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Comparison of PID Dead-Time Compensators for Industrial Systems using Smith-Rule

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Abstract: ***A dead-time is usually associated with input and output of industrial control systems. This dead-time is not fixed during the process function so conventional PID controller cannot be designed using normal methods. An adaptive scheme is designed to control systems using the prediction method of Smith Adaptive Rule. The paper gives the comparative study between the normal smith predictor(SP), modified smith predictor(MSP) and flexible smith predictor(FSP) based on their performance , robustness and stability using magnitude optimum multiple integration (MOMI) Controller Tuning method in MATLAB-SIMULINK. A MATLAB program with an objective is written to find out the optimum value for the PI controller parameter to maintain robustness and removal of dead time effect from system.***

Keywords: Dead-Time, Smith Predictor, PID Controller, MOMI Controller Tuning method, MATLAB, SIMULINK.

1. Introduction

In general, most of the process industries are facing major issues in controlling the various parameters. 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. Process delay which is known as dead-time in the industrial control systems is one of the major issue. In some of the cases the dead-time is fixed for the whole process so conventional PID controller [1] may be used to achieve desired performance of system. While in other cases the dead-time varies during operation of system due to characteristics and structural behavior of system. Therefore, prediction algorithm is needed to predict the dead-time and controlling the system. For this prediction Smith Rule is used and stability, performance of system is analyzed. The Smith predictor [2] is a popular and very effective long dead-time compensator for stable processes. The main advantage of the Smith predictor method is that the time delay is effectively taken outside to the control loop in the transfer function relating the process output to set point. However, this approach fails in a very significant way for an unstable process owing to the problem of stabilization.

Dead-Time is the delay between the application of a control effort and its first effect on the process variable. During that interval, the process does not respond to the controller's activity at all, and any attempt to manipulate the process variable before the dead-time has elapsed fails. The most essential and standard algorithm used in the feedback control is the Proportional-Integral control algorithm [3] . 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. 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. 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. In order to work controller satisfactory, controller must be tuned appropriately. Fine-tuning of controller can be done in number of ways, depending on the dynamics of the system. In this paper we demonstrate the trade off of the FSP[5] method between normal SP[2] and MSP[6] using MOMI tuning method[4]. Following block diagrams can be used to understand the basic controlling action of SP, MSP and FSP.

The tuning procedure is based on the multiple integration method and requires only the process open-loop step response to calculate the parameters of the Flexible Smith Predictor.

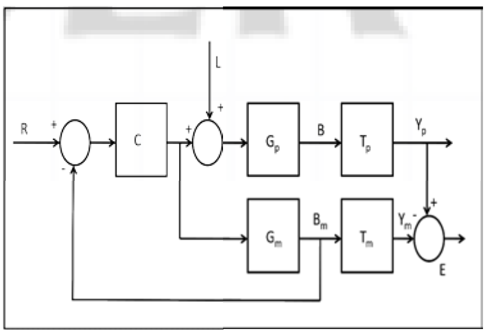

Figure 1.1: Basic Smith predictor

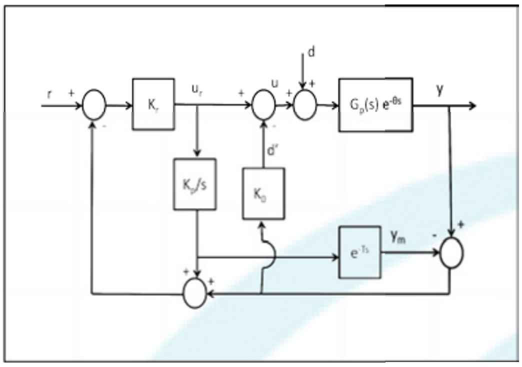

Fig. 1.2 Modified Smith Predictor

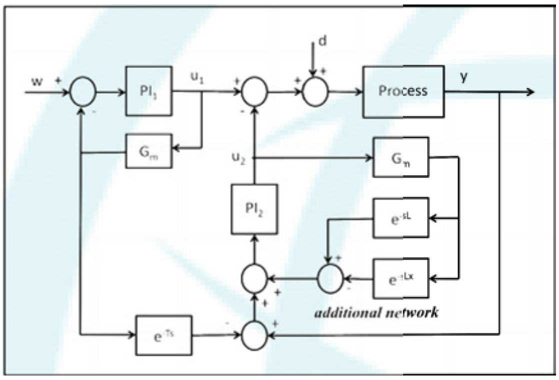

Fig. 1.3 Flexible Smith Predictor

2. FSP (Flexible Smith Predictor)

FSP is the extension of modified smith predictor control scheme(MSP)[6].As the FSP is improved version of MSP it gives desired trade-off between conventional SP and MSP o the basis of robustness and closed loop performance with disturbance rejection.

Conventional SP (fig 1.1) [2] lacks in robustness with respect to change in process parameters. This drawback is overcome using MSP (fig 1.2). The major advantage of MSP is, it has two PI controllers for reference tracking from load disturbance rejection. In order to improve disturbance rejection more an extra network is added in MSP scheme as shown (fig1.3).

FSP [5] scheme consist of two independent PI controller units. PI_1 is used for achieving desired speed of response with respect to reference signal and PI_2 is used for disturbance rejection.

L_x value is chosen by user which must be $L_x \geq 0$ .where $L_x = \alpha L$....... $0 < \alpha < 1$ and L is actual delay time.

When L_x=0, FSP acts as SP with fast response but reduced robustness. When L_x=L, acts as MSP with slower response but greater robustness. So, by selecting L_x, trade-off between response and robustness can be achieved as shown in table below:

Table: 1 Adjusting Lx

Lx	*Robustness*	*Performance*
0	low	High
L	High	Low
↑	↑	↓
↓	↓	↑

3. Controller Tuning

For tuning we use MOMI [4] (magnitude optimum multiple integration) tuning method. This method is particularly suitable for controller tuning on basis of step response. The MO method results in good closed loop response for large class of processes frequently used in industries with use of only simple PI controllers.

When applying the input step change ΔU, the process gain and first three areas can be obtained by integrating the process step response y(t). Following formulae are used for gain and area calculation [3].

$$A_0 = \frac{y(\infty)-y(0)}{\Delta U} \tag{1}$$

$$y_1(t) = \int_0^t \frac{y(\infty)-y(0)}{\Delta U} dt \tag{2}$$

$$y_2(t) = \int_0^t (A_1 - y_1(t))dt \tag{3}$$

$$y_3(t) = \int_0^t (A_2 - y_2(t))dt \tag{4}$$

where $A_1 = y_1(\infty)$, $A_2 = y_2(\infty)$, $A_3 = y_3(\infty)$

Hence, both controllers PI_1 and PI_2 can be easily tuned by calculating A_0 to A_3 and using following formulae for K_P and T_i.

$$K_p = \frac{A_3}{2[A_1 A_2 - A_0 A_3]} \tag{5}$$

$$K_i = \frac{A_2}{A_3} \tag{6}$$

4. Implementation of Discussion

The MATLAB code is written in order to take user defined transfer function and dead time so that it will tune the controllers using MOMI tuning and return the o/p response plot of the four process controlling models using FSP model i.e. simple PID, SP, MSP & FSP. Also we illustrate the effect of increase in process gain and increase in delay time by 20% on the above mentioned models.

For demonstration purpose we use following two different systems.

1) $G(s) = \frac{2.5}{s^3+2s^2+2s+1} e^{-5s}$

2) $G(s) = \frac{2.7}{2s^2+5s+6} e^{-3.9s}$

5. Consider First System

$$G(s) = \frac{2.5}{s^3+2s^2+2s+1} e^{-3s}$$

We implement above system in FSP scheme [5] in order to get response of all other schemes as follows:

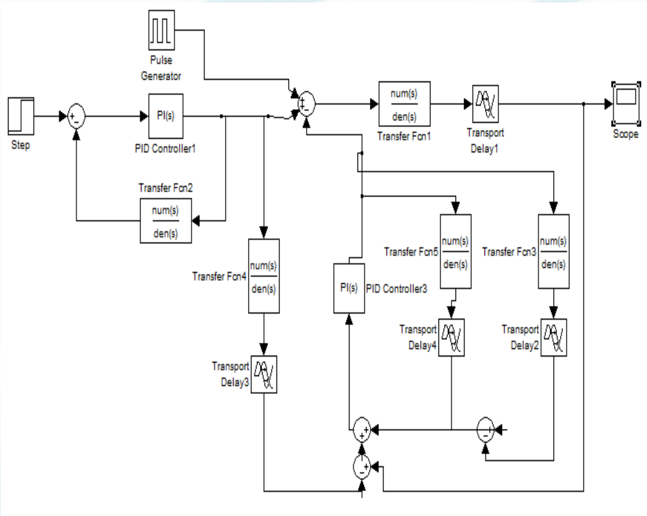

Figure 1: FSP Implementation

To get tuned controller parameters:

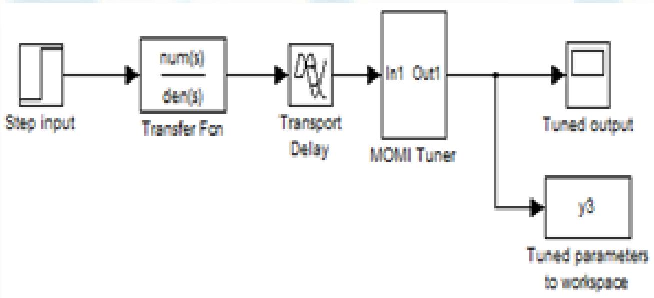

Figure 2: MOMI tuning method

After tuning we get controller parameters and the o/p response for tuned system is shown below. Observations for different parameters for each case of first system:

PI	K_p	K_i
1	0.0729	1.8716
2	0.0984	0.4336
3	0.0960	0.6855

Case I: Original process parameters

Control Scheme	*Settling time*	*Rise Time*	*Peak Time*	*% Mp*
Simple PID	25.10	14.40	19.90	5.891
Normal Smith	18.20	10.70	12.7	10.853
MSP	18.20	10.70	12.7	10.853
FSP	18.20	10.70	12.7	10.853

If there is change in delay time and process gain due to external disturbances then the response of tuned system is as below:

We consider 20% increase in delay time as well as in gain.

Case II: 20% increase in delay (L=6)

Control Scheme	*Settling time*	*Rise Time*	*Peak Time*	*% Mp*
Simple PID	39.95	15.2	19.90	15.113
Normal Smith	33.10	11.7	13.8	23.29
MSP	36.8	11.7	13.8	13.685
FSP	34.9	11.7	13.8	18.23

Case III: 20% increase in gain

Control Scheme	*Settling time*	*Rise Time*	*Peak Time*	*% Mp*
Simple PID	29.95	12.7	17.55	19.12
Normal Smith	24.5	10.10	12.7	33.04
MSP	29.8	10.10	12.7	33.04
FSP	26.9	10.10	12.7	33.03

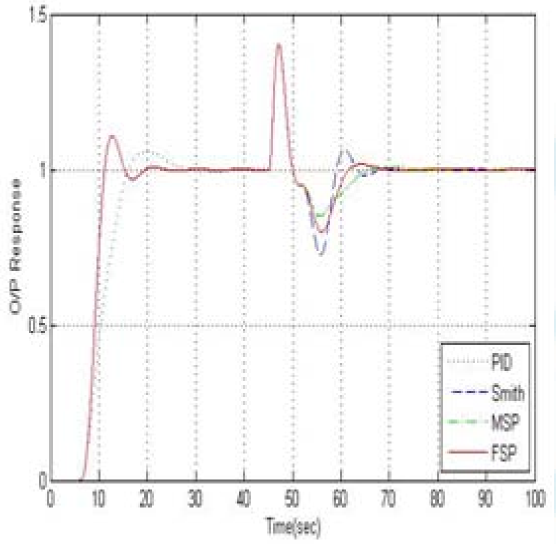

Figure 3: Original process parameters (L=5)

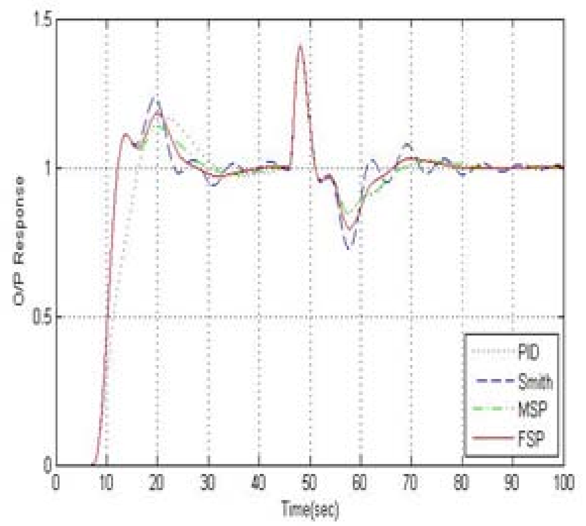

Figure 4: 20% increase in delay (L=.6)

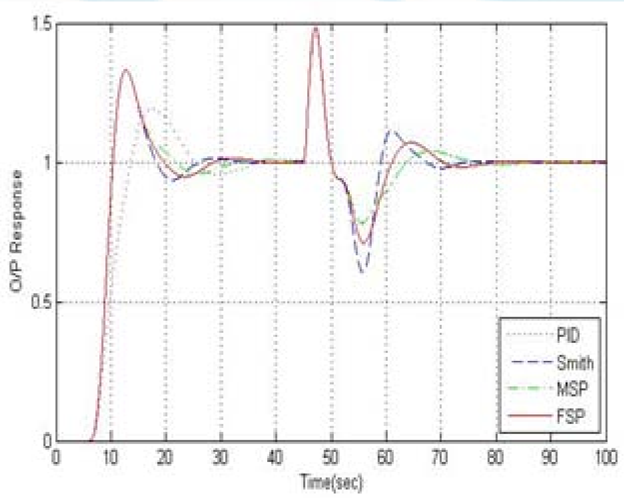

Figure 5: 20% increase in gain

6. Consider Second System

$$G(s) = \frac{2.7}{2s^2+5s+6} e^{-3.9s}$$

Similar implementation is also done in case of above system. Results of implementation are as follows:

PI	K_p	K_i
1	0.0927	15.5867
2	0.5536	0.6353
3	0.5420	1.0958

Case I: Original process parameters:

Control Scheme	*Settling time*	*Rise Time*	*Peak Time*	*% Mp*
Simple PID	17.25	10	13.7	6.077
Normal Smith	10.1	7.50	8.8	8.113
MSP	10.1	7.50	8.8	8.113
FSP	10.1	7.50	8.8	8.113

Case II: 20% increase in delay (delay L=4.68)

Control Scheme	*Settling time*	*Rise Time*	*Peak Time*	*% Mp*
Simple PID	28.95	10.65	15.2	18.396
Normal Smith	36.2	8.30	9.62	30.553
MSP	27	8.30	9.60	16.29
FSP	25	8.30	9.60	23.202

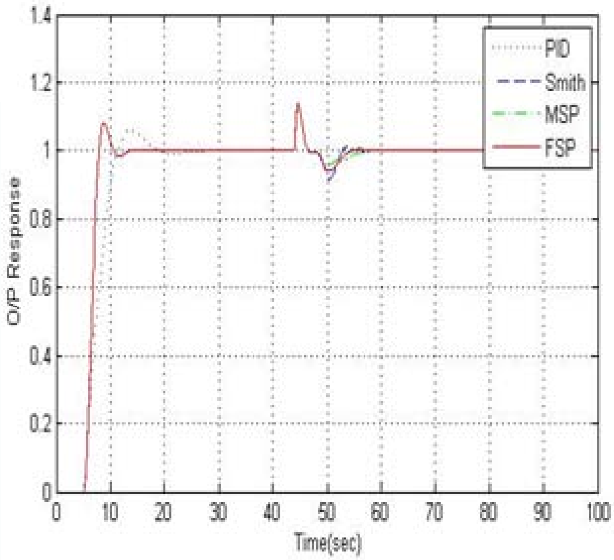

Figure 6: Original process parameters (L=3.9)

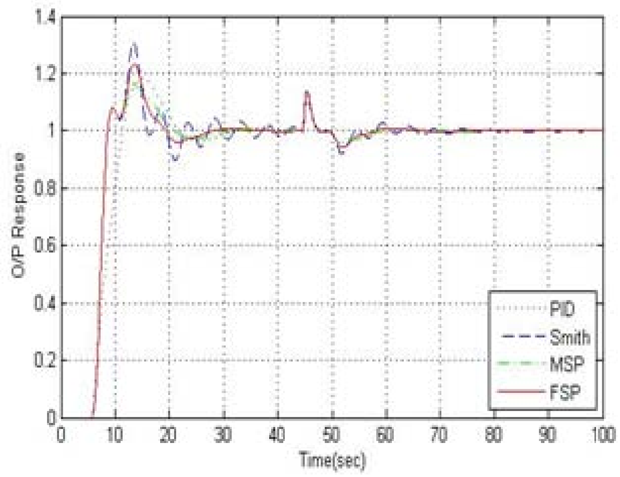

Figure 7: 20% increase in delay (L=4.68)

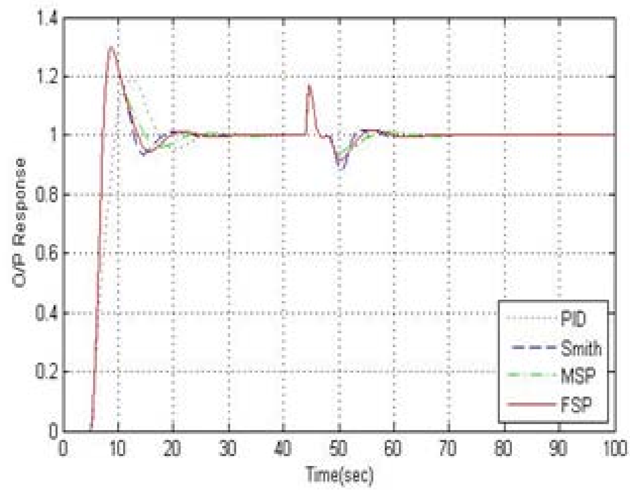

Figure 8: 20% increase in gain (L=3.9)

Case III: 20% increase in gain

Control Scheme	*Settling time*	*Rise Time*	*Peak Time*	*% Mp*
Simple PID	23.45	8.90	12.45	18.83
Normal Smith	17	7.10	8.80	29.37
MSP	20.50	7.10	8.80	29.37
FSP	18.20	7.10	8.80	29.37

From fig.3 and fig.6 we can see that the performance of simple PID controller [1] lags from that of Smith predictor schemes [2, 5, 6]. Although the set point responses of all the three smith predictor schemes are same, the disturbance rejection of conventional smith predictor (SP) is better than the other two schemes.

From figure 4,5,7,8 we can see that when the process parameters vary or, are not exactly known to us, the performance of SP degrades. But the MSP still gives a satisfactory response with minimum deviation from desired output. By comparing the response of MSP and SP, we can modify the value of Lx in FSP as mentioned in Table 1.

7. Conclusion

In this paper we have presented different types of control schemes for dead time compensation. Using conventional smith predictor, fast response is achieved as compared to simple PID controller. But for changing process parameters the performance of conventional smith predictor degrades. The implementation of Modified Smith Predictor (MSP) was used to overcome this drawback. But the disturbance rejection of conventional smith predictor outperforms MSP. The Flexible Smith Predictor (FSP) is so adjusted to achieve the desired trade-off between robustness and performance of the system.

References

[1] Astrom, K. J. and T. Hagglund "PID Controllers: Theory, Design, and Tuning (1995)" Instrument Society of America, 2nd edition.
[2] A. Terry Bahill "A Simple Adaptive Smith-Predictor for Controlling Time-Delay Systems A Tutorial" Biomedical Engineering Program, Department of Electrical Engineering, Carnegie-Mellon University, Pittsburgh, PA 15213
[3] Hagglund, T. "An industrial dead-time compensating PI controller (1996)" Control Eng. Practice, 4 (6), pp. 749-756
[4] "A magnitude optimum multiple integration tuning method for filtered PID controller": Automatica 37 (2001) 1473-1479 Technical Communique

[5] "Automatic Tuning of the Flexible Smith Predictor Controller" Proceedings of the American Control Conference San Diego, California June 1999

[6] M. R. Matausek and A. D. Micic "A Modified Smith Predictor for Controlling a Process with an Integrator and Long Dead-Time" IEEE Transactions on Automatic Control, VOL. 41, NO. 8, AUGUST 1996

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