Identification of Heating Process and Control using Dahlin PID with Smith Predictor

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Abstract—**Theheating process contains time delay and it induces oscillations in the response of the system. It is very difficult to get tighter control of such processes using conventional controllers. Using Smith Predictor algorithm the processes with time delay can be effectively controlled. This paper deals with design of Digital Smith Predictor and Identification of Heating Process using System Identification Tool of MATLAB. Dahlin PID is used in the structure of Smith Predictor and MATLAB/SIMULINK is used for the Simulation of this algorithm.**

Keywords—Heater; Identification; Smith Predictor; Dahlin PID; Time Delay

I. INTRODUCTION

Time-delay is key problem in many processes in industries and other fields like economical and biological systems, electric, hydraulic, pneumatic networks, robotics, long transmission line etc. They are caused by some of the following phenomena [2]:

- The time needed to transport mass, energy or information.

- The accumulation of time lags in a great numbers of low order systems connected in series.

- The required processing time for sensors, such as analyzers, controllers that need some time to implement a complicated control algorithms or process.

Consider a system with time-delay T_d. The transfer function of a pure time delay is e^{-Tds}. Transfer function with Time-delay is in the form

$$G_d(s) = G(s)e^{-T_d s} \qquad (1)$$

where G(s) is the transfer function without time-delay.

Processes with time-delay are difficult tocontrol using conventional controllers mainly because of the following [2]:

- The effect of the disturbances is not felt until a considerable time has elapsed.

- The effect of the control action requires some time to elapse.

- The control action that is applied based on the actual error tries to correct a situation that originated some time before.

PID controllers are commonly used in the majority industries. When the process is having a time-delay, the tuning of the PID controller is very difficult.The problem of controlling time-delay processes can be solved using Time delay compensators and Model Predictive technique.

Model Predictive technique is useful for processes with large time delay and it gives the tighter control.The first time-delay compensation algorithm was proposed by Otto Smith in 1957 so it is known as the Smith predictor. It contains a dynamic models of process.

The heating process contains time delay so it is very difficult to control by conventional controllers but Smith Predictor algorithm may give a better results.

II. SMITH PREDICTOR

The Block Diagram of Smith Predictor is shown in Fig. 1. The working of Smith Predictor can be divided into two parts; the first is controller and second is predictor part. The G_c is controller and the predictor part contains the models of the process without time delay (fast model) and G_m and a model of the time delay e^{-Tds}.The process with time delay is
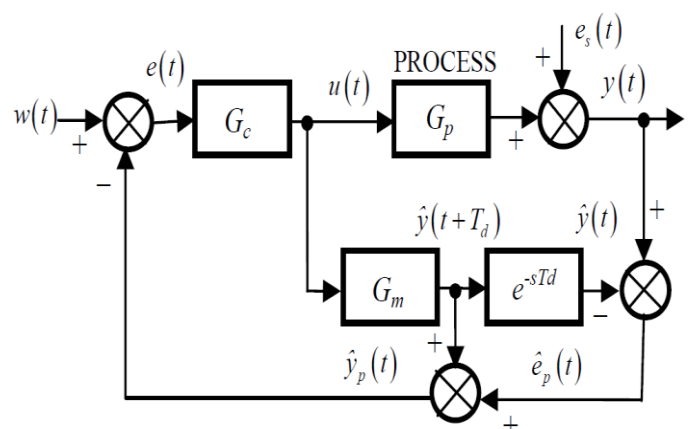
$$G_p(s) = G_m(s)e^{-T_d s} \qquad (2)$$

Fig.1 Block Diagram of Smith Predictor

The fast model $G_m$estimates an open-loop prediction. The comparison between the output of the process $y(t)$ and the output of model including time delay $\hat{y}(t)$ is the predicted error $\hat{e}_p(s)$. If modeling is errorless and not any disturbances then the predicted error is zero and the predictor

output signal $\hat{y}(t)$ is the output of the process without delay. The Smith Predictor structure for the without modeling errors has three fundamental properties: time-delay compensation, prediction and dynamic compensation [10].

The implementation of the Smith Predictor is very difficult in continuous domain so they were not used in industries. In the 1980s the digital algorithm of Smith Predictor can be implemented. Majority of Smith Predictors are implemented in digital version but they are analyzing the continuous work.

The discrete versions of the Smith Predictors are controlling the time delay processes in industries.The working of the digital Smith Predictor is similar to the analog Smith predictor. The structure of digital Smith Predictor is shown in Fig. 2.Here controller and model of the process are in the Z domain.
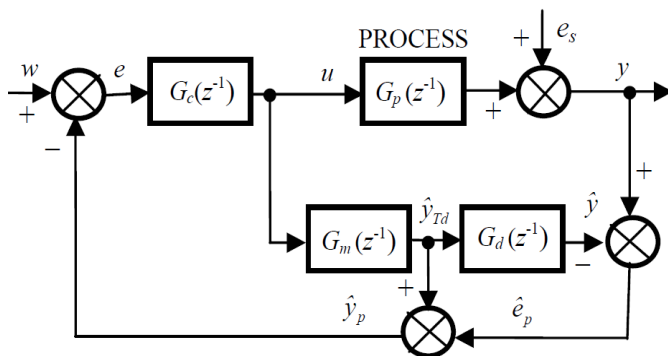

Fig.2 Block Diagram of Digital Smith Predictor

III. HEATING PROCESS

The Heating process contains time delay so that tighter control of that process is difficult. A heating process which is having time delay is considered for this study. The setup of heating process is shown in Fig. 3.
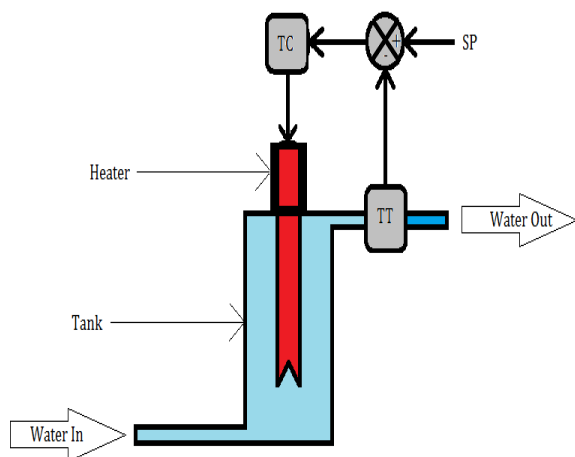

Fig.3Block Diagram of Heating Process

The inflow of water is from the bottom of the tank and the outflow of water is from the top of the tank as shown in Fig.3 so that the volume of water inside the tank remains constant. The flow of water is maintained constant using plunger pump.The electric heater is used for the heating of the water, input voltage of heater is controlled by the Solid state Relay

(SSR) and the input of SSR is controllers output. The temperature of the outflow of water is measured using RTD (pt100) and it is transmitted using temperature transmitter, output of temperature transmitter is in the range 4-20mA. The capacity of heater is 3KW output power and the input voltage is 230V. Input voltage of heater is control by the SSR and input of SSR is 4-20mA. The input flow of water is 20LPH. Specifications of the process components is given in Table 1.

Table 1 Specifications Table for Heating Process

Components	Specification	Value
Heater	Capacity	3 KW
	Type	Electrical 2 coil
Heating control (SSR)	input	4-20mA
	Type	Electrical
	Voltage	230V AC
Temperature transmitter	Input	RTD(Pt100)
	Output	4-20mA
Plunger pump	Type	Positive displacement Plunger pump

IV. IDENTIFICATION OF HEATING PROCESS

Model of the any process can be identified using input and output data of that particular process, System Identification Tool is available in MATLAB for the identification of process. For the identification of Heating process input and output data of process are need to be logged. For identification first of all random input to the system is required, input for the system can be generated by MATLAB and accordingly output of the process can be logged by MATLAB. So for real time communication between process and MATLAB, Arduino microcontroller can be used.
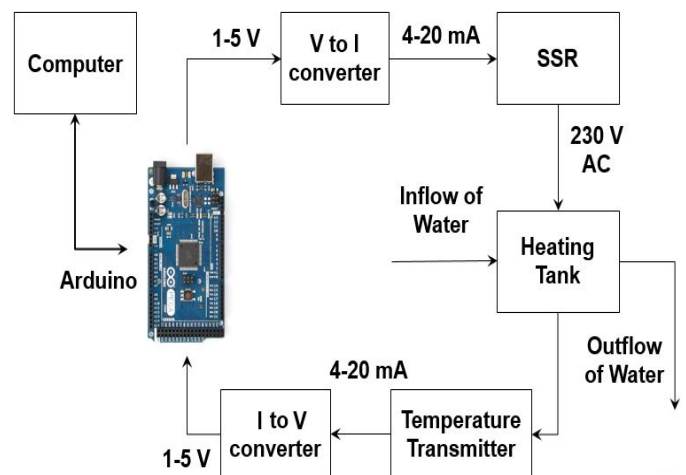

Fig.4 Block Diagram of Identification of Heating Process

The input of process is controlled by the SSR and the input of SSR is 4-20mA current but Arduino cannot generate current so voltage to current converter is needed. V to I converter convert 1-5V voltage to 4-20mA current. Output of the process is temperature which is measured by RTD, temperature transmitter converts it into 4-20mA current so I to V converter is also needed. The block diagram of

identification of heating process is shown in Fig. 4.Specifications of components used in identification are given in the Table 2.

Table 2 Specifications Table for identification components

Components	Specification	Value
Arduino Mega2560	Microcontroller	ATmega2560
	Operating Voltage	5V
	Digital I/O Pins	54 (of which 15 provide PWM output)
	Analog Input Pins	16
	DC Current per I/O Pin	40 mA
	Flash Memory	256 KB of which 8 KB used by boot loader
	SRAM	8 KB
	EEPROM	4 KB
	Clock Speed	16 MHz
V to I converter	Input	1-5 V
	Output	4-20mA
I to V converter	Input	4-20mA
	Output	1-5 V
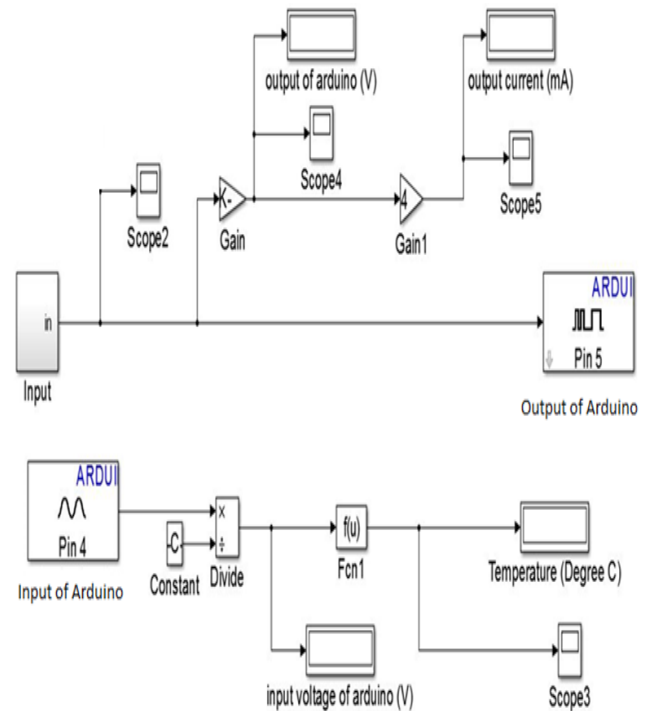
In the identification of the process the input quantity is voltage and the output is temperature in degree Celsius so that unit of transfer function is degree Celsius per Volt. Simulink diagram of identification is shown in Fig. 5.Random input is given to the Arduino output pin which generate analog voltage according to the input which is given to the V to I converter and output is taken from analog input pin which is temperature of the water.

Arduino mega 2560 microcontroller board can be used in external mode in Simulink. So that real time communication between process components and the MATLAB is possible. The data which is logged by MATLAB is stored in the variables in workspace. The delay of the process is 6 second which is measured by offline identification. Sampling time for data logging is 2 seconds, so the time delay is multiple of the sampling period. The prediction error has a main function in identification of model parameters derived from measured data. System Identification Tool is shown in Fig.6. Prediction error is very important in selection of the order of the model and a sampling period. Here the prediction error was used for selection of the time-delay dT_0.

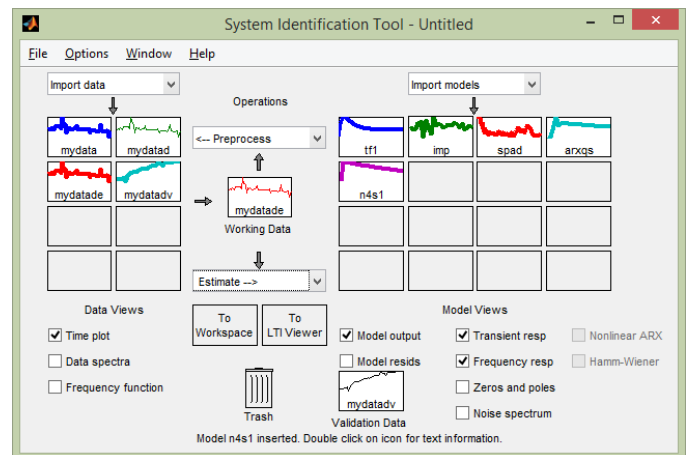Fig.5 Simulink Diagram of identification of process

Fig.6 System Identification Tool

Identified transfer function of the heating process from the process data is

$$G(s) = \frac{0.2942}{s+0.01435} e^{-6s} \qquad (3)$$

With gain is 20.5 and time constant is 70 seconds and Discretized transfer function with sampling period 2 second is

$$G(Z) = \frac{0.58}{Z-0.9717} Z^{-3} \qquad (4)$$

V. DAHLIN PID AND SMITH PREDICTOR WITH DAHLIN PID

Main controller in the Smith Predictor is designed by Dahlin PID algorithm so it is called PIDSP. The Dahlin PID algorithm is based on the desired close-loop transfer function in the form [3]

$$G_e(z^{-1}) = \frac{1-e^{-\alpha}}{1-z^{-1}} \qquad (5)$$

where $\alpha = T_0/T_m$ and T_0 is sampling period , T_m is desired time constant of the first order closed-loop response. T_m should not be chosen too small because of that it will demand a large control signal $u(k)$ which may cause the saturation of the actuator. Then the individual parts of the controller are described by the transfer functions [3]

$$G_c(z^{-1}) = \frac{(1-e^{-\alpha})\hat{A}(z^{-1})}{(1-z^{-1})\hat{B}(1)} \qquad (6)$$

$$G_m(z^{-1}) = \frac{z^{-1}\hat{B}(1)}{\hat{A}(z^{-1})} \qquad (7)$$

$$G_d(z^{-1}) = \frac{z^{-d}\hat{B}(z^{-1})}{z^{-1}\hat{B}(1)} \qquad (8)$$

where $B(1) = \hat{B}(z^{-1})\big|_{z=1} = \hat{b}_1 + \hat{b}_2$

Since $G_m(z^{-1})$ is the transfer function, the main controller $G_c(z^{-1})$ becomes a digital PID controller having the following form [9]

$$G_c(z^{-1}) = \frac{U(z)}{E(z)} = \frac{q_0 + q_2 z^{-1} + q_2 z^{-2}}{1-z^{-1}} \qquad (9)$$

Where $q_0 = \gamma$, $q_1 = \hat{a}_1\gamma$, $q_2 = \hat{a}_2\gamma$ using by the substitution $\gamma = (1 - e^{-\alpha})/\hat{B}(1)$. The PID controller output is given by

$$u(k) = q_0 e(k) + q_1 e(k-1) + q_2 e(k-2) + u(k-1) \qquad (10)$$

VI. SIMULATION OF DIGITAL SMITH PREDICTOR WITH PID CONTROLLER(PIDSP)

Simulation is helpful tool for the study of control systems, Simulation allows us to create and simulate mathematical models of a processes. It is used to design the simulated controllers in computer. The mathematical models provided are sufficiently close to a real object so by using simulation we can verify the results of processes for various controller. The simulation results are valuable for an implementation of a chosen control algorithm under laboratory and industrial conditions. The simulation and laboratory conditions can be very different from those in real plants, and therefore we must verify its practicability with regard to the process dynamics and the required standard of control quality.

A simulation of proposed design for identified model was performed in MATLAB/SIMULINK. The Simulink diagrams heating process controlled by Dahlin PID and PIDSP is shown in Fig.7 andFig.8 respectively. These schemes are used for systems with time-delay. Individual blocks of the Simulink scheme match to blocks of the general control scheme presented in Fig. 2. The Process block represents continuous-time system with delay. Blocks Fast Model and Delay Model are parts of the Smith Predictor and they correspond to $G_m(z^{-1})$ and $G_d(z^{-1})$ blocks of Fig. 2 respectively. The control algorithm is compacted in PID Controller which corresponds to $G_c(z^{-1})$ Fig. 2 block. The Dead-time is entered in the no. of samples. The responses of Dahlin PID and PIDSP are shown in Fig. 9 and Fig.10 respectively. The comparison of characteristics of responses are shown in Table 3.
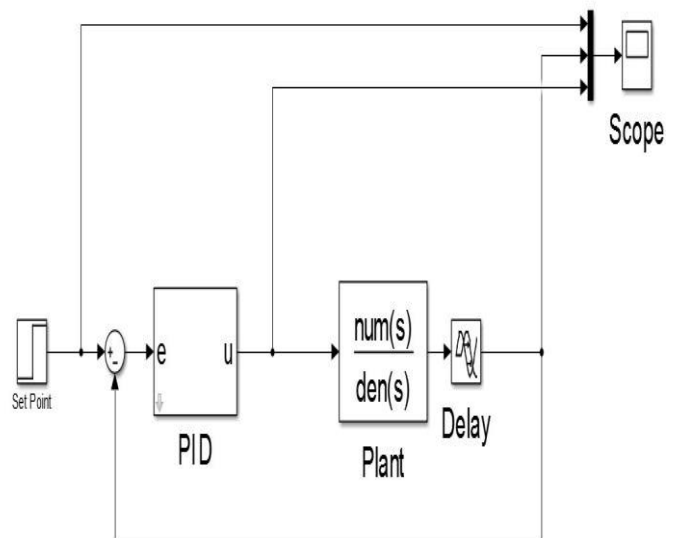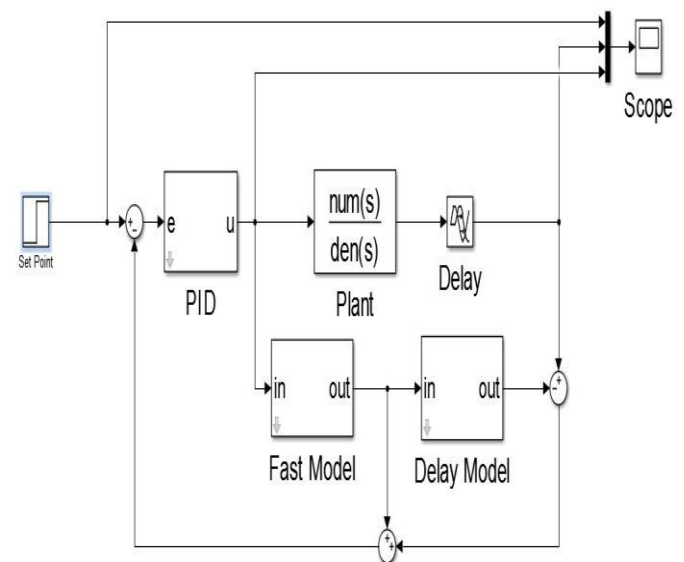

Fig.7 Simulink Diagram of Dahlin PID

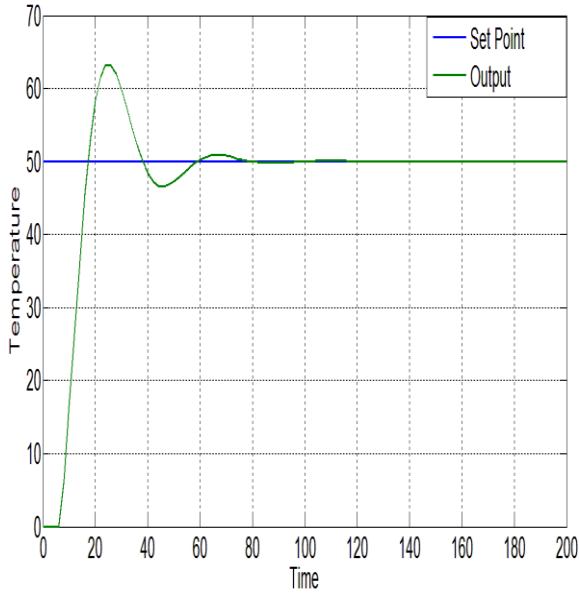Fig.8 Simulink Diagram of PIDSP
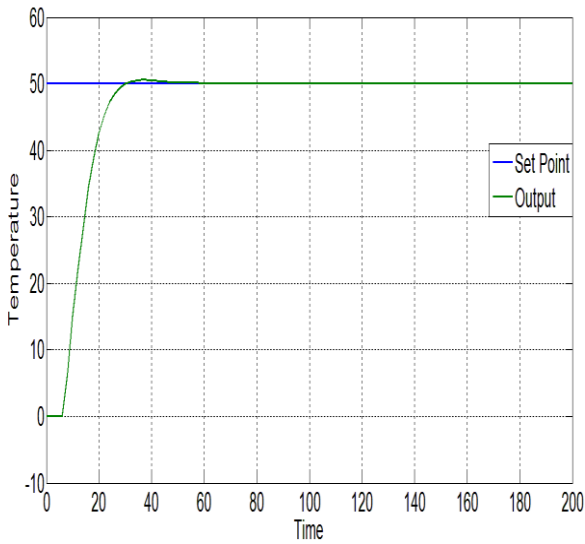
Fig.9 Response of Process controlled by Dahlin PID

Fig.10Response of Process Controlled by PIDSP

Table 3Comparison of Responses

Model	Characteristics of Responses			
	Max. Peak (%)	Rise time(s)	Peak time(s)	Settling time(s)
Heater model controlled by Dahlin PID	26.5	8.5	18	90
Heater Model controlled by PIDSP	1	14.2	30	50

VII. CONCLUSION

From the simulation results, it can be concluded that Smith Predictor with Dahlin PID gives better result than Dahlin PID for heating process with delay time. From Table 3 it can be also said that Smith Predictor gives better transient response characteristics than PID controller for process with time delay.

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