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Set Point Weighted Modified Smith Predictor for Higher Order Integrating Processes with Time Delay

P. Deepa, V. Vijayan, D.Sankaran, V.Supraja

Abstract: This Paper Presents About The Synthesis Of Two-Degree-Of-Freedom Control Structure Based On Modified Smith Predictor Control For Higher Order Integrating Processes With Time Delay. This Control Synthesis Is Done Based On Chengqiang Yin Method. It Has Two Pid Controllers- One Is Set Point Tracking Controller Based On Direct Synthesis Method And The Other Is Disturbance Rejection Controller Based On Imc Principle. In This Work, A Set Point Weight Is Added With Pid Controller To Reduce Peak Overshoots And Settling Time In The Modified Smith Predictor. Two Simulation Examples Are Given To Demonstrate The Validity Of This Method.

Key Words: Modified Smith Predictor, Two-Degree-Of-Freedom Control, Integrating Processes, Set Point Tracking, Disturbance Rejection, Direct Synthesis Method, Imc, Set Point Weighted Pid.

I. INTRODUCTION

While designing PID controllers if there occurs a large dominant time constant in a process, the dynamic response of the process becomes slower. In such a case, Two-degree-of-freedom control structure have been used based on Smith principle in order to deal with larger time delays. A survey has been carried out for various control methods of Smith predictors for various processes. Chengqiang Yin et al. [1] proposed a method for Enhanced PID controllers design based on modified Smith predictor control for unstable process with time delay. He used two PID controllers in his structure for set point tracking and disturbance rejection which can be adjusted independently.

Seshagiri Rao et al. [2] proposed a simple method of modified Smith predictors for integrating and double integrating process with time delay. Set point weighted PID control structure has been used and he used two controllers for set point tracking and disturbance rejection. Kaya [3] proposed a two-degree-of-freedom IMC structure and controller design for integrating processes based on gain and phase-margin specifications.Simple tuning rules are used to tune the PD controllers for integrating process with dead time to obtain desired gain and phase margins. Vilanova et al. [4] discussed about robust PI/PID controllers for load disturbance rejection. Nivetha [5] explained aboout tunbale method of PID controller for conical tank system. Grimholt and S. Skogestad [6] proposed an optimal PI/PID controller for first order plus delay process. Mandić et. Al [7] explained about dominant pole placment with fractional order controller.

Angel sujitha et al. [8] explained aboout tunbale method of PID controller for cascade system. Seer and Nandong [9] proposed a stabilization method and PID tuning algorithms for second-order unstable processes with time-delays. Ahila Devi [10] explained about Optimal Disturbance Rejection Method of PI Controller for Conical Tank System. Shahni et al. [11] explaied about Rapid estimation of PID minimum variance. Gao et.al [12] proposed a Novel Data-Driven Method for Simultaneous Performance Assessment and Retuning of PID Controllers. Yumuk et al. [13] proposed an analytical pid controller design based on bode's ideal transfer function plus time delay. Sardella [14] desing a controller based on linear algebra from a Reduced-Order Model for Regulation and Tracking of Chemical Processes under Uncertainties. Chengqiang Yin et al proposed a method based on two-DOF control structure by using Smith controller. In this work, the same method is implemented by adding set point weight to it for higher order integrating process with time delay.

II. CONTROLLER DESIGN

The modified Smith control structure proposed by Chengqiang Yin et al. is shown in figure 1 which uses two-degree-of-freedom structure. $K_1(s)$ is the set point tracking controller and $K_2(s)$ is the disturbance rejection controller. The analysis has been carried out for the given transfer function model:

$$P(s)=\frac{Ke^{-\theta s}}{s(Ts+1)} \qquad (1)$$

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* Correspondence Author

P. Deepa*, Associate Professor, Dept Of Eie, St. Joseph's College Of Engineering, Chennai 600119 deepakumaran2002@Gmail.Com,
V. Vijayan, Professor, Dept Of Eie, St. Joseph's College Of Engineering, Chennai 600119 vinvpn@Gmail.Com
D.Sankaran, Assistant Professor, Dept Of Eie, St. Joseph's College Of Engineering, Chennai 600119dsankaran72@Gmail.Com
V.Supraja, Pg Student, Dept Of Eie, St. Joseph's College Of Engineering, Chennai 600119 Suprajavenkat12@Gmail.Com

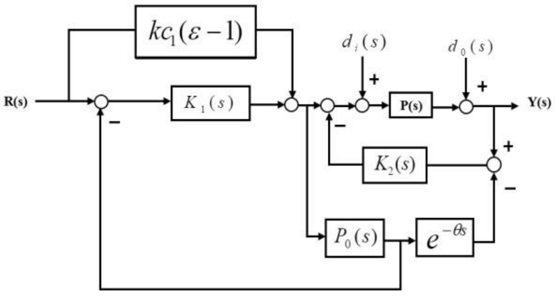

Figure 1. Modified Smith Control Structure

From figure 1, the transfer function from y(s) to r(s) can be determined in the form,

$$H_r(s)=y(s)/r(s)=\frac{P(s)K_1(s)}{1+P_0(s)K_1(s)}\frac{1+K_2(s)P_0(s)e^{-\theta S}}{1+K_2(s)P(s)} \tag{2}$$

The set point tracking controller $K_1(s)$ and disturbance rejection controller $K_2(s)$ given by Chengqiang Yin method is as follows

$$K_1(s)=\frac{(Ts+1)(a_2S^2+a_1S+1)}{K(\lambda^3S^2+(3\lambda^2-a_2)s+(3\lambda-a_1))} \tag{3}$$

The parameter obtained as follows:

$k_1=3T/k\lambda^2$ which is the proportional gain

$\tau_{i1}=3\lambda$ is the integral gain

$\tau_{d1}=\lambda(1-\lambda/3T)$ is the derivative gain $k_2=b1/k'(4\lambda'+\theta-b_1)$ is the proportional gain

$\tau_{i2}=b_1$ is the integral gain

$\tau_{d2}=\dfrac{b_2}{b_1}$ is the derivative gain

$\alpha'=0.5\theta$

$$\beta=((b_1\theta/2-b_2+2\lambda'\theta+6\lambda'^2)/(\theta+4\lambda'-b_1))+T+T'$$

Chengqiang Yin used set point filter in his structure in order to improve the set point tracking performance and to reduce peak overshoot. Here, set point weight ε is used in this method in order to reduce undesirable peak overshoot. The value of ε is chosen based on the lower values of ISE and IAE. The value of ε ranges from **0.7-0.8** which gives better ISE and IAE values and also produces less overshoot.

III. SIMULATION RESULTS

A. Example 1

An example of higher order integrating process with time delay given by Seshagiri Rao [2] is considered.

$$G_P(s)=\frac{e^{-4.5s}}{s(s+1)(s+2)(s+3)}$$

$$G_M(s)=\frac{0.167e^{-5.077s}}{s(1.863s+1)}$$

The PID tuning parameters obtained by Yin method is K_{c1} = 2.0287, τ_{i1} =12.1848, τ_{d1} =1.11, λ_1 =4.0616, a_1 =12.18, a_2 =13.5249, K_{c2} =1.1589, τ_{i2} =18.3183, τ_{d2} =1.6756, α =2.5385, β =0.8, b_1 =18.3183, b_2 =30.6932. For $\varepsilon=0.7$, better result is obtained and the ISE and IAE values are found to be less. The PID tuning parameters obtained in Seshagiri Rao method is given as, K_c =2.649, τ_i =10.661, τ_d =1.294, λ =3.553, ε =0.4, K_{c1}=0.45, τ_{d1}=2.

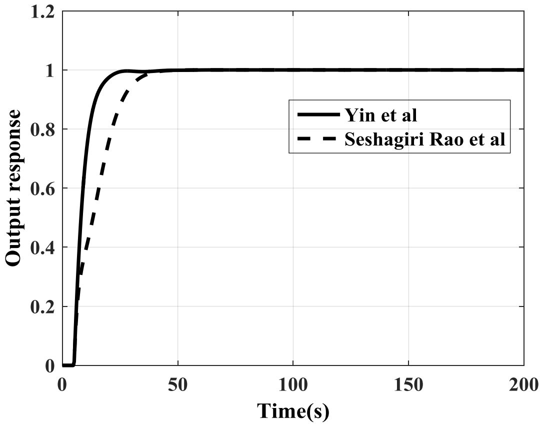

Figure 2 Servo Response Of Example 1

Table 1 Performance Index Of Example 1

Methods	**ISE**	**IAE**
Yin Method	**2.06**	**3.951**
Seshagiri Rao Method	4.963	9.546

B. Example 2

The higher order integrating process from Kaya [3] is given by,

$$G(s)=\frac{e^{-5s}}{s(10s+1)(s+1)(0.5s+1)(0.25s+1)}$$

The process can be reduced as follows:

$$G(s)=\frac{e^{-6.665s}}{s(10.141s+1)}$$

The PID tuning parameters obtained by Chengqiang Yin method is given by K_{c1}=2.7394, τ_{i1}=9.9975, τ_{d1}= 2.9675, λ_1 = 3.3325, a_1 = 9.9975, a_2 = 29.6672, K_{c2} = 0.1440, τ_{i2} = 20.6909, τ_{d2} = 5.6941, α = 3.3325, β =0.8, b_1 = 20.6909, b_2 =117.8161.

For $\varepsilon=0.8$, better result is

obtained and the ISE and IAE values are found to be less. The PID tuning parameters obtained in Kaya method is given as K_c =0.0786, τ_i =10.141, τ_d =10.141, λ =6.0652, K_{c1} =0.075.

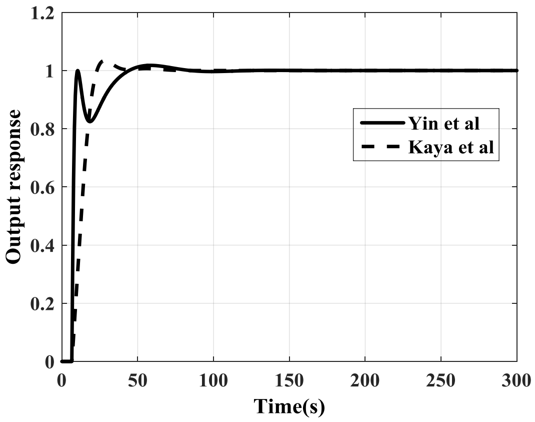

Figure 3 Servo Response Of Example 2

Table 2 Performance Index Of Example 2

Methods	ISE	IAE
Yin Method	**7.561**	**10.96**
Kaya Method	10.84	13.73

From the Figures 2 &3 and Tables 1 &2 of the above two examples, Chengqiang Yin method produces better result when compared to Seshagiri Rao and Kaya method for higher order integrating processes. Hence, Yin method can be successfully implemented in higher order integrating processes.

IV. CONCLUSION

The two-degree-of-freedom structure based on modified Smith predictor is implemented successfully for higher order integrating processes with time delay. The Chengqiang Yin method uses two PID controllers in his structure one for set point tracking and the other for disturbance rejection. Instead of set point filter, set point weighted structure is used in order to obtain better results. The set-point weight is chosen based on the better IAE and ISE values. A comparative analysis has been carried out for performance indices such as ISE, IAE and percentage peak overshoot for higher order processes with time delay. Hence, it is found that Chengqiang method produces better results when compared to Seshagiri Rao and Kaya methods.

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AUTHORS PROFILE

Dr. P. Deepa is currently working as an Associate professor in the department of Electronics and Instrumentation Engineering, St. Joseph’s College of Engineering, Chennai. Her filed of interest is Process Control and Soft Computing Techniques.

Dr. V.Vijayan is currently working as a Professor in the department of Electronics and Instrumentation Engineering, St. Joseph’s College of Engineering, Chennai. His filed of interest is Process Control and System Identification.

Mr. D. Sankaran is currently working as an Assistant Professor in the department of Electronics and Instrumentation Engineering, St. Joseph’s College of Engineering, Chennai. His filed of interest is Control System and Electronic Instruments.

Ms. V. Supraja completed her B.E Electronics and Instumenation in Jeppiaar Engineering College and M.E in St. Joseph’s College of Engineering. Her filed of interest is Process Control.