Digital Control Design for the Boiler Drum

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Abstract – A boiler drum (BDT921) that is installed in the Control Laboratory in UTHM is being used as a model plant to achieve the digital control system since its analog. Implementing a digital system to BDT921 quite a though work. This paper covers analysis from the experiment done to match with digital design that will be implemented to the real system. The digital control design will come up with the mathematical model of the BDT921 and will be analyzed with MATLAB and SIMULINK software named as *'Discrete Analysis of BDT921 Simulation'*, while *simulate with* LABVIEW. PID *controllers are* being chosen as the control element in discrete form as the real system is using the same control element. The output responses behave as the second order system with a bit difference in rise times and peak times compared with data obtained from experiment. With regarding to the analysis done, the digital control can be implemented to the boiler control system and for further viewing, to be controlled digitally with computer in the control room.

Keywords: *Boiler drum, digital control, PID controllers, MATLAB and SIMULINK*

INTRODUCTION

Boilers are commonly used in industries in almost all process and power plants to generate steam for the main purpose of electricity generation via steam turbines. Basic operation of boilers including boil water process in boiler drum (water are boiled to generate steam) and the steam generated will be used in generating turbines for electricity or for the other process like process heating [1]. Project task is using a simulation boiler (BDT921) that installed in the Control Laboratory in UTHM (see Figure 1 and Figure 2) as the pilot plant for implementing digital control that will be designed. However, this project only consists of simulation of the boiler drum level control. Though, this is not a real boiler system using in industry, it can be used to simulate boiler process involved. The important matter is the control system responds can be obtained from the simulation and then be analyzed for the PID control system. The control system can be changed within mode P, I, D and also with combinational of PI, PD and ID. However, the derivative component is not required for level control because of the noise that will cause instability [2]. The objective is to design a digital control for the boiler (BDT921) drum level control on single loop PID. It will include the understandings of the boiler drum overall process with experiment and obtaining mathematical model for the boiler control system. While data analyzed and modeled with MATLAB and SIMULINK. This paper covered the study of overall process operation of boiler (BDT921) as a control system plant. It encompassed the explanations of the roles of each instrument and control elements such as control valves and PID controllers. However, the study is focused more on the boiler drum system part. That is includes the water inflow process to the boiler drum till the outflow process. Various control system can be modeled within the boiler drum process. Because of that, this study merely cover the level control system using single loop PID of the boiler drum. After this project is completed, it will cover a mathematical model of boiler drum (BDT921) control system. In the other hand, the real system boiler process will be represented by a mathematical order. It then can be analyzed with either using a MATLAB or SIMULINK software to find control response characteristics. Discrete transfer function is simulated by using SIMULINK software in order to get the output response of discrete signal.

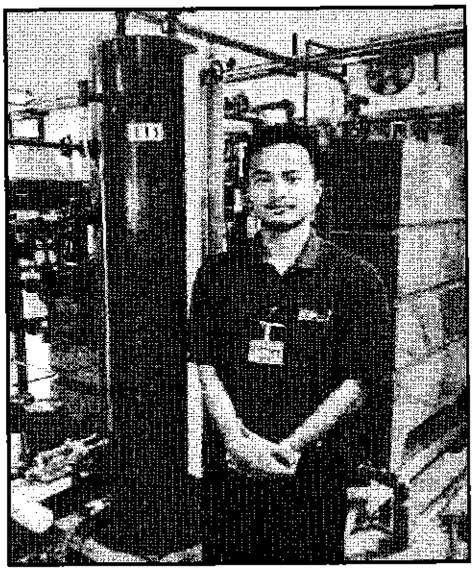

Figure 1 : Boiler drum tank (Real system) compared with normal human height (164cm)

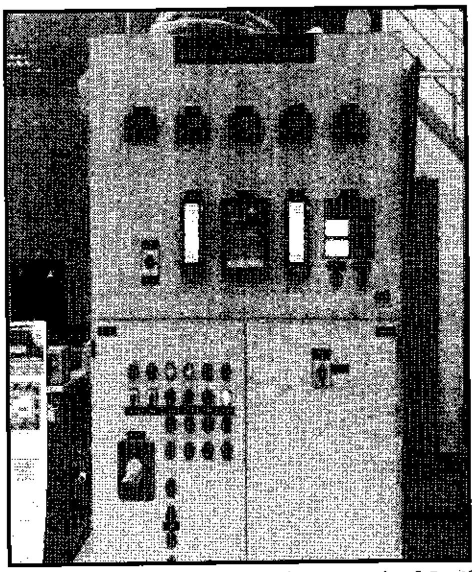

Figure 2 : The front panel control of Boiler drum tank (Real system)

Knowing the overall process of boiler drum, make it possible to represent the system process with block diagram. From the block diagram in Figure 3, it will display the graphical figure of connection between the system variables. Heated Water is used to simulate "steam". A tank T11, which can be opened (the vent is opened to atmosphere) or closed (pressurised with air with the vent closed), is used to simulate the boiler drum. It has a level transmitter (LT11) to measure the tank level of both an opened or closed tank [2,3].

The transfer function can be written as equation (1) follow.

$$\frac{C(s)}{R(s)} = \frac{(0.019.G_c)/s}{1+(0.019.G_c)/s} \quad (1)$$

Controller gain depends on the control mode set by the user. By applying various types of controllers, the transfer function for single loop controller can be written as equation (2) below [3].

$$G_C = 100/PB \quad (2)$$

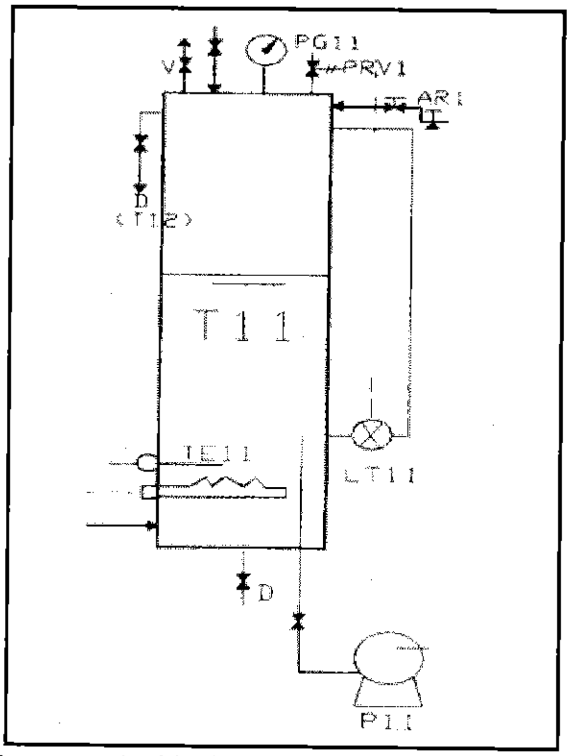

Figure 3 : The block diagram of Boiler drum tank

Where G_C is controller gain and PB is proportional band (determine by user). By applying the above equation, for the proportional controllers above, the transfer function for proportional control is shown in equation (3) below.

$$H(s) = \frac{1}{(52.63/G_c)s+1} \quad (3)$$

From the transfer function obtained, this shown a first order system and the time constant obtained (i.e. 52.63/G_C) will be used to compare with the result in experiment done early. The equation (4) shows the proportional plus integral controller [3].

$$\frac{P(s)}{E(s)} = G_C(1 + 1/\tau_I s) \tag{4}$$

Where τ_I is the integral time. By applying equation (4) for the proportional plus integral control above, the transfer function for this type of continuous signal is shown in equation (5).

$$H(s) = \frac{0.019G_C s + 0.019G_C / Ti}{0.019G_C s^2 + 0.019G_C s + 0.019G_C / Ti} \tag{5}$$

Equation (5) gives a second order system response. With PB setting is 10 and Ti setting is 30, the transfer function become as equation (6) below.

$$H(s) = \frac{0.019s + 0.0063}{s^2 + 0.19s + 0.0063} \tag{6}$$

While obtaining a continuous response, it then converted to discrete form by using MATLAB at 2 seconds time sampling as shown in equation (7) [4, 5,6].

$$H(z) = \frac{0.3259z + 0.305}{z^2 - 1.663z + 0.6839} \tag{7}$$

RESULT

After getting the transfer-function representation from the block diagram, it then analyzed by using SIMULINK feature. The output display is the characteristic of the system modeled. Parameters are set from experiment values. Therefore, comparison can be made between two signals. Figure 4 shows the simulation of transfer function by using the specified PI setting. Before going any further, the criteria of signal must be determined in order to lookup for comparison. Second order system has some criteria that useful to be the comparison tools or data between signals. For a better understanding, each of the amplitude value at a specific time is compared between signals as shown in Figure 5. To make a comparison between the experiment signal and the SIMULINK signal, the data is gathered in one graph that sharing the same time at x-axis. Both signals are set to unit step input signal and the final value is 50mm. Starting point is set to zero. With reference to Figure 5, each of the time value is shown in Table 1.

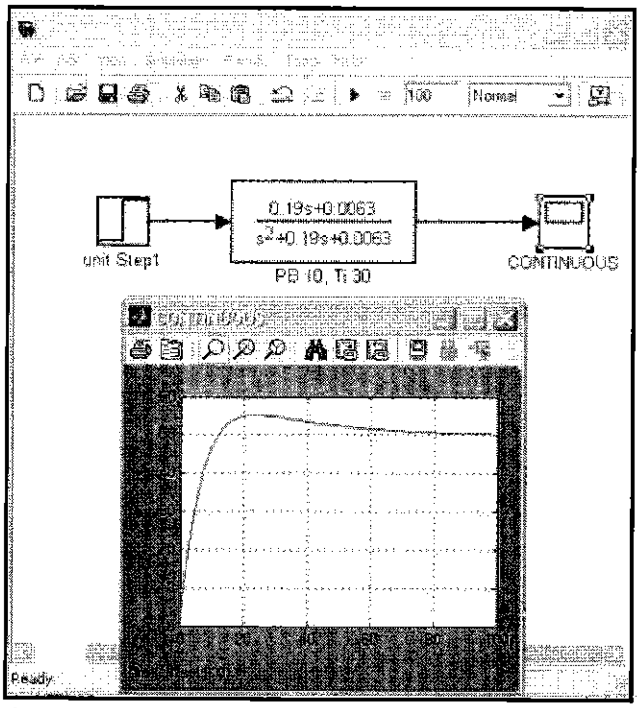

Figure 4 : Simulation using S-domain transfer function with PB = 10 and Ti = 30s

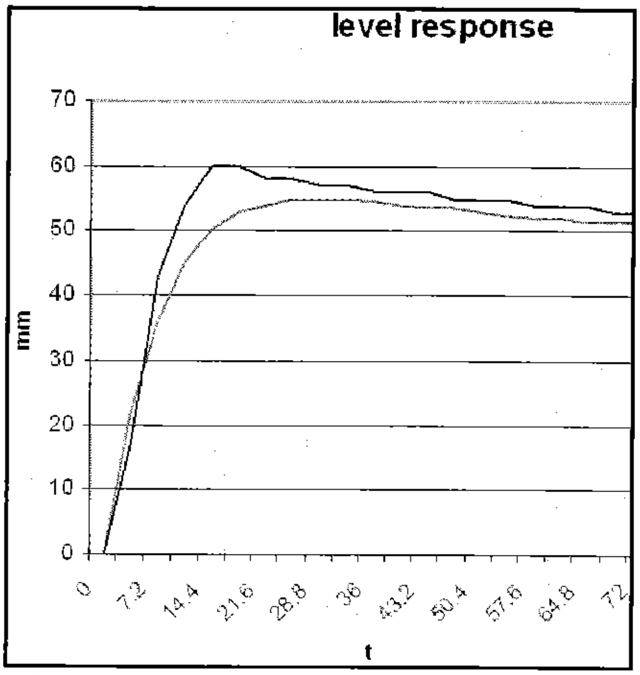

Figure 5 : Comparison between level response of the simulation signal using SIMULINK and signal from experiment by using the same parameters.

Table 1 : Comparison data obtained from experiment data and with SIMULINK.

Signal types	Time (s)	
	Rise Time, Tr	Peak Time, Tp
With Experiment	9.5	18
With SIMULINK	12.6	30.6
Difference	3	12.6

Figure 6 indicating the rise time and the peak time for both signals. However, the settling time is not included because of the lack of data taken from the experiment. Thus, it cannot be compared. The rise time and peak time is obtained by using another graph enlarged to see the time exactly. General observation from the simulation result shows that the system behaves like a second order system. The results have a little bit difference in analysis (see Table 1) because of the tuning used within PI setting. Low controller gain setting made it response as nearly as the real system. But with additional in controller gain, the responses became poor. This is because the response of this system is quite fast when the controller gain is high [3]. In addition, the boiler drum is influenced by the pressure of water height in the drum. While the water level is height, the water pressure to the outlet vent is higher and it helps the outlet pump discharge the water easily. While the water level is low, the water pressure in tank is lower and it made difference in pumping the water by inlet pump, compared to the first condition. Considering also that the model was developed based on the data taken from the instrument installed in the plant, that's result the ideal theoretical data and ignoring the instruments errors and mistakes. Other factors as the pressure exist in boiler drum, inconsistency of flow rate, and the disturbances were ignored.

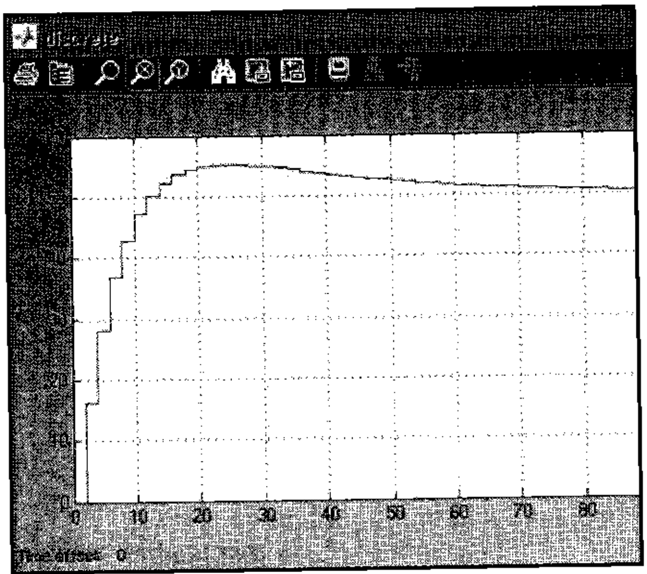

Figure 6 : Discrete signal generated with PB 10, Ti 30 and 2s sampling time

After getting the right simulation value for the control system, we go further with the digitization of the simulation. While simulating, the analog to digital converter is not used because of the continuous transfer function was replaced with the discrete transfer function. Therefore, the input signal is processed in discrete function. The discrete transfer function obtained from the continuous transfer function by using certain syntax from MATLAB command window. Figure 6 shows the response of discrete signal after processed by the discrete transfer function. Sampling time can be changed due to the system requirement. 2 second sampling time is chosen within this system. Smaller sampling time make it closer to the continuous signal, while bigger sampling time make it losing the signal figure. For better understanding of the real system, simulation using LABVIEW software is created to be base on the boiler control system process [7]. By using the same controller and continuous input signal, the output data can be used as to be compared to the experiment data taken. Simulation also gives unreachable data while using a real system is a risk. With the simulation established, users can perform experiment and gathering information on the computer. Analysis had done using MATLAB and SIMULINK software to extract mathematical data and output response graph. Data taken from boiler model is restructured by using MATLAB and SIMULINK to be analyzed mathematically. It's observed that the experiment data and the modeling data give a little bit difference in the rise time and the peak time at 3 and 12.6 seconds. While both responses are behave in the second order system. With the difference occur between the data, the reasons are observed and found some mismatch in the modeling compared to the real system. Such as water pressure in the tank are neglected and the use of PID controller. With regarding to the analysis done, it is suggested that the digital control can be implemented to the boiler control system. Digital control design for boiler drum is a project to propose a digital controller to be implemented to the boiler drum real system. As the pioneer of the project design, the scope study only covers some basics digital implementation of the system such as the mathematical model and the discrete signal for the plant. Without digital implementation yet to the real system, it's difficult to say that the digital control is the best suite to the boiler control. Analysis for stability such as the Nyquist stability criteria and Routh-Hurwitz criteria can be tested to the digital system for stability [4,5]. Beside stability checking, it's suggested that the simulation software can be interfaced with the real system using a DAQ card. When this happens, users can control the real system with monitoring the screen on the computer. All process is controlled using front panel of LABVIEW and each process is displayed accurately [6,7].

CONCLUSION

Mathematical model for a process control plant is important because it provides key information as to the nature and characteristic of the system which is vital for the investigation and prediction of the system operation. The set of equations that make up that model is an approximation of the true process. The modeling result in this project is a second order system as shown below with PB value is 10 and Ti is 30s;

$$H(s) = \frac{0.019s + 0.0063}{s^2 + 0.19s + 0.0063}$$

$$H(z) = \frac{0.3259z + 0.305}{z^2 - 1.663z + 0.6839}$$

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