Paweł KIECZMERSKI, Krzysztof ROGOWSKI

Białystok University of Technology

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Application of SIMATIC S7-1200 controllers for the water level control system in water reservoirs

Abstract. *The article describes the implementation process of the automatic control system controlling the water level in water reservoirs. The control plant, which is a laboratory model RT-010 by GUNT Hamburg, was described as well as the method of obtaining a parametric mathematical model for simulation purposes. Next, based on the obtained numerical and experimental results, an automatic control system was made consisted of two SIMATIC S7-1200 controllers, the HMI Comfort TP700 panel and SCALANCE X208 communication module. The parametric model was verified in MATLAB/Simulink, while the TIA Portal software was used to test automatic control system.*

Streszczenie. *W artykule opisano proces syntezy układu regulacji automatycznej poziomu wody w zbiorniku wodnym. Obiektem regulacji był model laboratoryjny RT-010 produkcji GUNT Hamburg składający się z dwóch zbiorników wodnych. Analiza obejmowała stworzenie modelu parametrycznego badanego obiektu, syntezę układu automatycznej regulacji w oparciu o dwa sterowniki SIMATIC S7-1200 oraz panel dotykowy HMI Comfort TP700 i moduł komunikacyjny SCALANCE X208. Na podstawie stworzonego modelu obiektu dobrano nastawy regulatora PID oraz zweryfikowano eksperymentalnie poprawność działania układu oraz jakość regulacji.* ***(Zastosowanie sterownika SIMATIC S7-1200 do regulacji poziomu wody w zbiorniku)***

Keywords: automatic control, tank, water level, PID controller, PLC controller.
Słowa kluczowe: układ regulacji, regulacja automatyczna, poziom wody, sterownik PLC, regulator PID.

Introduction

Due to the limitations of human perception and limited efficiency, there is a strong need for a technological solutions that will enable accurate and reliable management of diverse industrial processes [1, 2]. Automatic control systems significantly exceeded human capabilities in terms of response time and accuracy of execution, which consequently led to the revolution of the industry. Nowadays, we observe the next step of this revolution which is called Industry 4.0, where the control process becomes a complex system consisted of many intelligent devices communicating with each other using cloud services and internet of things (IoT) concept [3, 4, 5, 6].

One of the most important element of the aforementioned modern systems is a Programmable Logic Controller (PLC) , which is responsible for realization of a desired control strategy based on the measurements of the relevant process signals [7, 8, 9, 10, 11].

In this paper, the designing process of a control system that steers the water level in water tanks of a laboratory model Gunt Hamburg RT-010 will be presented. Two SIEMENS S7-1200 controllers and HMI Comfort TP700 operator panel will be used to implement the control system. The communication between elements took place via ethernet protocol using SCALANCE X208 communication module. The parametric model of a plant is obtained according to the integral nature of the process. The PID controller is tuned using the transfer function of a plant and by autotuning method. Quality indicators of control systems for different cases are presented and discussed. Despite its simplicity, this project is an ideal introduction to more complex automation systems.

Description of control plant

Laboratory model RT-010 shown in Fig. 1 was designed by Gunt Hamburg for water level control in installation made of two sealed tanks placed on top of each other. The device was powered by an AC voltage of 230 V and a frequency of 50 Hz. The tanks have a capacity of 1.2 dm^3 (upper tank) and 3.7 dm^3 (lower tank) and are separated by a controllable solenoid valve. The water pump with the power of 18 W and the flow of 8 dm^3/min is responsible for the flow of water from the lower tank to the upper one. A pressure sensor, with range 0-3 kPa, was used to measure the amount of liquid in the upper tank. In addition, the device was equipped with an overflow pipe to prevent to overflow the fluid outside the tank [12, 13].

Fig. 1. Control plant RT-010 by GUNT

RT-010 was equipped with a LabJack U12 measurement card, which measures the values from the pump, valve, and pressure sensor. Table 1 shows the addresses with ranges of signals. In the initial phase of the test, a program prepared by the manufacturer was used to control the device, which allows the user to set the desired value, the degree of solenoid valve opening and to observe the waveforms on the graph. The valve position has an influence on the operating conditions of the device and the parameters of the mathematical model of this plant. The pump played the role of actuator that steers the flow of the water between lower and uppper

Table 1. LabJack U12 measurement card signals [12, 13]

Address	Description	Range
AI0	Output signal from pressure sensor	0.5 – 2.8 V
AO0	the pump control signal	0 – 5 V
AO1	the valve control signal	0 – 5 V
IO2	ON/OFF button for pump	ON/OFF
IO3	On/OFF button for valve	ON/OFF

tank. The pressure sensor measures the controlled signal, i.e. the level of a liquid in the upper tank. After experimental measurements of the system response for different position of the valve, the parametric model has been created.

Parametric model of control object

The identification process of the control plant began with the observation of the system operation during a trial run of the device at any given value of the tank filling. With the constant actuation of the pump and the simultaneous position of the solenoid valve, the water level in the tank changed linearly in time. Considering the results of the observation, it was found that the control object behaves like an integrating element. Integrator is one of the basic elements of automatics, which, when imposing on its input a signal x(t) at the output, will give the signal y(t) proportional to its integral as follows [14]

$$y(t) = k \int_{0}^{t} u(\tau)\mathrm{d}\tau, \tag{1}$$

where k is a gain of a plant, $u(t)$ the input signal (supply voltage of the pump [V]) and $y(t)$ is the object's output (pressure sensor voltage [V]).

Using the bilateral Laplace transform for (1), the transfer function of the integrating element is described by [14]

$$G(s) = \frac{Y(s)}{U(s)} = \frac{k}{s}. \tag{2}$$

The step responses of the model for different values of the gain coefficients k are shown in Fig. 2.

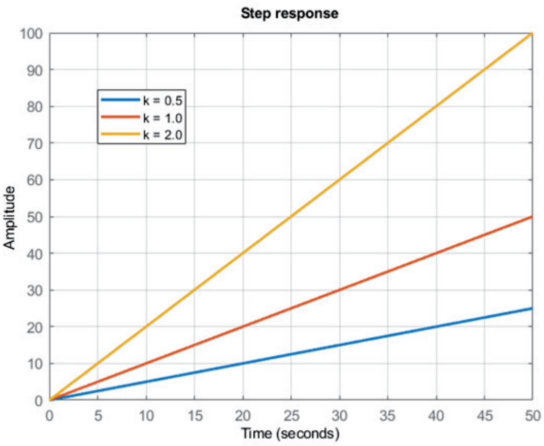

Fig. 2. Integrator's step response for different k value

To prove that the previously presented thesis about the nature of the control object is correct, three step responses were registered with the maximum pump output and different degree of valve position: 10%, 25%, 50% (see Fig. 3). All measurements were acquired using NI-myDAQ data acquisition device based on LabVIEW software. The graphs shows, that the process may be described by the transfer function (2) with gain coefficient k value depending of the valve position. This information forms the basis for developing the plant model in MATLAB/Simulink presented in Fig. 4 for further numerical analysis purpose.

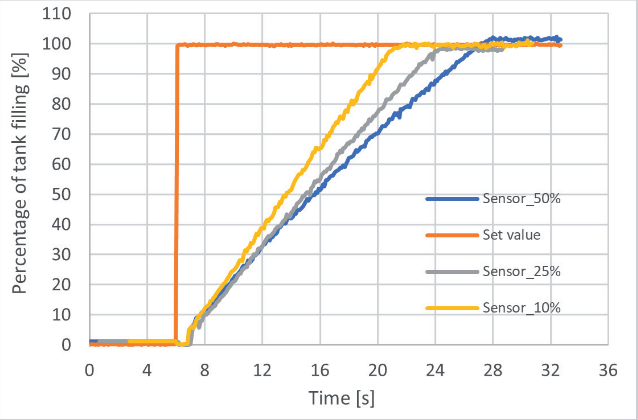

Fig. 3. Plant step responses for different position of the valve

Knowing that the value of the gain k changes with increasing degree of valve opening, it becomes a problem to create a single common model of a control plant for whole operating range. For this reason, a parametric model for the case of 10% of valve opening was estimated. The value of gain $k = 0.158$ was calculated from the slope of the characteristic shown in Fig. 3.

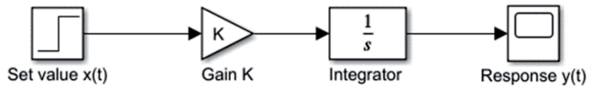

Fig. 4. Parametric model of control plant

The model of control plant for the case of 10% of valve opening was verified with the measurements of the original object. The results of comparison are shown on Fig. 5 and shows that the model is accurate. However, presented model is suitable only for those certain condition and is not a complete solution for different operating conditions.

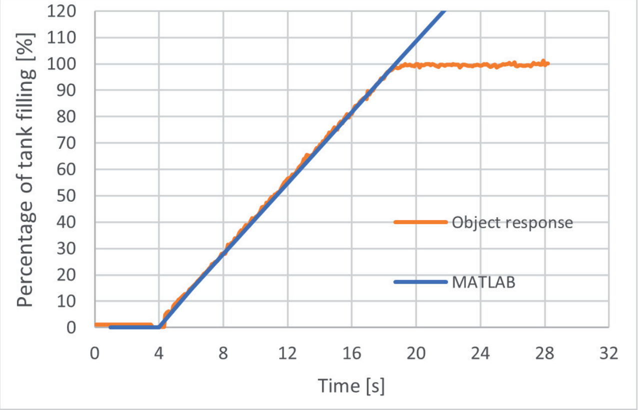

Fig. 5. Comparison of the model and object responses (10% of valve opening)

Therefore, the parametric model should be verified for other settings of solenoid valve postition. The values of gain k for degrees: 0%, 25%, 50%, 75% have been calculated and corresponding models were created. A special case appeared within range 75% - 100%, where control plant was behaving like first-order inertial dynamic system (see Fig. 6). Due to this phenomenon, it was difficult to estimate the value of the gain k for whole range of the valve position.

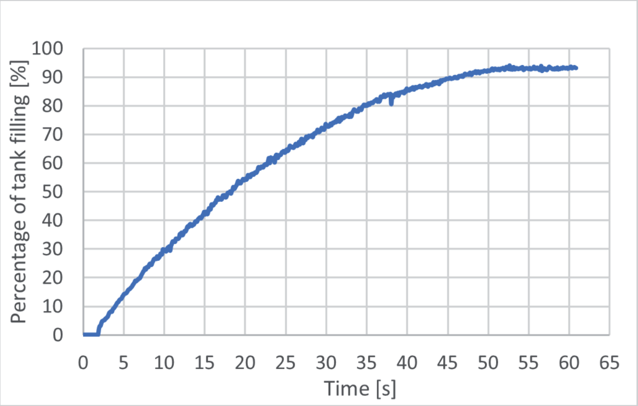

Fig. 6. Step response with 100% of valve opening

In order to successfully estimate the values of gain k, a graph containing all of previously calculated k values was created (Fig. 7). By applying linearization on to the graph, it was possible to estimate value of gain k in whole operating range.

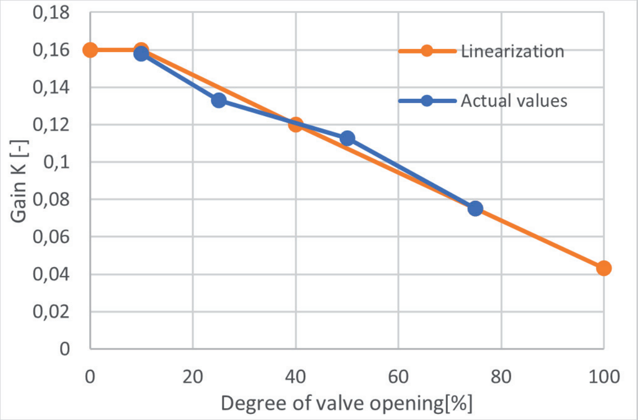

Fig. 7. Linearization of the gain dependence on valve opening degree

Automatic control system

The impact of changing value of the gain k on control system had to be examined to ensure the correct operation of the system. Therefore, previously designed model has been expanded by PI controller (Fig. 8), which was then tuned using formulas [15]

$$k_p = \frac{8}{t_r k} = 2.532, \qquad T_i = \frac{t_r}{2} = 10, \tag{3}$$
$$k_i = \frac{k_p}{T_i} = 0.253,$$

for desired settling time $t_r = 20$ s for valve position 10%.

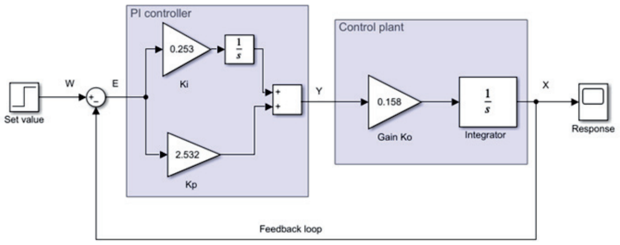

Fig. 8. Model of automatic regulation system in MATLAB/Simulink

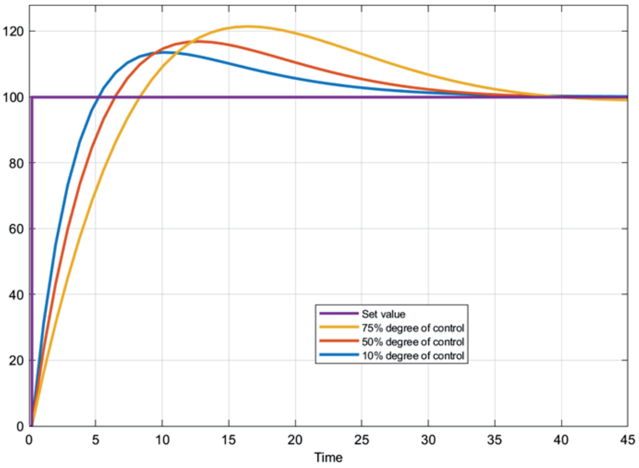

Fig. 9. Comparison of model response with different degree of control of the valve – settings calculated for 10%

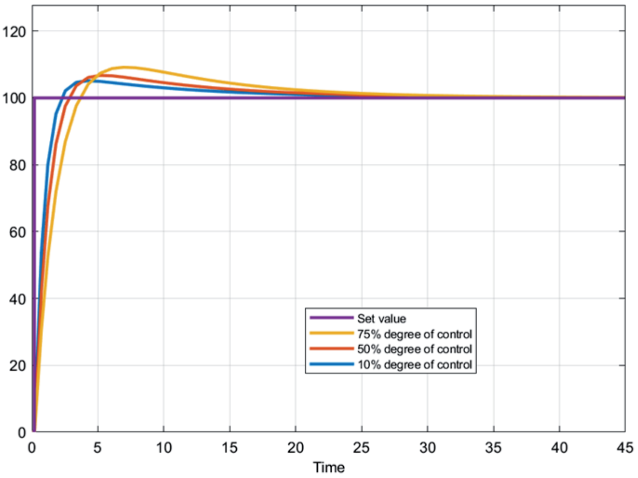

Fig. 10. Comparison of model response with different degree of control of the valve – settings calculated for 100%

The prepared model was then tested for various solenoid valve positions. The desired result would be to obtain a system that would change the settings of the regulator each time the degree of control of the valve is changed. However, this solution would be difficult to implement, therefore the system has been tested with settings calculated for samples with 10% and 100% valve open (see Fig. 9 and Fig. 10).

Considering the values of overshoots and the tettling times presented in Table 2, it is confirmed that the use of the settings determined at the maximum actuation of the solenoid valve has a positive effect on the quality of the system regulation in the entire operating range. With the settings for 100% control, the overshoot was almost three times smaller, while the settling time decreased by 2-5 times, depending on the case. Based on the results of the simulation, an automatic regulation system for RT-010 has been created (Fig. 11).

The system shown in Fig. 11 is consisted of two S7-1200

Table 2. Performance indices for tested control systems

Valve opening [%]	Overshoot [%]	Setting time [s]
Settings determined for 10%		
10	13.52	20.84
50	16.83	25.50
75	21.39	31.72
Settings determined for 100%		
10	5.12	4.94
50	6.72	9.10
75	9.15	14.02

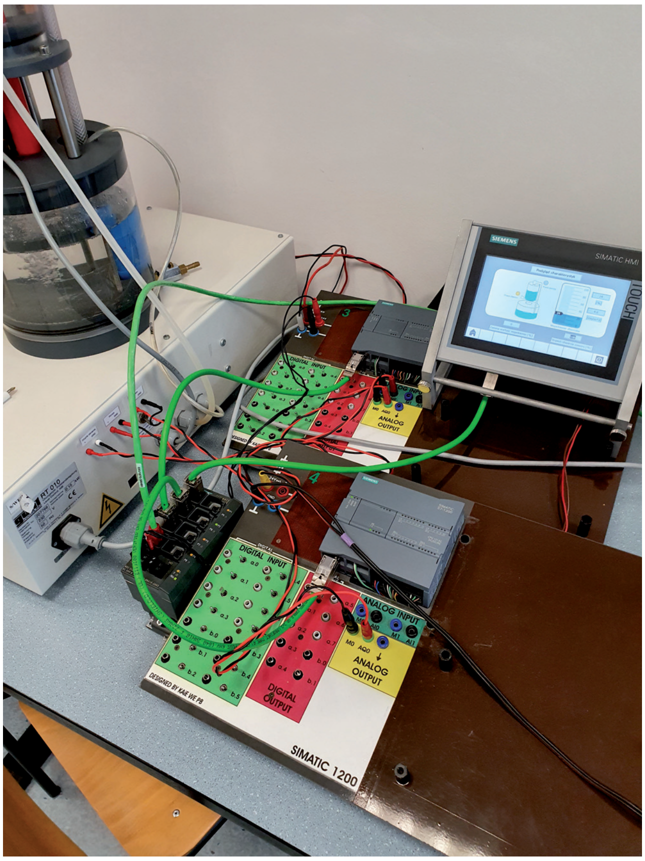

Fig. 11. Automatic control system for RT-010

PLC, HMI Comfort TP700 operator panel and SCALANCE X208 communication module. Both PLC and HMI have been programmed via TIA Portal to give the user complete control over the device. The HMI panel (see Fig. 12) made it possible to set the valve actuation value and the desired value of the tank filling, as well as to observe the processes taking place in the object. The system has been tested with settings acquired from simulation and with use of autotuning method.

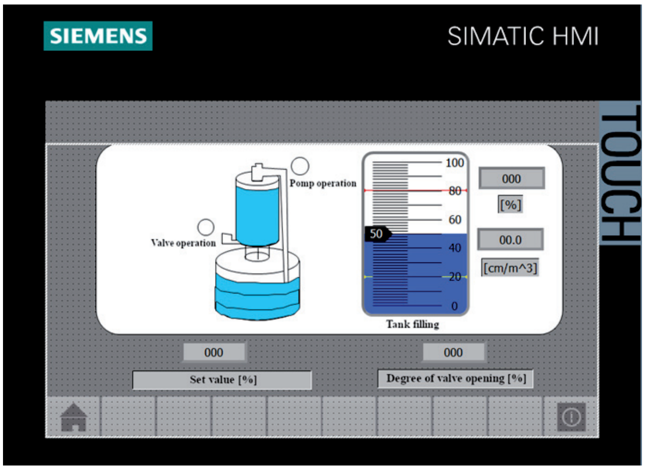

Fig. 12. HMI contol panel screen

When analyzing the settling time values presented in Table 3 for individual cases, it can be noticed that the difference in the control time between various methods of selecting the controller settings depends on the degree of valve control, where at 100% of control the difference is the smallest. It is worth mentioning that for each of the tested case, better control was ensured by settings selected automatically.

Measured step responses of the control system with controller parameters obtained by autotuning method is shown in Fig. 13 and computed using the parametric model of the process in Fig. 14.

Table 3. Comparison of settling times for tested methods

Degree of valve opening	Settings acquire method	Settling time [s]
10%	Autotuning	17.14
	Simulation	25.62
	Difference	**8.48**
50%	Autotuning	22.50
	Simulation	27.72
	Difference	**5.22**
75%	Autotuning	26.91
	Simulation	32.45
	Difference	**5.54**
100%	Autotuning	32.72
	Simulation	33.38
	Difference	**0.65**

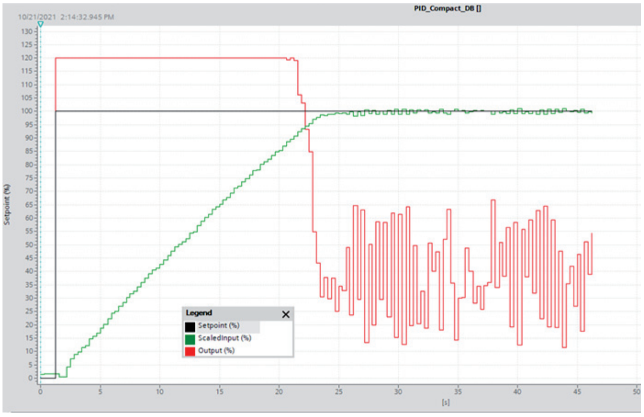

Fig. 13. System resposne – autotuning

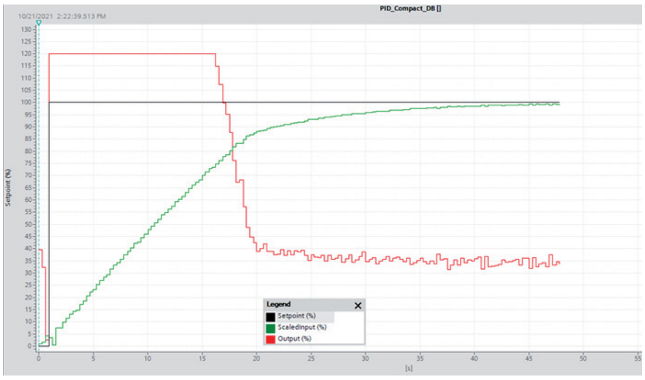

Fig. 14. System response - settings acquired through simulation

Conclusion

In the presented paper the method for acquiring automatic regulation system and simulation model of the system was developed. To verify this method an experimental verification was performed. The results confirmed that the simulation model was accurate in comparison to real plant. The influence of variable value of the gain k on the system was also investigated, which was finally eliminated by using the settings obtained for the critical case of the system operation. In case of the real system, the best performance was achieved with the automatic tuning of the regulator, as it provided the best settling control time and the use of the pump's capabilities.

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***Authors**: Eng. Paweł Kieczmerski, Ph.D. Krzysztof Rogowski Faculty of Electrical Engineering, Bialystok University of Technology, ul. Wiejska 45D, 15-351 Białystok, Poland, email: pawelkieczmerski@gmail.com, k.rogowski@pb.edu.pl*

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