Comparing PI controller Performance for Non Linear Process Model

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ABSTRACT

This paper demonstrates the efficient method of tuning PI controller parameters by comparing different tuning rules. The method implies an analytical calculation of the controller gainK_C , Integral time τ_i for a PI controlled system which is modeled to be a First Order Plus Dead Time (FOPDT) process. A bench mark non linear system, conical tank is considered for study for which the identified transfer function model to be a FOPTD model. A MATLAB program with an objective is written to find out the optimum value for the PI controller parameter which can achieve the system requirements to minimize the overshoot, to maintain a fast system response, removal of dead time and to maintain robustness. The performance of the controller for different tuning rules has been investigated in a MATLAB simulation environment. Out of these different controllers tuning methods Suyama, Tsang and Rad outperforms well with no overshoot. For setting time Astrom and Hagglund gives better result. This tuning method gives the better results based on performance indices also.

Keywords: FOPDT Model, PI Controller, Tuning.

1. INTRODUCTION

In general, most of the process industries are facing major issues in controlling the various parameters [1]. There are many challenges to control the process, like the change in the dynamic behavior, uncertain and time changeable parameters, constraint on manipulated variables and dead time [2]. The majority of the systems are with nonlinearity and so process industries are in need of conventional control technique. Conical tank find extensive application in industries. To keep hold of the level in a conical tank is important, because the difference in shape give rise to the non linearity [3]. The most essential and standard algorithm used in the feedback control is the Proportional Integral control algorithm [4]. PI control is extensively used in control strategy to manage most of the industrial automation process. The most important reason is their simple structure, which can be easily understood and put into practice. Finding design method that lead to best possible operation of PI controller is thus of considerable interest [5]. In order for the controllers to work satisfactory, controller must be tuned appropriately. Fine-tuning of controllers can be done in a number of ways, depending on the dynamics of the system and several methods have been developed in latest years [6]. The perfect continuous time domain PI controller for a SISO process is expressed in the Laplace domain as follows

$$U(s) = G_C(s)E(s) \tag{1}$$

$$\text{where } G_C(s) = K_C(1 + \frac{1}{s\tau_i}) \tag{2}$$

K_C = Proportional Gain, τ_i = Integral Time Constant.

2. EXPERIMENT SETUP

The laboratory bench mark set up in use for study consists of a conical tank, a water reservoir, pump, rota meter, a differential pressure transmitter, an electro pneumatic converter(I/P converter), a pneumatic control valve, an interfacing ADAM's module and a Personal Computer.[3].

3. SYSTEM IDENTIFICATION

In real time implementation, model identification of this nonlinear process was accomplished using empirical modeling. By means of the open loop procedure, for a specified variation in the input variable the output response for the system is recorded. Sundaresan and Krishnaswamy [7] have obtained the parameters of FOPDT transfer function model.

The experimental data for this bench mark arrangement are validated to be a FOPDT model and the model parameters are given by,

$$G(s) = \frac{12.6e^{-2.05}}{53.6s+1} \tag{3}$$

4. DESIGN OF CONTROLLERS

Controller tuning methods present the controller parameters in the type of formulae or algorithms [8]. They make sure that the obtained control system would be steady and would meet specified objectives. Also great advances on best possible methods based on stabilizing PI solutions have been achieved [9].

4.1 PI controller

A PI controller is commonly used in engineering control system. PI controller calculation involves two separate constant parameters, Proportional and Integral denoted by P and I [10]. P depends on present error and I on the accumulation of past errors. By tuning these two parameters in PI control algorithm the controller can provide desired action designed for specific process requirement [11]. Different tuning rules used for this benchmark nonlinear system is given in Table 1.

Table I: Values for K_C and τ_i for different tuning methods

Tuning Rule	K_C	τ_i
Ziegler and Nichols[12]	$[\dfrac{1.2\ \tau_m}{K_m\tau_m},\ \dfrac{2\tau_m}{K_m\tau_m}]$	$2\tau_m$
Astrom and Hagglund [13]	$\dfrac{0.94\ \tau_m}{K_m\tau_m}$	$2\tau_m$
Sain and Ozgen[14]	$\dfrac{1}{K_m}\left(0.6939\ \dfrac{\tau_m}{\tau_m} + 0.1814\right)$	$\dfrac{0.8647\tau_m + 0.226\tau_m}{\dfrac{\tau_m}{\tau_m} + 0.8647}$
Cohen and Coon[15]	$\dfrac{1}{K_m}\left(1.35\ \dfrac{\tau_m}{\tau_m} + 0.25\right)$	$\tau_m\ \dfrac{\dfrac{2.5\tau_m}{\tau_m}+0.46(\dfrac{\tau_m^2}{\tau_m^2})}{1+0.61\dfrac{\tau_m}{\tau_m}}$
Tsang and Rad[16]	$\dfrac{0.809\ \tau_m}{K_m\tau_m}$	τ_m
Suyama[17]	$\dfrac{1}{Km}[0.7236\dfrac{\tau_m}{\tau_m} + 0.2236]$	$\tau_m + 0.309\ \tau_m$
Fruehauf et al.[18]	$\dfrac{5\ \tau_m}{9\ K_m\tau_m}$	$5\tau_m$

After using the different tuning rules given in Table 1, the following Table 2 gives the optimum values K_C and τ_i used for the study in simulation environment.

Table II: Different values for K_c and T_i for different tuning method

Rule	K_C	τ_i (secs)
Astrom and Hagglund	108.07	0.07438
Suyama	1.5192	54.23345
Fruehauf et al.	1.152	10.25
Tsang and Rad	1.6787	53.6
Sain and Ozgen	1.4543	1.7387
Ziegler and Nichols	2.4901	4.10
Cohen and coon	2.82	8.5353

5. RESULT & DISCUSSIONS

By means of different controller tuning methods and the different control parameters K_C and τ_i for PI controller, is tested in MATLAB environment for analysis.

5 1 PERFORMANCE ANALYSIS

Performances of various controller tuning methods for PI controller are analyzed using MATLAB tested for a given step input. It is found that in Suyama and Tsang and Rad makes the system to settle without overshoot at all. Astrom and Hagglund tuning method settles faster compared to the other tuning rules. Tsang and Rad tuning method have got minimum peak overshoot which is given in Table 3.

From Fig 1, it is also clear that Suyama, Tsang and Rad based tuned controller tracks the set point quickly without any oscillations. From Fig 2 , it is observed that Astrom and Hagglund tuning rule settles almost at 0.295 Secs compared to the other tuning rules taken up for study. Table 4 gives the performance indices comparison for a nonlinear system taken for study.

It is evident from the table that similar to time domain analysis Astrom and Hagglund tuning method is very good in terms of ISE, IATE, IAE and MSE values also. From the observed values Cohen and Coon gives next better results on error analysis.

Table III: Time Domain Analysis

Tuning Method	Rise Time (Sec)	Peak time (Sec)	Peak overshoot %	Settling time (Sec)
Astrom and Hagglund	0.0630	0.135	21.2449	0.2610
Suyama	6.6000	16.50	0.3760	11.1000
Fruehauf et al	5.5648	13.21	12.6035	29.9108
Tsang and Rad	5.8300	14.57	0.2987	9.5400
Sain and Ozgen	2.8150	5.630	34.6449	20.8310
Ziegler & Nichols	2.3800	5.780	16.5913	11.5600
Cohen & Coon	2.6000	6.500	8.5419	16.9000

Table IV: Performance indices Analysis

Tuning Method	ISE	IATE	IAE	MSE
Astrom and Hagglund	2.7119	0.4681	6.1810	0.0903
Suyama	5.1897	25.9805	9.8525	0.0927
Fruehauf et al	3.0456	57.9526	7.1401	0.0544
Tsang and Rad	5.2994	23.7331	10.0451	0.0757
Sain and Ozgen	2.9999	35.4492	6.8183	0.0536
Ziegler & Nichols	2.9719	23.4613	6.8625	0.0826
Cohen & Coon	1.7049	19.2928	3.8544	0.0304

6. CONCLUSION

PI Controller with different tuning rules was considered for non linear system. The evaluation is done on the performance analysis based on peak overshoot and settling time is implemented in the software simulation by using different controller tuning methods. It is observed that controller tuning method projected by Astrom and Hagglund is appropriate for non linear process as it has least settling time than other controller tuning methods. This is also validated in the performance indices comparison using different tuning methods. For Suyama, Tsang and Rad tuning demonstrate with zero overshoot and quicker settling time.
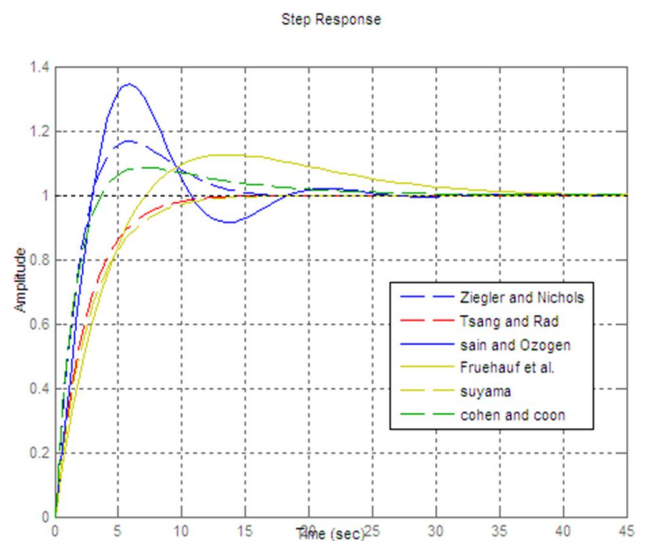

Fig 1: Unit Step response for a conical tank system using different tuning methods for PI controller
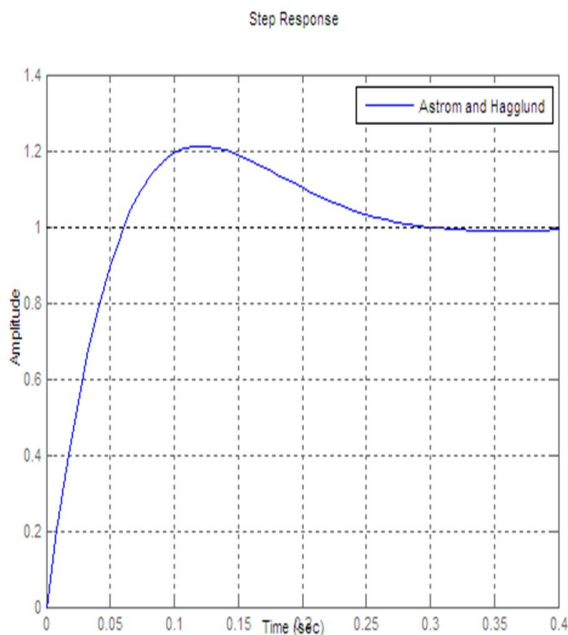
Fig 2: Unit Step response for a conical tank system using Astrom and Hagglund methods for PI controller

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