Enhanced Performance of PI-PD Controller Scheme for Unstable System with Dead Time

S. Mourouga Pragash[1], A. Asokan[2]
[1]Associate Professor, Department of EIE, Pondicherry Engineering College, Puducherry, India
[2]Assistant Professor, Department of EIE, Annamalai University, Annamalainagar, India

ABSTRACT

PID control systems are still used as a basic control technology in today's industries. In the literature, many publications can be found considering PID control design for unstable process. However due to structural limitations of PID controller, good closed loop performance cannot be achieved with a PID controller for mentioned process and usually a step response with high overshoot and oscillation is obtained. In order to improve the control performance of PID control system, we propose a new structure PID control system The PI-PD control conception implements a simple modification of the PID structure. It provides an improvement on the controlled system, especially when used in processes with large time constant, and integrator or unstable plant transfer functions plus dead-time. The PI-PD control can be implemented easily from an existing PID control and it can be tuned from the available PID parameters ones. Several procedure for obtaining the parameters of the PID controller are possible but one of the simplest approaches, which is used in this paper. The method is compared with several existing methods to control unstable processes and it is shown that the proposed method is superior to existing one. The new tuning methodology is assessed by a unstable first-order plus dead-time (UFOPDT), on simulated plants and the tuning of the PI-PD controller with the proposed methodology shows a good dynamic performance when compared to others methods.
Keywords: PID controller, dynamic, closed-loop system, pi-pd controller.

I. INTRODUCTION

The Proportional-Integral-Derivative (PID) controllers are still widely used in the process industries even though more advanced control techniques have been developed. The main reason is that the PID controllers have simple structure and are robust to modeling error and that many advanced control algorithms, such as model predictive control, are based on the PID control. As indicated in [8], more than 95% of the control loops are of PID type in process control. Over the years, there are many formulas derived to tune the PID controllers for stable processes, such as Ziegler-Nichols, Cohen-Coon, internal model control, integral absolute error optimum, IAE, and ITAE), however Designing controllers for open loop unstable processes is much more difficult than that of open loop stable processes. The closed loop response for unstable processes shows a large overshoot and settling time, compared with that of stable processes. Performance will be further limited when the unstable process contains a RHP zero. Many authors addressed the controller design methods for unstable first order plus time delay (UFOPTD) processes [1-6].

The controller has three parameters to be adjusted. This can often be done easily by trial and error or by using one of many tuning rules based on the stable first order plus dead time or second order plus dead time model or using critical point information for stable processes. In the conventional PID control algorithm, the proportional, integral and derivative parts are placed in the forward loop, thus acting on the error between the set point and closed loop response. This PID controller implementation apart from the derivative kick, which occurs if a step change takes place in the set point,[16] is suitable for control of stable processes with small time delays. However, it is well known that for processes with resonances, integrators and unstable transfer functions, difficulties are encountered.

Recently, Visioli (2001) has presented tuning formulas for the minimization of integral performance criteria for both integrating and unstable processes. However, large overshoots and long settling times resulted as a PD or PID was used for the control of integrating and unstable processes, respectively. The PI-PD controller has been proved to overcome the structural limitation of PID controllers in controlling unstable [9] and integrating processes [10], for both the set point tracking and disturbance rejection.

The purpose of this paper is to illustrate how the performance of a PID controller can simply be improved by converting the PID controller to a PI-PD controller. By doing so, the difficulty with selecting the four tuning parameters of the PI-PD controller can be abolished. The given approach can he applied to any existing PID design method for controlling processes with 'resonances, integrators and unstable transfer functions. Simulation examples are provided to show the use of the suggested design approach.

II. PI-PD CONTROL STRUCTURE AND TUNNING METHOD

In the conventional PID control algorithm, the proportional, integral and derivative parts are implemented in the forward loop, thus acting on the error between the set point and closed loop response. This PID controller implementation may lead to undesirable phenomena, namely the derivative kick. Also, by moving the PD part into an inner feedback loop, an unstable or integrating process can be stabilized and then can be controlled more effectively by the PI controller in the forward path.

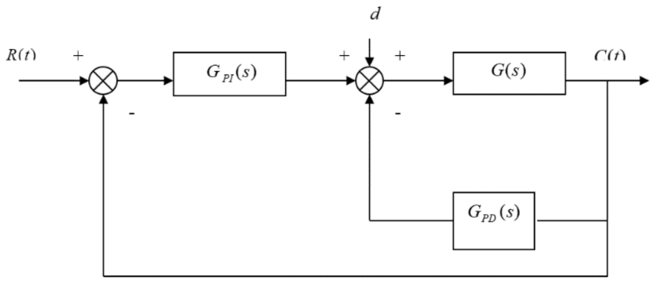

Fig.1 Structure of PI-PD control

The structure of the controller is shown in Figure (1), which an extension of the one is proposed. GPD(s) is the PD controller whose purpose is to stabilize the plant, while GPI(s) is a PI controller, which tries to improve the response of the inner loop. P and D of GPD(s) are chosen in such a way that the step response of the original process under P/PD control is either an S-shape curve or similar to the step response of a second-order under-damped system. Corresponding to the step response of the inner loop, GPI(s) will be tuned by either Ziegler-Nichols tuning method or tuning rules for stable second-order models with time delay. The filter F(s) is to reduce over-shoot when necessary

This structure, which uses an inner feedback loop, is not totally a new concept. Benouarets [13] was the first to mention the PI-PD controller structure. Unfortunately, its true potential was not recognized there as it was used to control plants with simple stable real pole transfer functions where its advantages are relatively minor. Later, Park et al. [14] used a PID-P control structure for controlling integrating and unstable processes, respectively. However, as they still use the derivative term, D, in the forward path the structure may result in a derivative kick. It is better to use an inner feedback loop with a PD controller rather than a P only controller, as this not only converts the open loop unstable or integrating processes to open loop stable processes but also guarantees more suitable pole locations [10]. Using a block diagram reduction for the PI-PD controller structure given in Fig. I, one can easily obtain the block diagram given in Fig. 2.

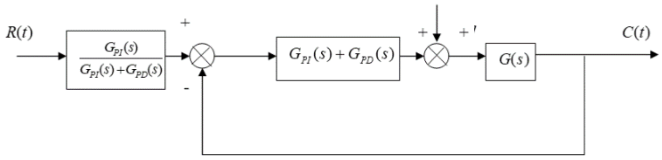

Fig. 2 equivalent PI-PD control structure

The forms of the controllers discussed in this paper are given by

$$G_{PID} = K_P^* \left(1 + \frac{1}{T_i^* S} + \frac{K_f}{K_P + K_f} \frac{T_d^* S}{\alpha T_d^* S}\right) \quad \text{........(1)}$$

GPID= GPI + GPD

$$G_{PI} = K_P \left(1 + \frac{1}{T_i S}\right) \text{..........(2)}$$

$$G_{PD} = K_f \left(1 + \frac{T_d S}{\alpha T_d S}\right) \quad \text{........(3)}$$

The controller in *(1)* is the most common series PID compensator and in **(3)** it is the proposed PI-PD controller. The latter provides a structure which for design purposes can be seen **as** one where the PD feedback is used to change the poles of the plant transfer function to more desirable locations for control by a PI controller. The possibility to split the P term is available in some commercial controllers. Hang et al[15] also suggested a split P configuration in their case with PI operating on the error, D on the output and an additional forward P from the reference input This controller can be converted to a PI-PD, which we believe provides a better strategy for design.

Substituting eqn 2 &3 weget

$$G_{PID} = K_P \left(1 + \frac{1}{T_i S}\right) + K_f \left(1 + \frac{T_d S}{\alpha T_d S}\right)$$

$$G_{PID} = K_P + K_f \left(1 + \frac{K_P}{K_P + K_f} \frac{1}{T_i S} + \frac{K_f}{K_P + K_f} \frac{T_d S}{\alpha T_d S}\right)$$
.....(4)

Obtaining the four parameters of PI-PD controller from the three parameters of PID the relation $k_p = \beta k_f$ and $T_i = \alpha T_d$ used Astrom [1984)

Comparing the equation (1) and (4)

$$K_P = \frac{K_P^* \beta}{1+\beta} \quad \text{.............(5)}$$

$$K_f = \frac{K_P^*}{1+\beta} \quad \text{...............(6)}$$

$$T_i = \frac{T_i^* \beta}{1+\beta} \quad \text{.............(7)}$$

$$T_d = \frac{T_d^* (1+\beta)}{\alpha T_d^*} \quad \text{..........(8)}$$

III. SIMULATION EXAMPLES

In this section, examples, which are taken from different publications considering PID controller design for processes with unstable is given to illustrate that with the proposed approach much better closed loop performances can be obtained. Acquire the PI-PD controller parameters from PID controller parameters by ISTE Optimization and have been proposed by some other authors for controlling processes with unstable transfer function.

Here, in order to compare the performance of PI-PD controller suggested by Xiang *et al.* [2] for controlling unstable processes with the PI-PD controller, the unstable plant transfer function of *G(s)* = **4e-2S /(4s - I),** which was used by many authors, **is** considered. the conventional PID controller parameters, K_c^*, T_i^* and T_d^* are obtained using the ISTE criterion. These parameters have also been acquired for a perturbation of +10% and -10% in time delay and time constant for the above system. These controller parameters have been given in Table 3.1.

Table 3.1 Tuning parameters for conventional PID controller

	K_c^*	T_i^*	T_d^*
Actual model	0.652	8.26	0.967
+10% in time delay	0.595	9.20	1.074
-10% in time delay	0.720	7.33	0.8605
+10% in time constant	0.7137	7.788	0.957
-10% in time constant	0.589	8.374	0.977

From equations 5 to 8, the PI-PD controller parameters can be obtained .It is required to determine a value of β using which the controller gives optimum performance. Figure 3.1 shows the performance of the controller for various values of β.

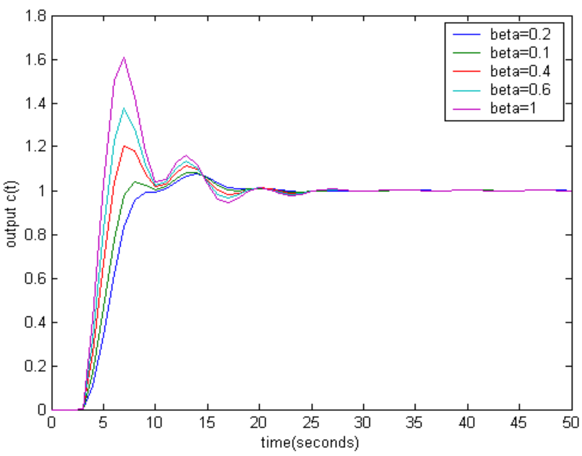

Figure 3.1 Responses for various values of β

Table 3.2 Comparison of ISE and IAE for various values of β

	$\beta = 0.1$	$\beta = 0.2$	$\beta = 0.4$	$\beta = 0.6$	$\beta = 1$
ISE	3.885	3.207	3.54	3.225	3.596
IAE	4.656	4.055	4.167	4.272	4.806

Thus by simulating for various values of β, we have found that $\beta = 0.2$ shows better performance. Extensive simulation examples revealed that $\beta = 0.2, \alpha = 0.1$ results in a good closed loop performance. Hence, throughout the paper this value *is* used. Using the PID settings given in Table 3.1 and value of $\beta = 0.2$, the corresponding PI-PD controller parameters K_p, T_i, K_f and T_d are obtained These values are given in Table 3.3.

Table 3.3 Tuning parameters for PI-PD controller

	K_p	T_i	K_f	T_d
Actual model	0.108	1.3766	0.5433	1.2644
+10% in time delay	0.099	1.5333	0.495	1.3575
-10% in time delay	0.12	1.221	0.60	1.132
+10% in time constant	0.1189	1.298	0.5947	1.2623
-10% in time constant	0.0981	1.395	0.4908	1.2671

controller settings Suggested by Xing **et** *al.* [2] are K_p = 0.2978, T_i=8, Td =4.296 and K_f =0.32. The ISTE criteria was used to find PID controller settings, which are k_p = 0.652, T_i= 8.26and T_d = 0.967. Once PID controller settings are known, eqns. (5)-(8) can then be used to calculate PI-PD controller parameters, which are found to be $Kp=0.108$, $T_i=1.3766$ $K_f=0.5433$ and $T_d=1.2$. With these controller settings, the proposed method is compared with that of Xiang et al. by giving unit step change in the set point and a step input in the load disturbance. Fig. 2 and Fig6 show the responses for perfect model parameters. From the responses it can be observed that the proposed method gives a better performance, particularly for load disturbance rejection. A simultaneous perturbation of +10% and -10%in process time delay is considered and the corresponding closed loop responses are shown in Fig. 3to Fig.12 for a unit step change in the set point and unit step input in the load. Here, Xiang et al. method shows oscillatory responses where as the proposed method gives a better performance. For quantitative performance comparison with the previous methods, sum of the integral of the absolute error (IAE) and integral square error (ISE) for servo and regulatory responses is considered. The IAE and ISE values are given in Table 4 & Table 5 for perfect model parameters and for perturbations in the process parameters. It is clearly evident that the proposed method gives low IAE ISE values compared to that of the previous methods. The corresponding control action responses for both the cases are shown in Figs. 4 and 5 respectively. It can be observed from the figures that the control action responses of the proposed method shows smooth variation compared to that Xiang et al.

Table.4 PERFORMANCE INDEX OF SERVO RESPONSE

	Proposed Method		Xiang &Nguyen		D.P. Atherton &Majhi	
	IAE	ISE	IAE	ISE	IAE	ISE
Perfect model	4.779	3.534	5.957	3.602	12.26	4.936
+10%in time constant	5.011	3.682	5.169	3.388	7.215	4.177
-10%in time constant	5.711	3.738	7.124	4.784	12.37	6.476
+10%in dead time	6.784	4.507	14.58	6.551	19.65	10.09
-10%in dead time	4.871	3.437	5.369	3.60	12.13	6.05

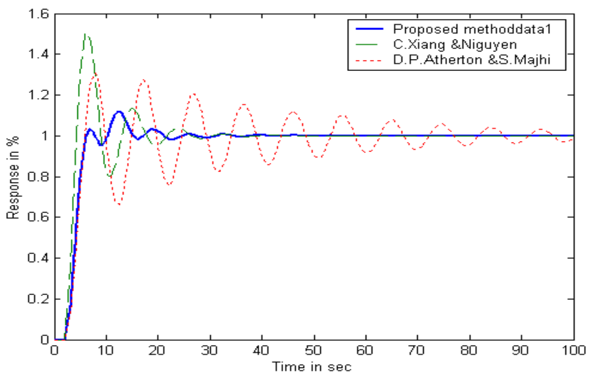

Fig. 3 Servo Responses for perfect model

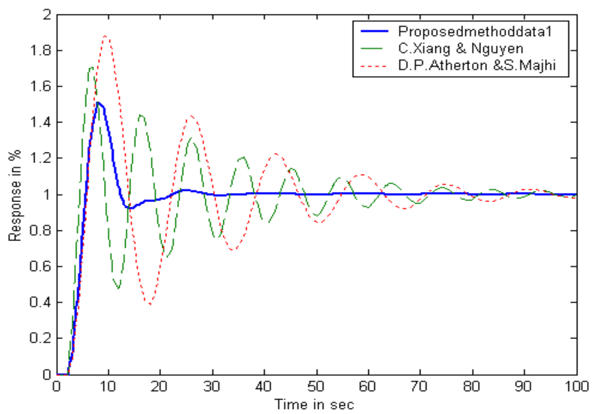

Fig.4 Servo responses for a perturbation of +10% in time delay

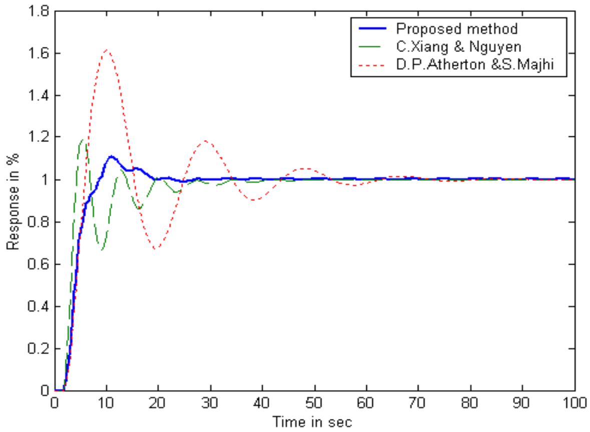

Fig.5 servo responses for a perturbation of -10% in time delay,

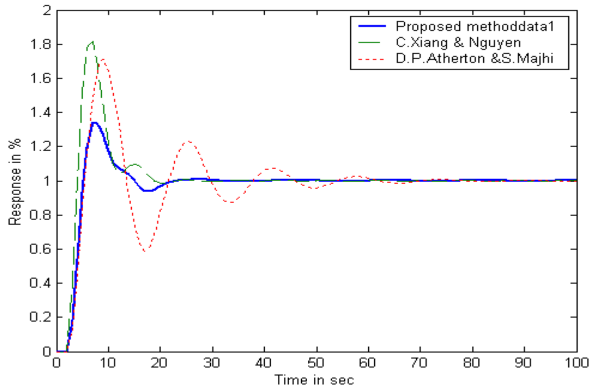

Fig.7 servo responses for a perturbation of -10% in time constant

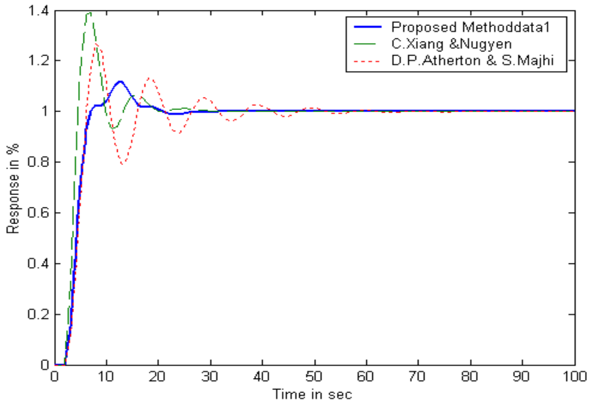

Fig.6 servo responses for a perturbation of +10% in time constant

TABLE.5 PERFORMANCE INDEX OF REGULATORY RESPONSE

	Proposed Method		Xiang &Nguyen		D.P. Atherton &Majhi	
	IAE	ISE	IAE	ISE	IAE	ISE
Perfect model	15.11	29.84	26.88	57.29	59.88	86.79
+10%in time constant	15.44	27.66	26.88	53.66	29.7	48.1
-10%in time constant	20.62	49.22	29.42	66.57	48.4	97.67
+10%in dead time	21.97	48.19	48.36	89.46	78.43	157.5
-10%in dead time	20.86	37.69	26.88	41.02	18.91	35.1

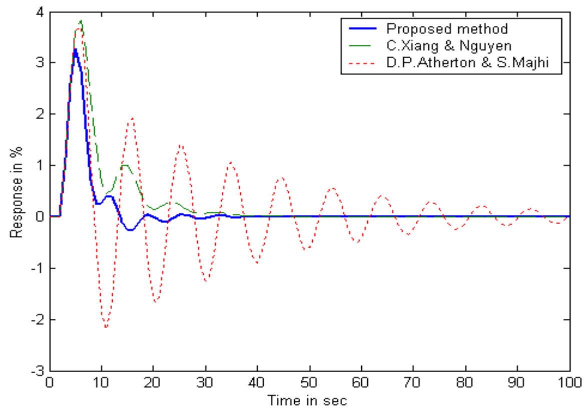

Fig.8 Regulatory Responses for perfect model

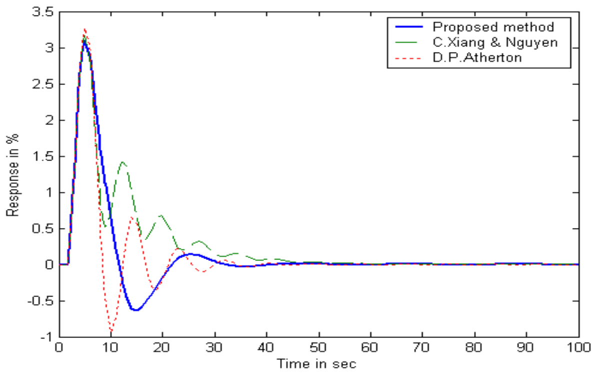

Fig.9 Regulatory responses for a perturbation of -10% in time delay,

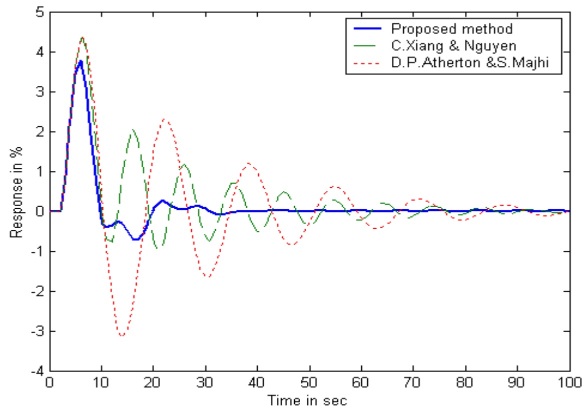

Fig.10 Regulatory responses for a perturbation of +10% in time delay,

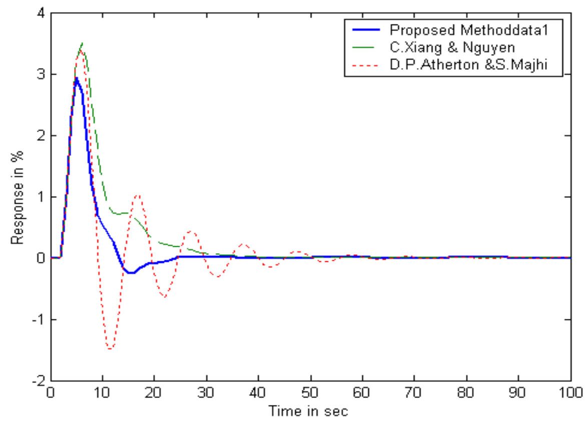

Fig.11 Regulatory responses for a perturbation of +10% in time constant

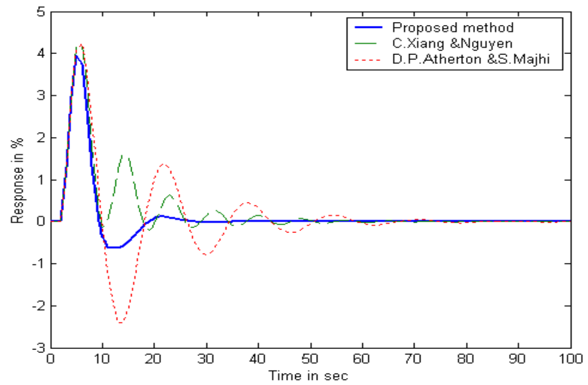

Fig.12 Regulatory responses for a perturbation of -10% in time constant

IV. CONCLUSIONS

Although, PID controllers are still widely used in industrial practice, they show poor performance in controlling unstable processes transfer functions. Therefore, the main aim of this paper has been improving the performance of a PID controller for controlling the aforementioned processes. For this, a simple method has been presented to obtain the PI-PD controller, which is proven to perform very well for the unstable process, parameters from a PID controller, with known settings. The introduced procedure can be applied to any PID controller in order to achieve an enhanced closed loop system performance where a PID controller results in poor performance. The PD feedback helps in repositioning the open loop poles to appropriate locations. From simulation study and analysis, it is concluded that the PI-PD control strategy provides an excellent four parameter controller for control of unstable processes to set point changes. Further, the same controller provides good disturbance rejection and its performance is often near to that of an optimum controller for disturbance rejection and is significantly better than the results of other design methods based on set point response Example have been provided to illustrate the **use** of the proposed approach and it is shown by example that with the proposed PI-PD controller the performance of a closed loop system can be improved significantly.

V. REFERENCES

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