Performance comparison between PID and PI-D controllers for electro-hydraulic cylinder

Zairulazha Zainal [1,3,*], Saleha Mohamad Saleh [2,3], Shamsul Anuar Shamsudin[1,4], Mohd Khairi Mohamed Nor[1,3], and Mohd Juzaila Abd Latif [1,4]

[1)] Fakulti Kejuruteraan Mekanikal, Universiti Teknikal Malaysia Melaka, Hang Tuah Jaya, 76100 Durian Tunggal, Melaka, Malaysia
[2)] Fakulti Teknologi Kejuruteraan Elektrik dan Elektronik, Universiti Teknikal Malaysia Melaka, Hang Tuah Jaya, 76100 Durian Tunggal, Melaka, Malaysia
[3)] Centre for Robotics and Industrial Automation, Universiti Teknikal Malaysia Melaka, Hang Tuah Jaya, 76100 Durian Tunggal, Melaka, Malaysia
[4)] Centre for Advanced Research on Energy, Universiti Teknikal Malaysia Melaka, Hang Tuah Jaya, 76100 Durian Tunggal, Melaka, Malaysia

[*]Corresponding e-mail: zairulazha@utem.edu.my

Keywords: hydraulic cylinder; PI-D; PID control

ABSTRACT – The objective of this paper is to compare the time specification performance between two conventional controllers for an electro-hydraulic cylinder. The goal is to determine which control strategy provides better performance with respect to hydraulic cylinder position. The hydraulic cylinder is one of hydraulic actuators that convert hydraulic power into useful mechanical works. Two controllers are presented such as Proportional Integral Derivatives (PID) controllers and Proportional Integral-Derivatives (PI-D) for controlling the linearized system of electro-hydraulic cylinder. Simulation study shows that both controllers are capable to control the position of the cylinder effectively. The results show that PI-D produced similar response compared to PID control strategies. Moreover, the effect of derivative elements in both configuration shows PI-D configuration has a better response compared with PID configuration.

1. INTRODUCTION

A hydraulic actuator converts hydraulic power into useful mechanical works by a pump with control elements. The basic system of hydraulic actuator consists of a pump, reservoir, directional valve, check valve, pressure relieve valve, selector valve, actuator, and filter. In hydraulic system, oil or less normally water are used as the fluid to distribute forces to numerous units to be actuated [1]. In terms of probability to use water in hydraulic technology, study on that area has been steered as a part of encouraging sustainability [2].

Moreover, hydraulic cylinder is usually used to produce a unidirectional force through a stroke. A servo-hydraulic cylinder is integrated in an electro-hydraulic servo system. Most of the multi-axial testing systems and control systems with servo-hydraulic test cylinders are widely used in an experimental mechanics and used in related test applications due to their advantages such as high energy density, good linearity, high sensitivity, fast response and high precision [3].

This paper presents investigations on performance between two types of controller, which are PID and PI-D control schemes for an electro-hydraulic cylinder. The dynamic model and design requirement have been taken from Adnan et. al. [4]. Performance of both control strategies with respect to cylinder position is examined. Comparative assessment of both control schemes to the system performance is presented and discussed.

2. METHODOLOGY

In this study, an industrial bidirectional hydraulic cylinder (Novotechnik model ZY3.IN) was used as model to generate the mathematical representation. Table 1 shows the specification of the hydraulic cylinder.

Table 2.1 Hydraulic cylinder parameters

1	Piston diameter	25 mm
2	Piston rod diameter	16 mm
3	Stroke	400 mm
4	Piston area ratio	1.6:1

The hydraulic cylinder was modeled by Adnan et. al. [4] using system identification technique where the signal was generated based on three different frequencies. The gathered open-loop transfer function in discrete-time form was written as,

$$\frac{B_o\left(z^{-1}\right)}{A_o\left(z^{-1}\right)}=\frac{0.1816z^{-1}+0.08286z^{-2}-0.02187z^{-3}}{1-0.9137z^{-1}-0.2321z^{-2}+0.1461z^{-3}} \tag{1}$$

From (1), the transfer function in s-domain can be described as

$$G(s)=\frac{1.423s^3+166.2s^2+6898s+267400}{s^4+46.21s^3+3449s^2+52670s+280.2} \tag{2}$$

Based on PID controller configuration, characteristic equation for closed-loop system can be described as

$$1+K_P\left(1+\frac{1}{T_i s}+T_d s\right)\left(G(s)\right)=0 \tag{3}$$

The value of K_P, T_d and T_i was set based on (2). Root locus technique was used in order to identify the value of

K_P, T_d and T_i under criterion of damping factor 0.677. The performance metric was used to tune the parameters of PID controller is an integral absolute error (IAE).

For PI-D configuration, the general structure is shown in Figure 2.1. For the value of K_P, T_d and T_i, similar value that been used for PID configuration is again used for PI-D configuration.

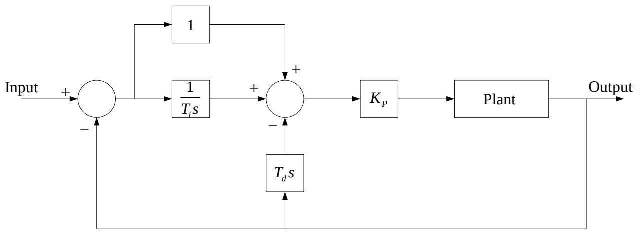

Figure 2.1 General structure for PI-D configuration

3. RESULTS AND DISCUSSION

The results for these two configurations are shown in Figure 3.1. The system is excited using step input. For PID and PI-D configurations, the value of K_P, T_i and T_d were as follows:

$$K_P = 13.95; T_d = 0.018; T_i = 50.02 \qquad (4)$$

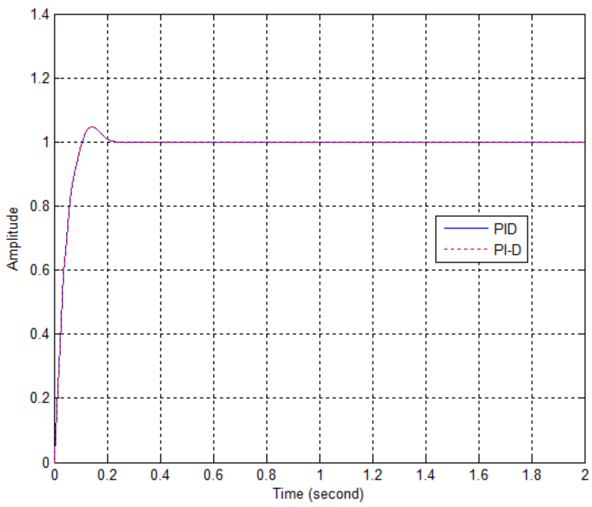

Figure 3.1 Response of the system with PID and PI-D configuration when been excited with step input

It can be seen that although the configuration of controller has changed, the performance of the system remaining the same. In other words, although the derivative part is moved to feedback route, the performance is same as a conventional PID. The performance of the system is tabulated in Table 3.1.

Table 3.1 Summary of the performance characteristics for hydraulic cylinder

Time response specification	PID	PI-D
Rise time	0.054 s	0.054 s
Settling time	0.178 s	0.178 s
Percentage overshoot	6.39 %	6.39 %

Meanwhile, the difference that can be observed is an impact of derivative action, as shown in Figure 3.2. It can be seen that for PID configuration, the output is decrease at the beginning of the response from derivative element, while for PI-D configuration, the output pattern is vice versa compared with the output from derivative element in PID configuration. If the response of derivative element is magnified at the small time range (starting from 0 to 1 x 10^{-3} second), it can be seen that the output for derivative element for PID has a large magnitude of amplitude at the beginning of the response, while for derivative element for PI-D, small amplitude is observed. This perhaps due to the reason that, for PI-D configuration, the derivative element is affected by a feedback signal only. While for PID configuration, the derivative element is affected by both feedback signal and reference signal. Therefore, it can be said that for PI-D configuration, sudden large amplitude occurs at derivative output can be avoided. In addition, for PI-D configuration, the response for derivative output is smoother than PID configuration. This fact is important to consider especially in realization of derivative controller that involve mechanical elements.

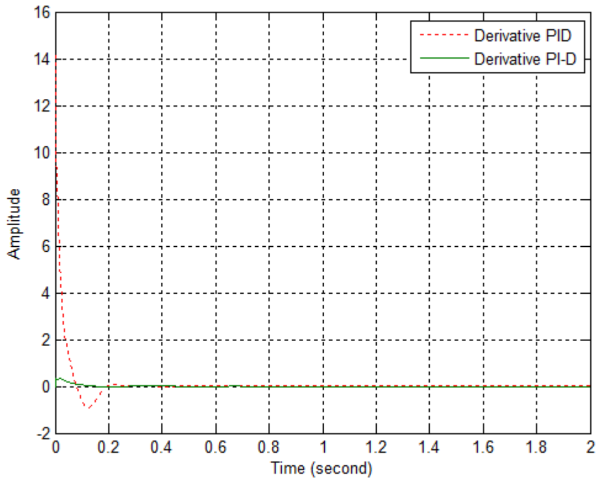

Figure 3.2 Derivative output for PID and PI-D configuration when been excited with step input

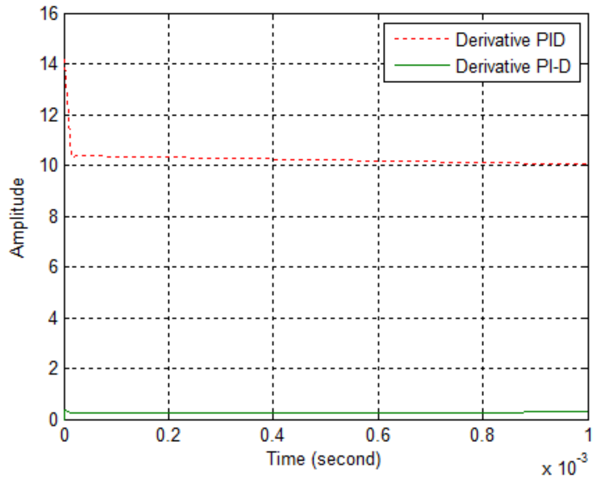

Figure 3.3 Derivative output for PID and PI-D configuration when been excited with step input (time range from 0 to 0.001 s)

4. SUMMARY

In this paper, two controller's configuration, PID and PI-D are successfully designed. Based on the results and analysis, a conclusion has been made that both configuration is capable of controlling the hydraulic cylinder. All the successfully designed controllers were compared. The responses of each controller were plotted in one window and are summarized in Table 3.1. Simulation results show that both controller have similar performance. Further studies show that the way derivative element is configured affect the output of the element itself. It can be said that derivative output for PI-D configuration has a smoother response than PID configuration.

REFERENCES

[1] Ponomareva, E. (2006). Hydraulic and pneumatic actuators and their application areas. *Mechatronics-Foundations and Applications*.

[2] Yusof, A. A., Mat, S. & Din, A. T. (2013). Promoting sustainability through water hydraulic technology – the effect of water hydraulic in industrial scissor lift. *Applied Mechanics and Materials*, 315, 488-492.

[3] Li, L. & Thurner, T. (2013). Accurate modeling and identification for servo-hydraulic cylinder system in multi-axial test applications. *Ventil*, 19(6), 462-470.

[4] Adnan, R., Rahiman, M. H. F. & Samad, A. M. (2010). Model identification and controller design for real-time control of hydraulic cylinder. *6th International Colloquium on Signal Processing & Its Applications (CSPA)*, 186-189.