World Journal of Engineering Research and Technology
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DISTURBANCE REJECTION WITH HIGHLY OSCILLATING SECOND-ORDER-LIKE PROCESS, PART VII: PIP CONTROLLER

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Article Received on 20/07/2015 Article Revised on 15/08/2015 Article Accepted on 08/09/2015

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ABSTRACT

The purpose of this paper is to investigate the possibility of using a PIP controller for disturbance rejection associated with highly oscillating second-order-like processes. The MATLAB control and optimization toolboxes are used to tune the PIP controller using five error-based objective functions. The best objective function for this control application is assigned. The effect of the controller parameters during the process of disturbance rejection is investigated. The PIP controller can reduce the maximum time response due to a unit step disturbance input to 0.0016. The effectiveness of using the PIP controller is quantitatively evaluated through comparing with PD-PI, PI-PD, IPD, PPI and 2DOF controllers.

KEYWORDS: Disturbance rejection, PIP controller, controller tuning, control system performance.

INTRODUCTION

This is the seventh paper in a series of research papers aiming at investigating the used of a specific controllers and compensators for disturbance rejection associated with highly oscillating second-order-like processes.

Dixon, Young and Shau, 1996 discussed the design and implementation of an optimal PIP controller for a large inverted pendulum system. They used a linear quadratic optimal design of the PIP controller. Taylor, Chotai and Young, 1998 discussed the robustness and disturbance response characteristics of two PIP control structures. They demonstrated the efficiency of the design method through simulation examples. Liu, Dixon and Daley, 2001 introduced a design step to stabilize the PIP controller and ensure that the equivalent closed-loop transfer function of the system remains identical in the absence of model mismatch to that of the original PIP closed-loop system. Quanten, Janssens, McKenna, Young and Berkmans, 2002 developed a PIP climate controller for a SISO system. The PIP controller was able to follow a temperature level of 18-23-21 ^{o}C at any point. Gue, Taylor and Seward, 2004 used a PIP controller to control the Lancaster University computerised intelligent excavator. They compared the PIP controller with a conventionally tuned PID controller demonstrating the feasibility of their approach.

Al-Hammouri, Liberatore, Branicky and Phillips, 2006 described a method for finding the stability regions of PI and PIP controllers for TCP AQM with delays. They showed that previously proposed PIP controllers can be unstable in the presence of time delays. Taylor, Shaban, Stables and Ako, 2007 considered PIP control of nonlinear systems. Their approach yielded a state-dependent parameter – PIP control algorithm with improved performance and robustness in comparison with conventional linear PIP control. Hu, Zhang, Wang, He and Xu, 2009 proposed a current control scheme force grid- connected PWM voltage source converter under unbalanced and distorted supply voltage conditions. Their control scheme was composed of a single PI regulator and multi-frequency resonant controllers. Nada and Shaban, 2014 investigated the use of parallel processing facilities for which a fixed point PIP control design algorithm was developed and implemented upon fast mechatronic system with high speed control. Their experimental results showed valuable enhancement of the implemented PIP controller.

Provallike, Sekhar and Reddy, 2015 used a fuzzy plus PI and self tuning of PIP fuzzy hybrid controllers. They obtained improved response when compared with conventional PI controller. Hassaan, 2015 investigated using a PIP controller to control a highly oscillating second-order-like process for set-point tracking. He tuned the controller using MATLAB optimization toolbox and four objective functions. He compared the performance of the control system with six other controllers used with the same process. Hassaan, 2015 investigated using a PIP controller for disturbance rejection associated with delayed double integrating processes. He used five objective functions in MATLAB optimization environment to tune the PIP controller. His tuning approach could generate an effective performance and robustness of the control system for time delay up to 20 seconds. The PIP could compare with the IPD controller.

Process

The process is a highly oscillating second-order-like process having the transfer function, $G_p(s)$:

$$G_p(s) = \omega_n^2 / (s^2 + 2\zeta\omega_n s + \omega_n^2) \quad (1)$$

Where ω_n = process natural frequency = 10 rad/s.

ζ = process damping ratio = 0.05.

The 10 rad/s natural frequency and 0.05 damping ratio produce an oscillating step time response of 85.4 % maximum overshoot which represents an challenge in selecting a specific controller to damp down the time response due to a disturbance input (disturbance rejection).

PIP Controller

The structure of the PIP controller is shown in Fig.1 for a linear control system with two inputs: a reference input R(s) and a disturbance input D(s) [Hassaan 2015]. The controller consists of two parts:

- A feedforward PI sub-controller part of $G_{PI}(s)$ transfer function.
- A feedback P- sub-controller part of $G_P(s)$ transfer function in an internal loop with the process transfer function $G_p(s)$.

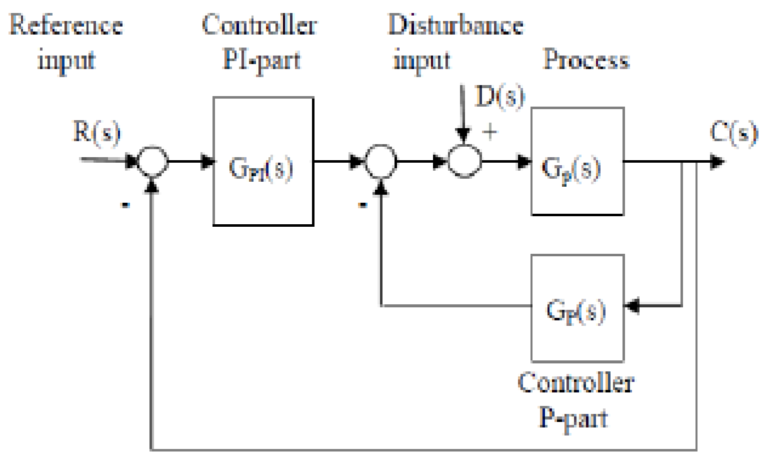

Fig 1. Control system block diagram with PIP controller [Hassaan, 2015].

The PI sub-controller has the transfer function:

$$G_{PI}(s) = K_{pc} + K_i/s \qquad (2)$$

Where:

K_{pc} = the proportional gain of the PI sub-controller.

K_i = the integral gain of the PI sub-controller.

The P sub-controller is a proportional controller having the transfer function:

$$G_P(s) = K_f \qquad (3)$$

Where:

K_f = the proportional gain of the feedback sub-controller.

Closed-loop Transfer Function

For sake of disturbance rejection study, only the disturbance input in the block diagram of Fig.1 will be considered and the reference input will be discarded. Doing this, the transfer function of the resulting control system , C(s)/D(s) using the block diagram of Fig.1 and Eqs.1, 2 and 3 will be:

$$C(s)/D(s) = b_0 s / (s^3 + a_0 s^2 + a_1 s + a_2) \qquad (4)$$

Where:

$b_0 = \omega_n^2$

$a_0 = 2\zeta\omega_n$

$a_1 = \omega_n^2(1 + K')$

$a_2 = \omega_n^2 K_i$

$K' = K_{pc} + K_f$

PIP Controller Tuning

- The PIP-controller is tuned, first, by the definition of an error based objective functions as follows [Martins 2005, Soni and Bhatt 2013, Karnavas 2006]:

ITAE: $\int t|e(t)| \; dt$ (5)

ISE: $\int [e(t)]^2 \; dt$ (6)

IAE: $\int |e(t)| \; dt$ (7)

ITSE: $\int t[e(t)]^2 \; dt$ (8)

ISTSE: $\int t^2[e(t)]^2 \; dt$ (9)

- The objective function will be a nonlinear function in the controller parameters K_i and K'.

- The MATLAB control toolbox is used to assign the step response of the control system to a unit disturbance input for any assigned controller parameters using its command '*step*' [Houpis and Sheldon 2014].
- The error function e(t) is defined as the difference between the time response of the control system c(t) to unit disturbance input and the desired response (which is zero in this case)
- The MATLAB toolbox is used to define one of the objective functions in Eqs.5 to 9 using its command '*fminunc*' [Venkataraman 2009].
- The tuning results for a guessed controller parameter K' of 200 and some of the performance characteristics of the control system disturbance response are give in Table1.

Table 1: PIP controller tuning parameters and system characteristics.

	ITAE	ISE	IAE	ITSE	ISTSE
K'	200.000	201.728	200.140	200.125	200.000
K_i	2.3223	0.4540	0.9916	9.9837	2.1435
c_{max}	0.0052	0.0048	0.0049	0.00448	0.0045
T_{cmax}(s)	4.585	11.8284	5.3734	3.7358	7.4525

- The effect of using five different objective functions on the compensator tuning process and the performance of the control system in response to a unit disturbance input is shown in Fig.2.

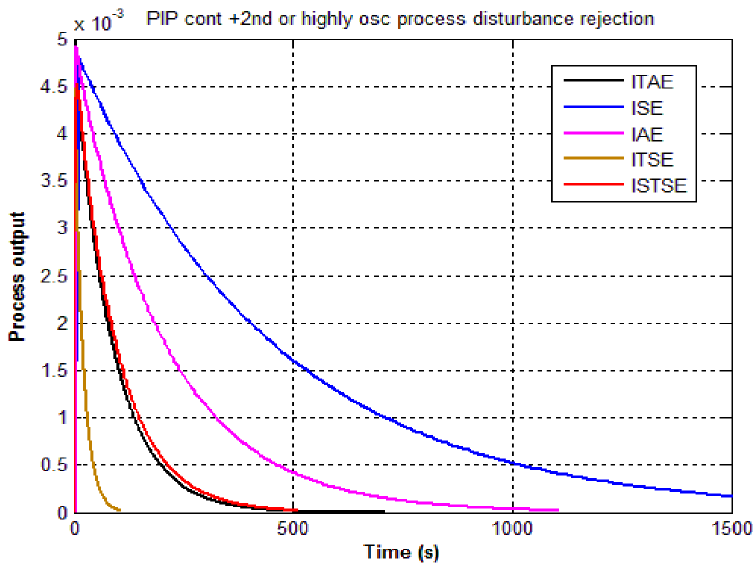

Fig 2. Effect of objective function on system time response.

Fig.2 shows that the type of the objective function used in the PIP controller tuning has a remarkable effect on the control system performance during disturbance rejection associated with the highly oscillating second-order-like process. The ITSE objective function provides the best control system performance. Therefore, it is used in the rest of the work.

- Because of the nonlinearity of the optimization problem, local minima are expected depending on the initial guess of the PIP controller parameters. The effect of the controller parameter K' on the time response of the control system for a unit disturbance input is shown in Fig.3.

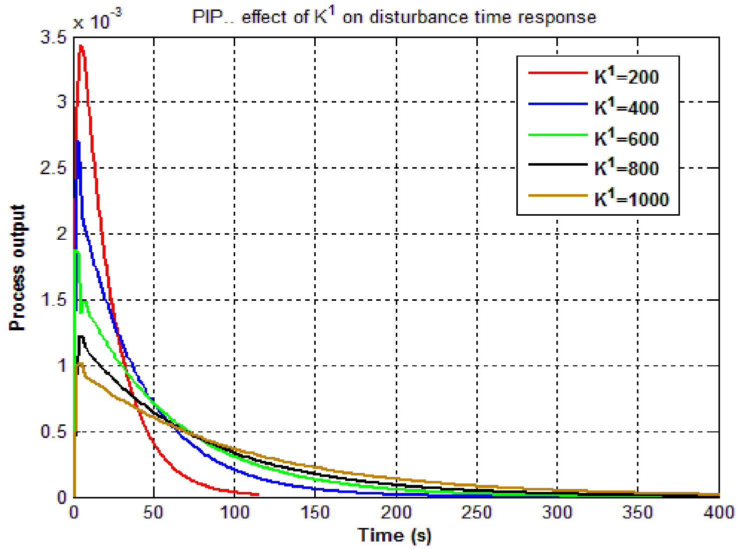

Fig 3. Effect of controller parameter K' on disturbance time response.

- The controller parameter affects both the maximum time response and its corresponding time for the unit step disturbance time response. This effect is illustrated in Fig.4 for K' in the range 200 ≤ K' ≤ 1000.

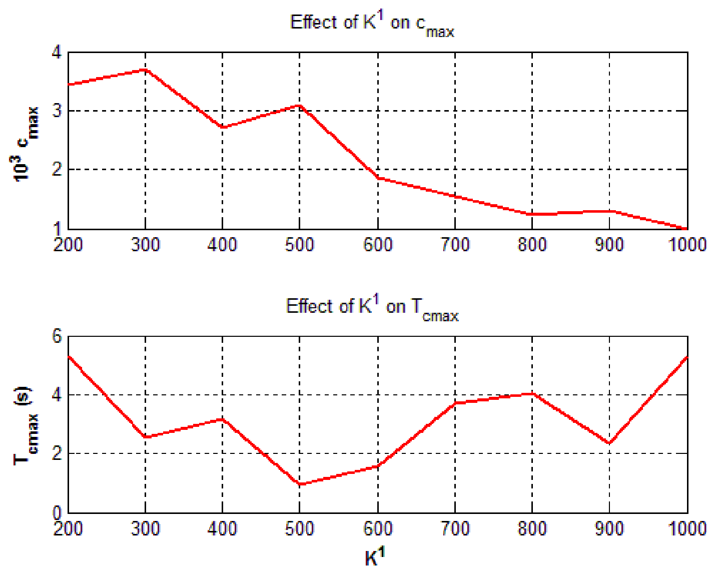

Fig 4. Effect of K' on maximum time response and its time.

- The effect of the PIP controller parameter K_i on the control system dynamics during disturbance rejection is shown in Fig.5 for K_i in the range $1.1 \leq K_i \leq 12.43$.

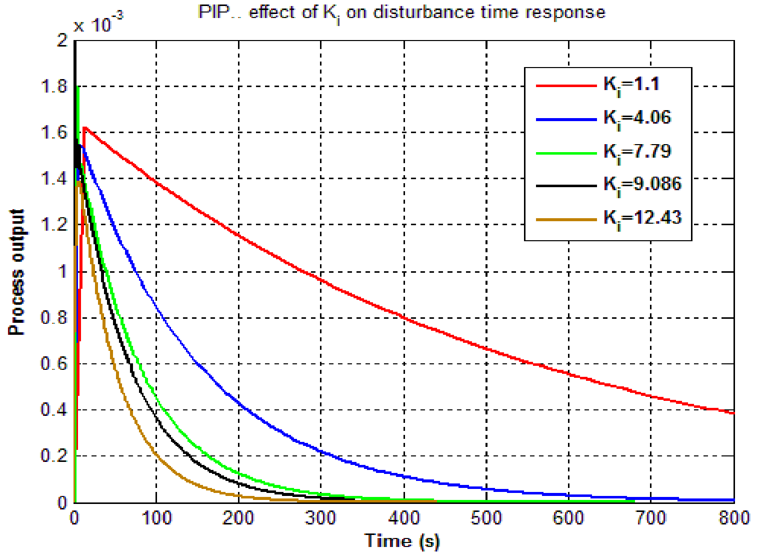

Fig 5. Effect of controller parameter K_i on disturbance time response.

Comparison with other Controllers

To investigate the effectiveness of using the PIP controller in disturbance rejection associated with the highly oscillating second-order-like process, the control system performance using the PIP controller is compared with that using PD-PI controller (Hassaan, 2015), PI-PD controller (Hassaan 2015), IPD controller (Hassaan 2015), 2DOF controller (Hassaan 2015) and PPI controller (Hassaan 2015). This comparison is shown in Fig.6.

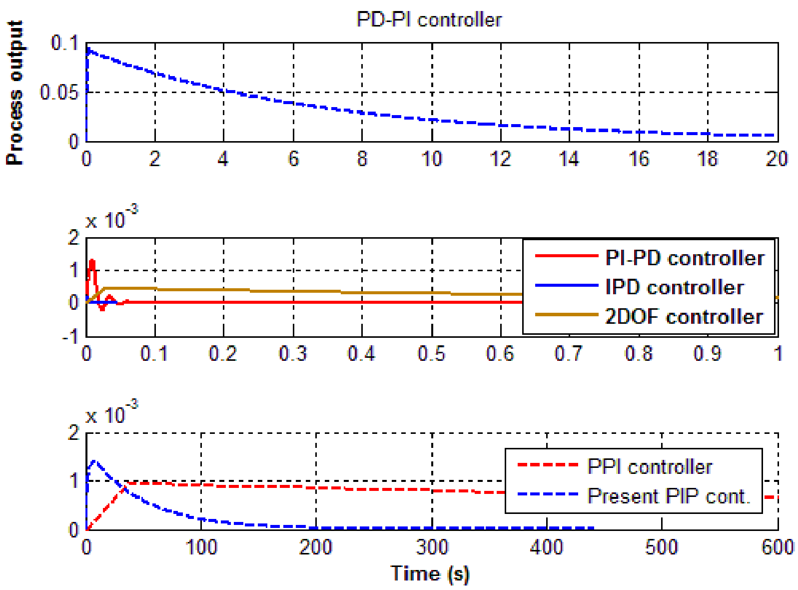

Fig 6. Comparison between different controllers used for disturbance rejection.

CONCLUSION

- The objective of this research work was to investigate using a PIP controller for disturbance rejection associated with highly oscillating second-order-like processes.
- The PIP controller had two parameters to be tuned.
- It was tuned using the MATLAB control and optimization toolboxes.
- Five objective functions based on the error between the disturbance time response of the closed-loop control system and the desired steady-state value were used to tune the PIP controller.
- The ITSE objective function has given the best results during the controller tuning process.
- The effect of changing the controller parameters K' and K_i was investigated in details.
- Using a PIP controller for disturbance rejection associated with a highly oscillating second-order process was relatively successful.
- It was possible to reduce the maximum time response due to a unit disturbance input to ≤ 0.0016.
- It was possible to generate a step disturbance response with zero settling time and a very small value.
- The PIP controller could compete with other controllers used with the same process as the PD-PI, PI-PD and PPI controllers.

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BIOGRAPHY

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