Study on Control of First Order Plus Delay Using Smith Predictor

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Abstract

This paper presents the implementation of Smith predictor structure for the control of a first order plus delay time process. Water heater for vacuum distillation apparatus is studied, the open loop transfer function shows a first order plus delay time. The control system is analyzed using open loop Bode plot and root locus method through “sisotool” in MATLAB control tool box. The Smith predictor control design carried out using MATLAB (7.11.0) command windows. The controller gain is found to be 96.3 and the integral time 256.4

Keywords**:** Smith predictor, FOPDT, First order plus delay time, Process control.

Introduction

Many tuning methods exist to predict the three PID gain parameters from the open loop transfer function, the most common ones are the Ziegler-Nichols process reaction method and Ziegler-Nichols ultimate-cycle method (continuous method). These relations are listed in Table (1). The listed equations are empirical, the 2nd one is an online tuning used for processes which are inherently stable. But where the system may become unstable, a proportional only control is used. If it is not possible to disable the integral and derivative control modes, the integral time should be set to its maximum value and the derivative time to its minimum. The proportional gain is slowly increased until the system begins to exhibit sustained oscillations with a given small step set point or load change. The proportional gain and period of oscillation at this point are the ultimate gain, Kcu, and ultimate period, Tu. These two quantities are used in a set of empirical tuning relations developed by Ziegler and Nichols-again listed in Table (1). These methods are thoroughly described in Chau (2001) [1, 2].

Stability can be studied by Bode and Nyquist plots. Bode plot is magnitude vs. frequency and phase angle vs. frequency plotted individually on a logarithmic scale. These plots address the problem but need other methods to reveal the probable dynamic response. Nyquist plot is a polar coordinate plot, thus the real and imaginary parts of G (jω) on the s-plane with ω as the parameter.

Table (1)
Zigler Nichols PID parameters for process reaction and continuous methods.

Method	*Controller Type*	*Ki*	*Ti*	*Td*
Process Reaction Method	P	1/RD	---	---
	PI	0.9/RD	D/0.3	---
	PD	1.2/RD	2D	0.5D
continuous method	P	Ku/2		
	PI	Ku/2.2	Tu/1.2	
	PD	Ku/1.7	Tu/2	Tu/8

Chemical processes may be self-tuned, for self-tuning the controller took measurements from field and calculates the three term control parameters automatically. to improve that, the controller should optimize the parameters for minimum error. Many chemical processes shows a delay time. In 1957, O. J. Smith developed the Smith predictor structure to compensate systems with time delay, where it is too difficult to control processes with long time delay using PID algorithm [3, 4].

The predictor is based on the idea of decreasing the manipulated variable by an amount equal to all that was computed in the last τ seconds A control scheme is shown in Fig.(1) [5,6]. Jianhong M. gives an equivalent transformation of the Smith predictor scheme as shown in Fig.(2) [9].

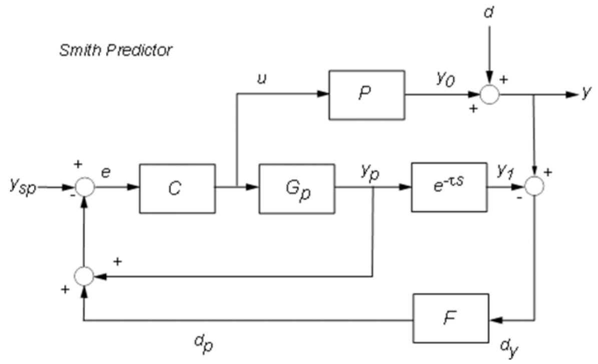


Fig. (1) Signal flow diagram of a Smith-Predictor.

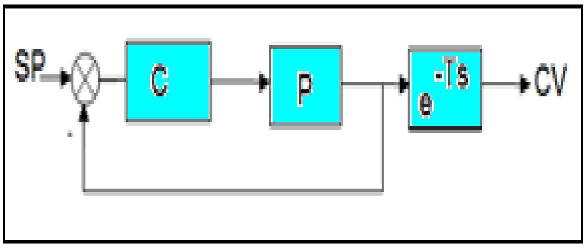


Fig. (2) Equivalent transformation of the Smith predictor scheme [9].

The aim of the work is to design a Smith controller to control a FOPDT process which is widely used in industry to describe the dynamics of many processes.

Experimental Apparatus

The apparatus used in this study is from Hanover, rotary vacuum distillation apparatus, Model HS-202005S, 220v, 50Hz, 1000W heater, equipped with on off controller. It is shown in Fig.(3). Readings were recorded with time, to get the open loop response, mere switched on directly on manual action.

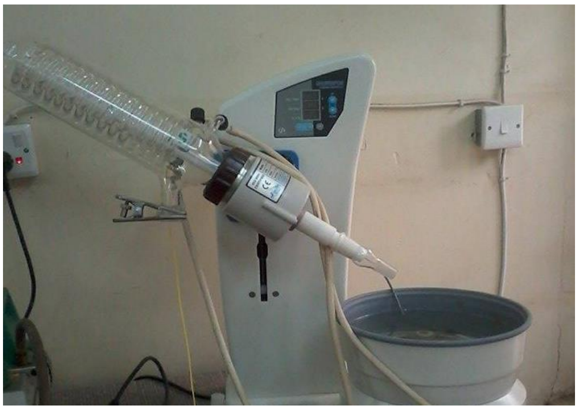


Fig.(3) The experimental apparatus.

Results and Discussion

Water Heater 1000 watt switched on at t=0 sec then switched of at t=5000 sec. the experimental response shows a FOPDT system. The process open loop response is modeled as a first-order plus dead time with a 900 second time constant and 47 second time delay Because 47 sec is very small compared with3000 sec, the time delay is not clear in the drawing. See Fig.(4) for open loop response.

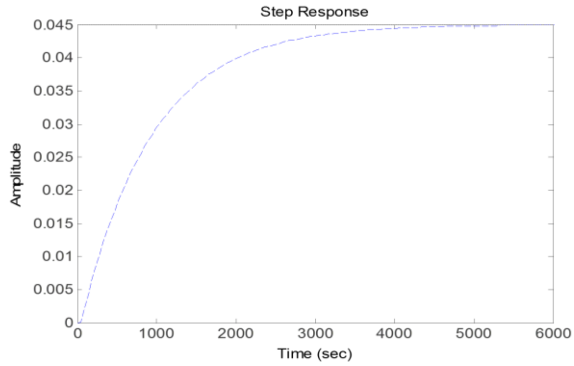


Fig. (4) Open loop transfer function.

$G(s) = \frac{T(s)}{PW(s)}$ .... (1)

The transfer function is written in Matlab command window:

```
>>s = tf('s');
>>P = tf(0.045,[900 1],'InputDelay',47)
>>P. Input Name = 'u'; P. Output Name = 'y';
```

$P(s) = \frac{0.045}{900\,S+1} e^{-47\,s}$

```
>> step (P)
   grid on
```

The open loop transfer function is shown in Fig.(4). Its shown that delay is very little when compared with the time constant because the analysis is carried out on experimental apparatus. For industrial purposes the time delay will be large because of the equipment size, and the quantities of fluids. Now a basic controller design is carried using Matlab control toolbox, the predicted controllers are tabulated in Table (2).

The step response for open loop transfer function (OLTF) is not enough to characterize the system, so it is necessary to use Bode plots to see the crossover gain and the stability of the system. Bode plots shown in Figs. (5, 6, 7 & 8) gives a good idea of stability, and cross over frequency.

Table (2)
Matlab suggested controllers "classical control design.

	P	*PI*	*PID*	*PID+DF*
Compensator Equation	444.73	$2.839\frac{(1+1400\,s)}{s}$	$5.678\frac{(1+47s)(1+47s)}{s}$	$50678\frac{1+96s+(49s)^2}{s}$
Crossover frequency @ 0 dB	0.013	0.0012	0.0012	0.002
Closed loop stable	yes	yes	yes	yes
Gain Margin @ min Stability margin	.0341 rad/sec @ 3.72 dB	.029 rad/sec @ 3.02dB	0.0503 rad/sec @ 2.63dB	0.048 rad/sec@ 1.97dB

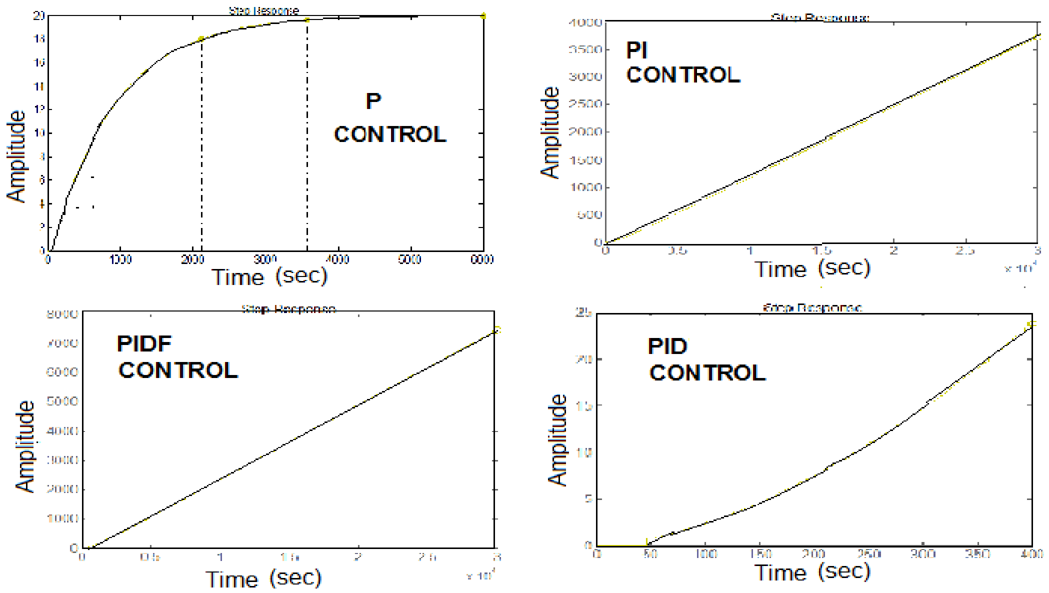


Fig. (5) O.L Response to step input for the 4 controllers.

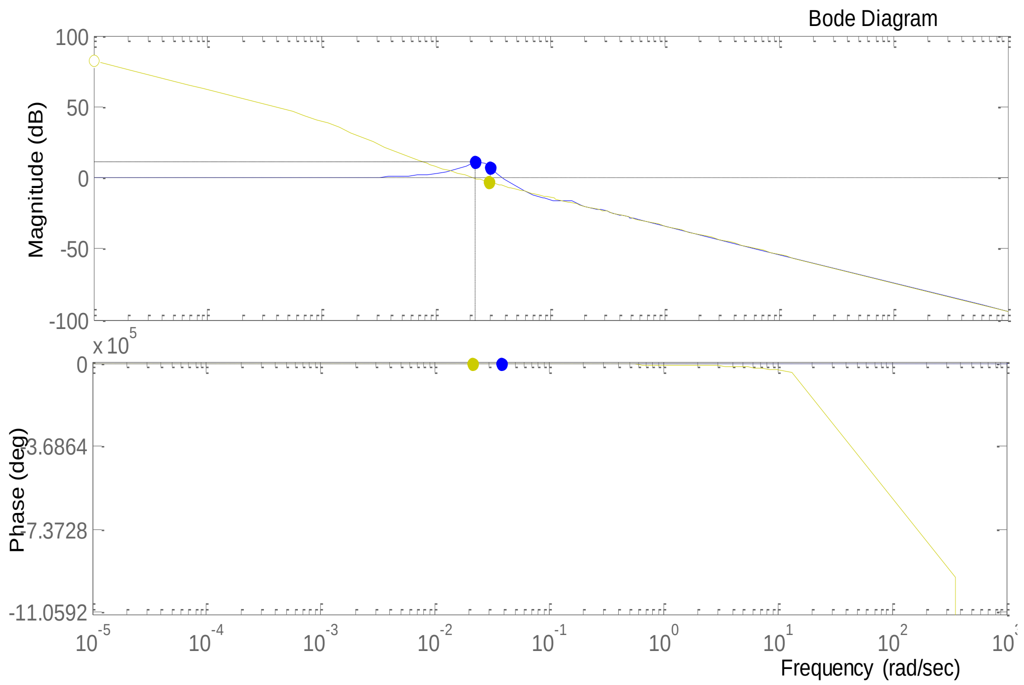


Fig. (6) Bode plots for PI- control system.

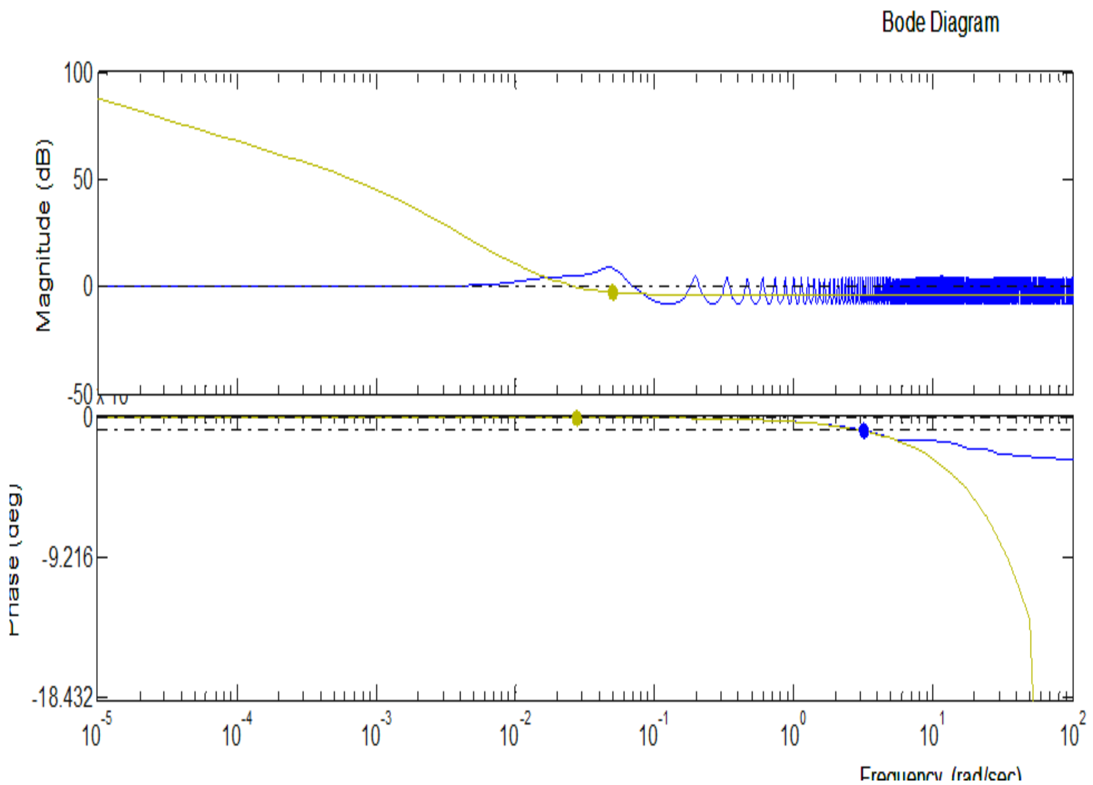


Fig. (7) Bode plots for P- control system.

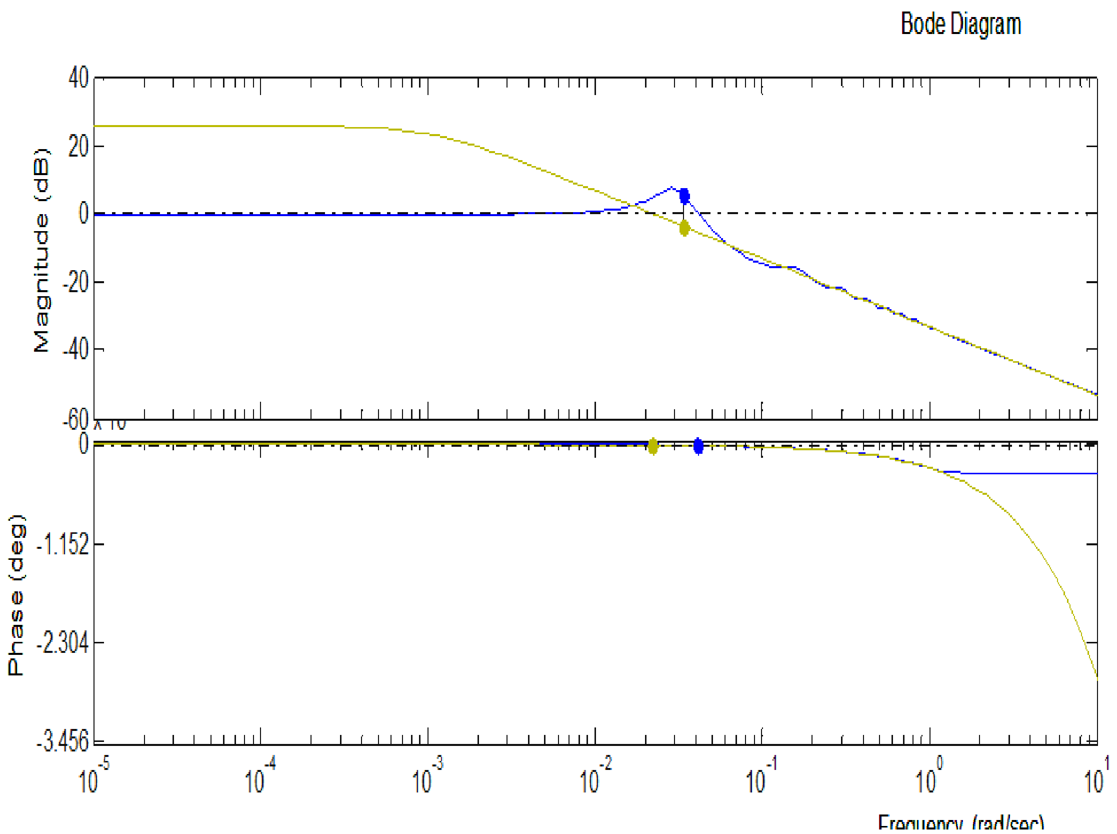


Fig. (8) Bode plots for PID- control system.

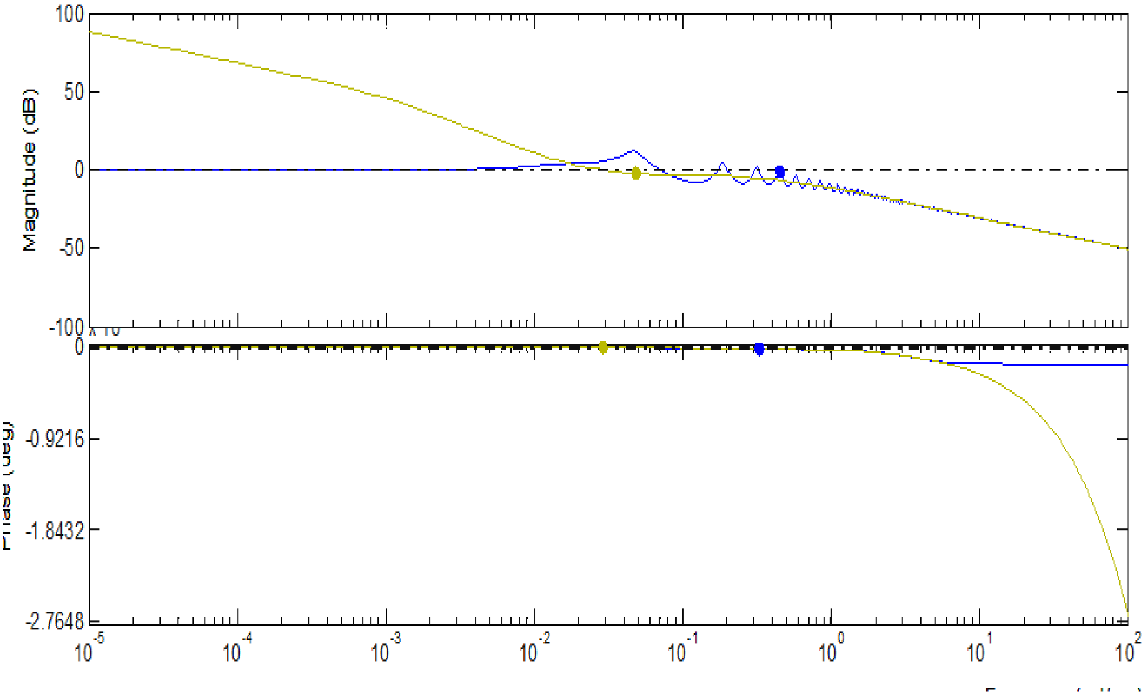
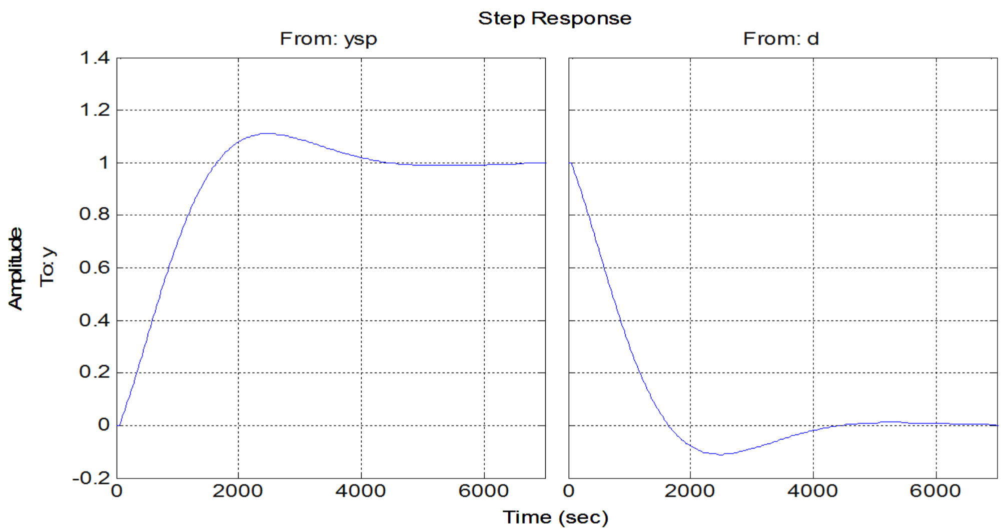


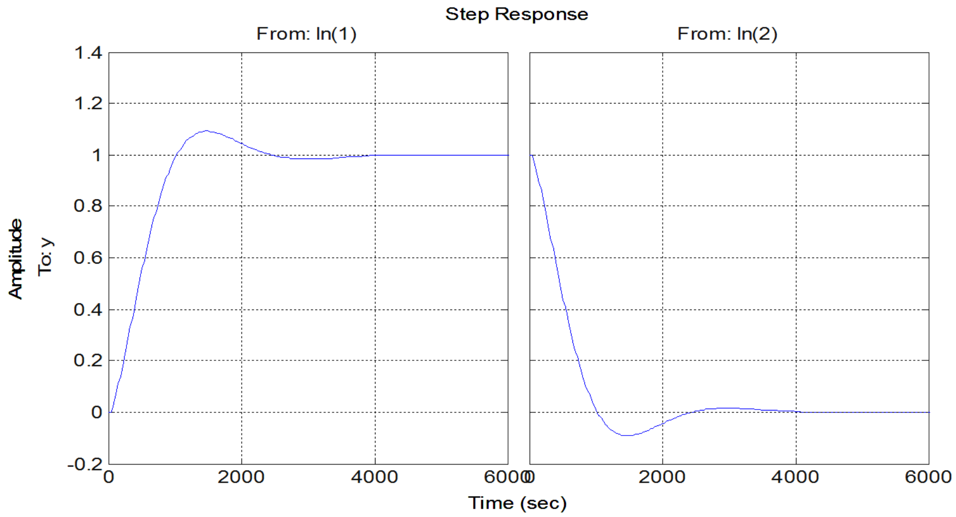
Fig. (9) Bode plots for PIDF- control system.

Response to load variation and set point variation is also studied, the results is shown in Fig.(10).

The response to step change in the input (set point) is shown in Fig.(11) for the three controller types.



PI– Control



(b) PIDF – control

Fig.(10) Response to set point ysp and disturbance (d).

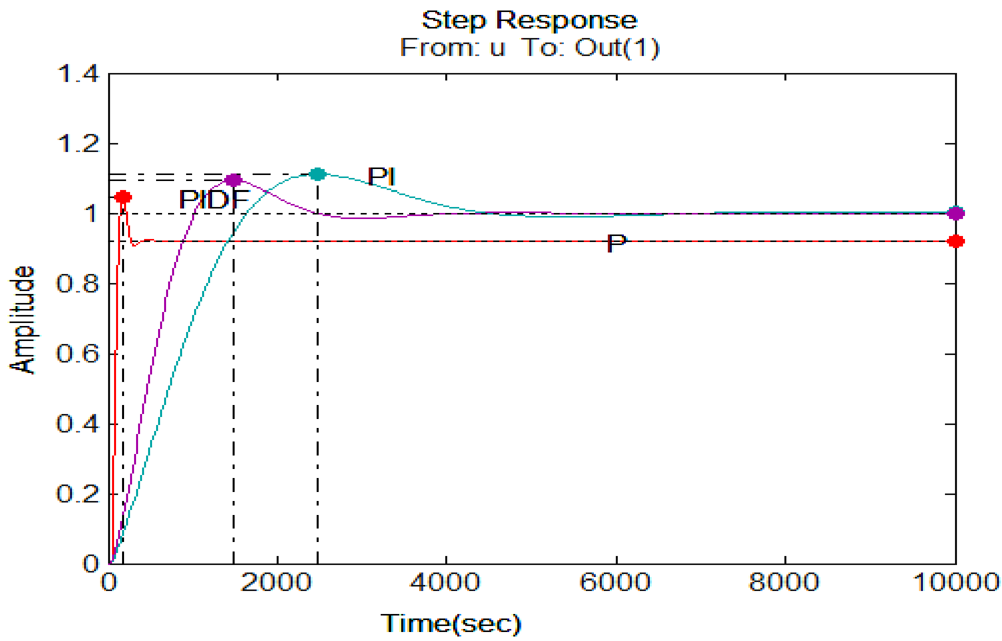


Fig. (11) Comparison between P,PI, PIDF Control response to step input.

The performance of the PI controller is severely limited by the long dead time. So in order to treat the time lag effects, the control system should wait before response taking action. Smith predictor treats that.

Smith Predictor

The predictor scheme is shown in Fig.(1) previously stated. Construction of the model is taken through the following program.

Computer Program

```
%Control of Processes with Long Dead Time:
The Smith Predictor
s = tf('s');
P = exp(-47*s) * 0.0045/(900*s+1);
F = 1/(20*s+1);F. Input Name = 'dy'; F. Output
Name = 'dp';
% Process
P = ss(P); P. Input Name = 'u'; P. Output Name
= 'y0';
% Prediction model
Gp = .0045/(900*s+1); Gp. Input Name = 'u';
Gp. Output Name = 'yp';
Dp = exp(-47*s); Dp. Input Name = 'yp'; Dp.
Output Name = 'y1';
% Overall plant
Sum1 = sumblk ('e','ysp','yp','dp','+--');
Sum2 = sumblk ('y','d','y0','++');
```

```
Sum3 = sumblk ('dy','y','y1','+-');
Sum4 = sumblk ('ym','dp','yp','++');
Plant = connect (P, Gp, Dp, F, Sum2, Sum3,
Sum4, 'u', 'ym');
% Design PI controller with
C = pidtune (Plant, pidstd (1,1), pidtune
Options ('Crossover Frequency', 0.0012,'
Phase Margin',60));
C. Input Name = 'e'; C. Output Name = 'u';
% Assemble closed-loop model from [y_sp,d]
to y
Cpi=C;
Tpi = feedback([P*ss(Cpi),1],1,1,1); % closed-
loop model [ysp;d]->y
Tpi. Input Name = {'ysp' 'd'};
Step (Tpi), grid on
T = connect (P,Gp,Dp,C,F, Sum1, Sum2,
Sum3, Sum4,{'ysp','d'},'y'); step (T,'b',Tpi,'r--')
```

C

Continuous-time PI controller in standard form, from input "e" to output "u":

$Kp*(1+\frac{1}{Ti}*\frac{1}{s})$

with Kp = 96.3331, Ti = 256.3668

Results have are the same because the time delay is small. So there is no need for it here but if the delay time is large relative to the time constant, then it is necessary to add it in the control program.

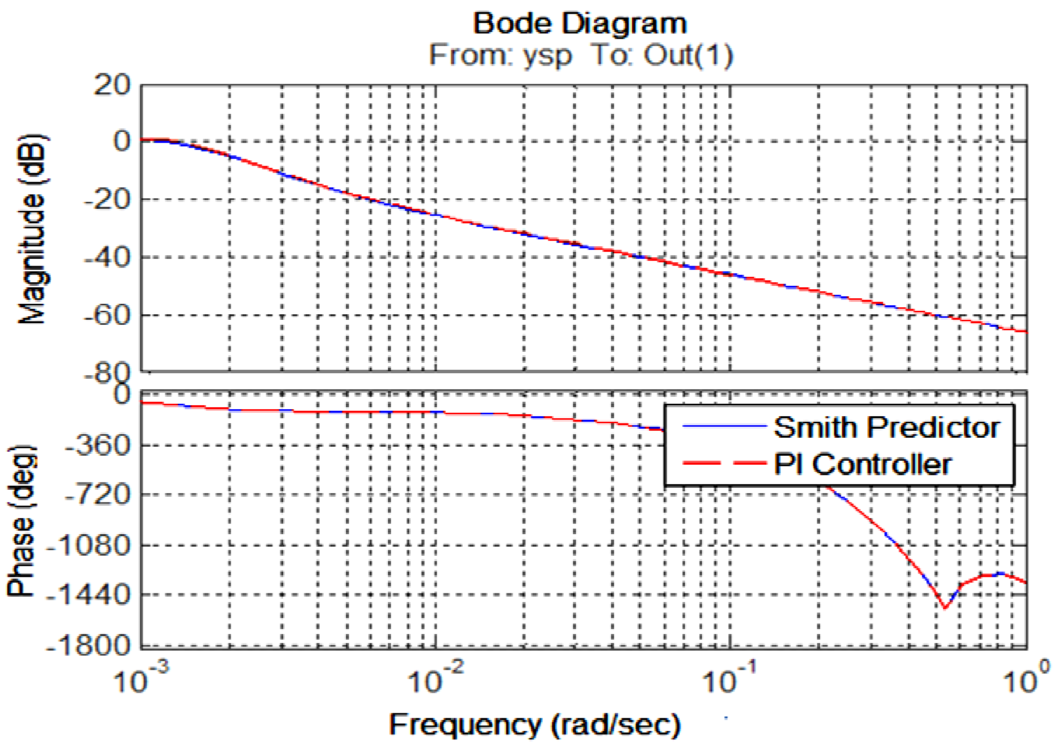


Fig. (11a) Bode plots comparison between PI- Control and Smith predictor.

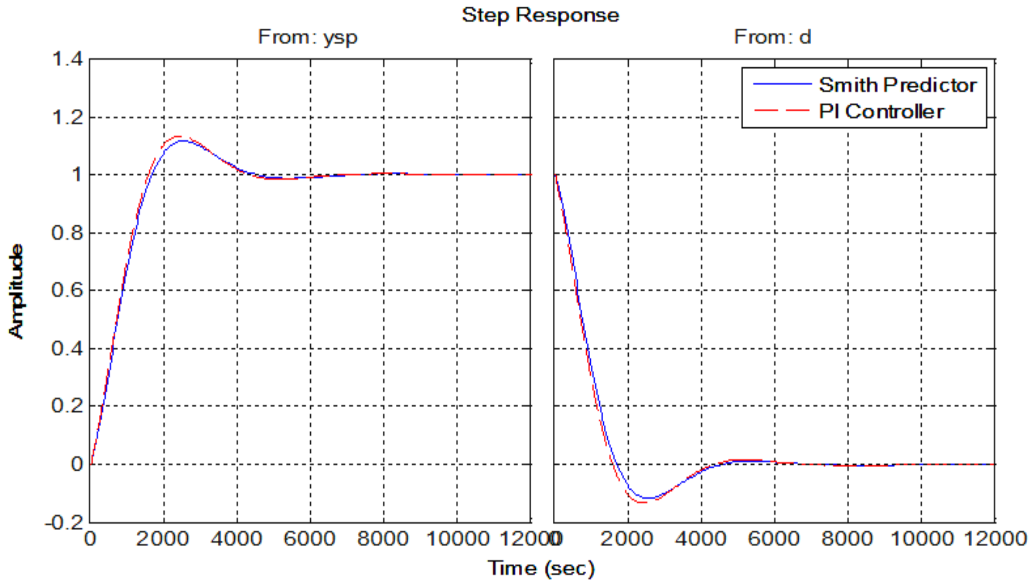


Fig. (11b) Control response to step input comparison between PI- Control and Smith predictor.

Conclusion

It has been shown that PI-control system has no difference than PID control, for phase margin an crossover frequency, but smith predictor achieves the best overall results for responses. it can be noticed that the Smith predictor structures are simple to tune,

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الخلاصة

يتضمن هذا البحث تطبيق تركيب مخمن سمث للسيطرة على عملية من الدرجة الاولى مع مؤخر زمني. استخدم في الدراسة جهاز تقطير فراغي مختبري, وقد اظهرت البيانات التجريبية ان العملية من الدرجة الاولى بوجود مؤخر زمني FOPDT. تم تحليل منظومة السيطرة للدائرة المفتوحة باستخدام طريقة رسم بود Bode plot وطريقة مواضع الجذور Root locus من خلال تقنية sisotools في نافذة الاوامر لبرنامج الماتلاب اصدار (٧,١١,٠). اجري تصميم تركيب مخمن سمث في نفس البرنامج وقد وجد بان قيمة العامل التناسبي للمسيطر =٩٦,٣ وعامل زمن التكاملي =٢٥٦,٤.