Smith Predictor for Control of the Process with Long Dead Time

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Abstract: **Process control is an engineering discipline it is used for maintaining the output of a specific process within a desired range. Generally PID controllers are used for tuning process in various industries due to its simplicity and reliable performance. PID controllers are mainly tuned using 'Trial and Error' method, Ziegler Nichols, etc.., which uses different PID algorithms. The major drawback of PID is inability to reduce long delay time. In order to eliminate the long delay time which significantly improves the performance of the system, we are proposing the smith predictor with PID or Dead Time compensator which is mainly working on the closed loop and it can be used to analyse open loop characteristics of the system. The simulation result has proved its performance over PID controller**

Keyword: PID controller, Long Delay Time, Dead time Compensation, Smith Predictor

I. INTRODUCTION:

Most control problems in the process industry are solved using PID controllers. There are several reasons for this. One is that the PID controller can be tuned manually by "trial and error" procedures, since it only has three adjustable parameters. The possibility to make manual adjustments of the controller parameters is important even when automatic tuning procedures are available.[1]

The proportional integral derivative (PID) control algorithm is widely used in process industries because of its simplicity, robustness and successful practical application. When there are long dead times in the process, the control performance obtained with a PID controller are, however, limited. For these processes, dead time compensating controllers DTCs may improve the performance considerably. These controllers require a process model to provide model predictive control. This usually means a significant increase in controller parameters.[1]

It has been found in practice that the widely used PID controller would rapidly lose its effectiveness when the process dead time becomes significant.[2] PID controllers with dead time compensation are reported to eliminate dead time in terms of a controllerseeing the effect of changes in its controller output. For set point changes where all the controller needs to be concerned with is how its output responds to a new set point, the results are impressive for an exact knowledge of the process dead time.

However, for unmeasured load disturbances at the process input, the ultimate performance is set by the total dead time from the process equipment, piping, control valves, instrumentation, and digital devices. This application note shows that a dead time compensator can offer some improvement in load rejection by facilitating more aggressive tuning of the PID but with a considerable risk of oscillations from an inaccurate dead time.

In the process industries, the occurrence of "dead time" or "transportation lag" is very common. For the majority of simple control loops, the amount of dead time is usually not significant when compared to the time constant.[2] For more complicated control loops like those for quality control, dead time can be very significant and may even be longer than the system time constant. The reasons for this include analysis delay and the down-stream location of the sampling point for the quality analyser. Another class of examples is characterized by a multitude of small lags, such as a long bank of heat exchangers, or a distillation column with many trays, giving rise to what is called "apparent" dead time.

The proposed approach Smith Predictor combines PID Process will eliminate the Long delay time in the system. It is a model-based controller that is effective for processes with long dead time. Smith Predictor control is theoretically a good solution to the problem of controlling the time delay systems. It approach improves the Performance and robustness of the system in the real time applications

The paper is arranged in the following manner. In Section 2 Existing Systems. In Section 3, Smith Predictor for Long Delay time (dead time compensating controller) is discussed. In Section 4 Simulation results for PD,PID and Smith Predictor. Finally conclusions are drawn in Section 5.

II. EXISTING SYSTEM

The proportional integral derivative (PID) control algorithm is widely used in process industries because of its simplicity, robustness and successful practical application. Although advanced control techniques can show significantly improved performance, a PID control system can suffice for many industrial control loops. Although, a PID controller has only three adjustable parameters, finding appropriate settings is not simple, resulting in many controllers being poorly tuned and time consuming plant tests often being necessary to obtain process parameters for improved controller settings.

There are several approaches for controller tuning, with that based on an open-loop model (g) being most popular. This model is typically given in terms of the plant's gain (K), time constant (τ) and time delay (θ). For a given a plant model, g, controller settings are often obtained by direct synthesis.

The PID controller is the most common controller used in industry .The following is the basic algorithm of PID Controller which has several variants of the basic algorithm

$$u(t) = K\left(e(t) + \frac{1}{T_i}\int_0^t e(\tau)d\tau + T_d\frac{d_e(t)}{dt}\right) \quad (1)$$

$$e(t) = y_r(t) - y(t) \quad (2)$$

Where u is the control signal, e is the error signal, yr the reference signal, y is the process variable, K the gain, Ti the integration time, and Td the derivative time

Thus, the PID controller can be understood as a controller that takes the present, the past, and the future of the error into consideration. The transfer function Gc*(s)* of the PID controller is:

$$G_c(s) = K_p(1 + \frac{1}{sT_i} + T_dS) \quad (3)$$

$$K_p + \frac{K_i}{s} + T_ds \quad (4)$$

It is difficult to obtain satisfactory performances of control systems with time delay, which is a well-recognized problem in many control processes. Time delay, also called dead time, is mostly aroused by transportation lags, measurement lags, analysis times, computation and communication lags and Sensor lags. And it exists in a lot of systems such as industrial process control systems, engineering systems, economical, and biological systems.

Any practical control system suffers from delays. These can stem from process dynamics, actuators or sampling. The delays are often either assumed negligible or constant, but in some cases the variance in delay times (jitter) plays a significant role. There exists a variety of methods for control of time-delay systems with constant delays, but the toolset for dealing with varying time-delays is much more limited

A first-order system is one whose output y(t) is modelled by a first-order differential equation. In the Laplace Domain, general first-order transfer functions are described by Equation:

$$G_p(S) = \frac{K}{1+sT} \quad (5)$$

Dead time (θ) is the time delay between the process and the sensor. The transfer function for dead time is:

$$G_p(S) = e^{-\theta ds} \quad (6)$$

A. Cause of dead time

- Transportation lag

The Transportation Lag is the delay between the time an input signal is applied to a system and the time the system reacts that input signal. It is common in Industrial process. It is called 'Dead Time'

- Sensor lag

Sensors and analyzer can take precious time to yield their measurement results

B. Effect of Dead Time on the system

Time delay occurs in the control system when there is a delay between command response and the start of output response. The delay cause a decrease phase margin which implies a lower damping ratio and a more oscillatory response for the close-loop system. Further it decreases the gain margin thus moving the system to instability .First-order process model with dead time which is represented as

$$G_p(S) = (\frac{K}{1+sT})e^{-\theta ds} \quad (7)$$

Where,

K: process gain
T: process time constant
θ: dead time constant

In this case, simple PID controller cannot meet the control performances therefore Smith predictor which was first presented by O. J. M. Smith in 1957 is introduced to improve the control performances.

The Figure given below shows the PID controller with transfer function and dead time

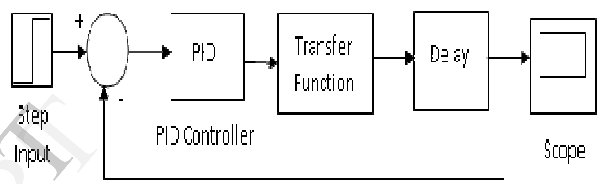


Fig 1.1 PID controller with dead time

The above diagram depicts the occurrence of oscillation with delay which will affect the system. This will automatically produce more delay. So we need to eliminate the Delay effect from the system using Smith Predictor.

III. SMITH PREDICTOR FOR LONG DELAY TIME

In this paper we propose a new control strategy for the Smith predictor that replaces the conventional controller by a PID structure. The Smith predictor (SP) was presented at the end of the 1950s (Smith, 1957) to improve the performance of classical controllers (PI or PID controllers) for plants with dead time. It is one of the most popular dead-time compensating methods and most widely used algorithm for dead-time compensation in industry. It is a model-based controller that is effective for processes with long dead time. It has an inner loop with a main controller that can be simply designed without the dead time. The effects of load disturbance and modelling error are corrected through an outer loop [2]

The Smith predictor is used to design a controller for a plant with a time delay or time delay approximation. It is implemented together with a closed-loop feedback controller.

The following diagram represents the structure of Smith Predictor [4]

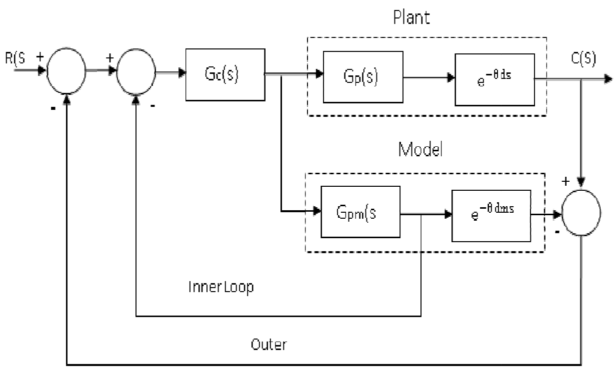


Fig 1.2 Basic Structure of Smith Predictor

Smith predictor is in the dotted line textbox, and Gc (s) is simple PID controller, Gp (s) is transfer function of the plant, $e^{-\theta ds}$ is Dead time of the plant. Gpm(s) is transfer function for the model of the plant, $e^{-\theta dms}$ is dead time of the plant model. The Smith Predictor Plant and Model both have the same transfer function with dead time. If without Smith predictor, the closed loop transfer function would be [4]

$$\frac{C(s)}{R(s)} = \frac{G_c(s)G_p(s)e^{-\theta ds}}{1+G_c(s)G_p(s)e^{-\theta ds}} \quad (8)$$

And the closed loop characteristic equation is:

$$1 + G_c(s)G_p(s)e^{-\theta ds} = 0 \quad (9)$$

We can see that there is a time delay item$e^{-\theta ds}$ in characteristic equation which could produce phase lag and make the system unstable.

Then the closed loop transfer function with Smith predictor 7

$$\frac{C(s)}{R(s)} = \frac{G_c(s)G_p(s)e^{-\theta ds}}{1+G_c(s)G_p(s)+G_c(s)G_p(s)e^{-\theta ds}-G_c(s)G_{pm}(s)e^{-\theta dms}} \quad (10)$$

In the case of Gp=Gpm and θd=θdm the Transfer function can be writing as

$$\frac{C(s)}{R(s)} = \frac{G_c(s)G_p(s)e^{-\theta ds}}{1+G_c(s)G_p(s)} \quad (11)$$

And the corresponding characteristic equation is:

$$1 + G_c(s)G_p(s) = 0 \quad (12)$$

The time delay item is eliminated in characteristic equation which will improve the control performance significantly. From the transfer function (12), we can transform the Figure 1.2 equivalently to Figure 1.3as follows

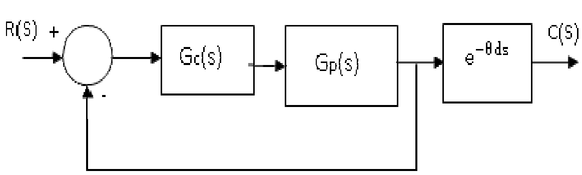


Fig 1.3 Equivalent form of Smith Predictor

IV. RESULTS AND DISCUSSION

This chapter presents the simulation results and the performance measures of the Smith Predictor. In the evaluation of the system we are analysing the performances and robustness of the process. This simulation is performed for eliminating the long delay time of the process system with the help of Smith Predictor and PID Controller

EXAMPLE 1: APLLICATION EXAMPLE

In this section, simulations are conducted to verify the performance and effectiveness of the proposed method. The designing of the controllers are performed as per the design procedures. The analysed process model to verify the usefulness of the method. The analysed process is a very slow process compared with other process. So PID controller is preferred for that process. But that process has the long delay time. So a smith predictor is designed for that process model.

The Fig 1.2 is the Smith Predictor structure for a process. The simulations results for the system after introduction of smith Predictor. The transfer function is obtained from the corresponding process station.

The smith predictor will reduce effects of delay time in the process. The taken process transfer function consider a first order process with a dead time is given as$G_{p1} = \frac{0.861\,e^{-47s}}{2.3s+1}$, the controller is designed for the e process and the parameters of PID controllers are Kp=0.089, Ki=0.02 and Kd=0.5

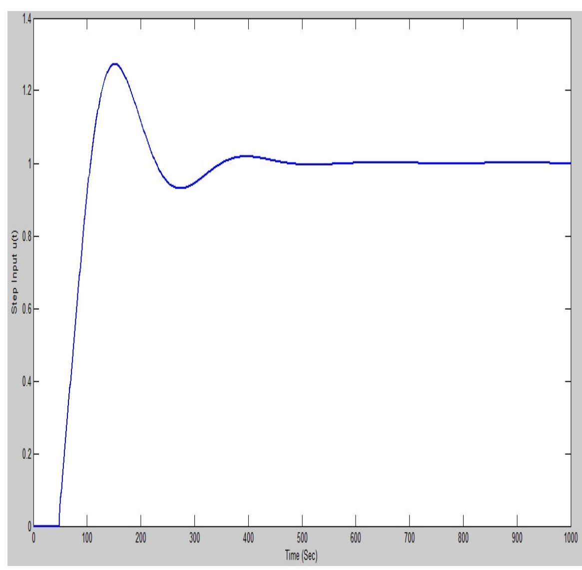


Fig 1.4 Output of the PID controller with Dead time and Maximum overshoot. This affect the performance of the system and it will take long time to reach setting point.

The smith predictor is introduced for the transfer function is given as $G_{p1} = \frac{0.861\, e^{-47s}}{2.3s+1}$ and delay is e^{-47s}. The dead time compensator or smith predictor to eliminate the Dead time effect from the process and the output of the both controllers are verified. The below response is the smith predictor response for the analysed process system transfer function with dead time.

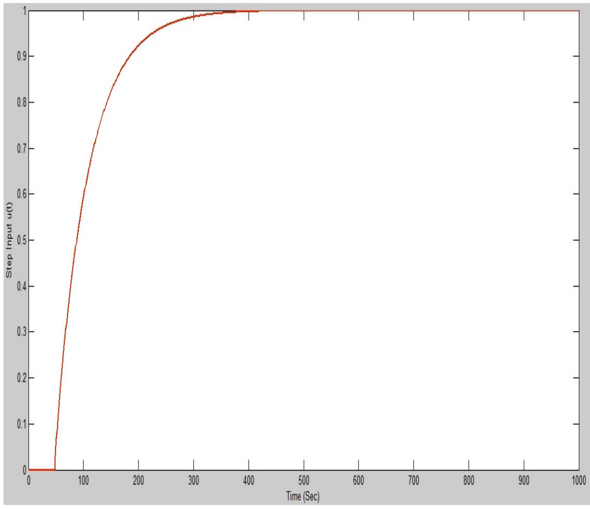


Fig 1.5 The Smith Predictor responses without delay free effect. This will take minimum time to reach the settling point.

The waveform given in Fig 1.6 contains a Comparison result between PID and Smith Predictor which proves that the smith predictor outperform over PID.

The time domain specifications such as rise time, settling time, overshoot time and peak time are obtained from the simulation results

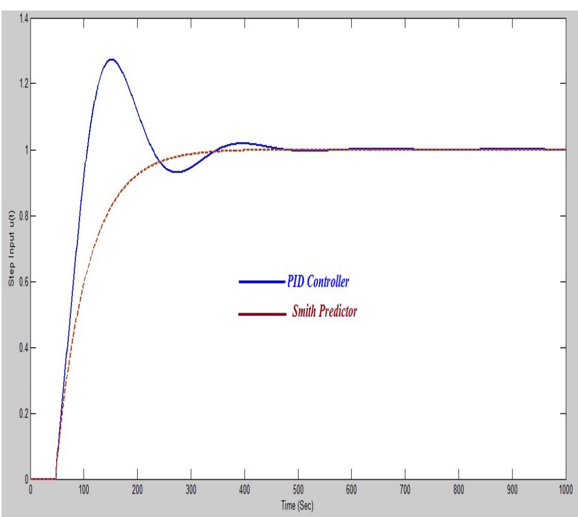


Fig 1.6 Comparison between PID response and Smith Predictor response

TABLE I

TIME DOMAIN SPECIFICATIONS OF THE PID AND SMITH PREDICTOR OUTPUTS

Controller	Settling Time (Sec)	Max. Overshoot (%)	Rise time (Sec)	Peak time (Sec)
PID	720	27.28	47.1	151.5
Smith Predictor	543	0	131.3	0

The above table compares time domain specifications of the PID and Smith Predictor outputs. It is very clear that the smith predictor compensator out performs PID

C. PD Controller Tuning:

The first order process with a dead time is given as $G_{p1} = \frac{0.861\, e^{-47s}}{2.3s+1}$ and the parameters of PD controllers are Kp=0.129 and Kd=0.5

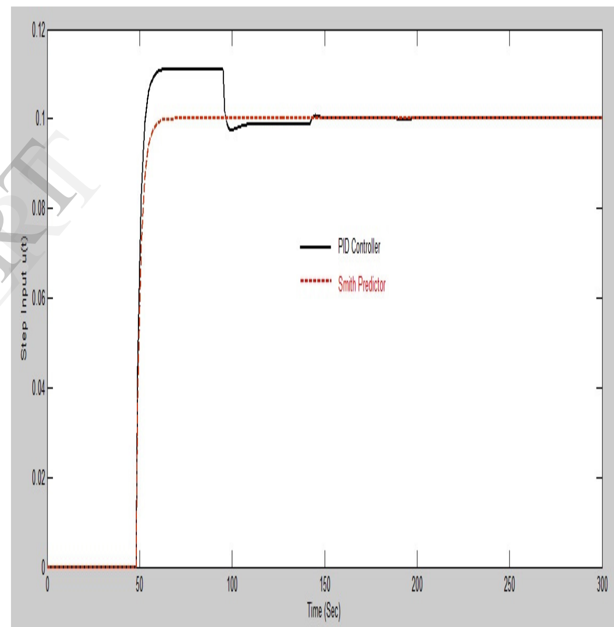
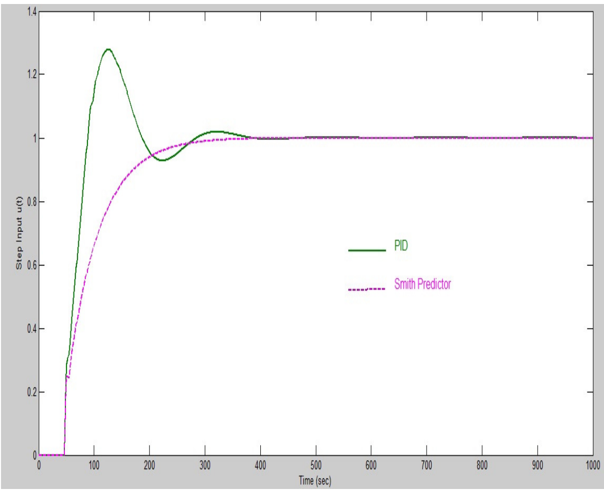


Fig 1.7 Comparison between PD controller response and Smith Predictor response

The waveform given in Fig 1.7 contains a Comparison result between PD Controller and Smith Predictor. The Time domain specification analyzed for the above mentioned first order Transfer function and obtained the result for PD controller and Smith Predictor. The PD controller has the Maximum overshoot and it will take the long time to reach settling point compare with Smith predictor.

EXAMPLE 2:

The transfer function consider a double integrator process with a dead time is given as $G_{p1} = \frac{e^{-45s}}{s^2+0.6s+0.5}$ and the parameters of PID controllers are Kp=0.089, Ki=0.01 and



Kd=0

Fig 1.8 Comparison between PID response and Smith Predictor response

TABLE II

TIME DOMAIN SPECIFICATIONS OF THE PID AND SMITH PREDICTOR OUTPUTS

Controller	Settling Time (Sec)	Max. Overshoot (%)	Rise time (Sec)	Peak time (Sec)
PID	689.34	27.75	88.35	125
Smith Predictor	499	0	122	0

V. CONCLUSION

The effect of dead time in the nominal set point response can be eliminated by DTC (Dead time Compensator). In the present work, the smith predictor is employed to increase the performance and robustness of the system. There are several methods possible to find out the parameter of the PID controller. One of the simple approach, which is used in this paper is trial and error method. So the proposed smith predictor with PID and the examples use were also demonstrated the improved performance of the system. The proposed approach can easily be implemented in real time industrial applications.The simulation is performed using MATLAB tool and the results are studied. The time domain specifications like rise time, settling time, peak time and overshoot percentage is compared for the PID controller and Smith Predictor.

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