Improved PI Controllers Tuning in Time-delay Smith Predictor with Model Mismatch

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***Abstract*— The problem Dead Time in control systems is an everlasting problem which is of primary importance in process control as well.**

The estimation and compensation of processes with time-delays have been of interest to academics and practitioners for several decades.The first proposed solutions for this problem was the Smith predictor in 1957. It was based on the idea of removing the time-delay from the characteristic equation of the control closed loop, which seemed to be very attractive at the first.Later investigations revealed that the method is very sensitive to model mismatches, which results in destabilizing effects on the loop performance.

In this paper, using work it was propose a new method for controller tuning using an optimization method. The optimization method is based on dominating the gain of the minimum phase term in the open loop transfer function of the loop, such that the non-minimum phase effects of the model and process become dominated by the minimum phase characteristic of the desired term. This idea was investigated by simulation on some selected examples among the proposed modified versions of the Smith predictor.

***Index Terms*— Smith predictor,Stability,Time-Delay,Model Mismatch,Optimization Tuning Algorithm, dominant gain.**

I. INTRODUCTION

When the process has a significant dead time, the performance of the closed-loop system can be improved by using a predictor structure. These predictor based controllers are known as dead-time compensators (DTC).

The first DTC structure, the Smith predictor, was presented to improve the performance of classical controllers (PI or PID controllers) for plants with dead time. It is one of the most popular dead-time compensating methods and most widely used algorithm for dead-time compensation in industry.

Watannabe and Ito [1] proposed a modified Smith predictor to eliminate this steady offset. Astrom et al. [2] point out that the resulting set-point response is very slow, and the steady offset cannot be eliminated if there is an estimating error in the process time delay. To overcome these drawbacks, they proposed a modified Smith predictor.

Zhang and Sun [3] simplified the modified Smith predictor and the design procedure. The four controller parameters are reduced to two and an analytical solution is provided. Later on, Zhang et al. [4] extended the new scheme to the control of stable plants. At the same time, there are many other researchers studying this problem and developed different methods. Also Chien and Fruehauf [5] showed a design example of industrial distillation columns with integrator and time delay. Matausek and Micic [6] developed an alternative two-degree-of freedom scheme.

And Ingimundarson and Hagglund [7] gave a frequency domain design. For recent developments, the readers are referred to Liu et al. [8]

Different from these methods, Normey-Rico and Camacho [9] recently modified the structure proposed by Watannabe and Ito [1] has developed empirical design formulas.

Over the past 25 years, numerous extensions and modifications of the SP have been proposed in order to:

1. Improve the regulatory capabilities of the SP for measurable or immeasurable disturbances
2. To allow its use with unstable plants
3. To improve the robustness
4. To facilitate the tuning in industrial applications

In this article a new method is presented to control stable delay processes in SISO and MIMO linear control system.

II. DEAD-TIME COMPENSATION AND PREDICTION

The open loop transfer function in Smith predictor is:

$$G_c G_m + G_c[G_p e^{-s\tau_p} - G_m e^{-s\tau_m}] = 0 \qquad (1)$$

Therefore for removing of time delay ideally, from the control loop (Figure 1), the term of $G_c(G_p e^{-s\tau_p} - G_m e^{-s\tau_m})$ must be equal to zero, But in new method we shows that if the term of $G_c(G_p e^{-s\tau_p} - G_m e^{-s\tau_m})$not equal to zero we can also obtain the good Performance, this mean is that we can also obtain the good performance with model mismatch.

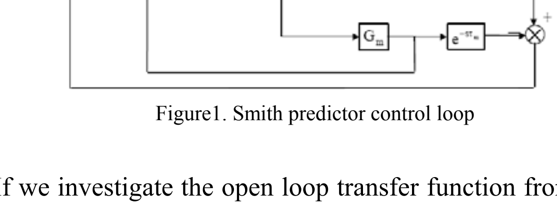

Figure1. Smith predictor control loop

If we investigate the open loop transfer function from the vector lookout the underside results are obtained:

1) Justification of existing time delay in $G_c G_p e^{-s\tau_p}$ and

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$G_c G_m e^{-s\tau_m}$ vectors, this vectors swirling rate are more than $G_c G_m$ vector.

2) If at the all frequencies the gain of $G_c G_m$ dominant of $G_c G_p e^{-s\tau_p}$ and $G_c G_m e^{-s\tau_m}$, consequent vector behavior allegiance from the $G_c G_m$ vector. Therefore if the $G_c G_m$ has minimum-phase behavior, the consequent vector also will have minimum phase behavior.

Therefore our objective in this paper is that using the dominant gain nature of $G_c G_m$ term and presented a new method for tuning of PI controllers and consequent Improving Performance of the control systems including Smith Predictor.

In this paper we recommend the new method and comparisons using the new method in Smith Predictor for Tuning of PI Controller and some of the modified Smith Predictors and at the end we will deduction.

In bellow figure suppose that:

$$G_1(s) = G_c G_m \quad (2)$$

$$G_2(s) = G_c G_p e^{-s\tau_p} - G_c G_m e^{-s\tau_m} \quad (3)$$

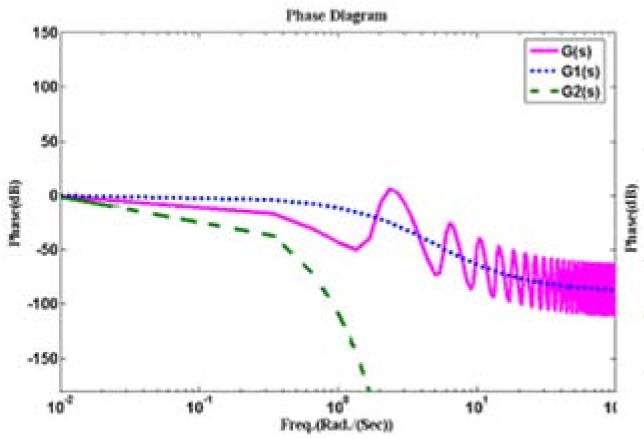

Figure 2. Phase behavior when term without time delay is the dominant term

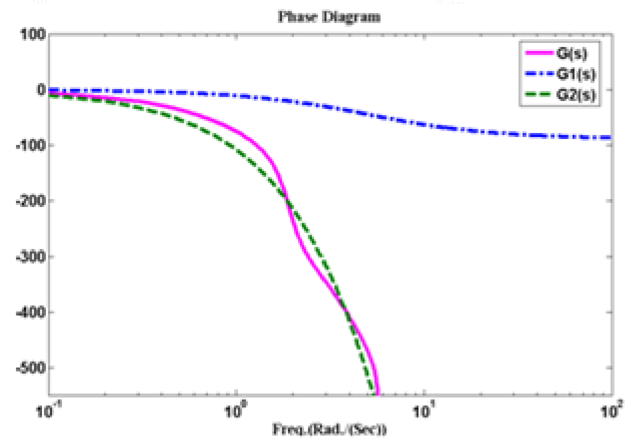

Figure 3. Phase behavior when term with time delay is the dominant term

III. How to Achieve a New Method and Compare Its Performance to Existing Methods

A. O'Dwyer's modified Smith predictor method: Initially, we use this method to achieve the new controller parameters. Transfer functions and parameters needed in this method are the following forms from [10].

$$G_p e^{-s\tau_p} = \frac{2}{18s^3 + 22.5s^2 + 8.5s + 1} e^{-s} \quad (4)$$

$$G_m e^{-s\tau_m} = \frac{1.82}{7.8s + 1} e^{-3.47s} \quad (5)$$

$$B(s) = \frac{(7.68s + 1)}{(7.68s + 20)} \quad (6)$$

PI controller transfer function is as follows:

$$G_c = \frac{k_c \tau_I s + k_c}{\tau_I s} \quad (7)$$

We come up with the relevant terms, G_1 and G_2 from open loop system transfer function:

$$G_1 = G_c G_m = \left(\frac{k_c \tau_I s + k_c}{\tau_I s}\right)\left(\frac{1.82}{7.68s + 1}\right) \quad (8)$$

$$G_2 = G_c G_p e^{-s\tau_p} - G_c G_m e^{-s\tau_m} \quad (9)$$

$$= \left(\frac{k_c \tau_I s + k_c}{\tau_I s}\right)\left(\frac{2}{18s^3 + 22.5s^2 + 8.5s + 1} e^{-s} - \frac{1.82}{7.68s + 1} e^{-3.47s}\right)$$

Our purpose in this section is to optimize the value of $\frac{|G_2|}{|G_1|}$ To do this, we must first achieve the optimized values of ω and λ.

We define the new function of $\psi(s)$ in this way:

$$|\psi(s)| = \frac{|G_2(s)|}{|G_1(s)|} = f(s) = f(\omega) \quad (10)$$

With differentiation of $\psi(s)$ from ω and putting it equal to zero, we can obtain the optimum values for ω and λ. Now with $\frac{d|G_2|}{d\omega}$ and putting optimum w in it, new values of τ_I, k_c are calculated.

$$G_c = \frac{3.61s + 1}{3.61s} \quad (11)$$

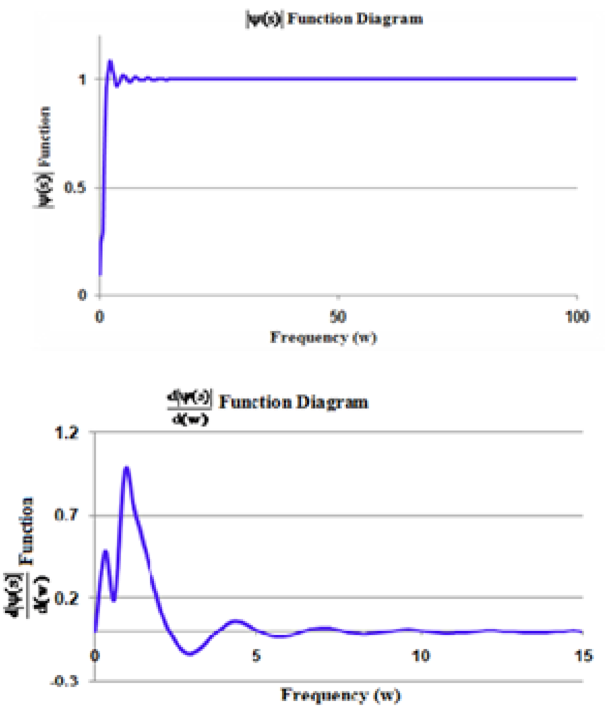

Figure 4. $|\psi(s)|$ And $\frac{d|\psi(s)|}{d(\omega)}$ diagrams when ω has increased

Comparison of the results of proposed method and Smith-O'Dwyer's improved method:

To determine the advantages of this method, step responses on the specified amount and the noise regulations method are compared with the proposed method compared to Smith-O'Dwyer's improved method.

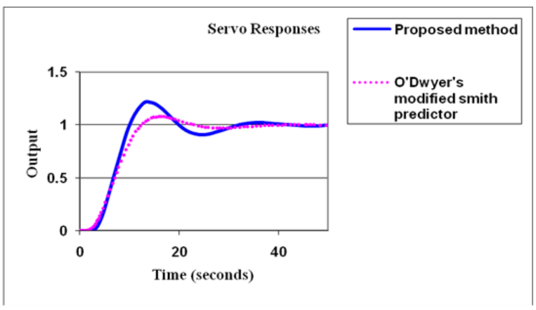

Figure 5. Comparison of the servo responses to the step change of the proposed method And O'Dwyer's modified Smith predictor.

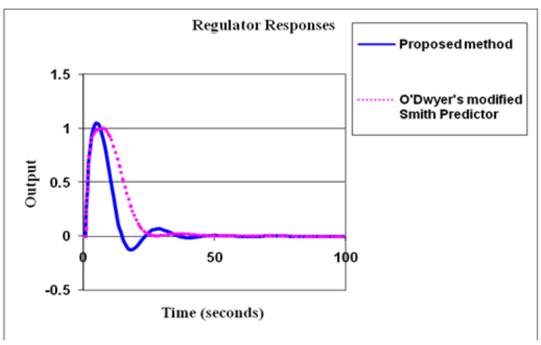

Figure 6. Comparison of the regulator responses to the step change of the proposed method And O'Dwyer's modified Smith predictor.

It is clear that in the new method, there is an acceptable improvement in the response to step change disturbance, but in response to the set point step change, integral value of error of the proposed method is more than the O'Dwyer's method and its reason is the more fluctuate in response to the new method at the step prescribed amount.

As shown in 5 and 6 figures, the responses from the new method have a more overshoot, but in terms of response speed, the new method shows an acceptable improvement. Later, we compare the integral absolute error to the O'Dwyer's method.

Table 1. Comparison of IAE amounts of the proposed method and O'Dwyer's modified Smith predictor

	IAE	
	Servo responses to the step change	regulator response to the step change
proposed method	8.2495	10.0204
O'Dwyer's modified Smith predictor	8.0838	15.2122

B. Comparison of proposed method to Rico and Camacho method: Transfer functions used for finding the parameters of controller design based on the transfer functions used in the Rico and Camacho method have been extracted from [11].

$$G_c = \frac{6.172s+1}{6.172s} \qquad (12)$$

This has improved the stability of the structure of the proposed method compared to the improved time delay Rico and Camacho.

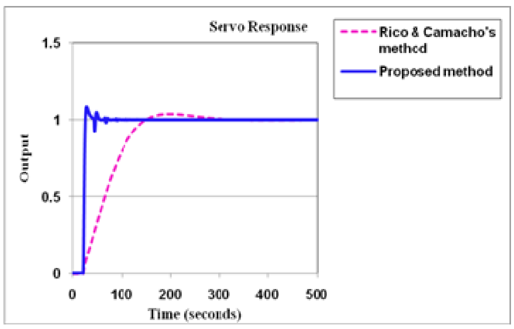

Figure 7. Comparison of the response to the step change set point amount of the proposed method and structure of the Rico and Camacho improved method

In this method, response rate has significantly improved compared to Rico and Camacho method. The value of the integral absolute error in the proposed method is 24.5952 and in the Rico and Camacho method is 73.2877(Figure 7).

C. Watanabe's modified Smith predictor method: Transfer functions used for finding the parameters of controller design based on the transfer functions used in the Watanabe's method have been extracted from [11].

$$G_c = \frac{6.172s+1}{6.172s} \qquad (13)$$

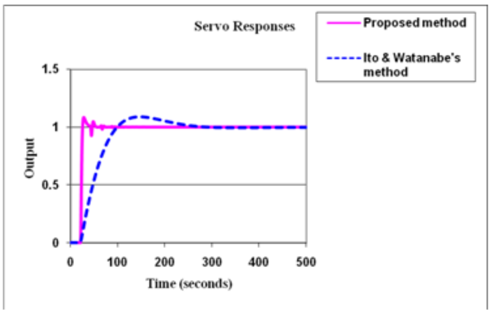

Figure8. Comparison of the response to the step change set point amount of the proposed method and structure of the Watanabe's method

As shown in figure (8) in this method, response rate has improved compared to Watanabe's method. The value of the integral absolute error in the proposed method is 24.5952 and in the Rico and Camacho method is 60.5881.

D. Majhe and Atherton's method and Xiang –Lu and partner's method**:** The following figure (Figure 9) shows that the response speed of the new method is faster than the other methods. Also Majhe and Xiang-Lu's control systems are unstable while the system that is tuning by the new method reaches the stability after some fluctuation.

Transfer functions used for finding the parameters of controller design based on the transfer functions to overwrought by this method, have been extracted from [12]

$$G_c = \frac{6.818s + 2}{3.409s} \quad (14)$$

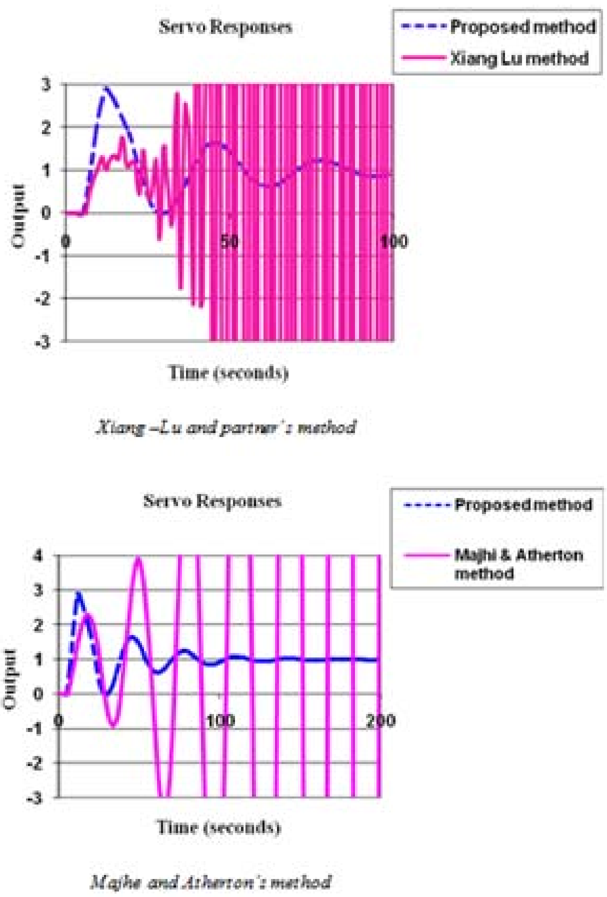

Figure 9. Comparison of the response to the step change set point amount of the proposed method and other structures

IV. Result

Any lack of conformity between the model and process control system can cause instability and the effects of non-compliance in terms of time delay in stability of system is more than the effects of non-compliance in fractional parts of model and process transfer function.

Unlike smith' opinion, complete lack of conformity between the model and the process never happens, so to achieve a good control structure we should always seek improved methods of smith or new methods of planning controllers. In this case, we can improve the performance of time delay smith predictor controller.

Using the property as the top destination without time delay when open-loop control system transfer function of Smith's predictor , helps us to present a new method of controller tuning parameters. New methods using this property could provide optimum PI controller parameters. After the placement of designed controller in the Smith's model, a new good performance of this method compared to other methods was observed.

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