank systems may be of a non-interacting nature if the output variable of one of the tanks affects, in one direction, the output variable of the next one; or the interacting nature in the event that output variable affects in both directions. Some similar works are described below. Benítez et. al. [4] built a liquid level prototype that is a plant formed by three tanks coupled to represent first, second and third order systems, and a main control module divided into two submodules, analog and digital, which is responsible for performing the control over the system, in order to comply with the assigned requirements. While, Anzurez et. al. [5] proposed a methodology for the stability analysis of nonlinear systems using the direct and indirect Lyapunov method. At the same time, the solution was proposed from a graphic point of view from the phase portrait obtained using Matlab. They presented a review of the main characteristics of nonlinear systems and listed the main points of equilibrium for these systems, as well as their properties. The analysis was developed for second order systems represented by state variables. The purpose of the present project is to model a system of tanks to control the level in an interacting mode using the Xcos software [6], in order to provide undergraduate students of the chemical engineering program of the University of Cartagena with a tool to understand the theory received in the process control course.

2 Process Control Fundamentals

2.1 System of tanks in interacting mode

Figure 1 shows diagram of system of tanks in interacting mode. Considering that the tanks are open to the atmosphere, and the liquid properties such as density and specific heat are constants. Furthermore, the liquid temperature is constant. In addition, the system of tanks has an ultrasonic level sensor, a proportional pneumatic valve, a PID controller and a pump.

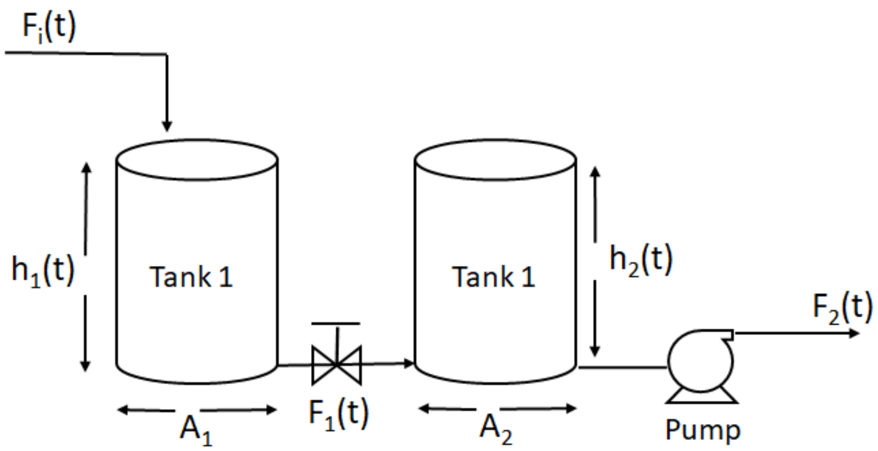

Figure 1. Diagram of system of tanks in interacting mode

2.2 Automatic Process Control

Process control is an engineering discipline that deals with architectures and mechanisms for maintaining the output variable of a specific process within a desired range [7]. For instance, the temperature of a chemical reactor may be controlled to maintain a consistent product output. Process control is extensively used in industry and enables mass production of consistent products from continuously operated processes such as oil refining, paper manufacturing, chemicals, power plants and many others. Process control enables automation, by which a small staff of operating personnel can operate a complex process from a central control room.

2.3 Tuning of feedback controller

Controller tuning involves finding proper values of three parameters (*Kp, Ti and* T_D) at which suit the process to be controlled. PID tuning is sometimes regarded as a hard task. A survey of process plants in the USA found that between 65% and 80% of the PID loops were badly tuned and were seriously affecting the performance and profitability of the process. In most cases, however, tuning a PID controller isn't really that difficult and just takes a bit of patience and experience. The tuning methods most common were published by Ziegler and Nichols in 1942 [8, 9] where they described two methods for tuning the parameters of P-, PI- and PID controllers. These two methods are the Ziegler-Nichols' closed loop method, and the Ziegler-Nichols' open loop method. The closed-loop method is the most useful, and it consists in obtaining a response with oscillations of constant amplitude of the variable of interest with a proportional controller. The gain of the controller (proportional) in this case is called "Last Gain" and the period of the oscillation is called "Last Period" [10]. Ziegler and Nichols [8, 9] used as criteria of acceptable stability the ratio of the amplitudes of subsequent peaks in the same direction (due to a step change of the disturbance or a step change of the set point in the control loop) is approximately 1/4. However, there is no guaranty that the actual amplitude ratio of a given control system becomes 1/4 after tuning with one of the Ziegler and Nichols' methods, but it should not be very different from 1/4.

3 Results and Discussions

3.1 Mathematical Modelling

Mass balances for tank 1 and tank 2 are given by equations 1 and 2, respectively.

$$A_1 \frac{dh_{1(t)}}{dt} = F_i(t) - F_1(t) \tag{1}$$

where A_1 is the area of cylindrical tank 1, F_i is volumetric inlet flow of tank 1, F_1 is volumetric outlet flow of tank 1.

$$A_2 \frac{dh_{2(t)}}{dt} = F_1(t) - F_2(t) \tag{2}$$

where A_2 is the area of cylindrical tank 2, F_1 is volumetric inlet flow of tank 2, F_2 is volumetric outlet flow of tank 2.

Considering that the openings of the valve is constants and the flow of liquid through the valves is given by

$$F(t) = C_v \sqrt{\frac{\Delta P(t)}{G_f}} \tag{3}$$

where C_v is valve coefficient, $\Delta P(t)$ is the pressure drop across valve (kPa), $F(t)$ is the liquid flow, G_f is the specific gravity of liquid. Thus, the valve equation for this system becomes

$$F_1\,(t) = c_v'' \sqrt{(h_1\,(t) - h_2\,(t))} \tag{4}$$

where $c_v'' = C_v \sqrt{\frac{\rho g}{G_f}}$. Substituting the equation 3 into mass balances (equations 1 and 2) yields the differential equations for both tanks.

$$A_1 \frac{dh_1(t)}{dt} = F_i - c_v'' \sqrt{(h_1\,(t) - h_2\,(t))} \tag{5}$$

$$A_2 \frac{dh_2(t)}{dt} = c_v'' \sqrt{(h_1\,(t) - h_2\,(t))} - F_2\,(t) \tag{6}$$

The equations 5 and 6 must be linearized using Taylor series and to transform in the deviation variables. Then, the transfer functions are determined (equations 7 and 8) by applying Laplace Transforms.

$$\bar{h}_1(s) = \frac{0.9\,\bar{F}_i\,(s)}{(0{,}11\,S+1)} + \frac{0.3\,\bar{h}_2(s)}{(0{,}11\,S+1)} \tag{7}$$

$$\bar{h}_2(s) = \frac{0.2\,\bar{h}_1(s)}{(3.52s+1)} - \frac{2.45\,\bar{F}_2\,(s)}{(3.52\,S+1)} \tag{8}$$

To obtain the transfer function of closed circuit of the feedback system, the valve and the sensor are mathematically modeled as detailed to continuation.

3.2 Sensor-Transmitter

The sensor-transmitter is ultrasonic of the Carlo Gavazzi model with analog output of 4-20 mA and a time constant of 0.34 min. The transfer function of sensor obtained is

$$H_{(S)} = \frac{0.9}{0{,}34S+1} \tag{9}$$

3.3 Proportional Control Valve

The valve is to be designed for 100% overcapacity and it is considered with constant pressure drop. According to manufacturer, the valve is an equal percentage with a rangeability parameter of 50. Furthermore, the valve actuator has a time constant of 0.17 min. The transfer function of valve obtained is

$$G_{v(S)} = \frac{0{,}39}{0{,}17S+1} \tag{10}$$

3.4 Simulation of Level Control System using Xcos Software

Figure 2 shows the block diagram using Xcos software of a feedback control system for interacting tanks. While, Figure 3 shows simulation of feedback level control of system of tanks in interacting mode, only proportional controller, at different proportional gain values. It is observed that error and stationary time decrease with increasing the value of proportional gain. While, the number of oscillations and its overshoot increase with increasing the value of proportional gain. These results are according with process control theory [1, 11, 12]. On the other hand, Figure 4 shows the effect of the step change of set point at tank 1 level from 0.9 m to 0.45 m, as it is observed the PID controller reacted to the change with a good performance. Likewise, a step change in the output flow of the pump was introduced from 0.04 m^3/min to 0.02 m^3/min at time 3 min, and the PID controller acted very well against the disturbance, while result contrary is obtained when only the proportional controller is used.

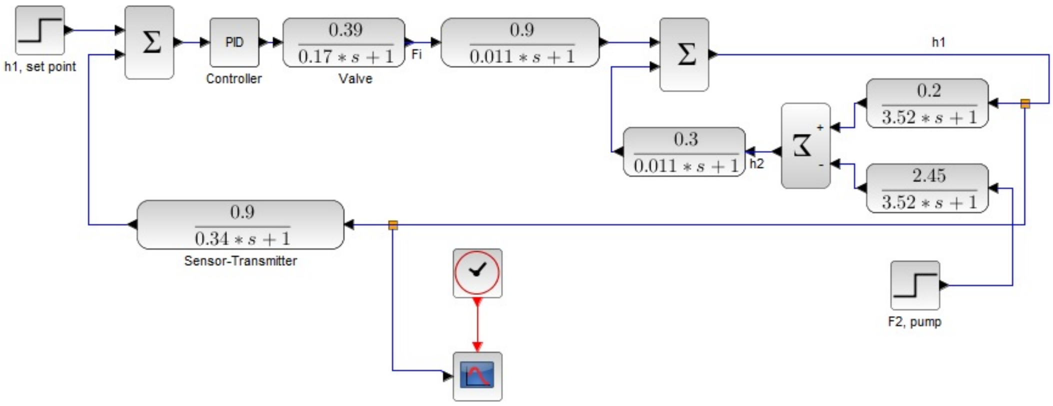

Figure 2. Diagram of blocks of a system of tanks in mode interacting for simulation

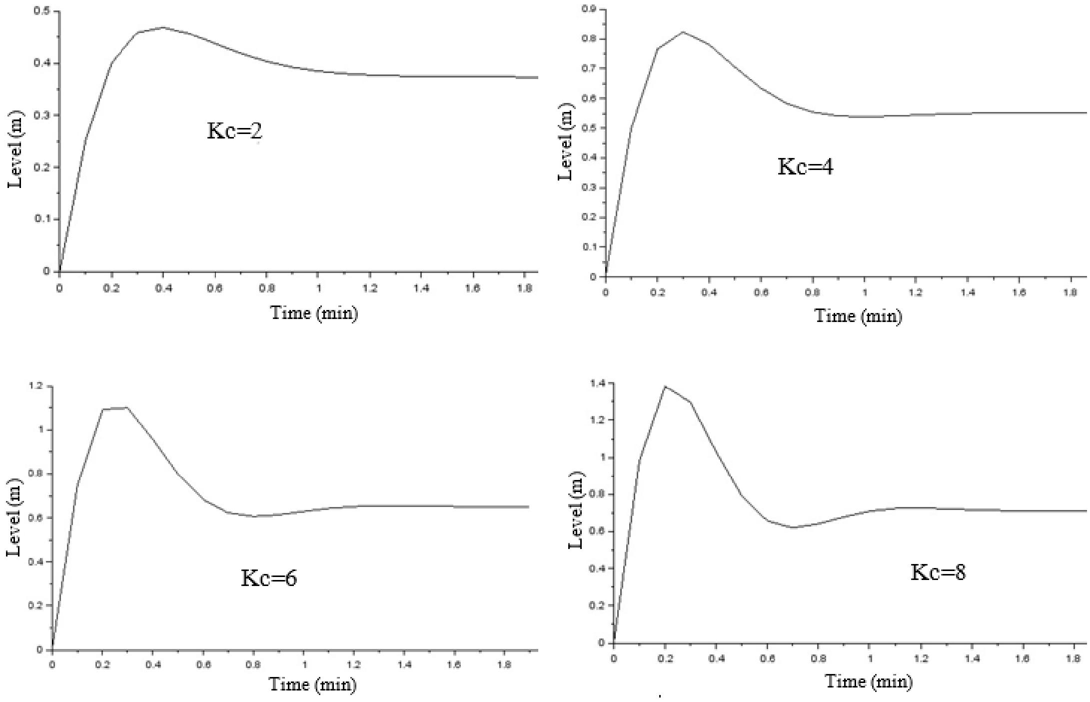

Figure 3. Simulation of feedback level control of tank 1 in interacting mode. Proportional feedback with a) Kc=2, b) Kc=4, c) Kc=6 and d) Kc=8

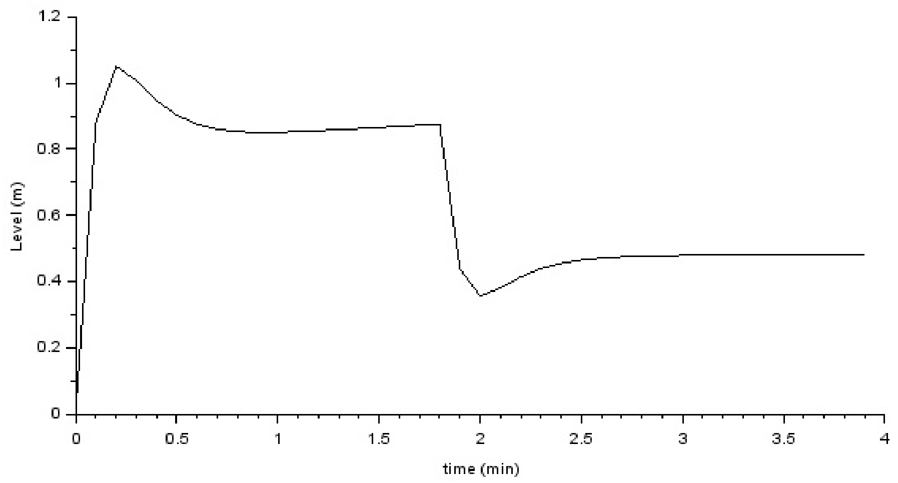

Figure 4. Simulation of PID feedback level control of tank 1 in interacting mode with step changes in set point of tank 1 level and disturbance in the pump flow.

4 Conclusions

Mathematical modelling and level control of a system of tanks in mode interacting were carried out using the Xcos software, that it is a good tool to understand the theory received in the process control course. Level control of liquid inside of tank using integral proportional controller (PID) reached steady state faster than proportional (P) and proportional integral (PI) controllers. Generally, the PID controller reacted very well to the step changes in the set point of level and in the output flow of the pump.

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