Various PID Controller Algorithms For Closed Loop Performance Of Consistency Parameter Of Paper Machine Headbox In A Paper Mill

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ABSTRACT

Different forms of PID controller reflect the development of the PID algorithm in different technologies and its use in diverse control systems. Besides, some PID forms ensure better performance and behavior of the control system than others. For most control applications, a well designed and properly tuned PID controller is all that is needed to achieve the control objectives.

In the present paper, different algorithms of PID controllers viz series, parallel, series with derivative filter, parallel with derivative filter and cascade form are implemented to compare the closed loop response of an important parameter in a process industry called consistency, which has a first order plus dead time (FOPDT) dynamics. Also the comparison is made between the closed loop responses achieved from different values of constant alpha for non ideal situations. The steady state and dynamic characteristics are analyzed and compared and important inferences are derived.

Keywords : PID controller algorithms, transfer function, FOPDT

Intorduction

In general, the controllers used in the industry can be divided into two main groups conventional controllers and unconventional controllers. The conventional controllers include Proportional, Derivative, Integral and their combinations. It is a characteristic of all conventional controllers that a mathematical model of the process is required in order to design a controller. Unconventional controllers utilize new approaches to the controller design in which knowledge of a mathematical model of a process generally is not required. Examples of unconventional controller are a fuzzy controller, neural controller and neuro-fuzzy controllers.

Many industrial processes are nonlinear and thus are complex mathematically. However, it is known that a good many nonlinear processes can satisfactory be controlled using PID controllers provided that controller parameters are tuned well. Practical experience shows that this type of control has a lot of sense since it is simple and based on 3 basic behavior types: proportional (P), integral (I) and derivative (D). Instead of using a small number of complex controllers, a larger number of simple PID controllers is used to control simpler processes in an industrial assembly in order to automate the more complex process. PID controller and its different types such as P, PI and PID controllers are today a basic building blocks in control of various processes.

There are five major classifications of PID algorithms: series, parallel, series with derivative filter, parallel with derivative filter and expanded form. In simple form these are illustrated in table 1, along with their popular names and the corresponding transfer functions. Also key characteristics of commercial PID controllers including the controller features, controller parameter for each controller feature and their typical ranges is given in table 2, for a quick reference [1].

Determination of controller parameters using Ziegler Nichol's Method

The transfer function of consistency control process can be adequately represented by first order plus dead time as under

$$G_p(s) = K_p [e^{-\ ds} / (1+\ s)]$$

Carrying out bump test on the approach flow system flow loop, Nancy [2] developed the following dynamics equation with dead time of the order of 5 s due to transmitter location relative to

Table 1 : Common PID controllers

Controller type	Other popular names	Transfer Function
Parallel	Ideal, additive, ISA form	$G_C = K_c [\ 1+ 1/ T_I s + T_D s]$
Parallel with derivative filter	Ideal, Realizable, ISA standard	$G_C = K_c [\ 1+ 1/ T_I s + T_D s / (1+?\ T_D s)]$
Series	Multiplicative, interacting	$G_C = K_c [\ (1+ T_I s) (1 + T_D s) / T_I s\ ]$
Series with derivative filter	Physically realizable	$G_C = K_c [\ (1+ T_I s) (1 + T_D s) / \{T_I s (1+?\ T_D s)\}]$
Expanded	Non-interacting	$G_C = K_C + K_I /s + K_D s$
Cascade		$G_C = K_C (\ 1 + T_D / T_I) [\ 1 + T_D s / (\ 1 + T_D / T_I) + 1/ \{T_I (\ 1 + T_D / T_I)s\}]$

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Table 2 : Key characteristics of Commercial PID controllers

Controller feature	Controller parameter	Symbol	Units	Typical Range
Proportional mode	Controller gain	K_C	Dimensionless	0.1 – 100
	Proportional band	PB	%	1 – 1000
Integral mode	Reset time	T_I	Min	0.02 - 20
	Reset rate	$1 / T_I$	Repeats/ min	0.06 - 60
	Integral mode gain	K_I	Min^{-1}	0.1 - 100
Derivative mode	Derivative time	T_D	Min	0.1 – 10
	Derivative gain	K_D	Min	01 – 100
	Derivative filter parameter	?	Dimensionless	0.05 – 0.2
Control interval (Digital Controllers)		? t	Sec, min	0.1 sec – 10 min

the dilution point. The time constant of 10 s is due to the sensor measurement dynamics.

$G_p(s) = 0.03\, e^{-5s}/(1+10s)$.

PI controller settings can be determined by a number of alternative techniques. Direct Synthesis method and IMC method are based on simple transfer function models. Controller tuning relations are analytical expressions for PID controller settings. Computer simulation technique can provide considerable insight into dynamic behavior and control system performance. The objective for these methods is to provide good controller settings that can subsequently be fine tuned online, if required. It is very useful to have good initial controller settings in order to minimize the required time and effort, as online tuning can be time consuming task.

The tuning relations reported by Ziegler and Nichols [3] were determined empirically to provide closed-loop responses that have a quarter decay ratio the Z- N controller settings have been widely used as a benchmark for evaluating different tuning methods and control strategies. The ultimate gain and ultimate period are determined as

$K_{CU} = 35.54$ and $P_U = 16.97$

Thus, the controller parameters are calculated as

$K_C = 21.32$; $T_I = 8.48$; $T_D = 2.12$

Determination of PID controller for different types of PID algorithms

Parallel form

It is also called ideal, additive or ISA form. Derivative action can be combined with proportional and integral actions by having each of the modes operating in parallel.

The transfer function of PID controller for this type of algorithm is given as:

$G_C = K_c[\,1 + 1/T_I s + T_D s]$

The controller transfer function is mathematically derived as:

$(45.12\, s^2 + 21.28\, s + 2.51) / s$

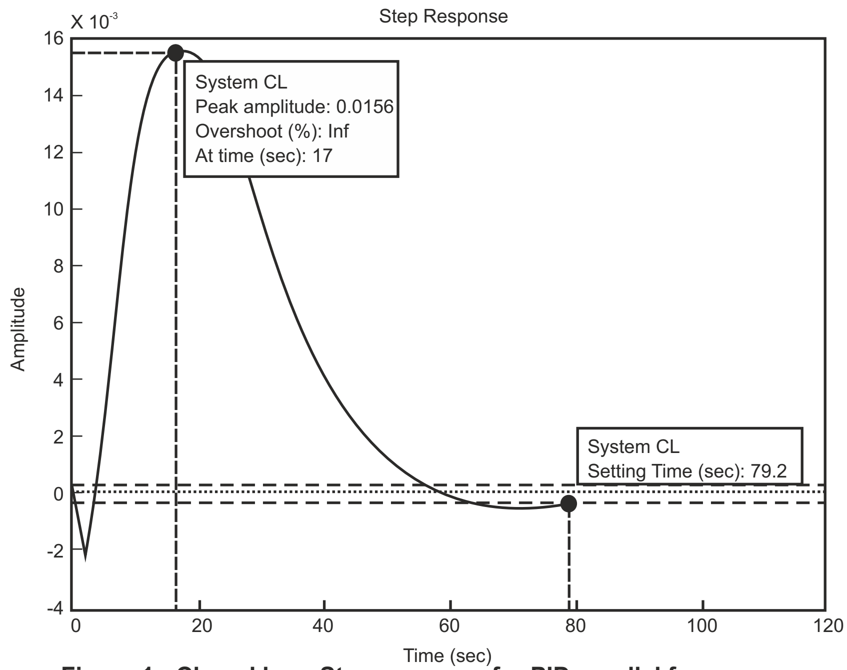

Figure 1 : Closed loop Step response for PID parallel from

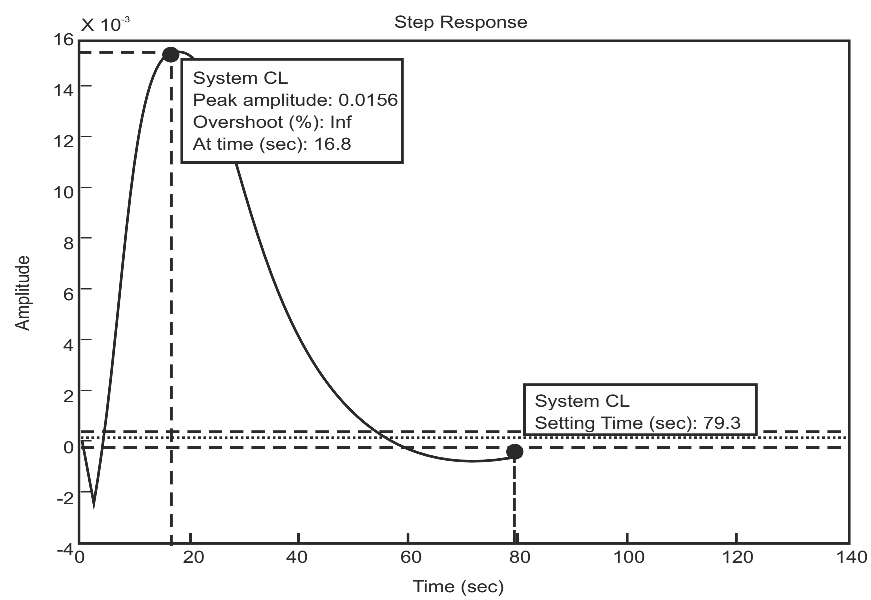

Figure 2 : Closed loop Step response for PID parallel from with derivative filter for alpha = 0.1

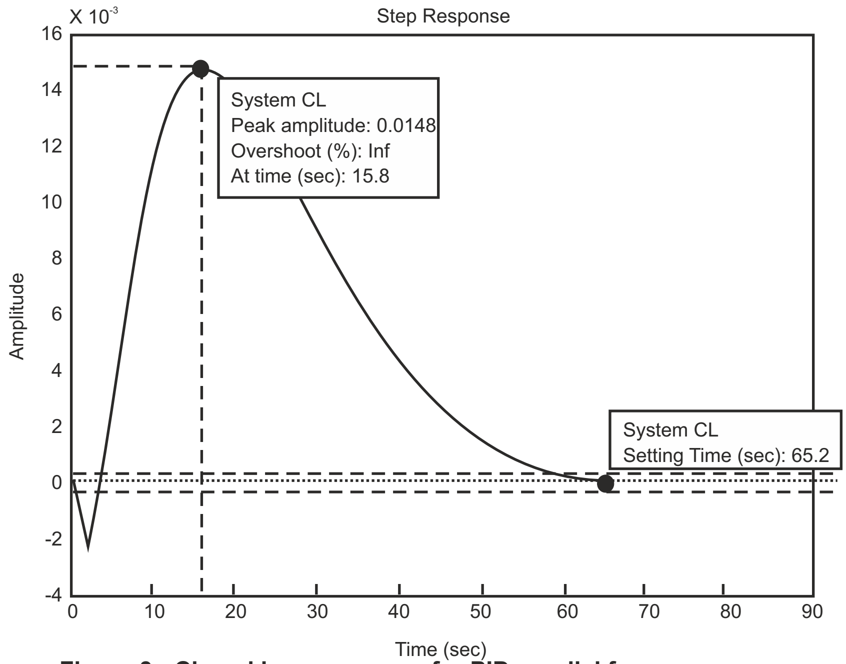

Figure 3 : Closed loop response for PID parallel from

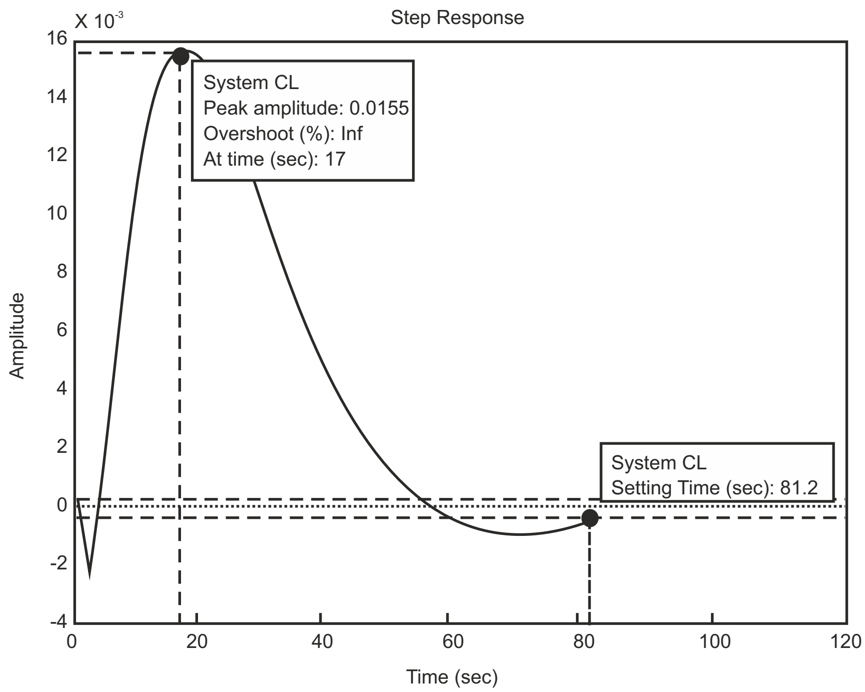

Figure 4 : Closed loop response for PID parallel from with derivative filter for alpha = 0.05

Thus, the closed loop transfer function is given as:

$(-0.03\ s^2 + 0.012\ s) / (8.64\ s^3 + 4.9\ s^2 + 0.58\ s + 0.03)$

Fig. 1 shows the closed loop response for the system with PID controller in parallel form. From fig. 1, it can be depicted that the peak amplitude is 0.0156, peak time is 17 seconds and settling time is 79.2 seconds for closed loop response of consistency process with controller in parallel form.

Series form

It is also called multiplicative or interacting form of PID controller. In principle, it makes no difference whether the PD element or the PI element comes first.

The transfer function of PID controller for this type of algorithm is given as:

$G_C = K_c[\ (1+T_I s)\ (1 + T_D s\ ) / T_I s\ ]$

The Controller transfer function for the consistency process is derived as:

$(45.19\ s^2 + 26.6\ s + 2.51) / s$

Thus, the closed loop transfer function is given as:

$(-0.03\ s^2 + 0.012\ s) / (8.644\ s^3 + 4.744\ s^2 + 0.6439\ s + 0.03012)$

Fig. 3 shows the closed loop response for the system with PID in series form. From fig. 3, it can be depicted that the peak amplitude is 0.0148, peak time is 15.8 seconds and settling time is 65.2 seconds for closed loop response of consistency process with controller in series form.

Parallel with derivative filter type PID form

It is also called Realizable or ISA standard form. The derivative mode is usually used with a derivative filter. The transfer function of PID controller for this type of algorithm is given as:

$G_C(s) = K_C[\ 1 + 1/ sT_I + T_D s / (\ T_D s\ \boldsymbol{\alpha} + 1)\ )]$

Case I. alpha = 0.1

The controller transfer function is mathematically derived as:

$(49.44\ s^2 + 21.73\ s + 2.5) / (0.21\ s^2 + s)$

Thus, the closed loop transfer function is given as:

$(-0.0063\ s^3 - 0.02748\ s^2 + 0.012\ s) / (2.1\ s^4 + 9.567\ s^3 + 5.025\ s^2 + 0.5858\ s + 0.03)$

Fig. 2 shows the closed loop response of the system with PID controller in parallel form having the derivative filter gain as 0.1. From fig. 2, it can be depicted that the peak amplitude is 0.0156, peak time is 16.8 seconds and settling time is 79.3 seconds for closed loop response of consistency process with controller in parallel form with derivative filter and for value of alpha to be 0.1.

Case II. alpha = 0.05

The controller transfer function is mathematically derived as:

$(52.44\ s^2 + 21.46\ s + 2.5)/ (0.106\ s^2 + s)$

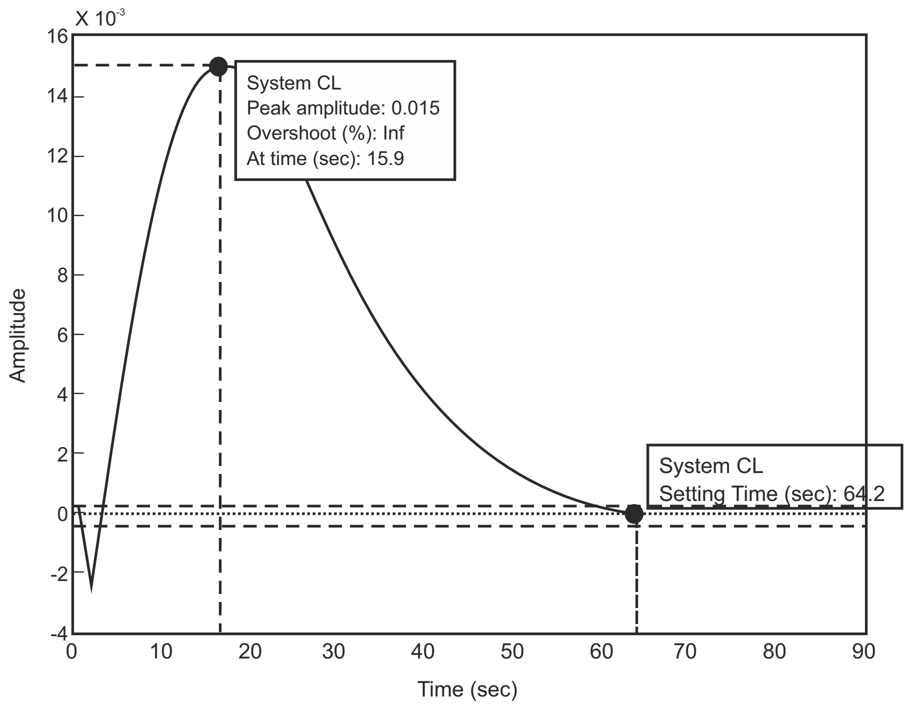

Figure 5 : Closed loop response for PID series from with derivative filter for alpha = 0.1

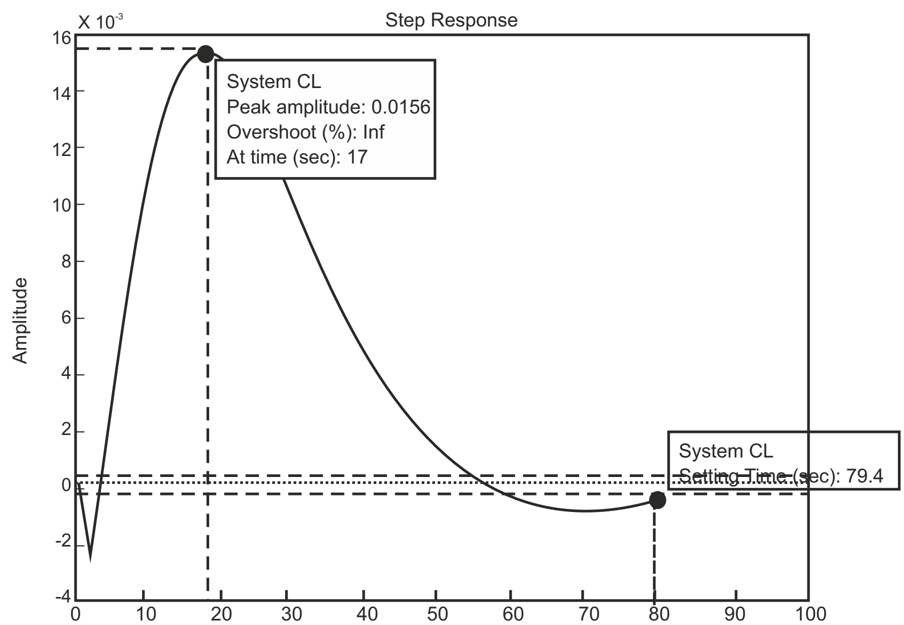

Figure 6 : Closed loop response for PID parallel from with derivative filter for alpha = 0.2

Thus, the closed loop transfer function is given as:

$(-0.00318\ s^3 - 0.02873\ s^2 + 0.012\ s\ ) / (1.06\ s^4 + 8.957\ s^3 + 5.028\ s^2 + 0.5825\ s + 0.03)$

Fig. 4 shows the closed loop response of the system with PID controller in parallel form having the derivative filter gain as 0.05. From fig. 4, it can be depicted that the peak amplitude is 0.0155, peak time is 17 seconds and settling time is 81.2 seconds for closed loop response of consistency process with controller in parallel form with derivative filter and for value of alpha to be 0.05.

Case III. alpha = 0.2

The controller transfer function is mathematically derived as:

$(53.94\ s^2 + 22.26\ s + 2.5) / (0.424\ s^2 + s)$

Thus, the closed loop transfer function is given as:

$(-0.01272\ s^3 - 0.02491\ s^2 + 0.012\ s) / (4.24\ s^4 + 10.5\ s^3 + 5.149\ s^2 + 0.5921\ s + 0.03)$

Fig. 6 shows the closed loop response of the system with PID controller in parallel form having the derivative filter gain as 0.2. From fig. 6, it can be depicted that the peak amplitude is 0.0156, peak time is 17 seconds and settling time is 79.4 seconds for closed loop response of consistency process with controller in parallel form with derivative filter and for value of alpha to be 0.2.

Series with derivative filter

It is also known as physically realizable form. The transfer function of PID controller for this type of algorithm is given as:

$G_C(s) = K_C[(1+ T_I) (1+ s\ T_D) / sT_I(1 + s\ T_I\boldsymbol{\alpha})]$

Case I. alpha = 0.1

The controller transfer function is mathematically derived as:

$(45.12\ s^2 + 26.6\ s + 2.51) / (0.21\ s^2 + s)$

Thus, the closed loop transfer function is given as:

$(-0.0063\ s^3 - 0.02748\ s^2 + 0.012\ s) / (2.1\ s^4 + 9.696\ s^3 + 4.827\ s^2 + 0.6439\ s + 0.03012)$

Fig. 5 shows the closed loop response of the system with PID controller in series form having the derivative filter gain as 0.1. From fig. 5, it can be depicted that the peak amplitude is 0.015, peak time is 15.9 seconds and settling time is 64.2 seconds for closed loop response of consistency process with controller in series form with derivative filter and for value of alpha to be 0.1.

Case II. alpha = 0.05

The controller transfer function is mathematically derived as:

$(45.12\ s^2 + 26.6\ s + 2.51) / (0.106\ s^2 + s)$

Thus, the closed loop transfer function is given as:

$(-0.00318\ s^3 - 0.02873\ s^2 + 0.012\ s) / (1.06\ s^4 + 9.176\ s^3 + 4.786\ s^2 + 0.6439\ s + 0.03012)$

Fig. 6 shows the closed loop response of the system with PID controller in series form having the derivative filter gain as 0.05. From fig. 8, it can be depicted that the peak amplitude is 0.0149, peak time is 15.9 seconds and settling time is 64.7 seconds for closed loop response of consistency process with controller in series form with derivative filter and for value of alpha to be 0.05.

Case III. alpha = 0.2

The controller transfer function is mathematically derived as:

$(45.12\ s^2 + 26.6\ s + 2.51) / (0.424\ s^2 + s)$

Thus, the closed loop transfer function is given as:

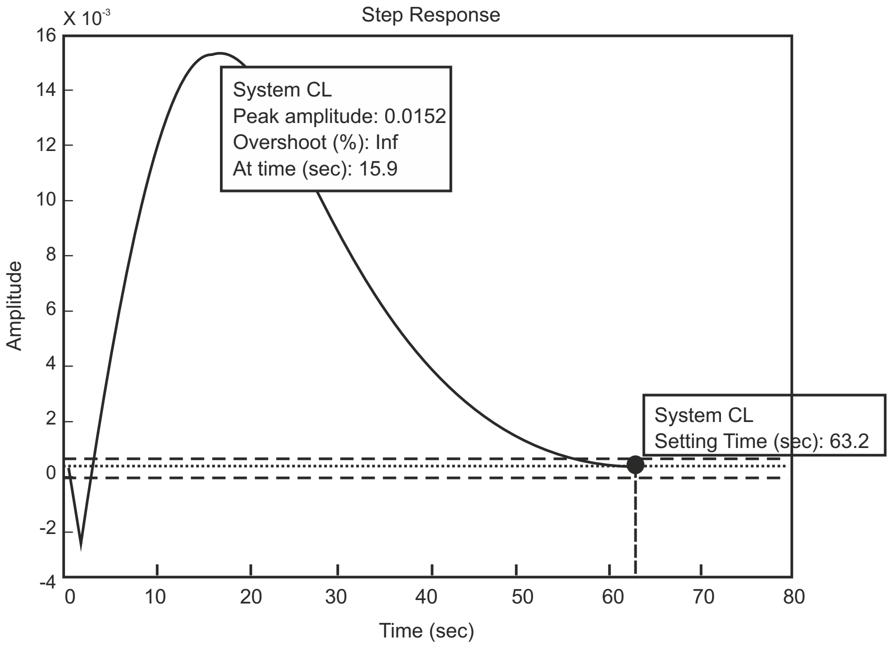

Figure 7 : Closed loop response for PID series from with derivative filter for alpha = 0.2

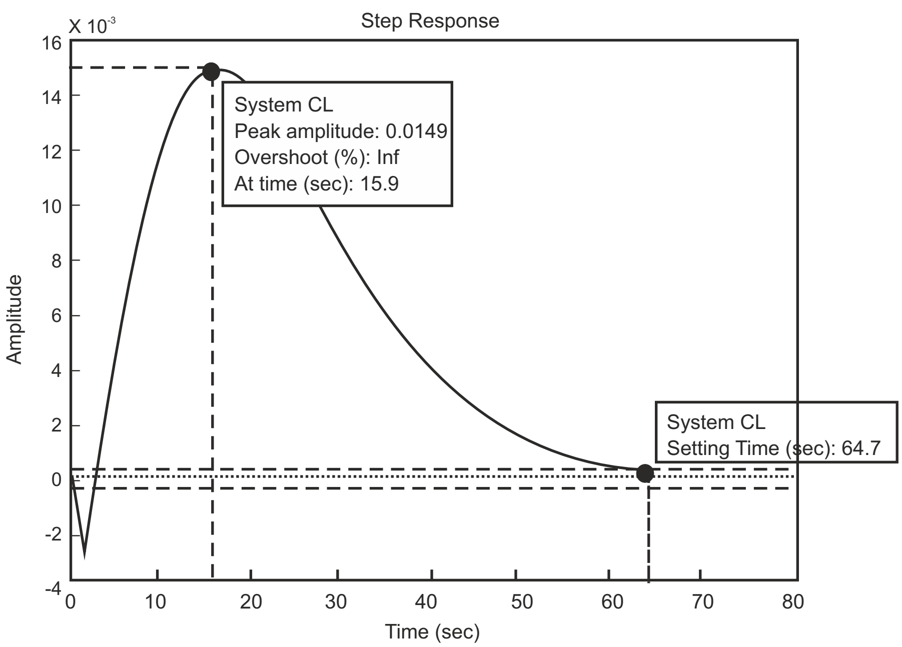

Figure 8 : Closed loop response for PID series from with derivative filter for alpha = 0.2

$(-0.01272\ s^3 - 0.02491\ s^2 + 0.012\ s) / (4.24\ s^4 + 10.77\ s^3 + 4.913\ s^2 + 0.6439\ s + 0.03012)$

Fig. 7 shows the closed loop response of the system with PID controller in series form having the derivative filter gain as 0.2. From fig. 7, it can be depicted that the peak amplitude is 0.0152, peak time is 15.9 seconds and settling time is 63.2 seconds for closed loop response of consistency process with controller in series form with derivative filter and for value of alpha to be 0.2.

Cascade form

One distinctive advantage of PID controllers in cascade form is that two PID controllers can be used together to yield better dynamic performance. In cascade control there are two PIDs arranged with one PID controlling the set point of another. A PID controller acts as outer loop controller, which controls the primary physical parameter, such as fluid level or velocity. The other controller acts as inner loop controller, which reads the output of outer loop controller as set point, usually controlling a more rapid changing parameter, flowrate or acceleration. In this way the working frequency of the controller is increased and the time constant of the object is reduced by using cascaded PID controller.

The transfer function of PID controller for this type of algorithm is given as:

$G_C(s) = K_C[\ 1 + 1/ sT_I + T_D s / (T_D s\ \boldsymbol{\alpha} + 1))]$

The controller transfer function is mathematically derived as:

$(45\ s^2 + 26.65\ s + 2.5) / s$

Thus, the closed loop transfer function is given as:

$(-0.03\ s^2 + 0.012\ s) / (8.65\ s^3 + 4.74\ s^2 + 0.64\ s + 0.03)$

Fig. 9 shows the closed loop response of the system with PID controller in cascade form. From fig. 9, it can be depicted that the peak amplitude is 0.0148, peak time is 15.8 seconds and settling time is 65.7 seconds for closed loop response of consistency process with controller in cascade form.

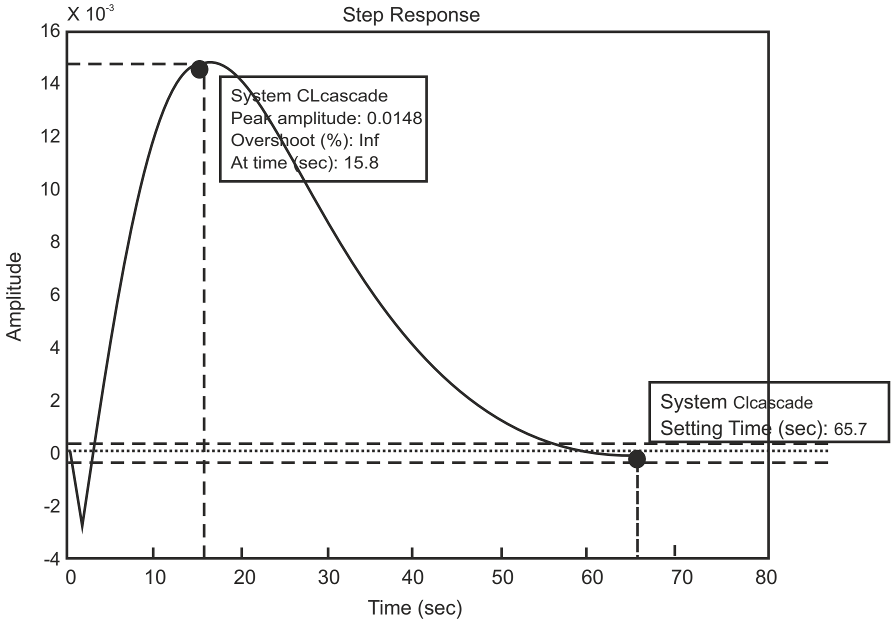

Figure 9 : Closed loop response for consistency process with Cascade Form of Controller

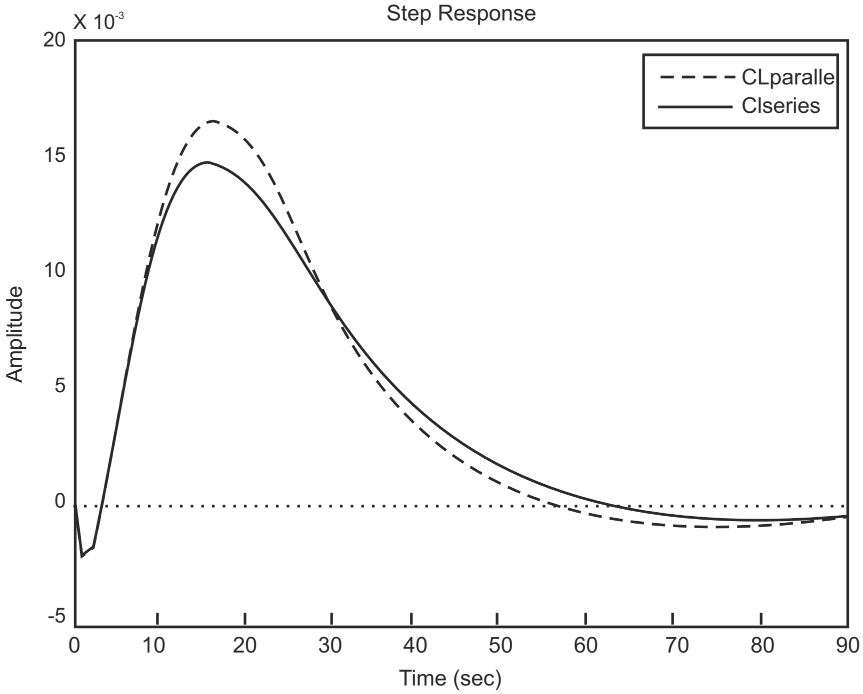

Figure 10 : Comparison of PID parallel form and PID series form

Table 3: Comparison of important steady state and dynamic characteristics for different PID algorithms for consistency process

	Parallel form	Series form	Parallel with derivative filter ? = 0.1	Parallel with derivative filter ? = 0.05	Parallel with derivative filter ? = 0.2	series with derivative filter ? = 0.1	Series with derivative filter ? = 0.05	Series with derivative filter ? = 0.2	Casc--ade form
Peak amplitude	0.0156	0.0148	0.0156	0.015	0.0156	0.015	0.0149	0.0152	0.0148
Peak time (sec)	17	15.8	16.8	17	17	15.9	15.9	15.9	15.8
Settling time (sec)	79.2	65.2	79.3	81.2	79.4	64.2	64.7	63.2	65.7

Result and discussion

Fig. 10 shows the comparison for PID parallel form and PID series form for the system under consideration. Fig. 11 shows the comparison of closed loop responses for the system with PID in series form for different values of alpha viz. alpha = 0.1, 0.05 and 0.2. Fig. 12 shows the comparison of closed loop responses for the system with PID in parallel form for the same set of values of alpha.

From the table 3, it is evident that the minimum peak amplitude is 0.0148 for PID controller in series form. The peak time is also minimum for PID controller in series configuration, where as settling time is minimum for PID controller in series with derivative controller with alpha value of 0.2. These characteristics peak amplitude, peak time and settling time resemble closely in case of standard parallel form and parallel with derivative filter for alpha as 0.1. Settling time is maximum in case of Parallel form with derivative filter in case when alpha is 0.05. This value is 81.2, which is much larger than the minimum value of 63.2, which is for series form with derivative filter and having value of alpha as 0.2. It can be clearly inferred from the table 3 that the peak value has the least variation in its value for different PID algorithms used and it remains around 0.156 with little deviations. The peak time is lesser for series form or for series form with derivative filter with different cases of alpha values than any of the parallel configuration dealt with.

Conclusion

Choosing the best algorithm for a process is dependent on the process control needs and objectives. Different algorithms perform better in different situations. In present case, for a consistency process dynamics, the overall best algorithm is series form for which the peak amplitude and peak time are minimum and settling time is also close to the minimum value achieved in case of series with derivative filter.

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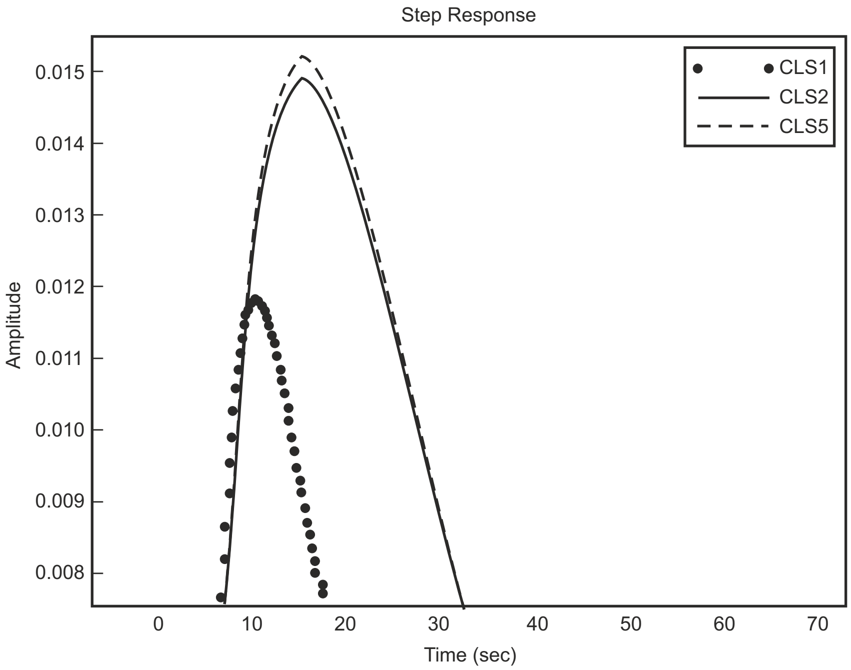

Figure 11 : Comparison of step responses for PID series form with derivative filter for alpha = 0.1 (CLSI), 0.05(CLS5) and 0.2(CLS2).

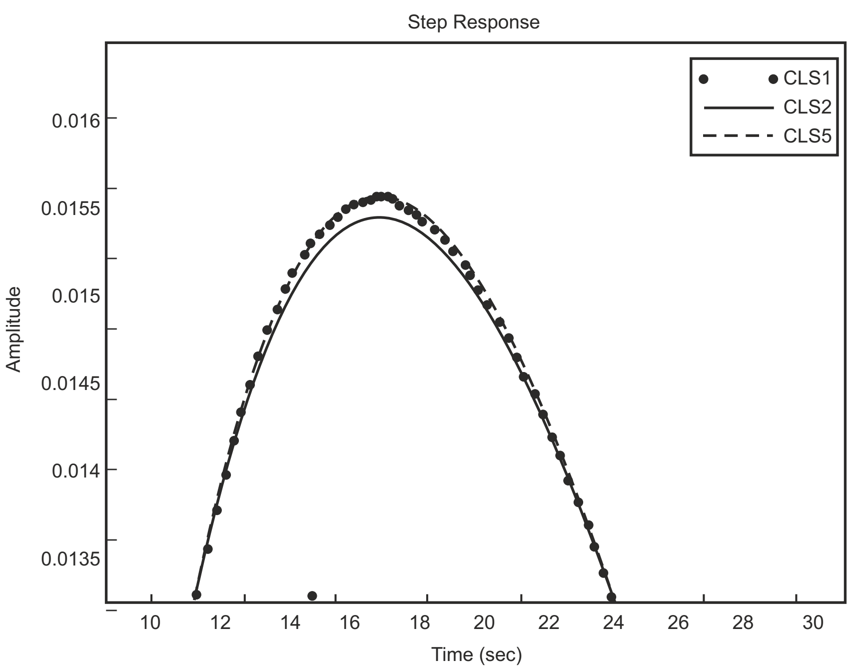

Figure 12 : Comparison of step responses for PID parallel form with derivative filter for alpha = 0.1 (CLSI), 0.05(CLS5) and 0.2(CLS2).

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