Various Tuning Methods for the Control of pH in Head box of a Paper Machine

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ABSTRACT: *The parameters of PID controller are adjusted in order to obtain the desired response which involves tuning the controller. Various methods of tuning are available for the same purpose with their own advantages and disadvantages. In this paper, different tuning methods i.e. Ziegler-Nichols method, Cohen-Coon method and Internal Model Control method have been used in order to improve the PID parameters for the transfer function of pH which is an important parameter in head box of the paper mill industry. Smith Predictor is finally used for much better performance and its result is then compared with that of the conventional controller.*

KEYWORDS: *Tuning, Smith Predictor, IMC, FOPTD.*

I. INTRODUCTION

Many process industries have non-linear and time delay system parameter during their operation due to the presence of various instruments like sensors and actuators. Control valves in paper machine headbox also result in the time delay which results in an unstable system and an undesirable response. In order to obtain the desired output conventional controllers i.e. PID (Proportional, Integral and Derivative) are used in various forms (series, parallel, expanded and cascade) and combinations (P, PI and PID). The values of these parameters are to be decided properly so as to obtain the required output. This requires the controller to be tuned by one of the various methods available like Ziegler-Nichols, Cohen-coon and Internal Model Control tuning methods. Smith Predictor is basically used for systems with time delay more than the time constant of the system as in[2].

Ziegler-Nichols or ultimate gain method does not require the process model and forces the system into the condition of marginal stability which may lead to an unstable operation. Loops tuned with this method will be underdamped as in [1] and disturbances may propagate in the process. Cohen-Coon method is the modification of the open loop Ziegler-Nichols method. The formulas used for the calculation of the controller parameters for Zeigler-Nichols and Cohen-Coon methods are as in [3] &in [6]. Internal Model Control is based on the approximation of the process model as in [3]. Smith Predictor method uses an internal model to predict the delay free response of the process and hence it is used for the compensation of time delay. Here, a minor loop is introduced around the conventional controller as in [4].

II. PROCESS MODEL

The model of the process for pH proposed by Hariott [5] which is a FOPTD function is:

$$\mathrm{G_{pr}} = \frac{5.67\mathrm{e}^{-19.9\mathrm{s}}}{1.8\mathrm{s}+1} \dots\dots (1)$$

By Pade's approximation:

$$G_{pr} = \frac{5.67(-9.95s+1)}{(1.8s+1)(9.95s+1)},$$

$$G_{pr} = \frac{-56.4165s+5.67}{1.8s+117.91s^2+11.75s+1} \dots\dots (2)$$

III. TUNING PARAMETERS OF THE CONTROLLER

The closed loop response for eq. (1) with controller as obtained by various methods is obtained as in Table 1.Smith Predictor is designed according to the method described as in [3]. The output is then obtained by the MATLAB program. The output response for various methods is shown from Fig. 2 to Fig. 5.

IV. MATHEMATICAL MODEL FOR SMITH PREDICTOR

The smith Predictor for the given function in eq. (1) is designed as follows:

$$G_{pr} = G_p \times d \dots\dots (3)$$

$$G_p = \frac{5.67}{1.8s+1} \dots\dots (4)$$

$$dp = e^{-19.9} \dots\dots (5)$$

$$fr = \frac{1}{20s+1} \dots\dots (6)$$

The Conventional PI controller has K_p=1.76e-05 and T_i = 0.0167s.

The controller designed using smith predictor has K_p = 2.49e-05, T_i = 0.00125s. The closed loop response for both conventional PI controller and Smith Predictor is shown in Fig. 5.

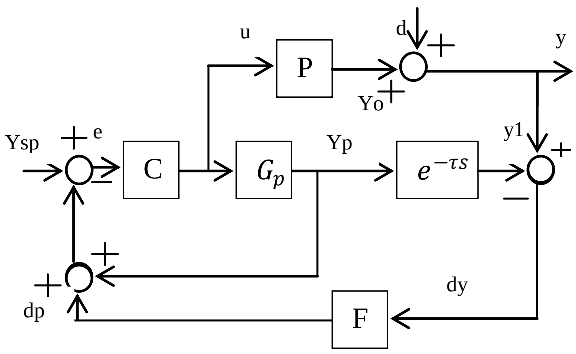

Fig.1: Smith Predictor Design

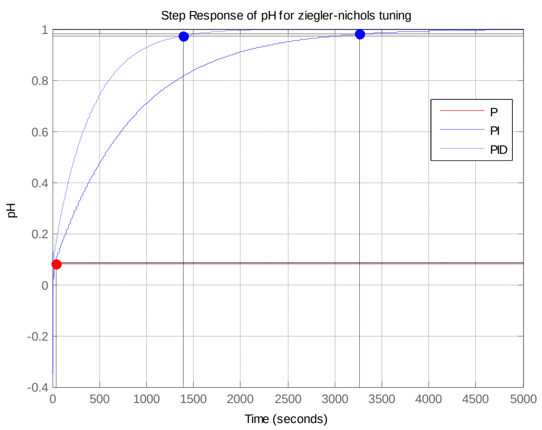

Fig. 2. Comparison of different types of controllers (P, PI and PID) for Ziegler-Nichols tuning method of pH parameter.

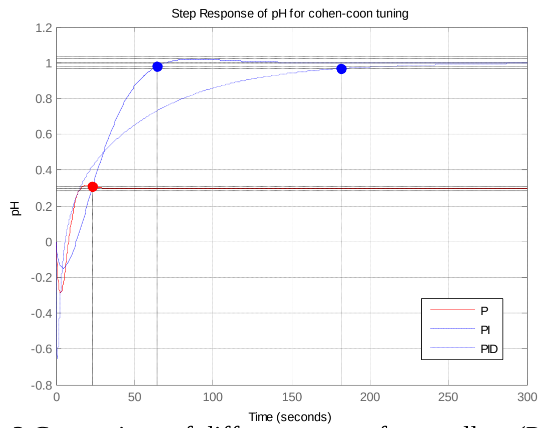

Fig. 3.Comparison of different types of controllers (P, PI and PID) for Cohen-coon tuning method of pH parameter.

V. PERFORMANCE ANALYSIS

Table 2 shows the comparison of performance indices for different tuning methods. It can be seen that when Ziegler-Nichols tuning method is used to control pH in the headbox of paper machine, P type of controller has lesser rise time and settling time than that of PI and PID type of controller. PI controller has very large values for both rise time as well as for the settling time. In case of Cohen-Coon method, similar comparison occurs with P type at lesser settling and rise time than that of PI and PID type of controller. In case of Cohen-Coon method PI controller gives acceptable results than that of Ziegler-Nichols tuning method. When IMC method is used, PI controller (employing Taylor series expansion) has large settling time in comparison to the PID controller for IMC (employing Pade's approximation). Smith Predictor has the rise time of 15.1s for set point tracking and PI controller has 315s which is much larger than that of smith predictor. Disturbance is also rejected much faster in smith predictor than in the conventional PI controller.

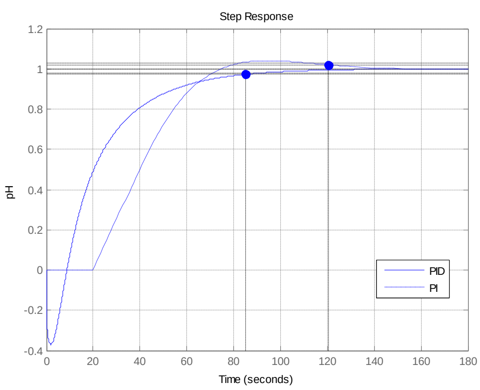

Fig. 4.Comparison of PI and PID types of controller for IMC tuning of pH parameter.

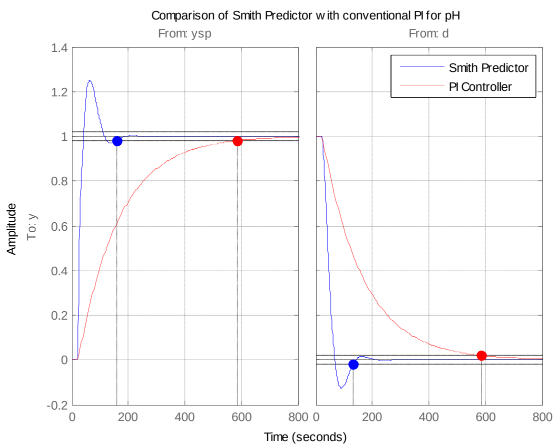

Fig. 5.Comparison of Smith Predictor control and PI controller for pH parameter.

VI. CONCLUSION

From various tuning methods employed in this paper it can be seen that although Z-N,cohen-coon and IMC give quite high setting time in comparison to smith predictor. Therefore, it can be concluded that as the time delay is larger than the time constant for pH in headbox, Smith predictor provides much better result than other tuning methods. On comparison with PI controller it can be seen that set point tracking and disturbance rejection is also achieved much earlier when smith predictor is used. Higher bandwidth is also obtained when frequency domain analysis is done.

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Table I

CONTROLLER PARAMETERS FOR DIFFERENT METHODS

Controller	**Z-N Method**	**Cohen-Coon Method**	**Internal Model Control Method**
P	K_c= 0.1595	K_c= 0.74841727	------
PI	K_c=0.0143 τ_I=65.67s	K_c=0.02905 τ_I=5.4626s	K_c=0.00797 τ_I=1.8s
PID	K_c=0.019143 τ_I=39.8s τ_D=9.95s	K_c=0.06536 τ_I=19.289s τ_D=2.40402s	K_c=0.0694 τ_I=11.75s τ_D=0.99502s

Table II.

COMPARISON OF PERFORMANCE INDICES FOR DIFFERENT TUNING METHODS

Tuning / Performance measure	Z-N Method			Cohen-Coon Method			IMC Method		Smith Predictor		PI Controller	
	P	**PI**	**PID**	**P**	**PI**	**PID**	**PI**	**PID**	**Set Point**	**Distur- -bance**	**Set Point**	**Distur- -bance**
Rise Time(s)	17.5	1.88e+03	874	5.44	36.6	112	38	44.7	15.1	32.3	315	315
Settling Time(s)	35.8	3.26e+03	1.4e+03	23.4	64	182	121	85.1	159	132	584	584