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Analysis of Linear-time invariant system in PID controller for industrial applications

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Abstract:*In this research, we are analysis the open-loop and closed-loop system identification from closed-loop experiments and using different design methods of the PID controller. Develop the closed-loop and the open-loop models using closed-loop test. Carry out mathematical analysis to develop the correlation between the process parameters and the data obtain in the closed-loop test. . Develop a PID controller design method for open-loop and closed-loop models of the linear time invariant industrial systems. The method would incorporate the advantages of the IMC method, the DS method along with the approximate frequency response matching method. Test the proposed method for wide range of the process models for observing its performance in terms of set-point and load-disturbance responses, controller output, robustness, stability margins, immunity to measurement noise, etc.*

Keywords*-Direct synthesis design, PID controller, Process control, Inverse response Integrating process, Higher-order process.*

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I. INTRODUCTION

In recent trends, most of the process industries use proportional-integral-derivative (PID) controllers because of there are several advantages and cost to benefit ratio it provides in terms of simplicity in control structure, easy to understand, low cost, easy to maintain and satisfactory performance in many applications. Various design methodologies are prevalent in the literature like model based design methods, optimization of integral error performance criteria, design methods utilizing frequency response data, loop shaping method, robust controller design, etc. [1]. The proportional-integral-derivative (PID) controlleris widely used in the process industries due to its simplicity, robustness and wide ranges of applicability in the regulatory control layer.

On the basis of a survey of more than 11 000 controllers in the process industries, Desborough and Miller [1] report that more than 97% of the regulatory controllers utilize the PID algorithm. A recent survey (Kano and Ogawa [2]) from Japan shows that the ratio of applications of PID control, conventional advanced control (feed forward, override, valve position control, gain-scheduled PID, etc.) and model predictive control is about 100:10:1. In addition, the vast majority of the PID controllers do not use derivative action. Even though the PI controller only has two adjustable parameters, it is not simple to find good settings and many controllers are poorly tuned. One reason is that quite tedious plant tests may be needed to obtain improved controller settings. Due to the simplicity and improved performance of the internal model control (IMC)-based tuning rule, the analytically derived IMC–PID tuning methods have attracted the attention of industrial users over the last decade.

The IMC–PID tuning rule has only one user–defined tuning parameter, which is directly related to the closed–loop time constant. The IMC–PID tuning methods and the direct synthesis (DS) methodare two examples of typical tuning methods based on achieving a desired closed–loop response. These methods obtain the PID controller parameters by computing the controller whichgives thedesired closed–loop response. Although this controller is often more complicated than a PID controller, its form can be reduced to that of either a PID only controller or a PID cascaded with a low–order lag filter by some clever approximations of the dead time in the process model.

The IMC–PID controller provides good set–point tracking but sluggish disturbance response, especially for processes with a small time–delay/time–constant ratio.However, for many process control applications, disturbance rejection is much more important than set–point tracking. Several researchers have reported that the suppressing load disturbance is poor when the process dynamics are significantly slower than the desired closed–loop dynamics. Therefore, a controller design emphasizing disturbance rejection rather than set–point tracking is an important design problem that has received renewed interest recently.

Therefore, there is need of an alternative closed-loop approach for plant testing and controller tuning which avoids the instability concern during the closed-loop experiment, reduces the number of trails, and works for a wider range of processes.

II. Feedback Control System

Most tuning approaches are based on an open-loop plant model (g) as shown in Fig.1; typically given in terms of the plant's gain (k), time constant (τ) and time delay (θ); see O'Dwyer [3] for an extensive list of methods. Given a plant model g, one popular approach to obtain the controller is direct synthesis (Seborg et al., [4]) which includes the IMC-PID tuning method of Rivera et al. [5].

The original direct synthesis approaches, like that of Rivera et al. [5], give very good performance for set point changes, but give sluggish responses to input (load) disturbances for lag-dominant (including integrating) processes with τ/θ larger than about 10. To improve load disturbance rejection, Skogestad [6] proposed the modified SIMC method where the integral time is reduced for processes with a large value of the process time constant τ. The SIMC rule has one tuning parameter, the closed-loop time constant τ_c, and for "fast and robust" control is recommended to choose $\tau_c = \theta$, where θ is the (effective) time delay.

However, these approaches require that one first obtains an open-loop model (g) of the process. There are two problems here. First, an open-loop experiment, for example a step test, is normally needed to get the required process data. This may be time consuming and may result in undesirable output changes. Second, approximations are involved in obtaining the process model g from the open-loop data.

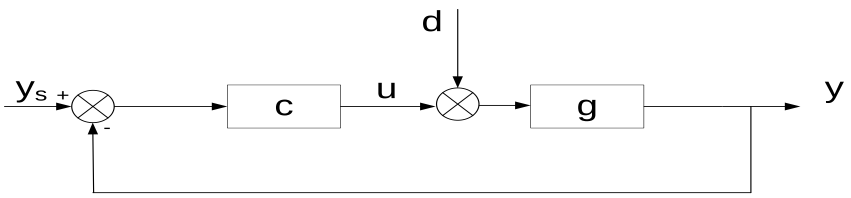

Fig.1. Block diagram of feedback control system.

In this paper, the objective is to derive controller tunings based on closed-loop experiments. The simplest is to directly obtain the controller from the closed-loop data, without explicitly obtaining an open-loop model g. This is the approach of the classical Ziegler-Nichols method [7] which requires very little information about the process; namely, the ultimate controller gain (K_u) and the period of oscillations (P_u) which are obtained from a single experiment. For a PI-controller the recommended settings are K_c=0.45K_u and τ_I=0.83P_u. However, there are several disadvantages. First, the system needs to be brought its limit of instability and a number of trials may be needed to bring the system to this point. To avoid this problem one may induce sustained oscillation with an on-off controller using the relay method of Åström and Hägglund, [8].

However, this requires that the feature of switching to on/off-control has been installed in the system. Another disadvantage is that the Ziegler-Nichols [7]tunings do not work well on all processes. It is well known that the recommended settings are quite aggressive for lag-dominant (integrating) processes (Tyreus and Luyben, [9]) and quite slow for delay-dominant process (Skogestad, [6]). To get better robustness for the lag-dominant (integrating) processes, Tyreus and Luyben [9] proposed to use less aggressive settings (K_c=0.313K_u and τ_I=2.2P_u), but this makes the response even slower for delay-dominant processes (Skogestad, [6]). This is a fundamental problem of the Ziegler-Nichols [7] method because it uses only two pieces of information about the process (K_u, P_u), which correspond to the critical point on the Nyquist curve. This does allow one to distinguish, for example, between a lag-dominant and a delay-dominant process. A third disadvantage of the Ziegler-Nichols [7]method is that it can only be used on processes for which the phase lag exceeds -180 degrees at high frequencies. For example, it does not work on a simple second-order process.

A two-step procedure, based on a closed-loop setpoint experiment with a P-controller, was originally proposed by Yuwana and Seborg[10]. They identified a first-order with delay model by matching the closed-loop setpoint response with a standard oscillating second-order step response that results when the time delay is approximated by a first-order Pade approximation. They identified from the setpoint response the first overshoot, first undershoot and second overshoot, but the method may be modified to not use the second overshoot, as in the present paper. Yuwana and Seborg[10] then used the Ziegler-Nichols [7]tuning rules, which as mentioned in the introduction may give rather aggressive setting.

Recently Shamsuzzoha and Skogestad, [11,12] have developed one step procedure for PI/PID controller tuning in closed-loop mode. This method can be utilized for the broad class of the process model. They reported the result after testing on 33 different type of process model which shows clear advantage over other method.

III. Proposed Closed Loop Set Point

Therefore, in this paper we want to develop the plant identification and controller tuning based on the closed-loop experiment for stable and unstable processes. The method can extend for robust and acceptable tuning for plant model mismatch. The method will use a single closed-loop experiment with proportional only control. This is similar to the Ziegler-Nichols [7]method, but the process will not force to its stability limit and it requires less trial-and-error adjustment of the P-controller gain to get to the desired closed-loop response.

1. Of the many parameters that can be obtained from the closed-loop set point response, the simplest to observe is the time (t_p) and magnitude (overshoot) of the first peak (see Figure2) which will be the main information used in the proposed method.
2. The proposed method will work well on a wider range of processes than the Ziegler-Nichols [7]method. In particular, it will work well also for delay-dominant processes. This will make use of a third piece of information, namely the relative steady-state change $b = y(\infty)/y_s$.
3. The method should apply to processes that give overshoot with proportional only control. This will be less restrictive than the Ziegler-Nichols [7]method, which requires sustained oscillations. Thus, unlike the Ziegler-Nichols method, the method will work on a simple second-order process.

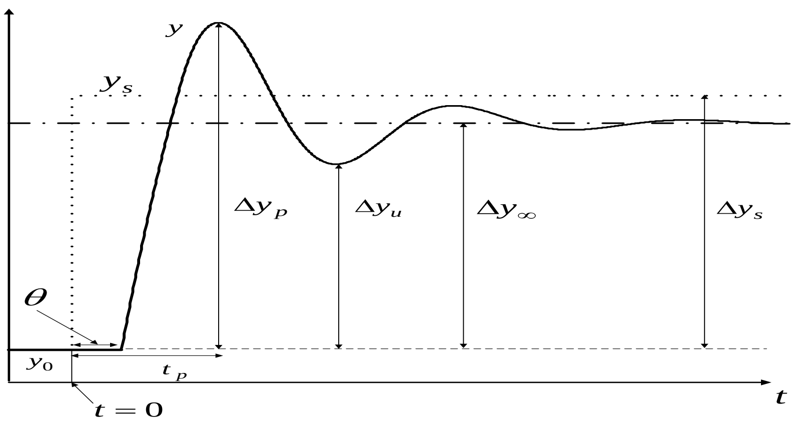

Fig.2. Closed-loop step set point response with P-only control.

IV. Primary Mathematical Setup

We know that the real function f(x) with derivatives and sometimes $x=x_0$. So we can write the value of f(x):

$f \quad [x_0x_1] = (f[x_0] - f[x_1])/(x_0 - x_1)$

$f[x_0x_1x_2] = (f[x_0x_1] - f[x_1x_2])/(x_0 - x_2)$ (1)

$[x_0x_1. . . .x_k] = (f[x_0x_1. . .x_{k-1}]$

$-f[x_1 x_2. . . .x_k])/(x_0-x_k)k \in [1, n]$

Assume the value of intervals (a,b),which are greatest to least of $x_{0,}\, x_1 \ldots\; x_{n.}$.If we are talking about function real variable x with first derivative (n-1) which are finite and continuous.so,

$f[x_0x_1x_2\ldots x_n] = h^{-n} \sum_{i=0}^{n} (-1)^{(n-i)}/\, i!(k\text{-}i)!\; xf(x_i) = 1/n!\; f^{(n)}(\eta)$ (2)

Where η lies in the interval $x_0 \le \eta \le x_0+nh$.

Again write 2nd real function ψ (x) with finite and continuouswhere derivative points $x=x_0$such that

$\Psi(x_i) = f(x_i)$, i € [0,n] (3)

From equation 2.we focus on the small non-negative value.

$F^{(i)}(x) = \psi^{(i)}(x)$, i € [0,n](4)

Thus, all equations suitable for the parameter h, given for the f (x).we know another real value of ψ (x)which fitted for the equation 3.thats why equation 4. Satisfied for this systempart is very useful for the controller design approximation section.

V. Method Of Controller Design

We know the basic form of transfer function.

$$G(s) = N(s) / D(s)\, e^{-sL} \quad (5)$$

Where, N(S)/D(S) transfer function rational part and L is related to the time.fig.1 show the unity negative output feedback configuration with C(S).set-point filter performance mostly improve by the F(S).Most of the time its designed based on the disturbance rejections. Now system design of the controller showing below without any setpoint filter.

The closed-loop transfer function for both the set-point and disturbance rejection are given as

$y(s)/ r(s) = C(s) G(s) / 1+ C(s) G(s)$ (6)

$y(s)/ d(s) = G(s) / 1+ C(s) G(s)$ (7)

Direct synthesis method, is controller design which based on the process control and closed loop system. We design the controller with desired set point response or load disturbance response.so we can chose the closed loop transfer function with desired set point as $G_{r,y}(s)$ and controller ,c(s).

Fig.3.Block diagram of the classical feedback control systems

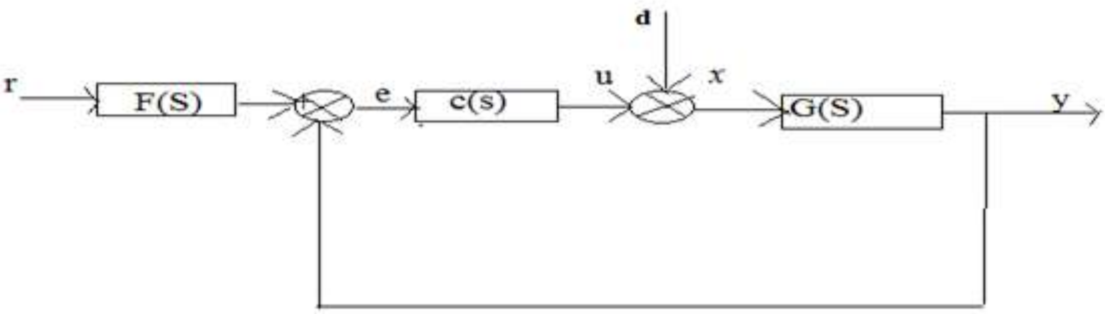

Fig.3.Block diagram of the classical feedback control systems

Equation.6 as

$C(s) = G_{r,y}(s) / G(s)[\, 1- G_{r,y}(s)]$ (8)

Similarly, $C(s) = 1/G_{d,y}(s) - 1/G(s)$ (9)

Equation 8, 9 based on the order of the controller which is design closed loop model, and then get PID controller. The proposed method is model free high order to low order rational approximation of the delay term e^{-SL}. So model reduction is based on the controller C(S) is directly related to the $C^{PID}(S)$ as,

$C^{PID}(S) = K_P + K_I /s + K_D s$ (10)

Where, K_P, K_I and K_D are proportional, integral and derivative gains.

VI. Simulink And Experiment Of Closed Loop Set-Point

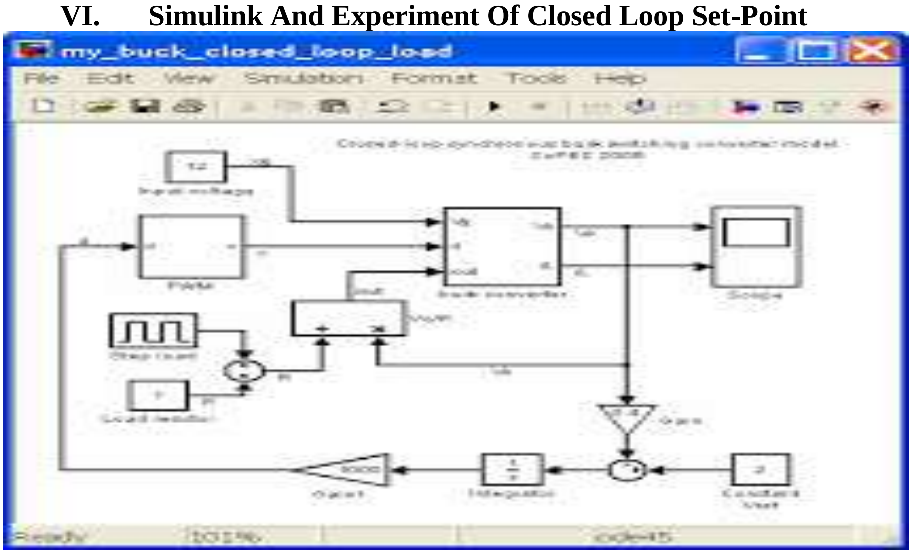

Fig.4 Simulink Model of Closed loop

As mentioned earlier, the objective is to base the controller tuning on closed-loop data. The simplest closed-loop experiment is probably a set point step response where one maintains control of the process, including the change in the output variable. From the set point experiment (fig.1) one may observe many values, like rise time, period of oscillations, magnitudes and times of overshoots and undershoots, etc. Of all these values, the simplest to observe is the magnitude and time (t_p) of the (first) overshoot, and this information is therefore the basis for the proposed method. We propose the following procedure:

Step 1. Switch the controller to P-only mode (for example, increase the integral time $_I$ to its maximum value or set the integral gain K_I to 0). In an industrial system, with bump less transfer, the switch should not upset the process.

Step 2. Make a set point change with a P-only controller. The P-controller gain K_{c0} used in the experiment does not really matter as long as the response oscillates sufficiently with an overshoot between 0.10 (10%) and 0.60 (60%); about 0.30 (30%) is a good value. Most likely, unless the original controller was tightly tuned, one will need to increase the controller gain to get a sufficiently large overshoot. Note that the controller gain to get 30% over-shoot is about half of the "ultimate" controller gain needed in the Ziegler–Nichols closed-loop experiment.

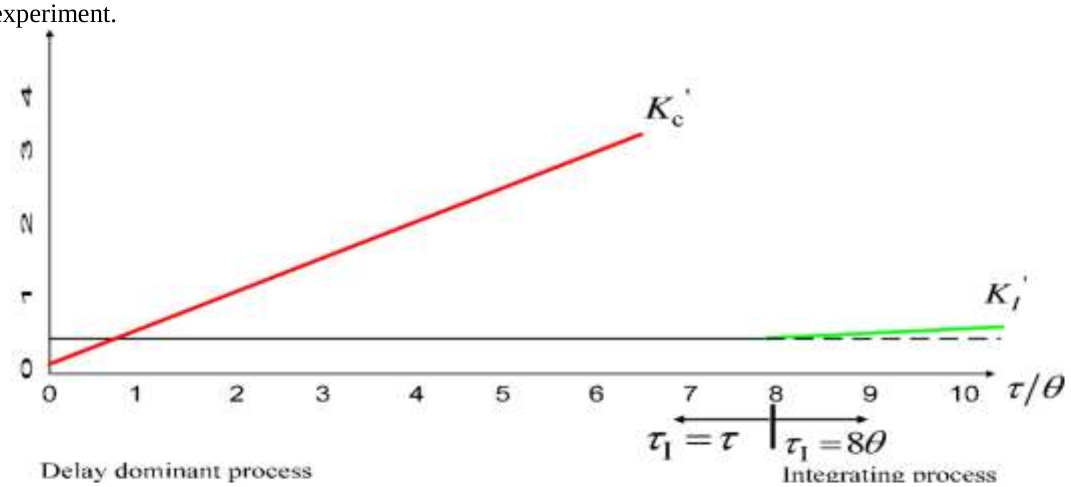

Fig.5. Scaled PI gain for tuning rule, step responses with various overshoots for first-order plus time delay process.

To find y_∞ one needs to wait for the response to settle, which may take some time if the overshoot is relatively large (typically, 0.3 or larger). In such cases, one may stop the experiment when the set point response reaches its first minimum (undershoot) and record the corresponding output, y_u . As shown in Appendix A, one can then estimate the steady-state change from the following correlation:

$\Delta y_\infty = 0.45(\Delta y_p + \Delta y_u)$ (11)

We have actual variables,

$y_\infty = 0.45(y_p + y_u) + 0.1y_0$ (12)

To illustrate the use of the closed-loop set point experiment, we show in these fig (4) closed-loop responses for a typical process with a unit time delay ($\theta = 1$) and a ten time's larger time constant ($\tau = 10$).

$g(s) = e^{-s} /10s+1$ (13)

The responses in fig (5) are for six different controller gains K_{c0} , which result in overshoots of 0.10, 0.20, 0.30, 0.40, 0.50 and 0.60, respectively. As expected, the closed-loop response gets faster and more oscillatory as the overshoot increases. Note that small over-shoots (less than 0.10) are not shown. The main reason is that it is difficult in practice to obtain from experimental data accurate values of the overshoot and corresponding time if the overshoot is too small. Also, large overshoots (larger than about 0.6) are not shown, because these give a long settling time and require more excessive input changes. For these reasons we recommend using an "intermediate" overshoot of about 0.3 (30%) for the closed-loop set point experiment.

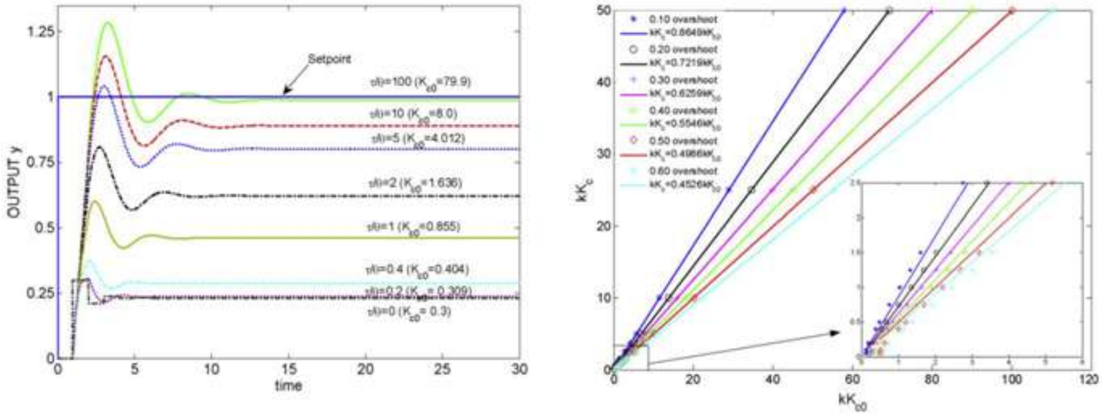

Fig.6. Step set point responses with overshoot of 0.34 for eight first order plus time delay processes, relationship between P-controller gain.

A. Controller Setting:

In control setting we express the nominal controller settings which time constant equal to the effective delay ($\tau_c = \theta$). Here so many situations based on the responses sometimes its use less settings ($\tau_c > \theta$), or sometimes speed up($\tau_c < \theta$).

Where, F > 1 corresponds less aggressive settings and F < 1 to more aggressive settings.

To find out how the factor F should be included in the expressions for the controller gain and integral time we go back to the SIMC settings.

$K_C = (0.5\tau / k\theta)$, $\tau_1 = \min(\tau, \tau_{12})$ where $\tau_{12} = 8\theta$ (14)

We can write the basic formula as,

$K_C = K^*_C / F$ (15)

$\tau_1 = \min(\tau, \tau_{12} F)$ (16)

Where

$F = \tau_c + \theta / 2\theta$

Now, the conclusion of the final tuning formulas for the proposed Set point Overview Method

$K_c = K_{CO} A / F$ (17)

$\tau_1 = \min(0.86A \mid b/1-b \mid \tau_p, 2.45\, \tau_p F)$ (18)

F is a detuning parameter. When detune the responses we get lots of robustness select one F>1, but sometimes in special cases one may choose F<1 to speed up the closed loop response.

B. Analysis Of The PID Controller:

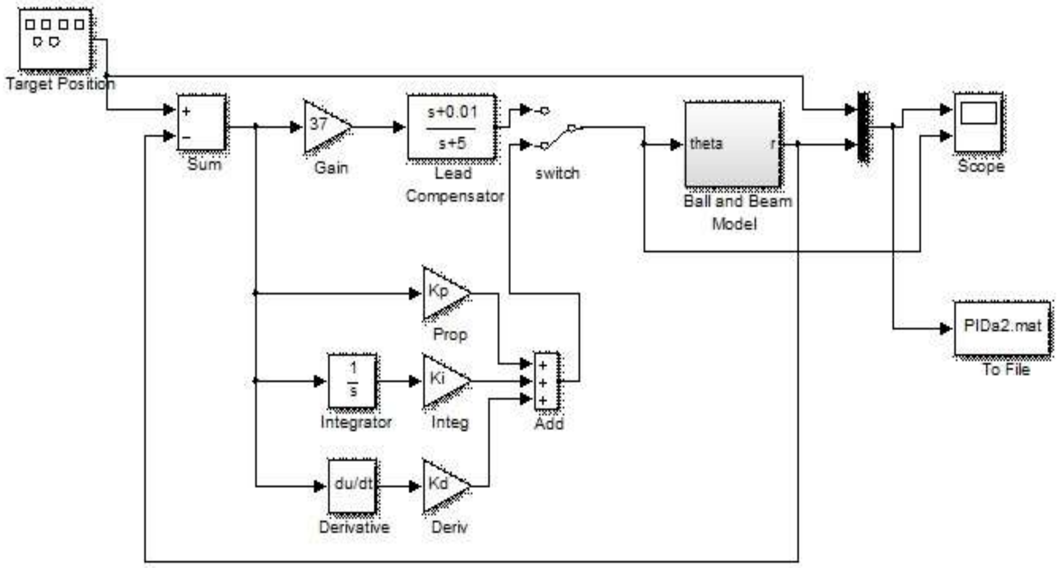

Fig.7. Simulink Model for PID controller

Simulation of closed-loop has been different variety for proposed process of all cases which are suitable for both performances. We can assume for PI setting which based on step response experiments with three different overshoot.

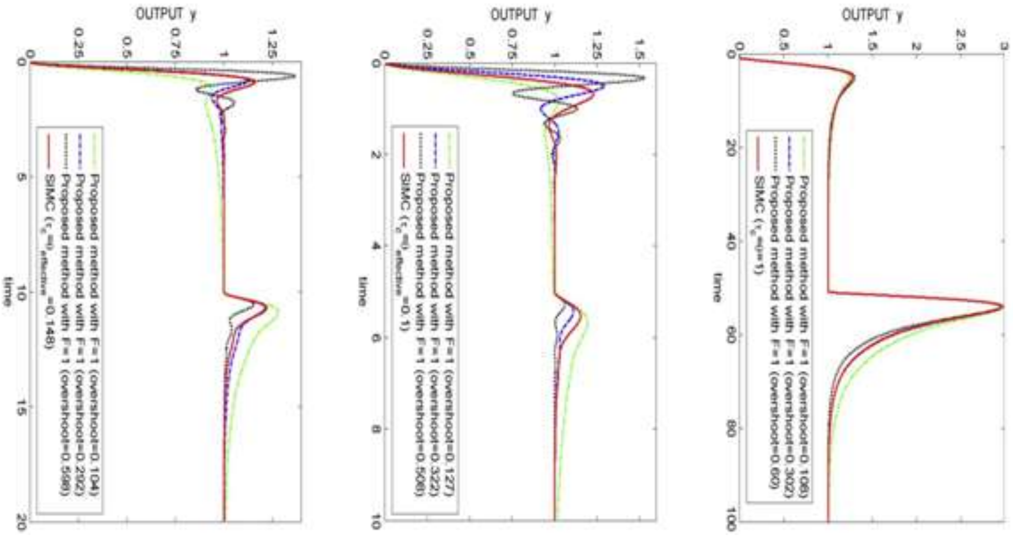

Fig 8.- Responses for PI control of integrating process, second-order process, high-order process. Set point change at τ = 0; load disturbance of magnitude 1 at τ = 50,5,10.

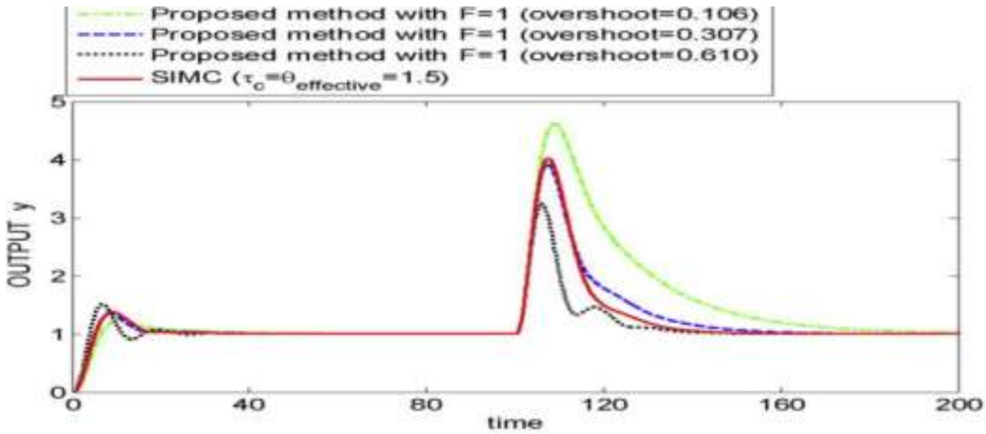

Fig.9. Responses for PI control of integrating process, third order. Set point change at τ = 0; load disturbance of magnitude 1 at τ= 100

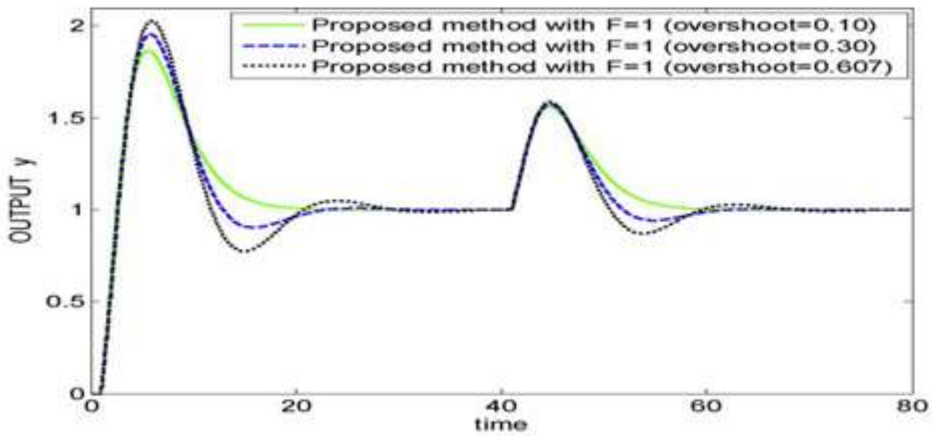

Fig-10 Responses for PI control of first order unstable process. Set point change at τ = 0; load disturbance of magnitude 1 at τ = 40.

In this fig.10somewhere sometimes may be became unstable.so we can make again for new proposed method for more robust controller settings.

C. Derivative Controller:

We know the, tuning rules explain here PI control. So we can get a better output performance by adding derivative action with PID control. We have lots of example of PID controllers and what is better for your system you can chose as per as your choice.

So according to the system we follow classical PID controller with cascade form.

C_{PID} (S) = K_C (1+1/τ_Is) 1+τ_Ds /1 +($\tau_{D/N)S}$ (19)

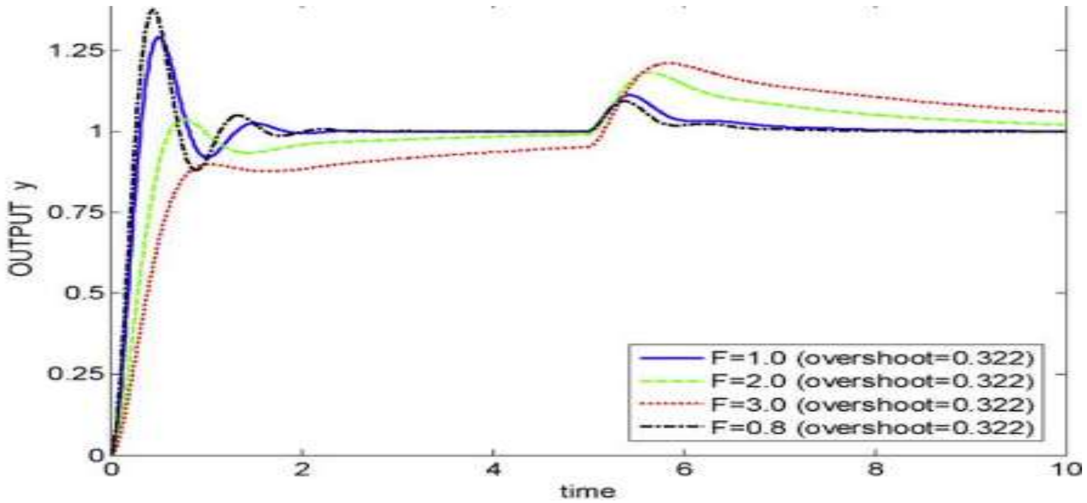

Fig11. Effect of detuning factor for PI control of second-order process. Set point change at τ = 0; load disturbance of magnitude 1 at τ=5

We can see the effect of detuning factor for PI controller with 2nd order. Here used typically time or filter parameter N approx.10. We know the derivative controller create more complexity adding by the stage of the measurement process so that's why we prefer PID controller. Its only chooses for justification of the second order,

g(s) = $e^{-\theta s}$ / (τ_1s+1) (τ_2s+1) (20)

Here second order time constant related term dominant, its effective time delay. So many examples clarify the above graphs. We can choose the cases and apply the situations.Given equation may be able to be stabilized only when added derivative action to the PI controller. Here we used derivative action with closed loop tuning and used derivative action to the PI controller. It's beneficial for the gain and changing the addition of the derivative actions.

So we can write the derivative action before touch of PD controller during set point experiment,

C_{PD} (S) = K_{C0} (1+τ_Is) / 1+($\tau_{D/N)S}$) (21)

VII. Proposed Approach For Pid Control

We know the procedure is unchanged of the set point experiment, only expect PD-controller uses. Let explore the whole process step by step.

Step1. Select the derivative time D with use of PD-controller. So let 2nd time constant D=2. If it's not known value then we take lowest value is D=0.27 t_p.We know, t_p is the used only time to reach only peak controller P, and the output y_D recorded differentiated .

Step2. It's totally depends on the set point overshoot which are adjust K_{CO} for get ratio of set point overshoot between 10% and 60%.Its unchanged step only expected PD controller. It's given good advantages for system balancing.

Step 3. Data collection for the experiment of the set point overshoots. This is already mentioned in unchanged mode.

Step 2. Adjust K_{c0} to get a set point overshoot between 10% and 60% (this step is unchanged, except that we use a PD-controller).

Step 3. Collect data for the set point experiment (unchanged).

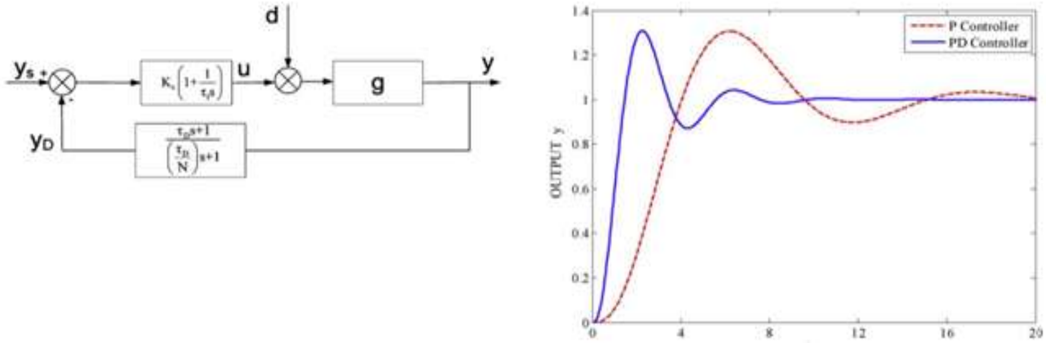

Fig.12. Without differentiation of set point implemented Cascade PID controller and set-point experiment with P and PD controller for third integrating process.

According to the experiment's K_C and $\tau_I$is changed .So we can assume we having cascade PID controller. We can see the cascade implementation in above diagram.So, common ideal PID controller

$C(s) = k'_c[(1+1/\tau'_1 s + \tau'_D s / 1+ \{\tau'_D/ N\} s)]$ (22)

If we assume the value of given equation (22) ,then we have to modified the setting of cascade by a factor,

$C = 1+ \tau_D/ \tau_1$ (23)

Using above translation formula. In this system we are choose to neglected the parameter N effected by some area of filters.

$K'_C = CK_C,$ $\tau'_1 = C\tau_1,$ $\tau'_D= \tau_D/C$ (24)

Here we see the experiment of PI/PD controller with the resulting process,

$g(s) = 1 / s (s+1)^2$ (25)

TABLE.1. PI/PD SET POINT EXPERIMENT

S.NO.	CASE	K_CO	τ_D	OVERSHOOT	τ_D	b
1.	FIRST	0.59	0	0.309	6.3	1.01
2.	SECOND	1.55	1.67(N= 10)	0.310	2.35	1.01

TABLE.2. RESULTING PI/PD CONTROLLER

S.NO.	CASE	K_C	τ_1	M_S	SET-POINT			LOAD DISTURBANCE		
					IAE(y)	TV(u)	Overshoot(y)	IAE(y)	TV(u)	Peak value
1.	1st	0.360	15.11	1.78	6.25	0.92	0.38	42.40	1.75	2.93
2.	2nd	0.950	5.50	1.50	2.70	1.53	0.085	5.85	1.80	0.85

Now, we can see the overshoot of PD controller with D-action on the set point is 0.310 and PID controller without D-action is 0.081. So, we proposed the simulation graph of responses PID controller has filter parameter N=10 and set point is not differentiated.

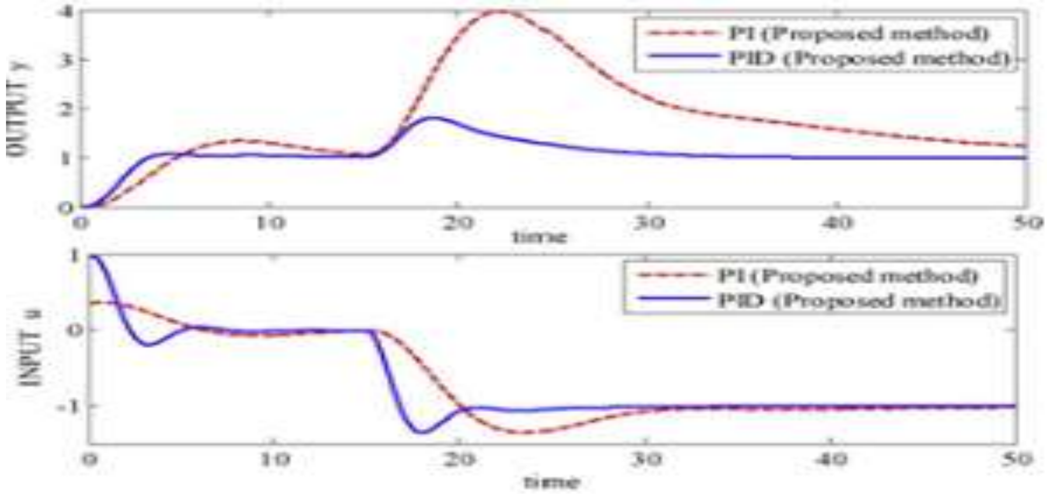

Fig.13. Responses with PI and PID controller for 3rd order integrating process

VIII. Proposed Tuning Method For Industrial Verification

The proposed method of the PI controller has been used of large hub like industries. So, for the industrial verification we assume an industry for example, how we can use for the future.so verified industrial reading the refinery at Jamnagar, Gujarat. They work like preplan always, which is based on the algorithm .most of the cases they only work for the useful results, or we can say good advantage.We replace the open loop and using closed loop, because open loop raking so much time than the closed loop. We check the refinery industry work so obviously we will go with the pressure measurement so we can see the simulation graph of the pressure control loop for crude.

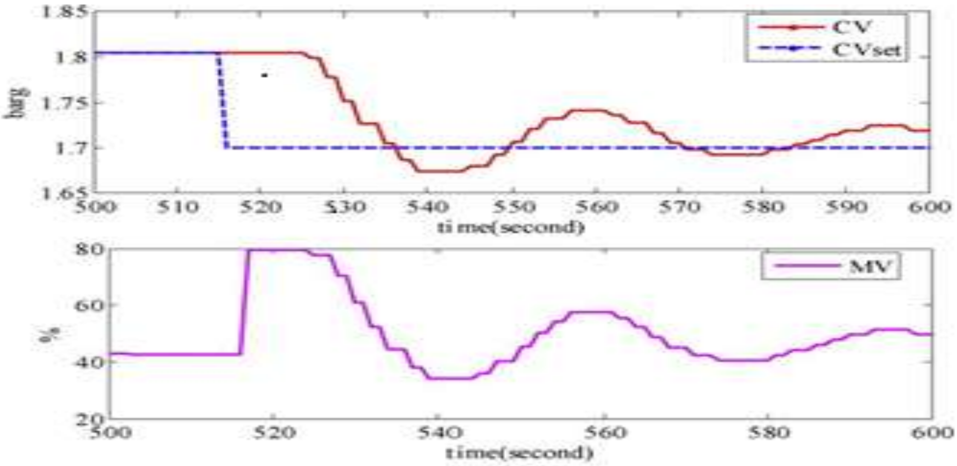

Fig.14. Tuning method for PI control industrial verification for, set point experiment.

Where,CV = (y) output, pressure and MV = (u) input, valve position So, we get all responses but they are a bit twitchy and the reason of this exceptional updates of the pressure measurement. From fig 12, we can see the all data of the set point experiment

Table.3. Set point experiment with obtain data

S.NO.	$K_{C0} = 35$	
1.	t_p	542-517 = 26s= 0.418
2.	y_o	1.806 barg
3.	y_s	1.701barg
4.	y_p	1.672 barg
5.	Y_u	1.741 barg min

Table.4. Set point experiment with obtain output changes

S.NO.		CHANGES OUTPUT	
1.	Δy_s	$\| y_s - y_0 \|$	0.106barg
2.	Δy_p	$\| y_p - y_0 \|$	0.135barg
3.	Δy_u	$\| y_u - y_0 \|$	0.065 barg

Now we can check the Save time of the experiment was not run to steady state and predicted steady state changes is

$\Delta y_\infty = 0.46(\Delta yp + \Delta yu) = 0.46\ (0.135 + 0.065) = 0.090$ barg (26)

From this we get

Overshoot = Δyp- $\Delta y_\infty / \Delta y_\infty = 0.507$ (27)

Steady state ratio, $b = \Delta y_\infty / \Delta ys = 0.848$ (28)

Final settings are

$K_c = K_{c0}$ A/F = 15.0 (29)

$\tau_1 = \min(0.96, 1.23) = 0.95$

Now the proposed final control loop responses with PI control. They are given better responses comparison to others.

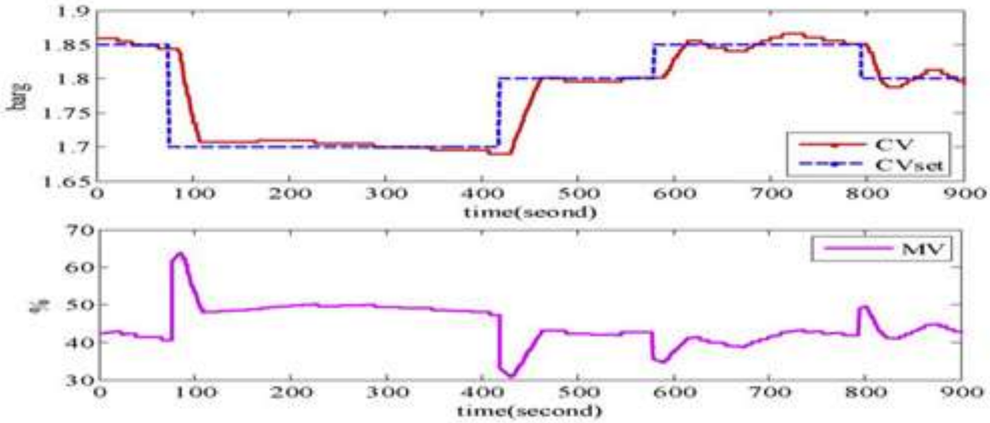

Fig.15. Tuning method for PI control industrial verification for final closed loop responses.

IX. Conclusion

In this research, we proposed a simple DS based PID controller design method for the industrial verification. Basically we get a new process of ds control and further change into a PID controller, which use frequency matching method.In this study, a simple DS-based PID controller design method for industrial processes have been proposed. It's based on the closed loop set point experiment. PI controllers directly get three data of this experiment.

- Overshoot = $(y_p - y_\infty)/ y_\infty$
- First peak, t_p
- Output change of steady state, b = y_∞ / y_s

So, this method is basically proposed a free model reduction process for high order to low order process. This method also can be accept by computation burden and proposed PID controller settings. Proposed method unified way for better results. We can see the working of set point overshoot method, which work very good for wide areas.

Reference

[1]. Rohit S. Patwardhana and R. BhusanGoapluni, "A moving horizon approach to input design for closed loop identification", Journal of Process Control, vol. 24, no. 03, pp. 188-202, March 2014.

[2]. RaghunathBajarangbali, SomanathMajhi and SaurabhPandey, "Identification of FOPDT and SOPDT process dynamics using closed loop test", ISA Transactions, vol. 53, no. 04, pp. 1223-1231, July 2014.

[3]. S. Bezergiannia and L. Ozkan, "On the assessment of multivariable controllers using closed loop data. Part I: Identification of system models", Journal of Process Control, vol. 22, no. 01, pp. 125-131, Jan. 2014.

[4]. Jyh-Cheng Jeng and Ming-Wi Lee, "Simultaneous automatic tuning of cascade control systems from closed loop step response data", Journal of Process Control, vol. 22, no. 06, pp. 1020-1033, July 2012.

[5]. Q. B. Jin, Z. J. Cheng, J. Dou, L.T. Cao and K. W. Wang, "A novel closed loop identification method and its application of multivariable system", Journal of Process Control, vol. 22, no.01, pp. 132-144, Jan. 2012.
[6]. Mohammad Shamsuzzoha and SigurdSkogestad, "The set point overshoot method: A simple and fast closed-loop-approach for PID tuning", Journal of Process Control, vol. 20, no. 10, pp.1220-1234, Dec. 2010.
[7]. A. S. Rao, V. S. R. Rao and M. Chidambaram, "Direct synthesis-based controller design for integrating processes with delay time", Journal of the Franklin Institute, vol. 346, no. 01, pp. 38-56, Feb. 2009.
[8]. M. Shamsuzzoha and M. Lee, "IMC-PID controller design for improved disturbance rejection of time delayed processes", Ind. Chem. Eng. Res., vol. 46, no. 07, pp. 2077-2091, March 2007.
[9]. A.O'Dwyer, Handbook of PI and PID controller tuning rules, 2nd ed.: Imperial College Press, 2006.
[10]. K. H. Ang, G. Chong and Y. Li, "PID control system analysis, design and technology", IEEE Transactions on Control System Technology, vol. 13, no. 4, pp. 559-576, July 2005.
[11]. S. Skogestad, "Simple analytic rules for model reduction and PID controller tuning", Journal of Process control, vol. 13, pp. 291-309, 2003.
[12]. Jing-Chung Shen, "New tuning method for PID controller", ISA Transactions, vol. 41, no. 04, pp. 473-484, Oct. 2002.
[13]. Dan Chen and Dale E. seborg, "PI/PID controller design based on direct synthesis and disturbance rejection", Ind. Eng. Chem. Res., vol. 41, pp. 4807-4822, 2002.
[14]. Q. G. Wang, Y. Zhang and X. Guo, "Robust closed loop identification with application to auto-tuning", Journal of Process Control, vol. 11, no. 05, pp. 519-530, Oct. 2001.
[15]. A. Visioli, "Tuning of PID controllers with fuzzy logic", IEE Proc.-Control Theory Appl., vol. 148, no. 1, pp. 1-8, Jan. 2001.
[16]. J. G. Ziegler and N. B. Nichols, "Optimum settings for automatic controllers", Trans. ASME, vol. 64, pp. 759-768, 1942.
[17]. K. J. Astrom and T. Hagglund, "Automatic tuning of simple regulators with specifications on phase and amplitude margins," Automatica, vol. 20, no. 05, pp. 645-651, Sep. 1984.
[18]. Daniel E. Rivera, Manfred Morari and SiguardSkogested, "Internal model control PID controller design", Ind. Eng. Chem. Process, vol. 25, pp. 252-265, Jan. 1986.
[19]. K. J. Astrom and T. Hagglund, PID controllers theory design and tuning, 2nd ed. North Caorlina: Instrument Society of America, Research Triangle Park, 1995.
[20]. W. K. Ho, C. C. Hang and L. S. Cao, "Tuning of PID controllers based on gain and phase margin specification", Automatica, vol. 31, no. 3, pp. 497-502, March 1995.
[21]. R. Mamat, and P. J. Fleming, "Method for online identification of a first order plus dead time process model", Electronics Letters, vol. 31, pp. 1297-1298, 1995.
[22]. W. L. Luyben, "Tuning proportional-integral-derivative controllers for integrator/dead time processes", Ind. Eng. Chem. Res., vol. 35, no. 10, pp. 3480-3483, Oct. 1996.
[23]. E. Poulin and A. Pomerleau, "PI settings for integrating process based on ultimate cycle information", IEEE Transactions on Control Systems Technology, vol. 7, no. 4, July 1999.
[24]. L. Ljung, System Identification: theory for the user, NJ: Prentice-Hall, Englewood Cliffs, 1999.

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