Design of PI Controller using First Order Plus Time Delay Model for Process Control

[1]A.Iyswariya, [2]N.Nimitha, [3]Aarthi K.J Veronica, [4]R.Selvarasu
[1, 2, 3] Dept. of ECE, RMK College of Engineering and Technology, India
[4] Dept. of EIE Arunai Engineering College, India

Abstract - **The Pressure control unit approximated by the First Order Plus Time Delay Model (FOPTD) is considered and the proposed Skogestad Internal Model Control (SIMC) tuning method is applied to calculate the Proportional and Integral gains (k_P &k_I) of PI controller. This study is conducted to get the optimum PID controller parameters (K_c, τ_I, τ_D) for first order process model. Two well known methods Cohen-Coon (C-C) and Skogestad method are used to tune controller. Both methods are compared to get the optimum condition for the process model. The responses for both methods are analyzed using Simulink in MATLAB software. This method gives simple equations for controller settings in terms of model parameters. The scope of this project is to design PI controller using First Order plus Time Delay Model for process control. The results indicated that responses using Skogestad Internal Model Control tuning are slightly better than those with the Cohen-Coon tuning method.**

Key words- **First Order Plus Time Delay Model, Skogestad Internal Model Control, Cohen-Coon tuning method.**

1. INTRODUCTION

Methods of designing PI controllers for stable FOPTD model are based on stability analysis, constant open loop transfer function, pole placement method, stable inverse of the model and synthesis method. The design of PI controller for unstable FOPTD model has attracted attention recently. The performance specifications that are normally obtained for stable FOPTD model cannot be obtained for unstable systems. The methods for designing PID controllers for unstable FOPTD systems are
given by the modified Ziegler Nichols method, IMC method, pole placement method, Optimization method, two degrees of freedom method and synthesis method. In all the above procedures, the design methods
are somewhat complicated. Recently, a simple method is proposed by *Skogestad*. to design PI controller for stable FOPTD by
equating the coefficient of the corresponding powers of *s* in the numerator and that in the denominator of the closed loop transfer function for a servo problem. Performance of the controller designed by this method is shown to be similar to that of Ziegler-Nichols method. Currently, more than half of the controllers used in industry are PID controllers. In the past, many of these controllers were analog. however, many of today's controllers use digital signals and computers. When a mathematical model of a system is available, the parameters of the controller can be explicitly determined. However, when a mathematical model is unavailable, the parameters must be determined experimentally. Controller tuning is the process of determining the controller parameters which produce the desired output. Controller tuning allows for optimization of a process and minimizes the error between the variable of the process and its set point.

II. DESIGN OF CONTROLLER

The acronym PID stands for **P**roportional-**I**ntegral-**D**ifferential control. Each of these, the **P**, the **I** and the **D** are terms in a control algorithm, and each has a Special purpose. Sometimes certain of the terms are left out because they are not needed in the control design. This is possible to have a PI, PD or just a P control. It is very rare to have a ID control.

Although the proportional-integral-derivative (PID) controller has only three parameters, it is not easy, without a systematic procedure, to find good values (settings) for them. In fact, a visit to a process plant will usually show that a large number of the PID controllers are poorly tuned. The tuning rules presented in this paper have developed mainly as a result of teaching this material, where there are several objectives:

1. The tuning rules should be well motivated, and preferably model-based and analytically derived.
2. They should be simple and easy to memorize.
3. They should work well on a wide range of processes.

In this paper a simple two-step procedure that satisfies these objectives is presented:

Step 1. Obtain a first- or second-order plus delay model. The effective delay in this model may be obtained using the proposed half-rule.

Step 2. Derive model-based controller settings. Pi-settings result if we start from a first-order model,

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whereas PID-settings result from a second-order model.

A. Fitting First-Order Plus Time Delay Transfer

Sundaresan and Krishnaswamy have proposed a simple method for fitting the dynamic response of systems in terms of first order plus time delay transfer functions

$$G(S) = \frac{K}{\tau s + 1 e - \theta s}$$

The method is based on computing the times t_1 and t_2 at which the 35.3% and 85.3% of the system response is obtained, as depicted in the following Figure 2.1

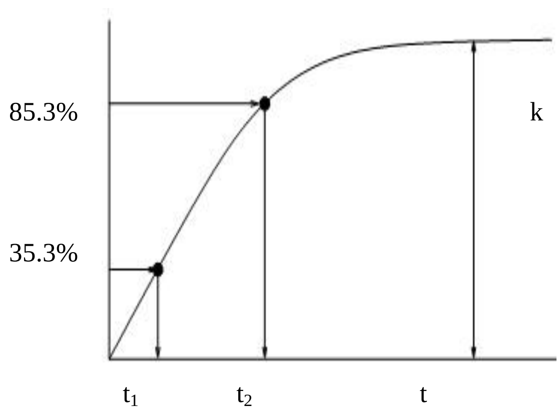

Figure 2.1 Time Vs System Response graph

After computing the t_1 and t_2 times, the time delay (θ) and process time constant (τ)

can be obtained from the following equations:

$$\theta = 1.3t_1 - 0.29t_2$$

$$\tau = 0.67(t_2 - t_1)$$

Let us consider the following second order transfer function:

$$G(S) = \frac{1}{S + 2S + 3}$$

and let us approximate it by a FOPTD transfer function. The following Mat lab code

```
g=tf([1],[1 2 3]);
[y,t] = step(g);
gain = y(end);
t1 = spline(y,t,0.353*gain);
t2 = spline(y,t,0.853*gain);
```

Therefore the FOPTD transfer function will be given by:

$$G(S) = \frac{0.3333}{0.5547S + 1e0.374s}$$

III.TUNING METHODS

A. Ziegler-Nichols Methods

The Ziegler-Nichols design methods are the most popular methods used in process control to determine the parameters of a PID controller. Although these methods were presented in the 1940s, they are still widely used. The first method of Ziegler and Nichols known as the continuous cycling method was proposed in 1942.In this method, integration and derivative terms of the controller are disabled and the proportional gain is increased until a continuous oscillation occurs at gain *Ku* for the closed loop system. Considering *Ku* and its related oscillating period,*Tu* , the PID parameters .

Like all the other tuning methods, it consists of two steps:

1. Determination of the dynamic characteristics, or personality, of the control loop
2. Estimation of the controller tuning parameters that produce a desired response for the dynamic characteristic determined in the first step, in other words, matching the personality of the controller to that of the other elements in the loop.

B. Cohen Coon Method

The Cohen-Coon method of controller tuning corrects the slow, steady-state response given by the Ziegler-Nichols method when there is a large dead time (process delay) relative to the open loop time constant; a large process delay is necessary to make this method practical because otherwise unreasonably large controller gains will be predicted. This method is only used for first-order models with time delay, due to the fact that the controller does not instantaneously respond to the disturbance (the step disturbance is progressive instead of instantaneous). The Cohen-Coon method is classified as an 'offline' method for tuning, meaning that a step change can be introduced to the input once it is at steady-state. Then the output can be measured based on the time constant and the time delay and this response can be used to evaluate the initial control parameters.

The most popular of the empirical tuning methods,

$$K_C = \frac{1}{k}\frac{\tau}{t_d}\left(0.9 + \frac{t_d}{12\tau}\right)$$

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known as the process reaction curve method, developed by Cohen and coon.

$$\tau_1 = t_d \frac{30+3t_d/\tau}{9+20t_d/\tau}$$

C.Skogestad's method **:**

Skogestad's method which is a model-based method. It is assumed that you have mathematical model of the process (a transfer function model). It does not matter how you have derived the transfer function - it can stem from a model derived from physical principles, or from calculation of model parameters (e.g. gain, time-constant and time-delay) from an experimental response, typically a step response experiment with the process (step on the process input).There is a large number of tuning methods, it is my view that the above methods will cover most practical cases. What about the famous Ziegler-Nichols' methods the Ultimate Gain method (or Closed-Loop method) and the Process Reaction curve method (the Open-Loop method) The Good Gain method has actually many similarities with the Ultimate Gain method, but the latter method has one serious drawback, namely it requires the control loop to be brought to the limit of stability during the tuning, while the Good Gain method requires a stable loop during the tuning. The Ziegler-Nichols'Open-Loop method is similar to a special case of Skogestad's method, and Skogestad's method is more applicable.

Skogestad's tuning method is a model-based tuning method where the controller parameters are expressed as functions of the process model parameters.

$$G(S) = \frac{K_P}{\tau S+1} e^{-\theta S}$$

$$k_c = \frac{1}{k}\frac{\tau}{\tau_c} + \theta$$

$$\tau_i = \min[\tau, 4(\tau_c + \theta)]$$

$$where \tau_c = \theta$$

IV.PROPOSED WORK

To design the PI controller using first order plus time delay model the following tuning methods are Zeigler Nichols method, Skogestad method and Cohen Coon method, among the three methods Skogestad method is the proposed method of this project work in the pressure process station for process control. Comparison of the above three methods should be shown in the following result analysis.

Pressure Process Station:

The Pressure Process Training System is a compact and mobile unit for a wide range in pressure control as shown in Figure 4.1. It gives a greater understanding of the Stability of simple control systems.The self-contained unit can do many experiments, but it can also connect to other products in the TE3300 range. For cascade control of pressure, it can link to the optional Pressure Process Training System (TE3300/03). The main parts of the Pressure Process Training system are:

- Industrial controller with auto-tune feature
- Two-channel chart recorder
- Current-to-pressure (IP) converter
- Gauge pressure transmitter
- Pneumatic control valve
- Pressure accumulator
- Three-speed pump and reservoir

Figure 4.1 Pressure Process Training System

Calculation

Using krishnaswamy method

t_1 =13.12sec and

t_2 =30.38sec

These are the two times obtained from which the 35.3% and 85.3% of the system response.

Where, K=32.5 and Steady State Gain, kp=0.6

$\theta = 1.3t_1 - 0.29t_2$

$\tau = 0.67(t_2 - t_1)$

therefore, θ = 8.24sec , τ = 11.56sec

$$G(S) = \frac{0.6}{8S+1} e^{-15S}$$

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V.SIMULATION RESULTS AND ANALYSIS

Simulations were performed by varying the dead time and the time constant in the range from 1 to 200 in the simulink model. The ratio of the dead time to the time constant of the process (θ/τ_1)corresponding to the above settings varied from 0.1 to 2 in the pressure process station. The tuning parameters thus obtained for a step change in set point and load were separately correlated with the fraction dead time.

A. *Simulink Model For Cohen Coon Method*

The input for PID controller, where P = 1.07 and I = 0.095 values are calculated from the FOPTD model.

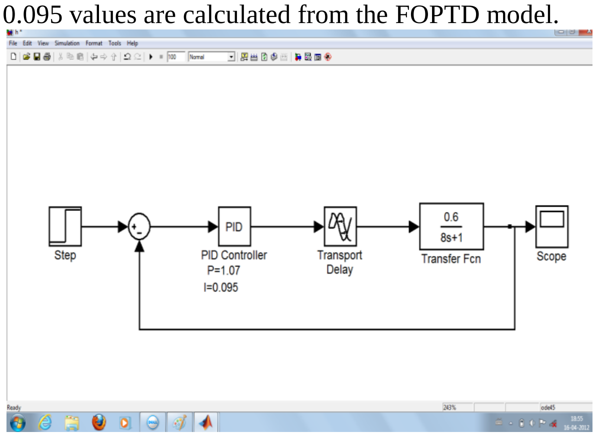
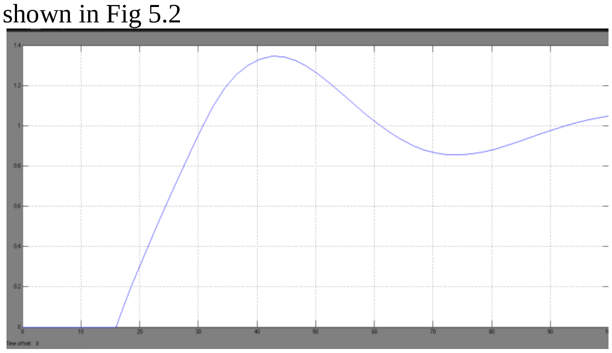


Figure 5.1 Simulink Model for Cohen Coon Method

B.Scope For Cohen Coon Method

The simulated output for Cohen Coon method as shown in Fig 5.2



Time (sec)

Figure 5.2 Scope for Cohen Coon Method

Simulink Model For Skogestad Method

C.The input for PID controller, where P = 0.568 and I = 0.049 values are calculated from the FOPTD model. The simulink model for Skogestad method as shown in Fig 5.3

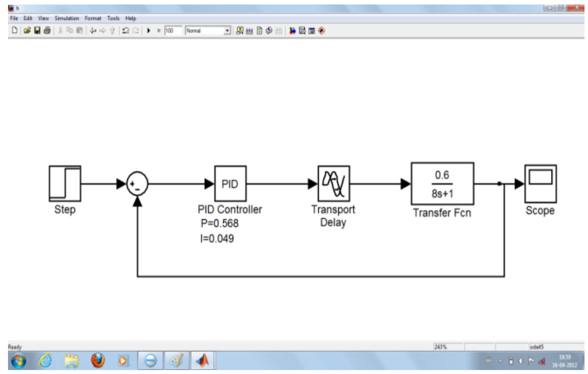
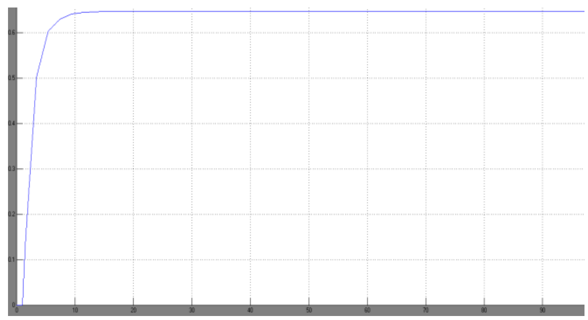


Figure 5.3 Simulink Model for Skogestad Method

Scope For Skogestad Method

The simulated output for Cohen Coon method is shown in Fig 5.4



Time(sec)

Figure 5.4 Scope for Skogestad Method

D. Comparison Of Cohen Coon Method And Skogestad Method

The simulink output for Cohen Coon and Skogestad method was compared in the graph as shown below Fig 5.5

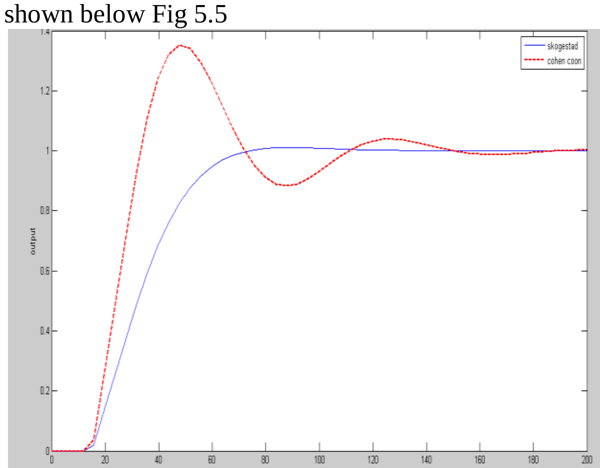


Figure 5.5 Comparison of Cohen Coon and Skogestad Method.

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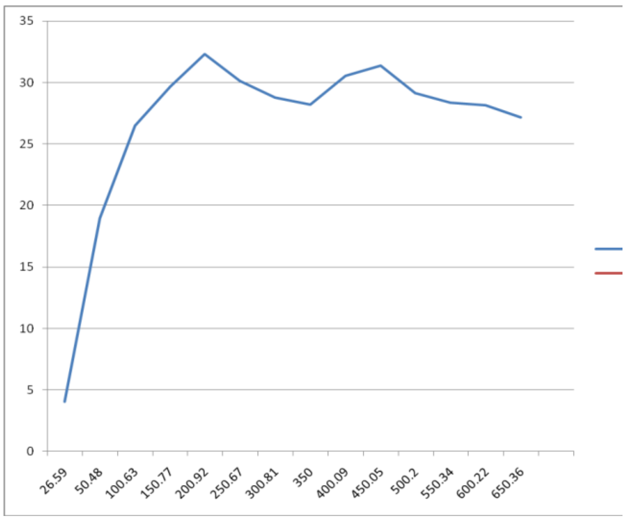
E.Real Time Output For Cohen Coon Method

From the Cohen coon method k_c, τ_i and k_c/τ_i are calculated and those values are given as input for Proportional and Integral controller of pressure process station and the maximum set point 50 is fixed and it reaches 33. From the graph the calculated dead time is 17 as shown in below graph Fig 5.6

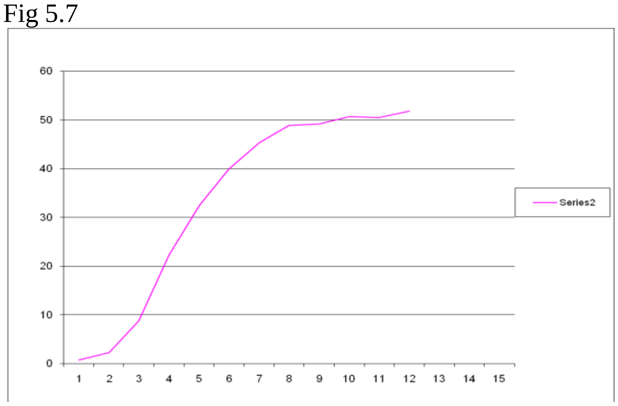


Time (sec)

Figure 5.6 Real Time Output for Cohen CoonMethod

F.Real Time Output For Skogestad Method

From the Skogestad Internal Model Control method are calculated and those values are given as input for Proportional and Integral controller of pressure process station and the maximum set point 50 is fixed and it reaches the setpoint as shown in below graph Fig 5.7

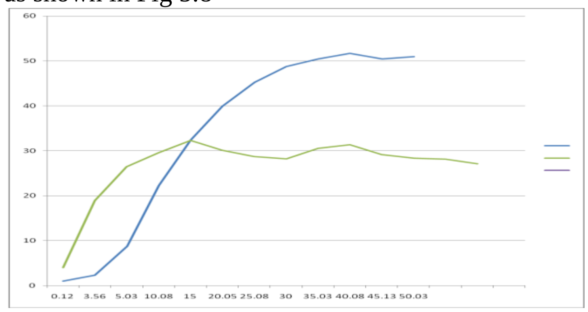


time(sec)

Figure 5.7 Real Time Output For Skogestad Method

G. Comparison Of Experimental Data

The Cohen Coon method and Skogestad Internal Model Control are compared using experimental data as shown in Fig 5.8



Time(sec)

Figure 5.8 Comparison between cohan coon and Skogestad internal model.

VI.CONCLUSION

A simple method is proposed for PI settings for FOPTD system The proposed method is used to design controller for various transfer function models and also applied to design controller.Understanding the dynamic behaviour of a process is essential to the proper design and tuning of a PID controller. Cohen-Coon (C-C) and Skogestad method are used to tune the controller. Both methods are compared to get the optimum condition for the process model. The responses for both methods are analyzed using MATLAB simulink. From the graph it is clear that there is no oscillation and absence of over shoot. Also the results indicated that responses using Skogestad Internal Model Control tuning are slightly better than those with the Cohen-Coon tuning method.

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