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TRANSIENT ANALYSIS OF AN OPTIMIZED ROBUST CONTROLLER IN A HYDRAULIC SYSTEM

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ABSTRACT

An electro-hydraulic actuator (EHA) system is a prevalent mechanism in industrial sectors that required high force such as steel, automotive and aerospace industries. It is a challenging task to acquire precision when dealing with a system that can produce high force. Besides, since most of the mechanical actuator performance varies with time, it is even difficult to ensure its robustness characteristic towards time. Therefore, this paper proposed the industrial's well-known controller, which is the proportional-integral-derivative (PID) controller that can improve the precision and the robustness or the EHA system. Then, an enhanced PID controller, which is the fractional order PID (FOPID) controller will be applied. Both controllers are optimized using particle swarm optimization (PSO) algorithm. Then, this paper will focus to analyse the transient response performance of both controllers through the step and multiple-step response. As a result, it is observed that the precision and robustness characteristic of the FOPID is greater than the PID controller.

Keywords: positioning tracking analysis, electro-hydraulic actuator (EHA), robust control design.

1. INTRODUCTION

Commonly, the dynamics delivered to the Electro-Hydraulic Actuator (EHA) system are either linear or rotary, which are also referred to the cylinder or motor. Due to its character that capable to deliver high forces, widespread engineering applications dealing with these high-forces dynamics have been found in construction [1], agriculture [2], oil and gas [3], mining and material handling machinery [4]. Whereby, EHA system produces massive contribution in engineering sector that impetus the world economy [5].

However, the existence of uncertainties, nonlinearities behaviour and disturbances in the EHA system normally causing tracking errors and phase lag during the position tracking process, which consequently increase the challenge of the controller design [6]. These existing drawbacks motivate researchers to further investigate the potential method that capable to enhance the hydraulic actuator performance. Where, control system emerged to be effectively improved the EHS system performance by reducing the effect of the existing drawbacks.

Dealing with the characteristic of the proportional-integral-derivative (PID) controller, which is easy to be understood, it is a universal control strategy in industrial sector, and a control strategy trademark for researchers to conduct their research. In a recent trend, researchers have intended to alter the structure of this controller so that the enhancement can be achieved. Most common structures including gain-scheduling and fractional order that is evidence to be performed better than the conventional PID controller [7–10]. With the synthetization of computational optimization algorithm in these control strategies, great improvement has been obtained in the EHA system [11-13].

This paper addressing the tracking performance of the PID and FOPID controller in terms of transient response analysis implemented in the nonlinear EHA system. Both of the control parameters will be optimized using PSO algorithm and examine comprehensively in a simulation environment. The work will be implemented in a hardware in a near future. The organizations of this paper are, the discussion of the step and multiple-step responses analyses are first presented. Then, the comprehensive examination of the controller performances is carried out. Subsequently, overall performances of both controllers implemented in the EHA system will be concluded.

2. METHODOLOGY

Step response is a commonly used reference trajectory that can be used for transient response and steady-state error analyses which including percentage of overshoot, time delay, rise time, settling time, and steady-state error of particular controller and system performance. In a control system, steady state response performed as close as possible to the desired response is crucial. Where the system errors, that reflecting the differences between the actual and the desired system output responses at steady-state should be examined carefully so that these errors can be reduced or even eliminated. Several researchers have conducted their study according to the step input reference signal in the evaluation of the controller performance [14-18].

Knowing how a system responds to the desired input or response or trajectory is crucial since the deviation or the so-called error leads to the severe consequence that causing unnecessary loss. Besides, a system will perform abnormally or the so-called unstable until it has achieving a settling condition. Thus, step

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response of a system produced the stability information and the information of the ability of a system to reaching stationary state [19].

Figure-1 depicts an example of a step response, where the solid line denotes the desired response, and the dash line represents the output response. It can be seen in Figure-1, the output response of the system produced unsatisfied transient response. Thus, the assistance of an appropriate controller will be needed in order to obtain more satisfies performance.

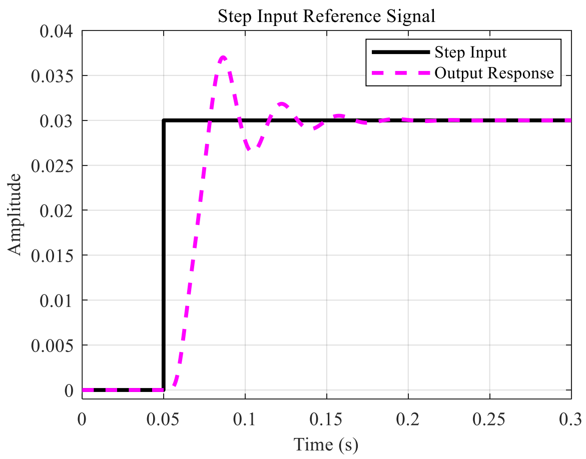

Figure-1. Step reference input signal.

In order to obtained more information from a system response, the synthesisation of multiple-step response that consist of different velocity and acceleration can be used. Different set points in a multiple-step response composed of more different information in term of fast and slow velocity, which is useful to examine the performance of the designed control system in terms of its accuracy, tracking performance, and robustness characteristics. The study conducted in [20] showed the embedded of multiple trajectories in a response possess different characteristics of a system. Figure-2 depicts the example of a system response in desired multiple trajectories.

Referring to the Figure-2, an example response of "controller A" denoted in a dot line, and "controller B" denoted in a dash line, while the solid line is the desired response implemented in a particular system. Roughly extracting the data from Figure-2 and referring to the response with respect to the transient response and steady-state error, controller B generates better performance than controller A. Based on the performance produced by controller A, it can be roughly seen that the controller is not robust enough toward the changes of system operation over time, where the response in the time between 28 to 30 seconds demonstrated higher overshoot and slower settling time compared with the response before 28 seconds. Thus, appropriate control strategy is needed to achieve the performance as performed by controller A.

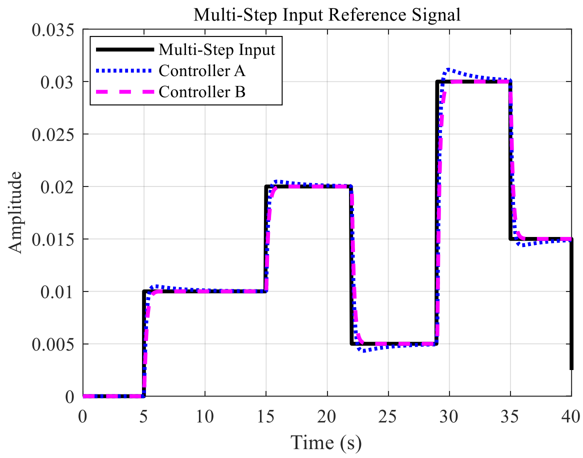

Figure-2. Multiple-step reference input signal.

3. OUTPUT PERFORMANCE

Proper design of a control system is essential to ensure the performance accuracy of a mechanical system that leads to time saving and energy saving. The design process usually difficult when dealing with mechanical systems that are inherently nonlinear. In this study, two controllers have been proposed to dealing with the nonlinear EHA system. The industrial favourite control scheme which is PID controller and the upgraded PID controller, called FOPID controller is designed to control and enhance the performance of the EHA system. By synthesizing PSO algorithm, optimized control parameters were obtained as listed in Table-1.

Table-1. Optimized parameters using PSO algorithm.

Controller	Parameter				
	K_p	K_i	K_d	λ	δ
PID	10.0910	0.0013	-4.6985	1	1
FO-PID	54.8021	0.8051	7.3401	2.8260	8.0205

To examine the transient response and steady state error of the EHA system, step reference input response is first applied. The overshoot percentage, rise time, settling time is extracted from the result to verify the performance of both controllers. Furthermore, root means square error also used to inspect the error produced by both controllers along the process. Figure-3 depicts the output response with respect to the step reference response. The numerical results of the response are tabulated in Table-2.

Noted that same parameters were used in the PSO algorithm including swarm size, acceleration, iteration and

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inertia weight. Only one attempt is conducted to obtain the parameters of both PID and FOPID controllers. In other word, better parameters might be obtained over attempts since the random values are implemented in the searching process of the PSO algorithm.

Based on the response in Figure-3, both controllers with optimized controller gains capable to cope with the desired response. However, when the hydraulic actuator extended to the maximum desired value, PID controller slides out due to the very high dynamic that formed an overshoot situation. Conversely, even dealing with the high dynamic response, FOPID showed outstanding performance by properly tracking the desired step response.

However, to accurately examine the performance of both controllers, numerical data showed the overshoot value of $4.69\text{x}10^{-08}$ for the FOPID controller. Besides that, the numerical result also showed the existent of the steady-state-error which is hardly detected through vision. Therefore, numerical data is essential in the control system performance analysis, especially in the experimental platform.

In the experimental design, multiple-step that composed of various amplitude and frequency usually lead to more details information with respect to the system behaviour. The multiple-step response of the EHA system with the assistant of the PID and the FOPID controller is illustrated in Figure-4.

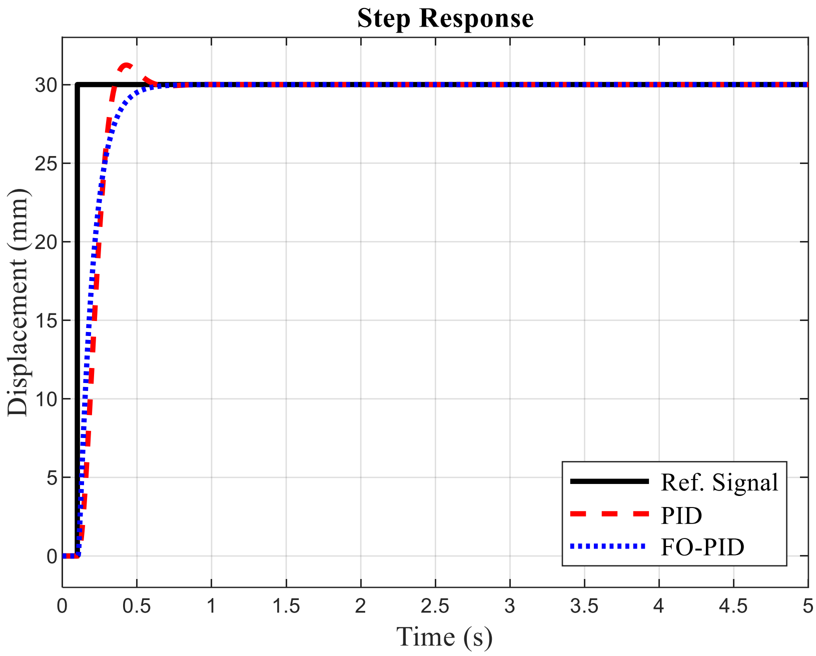

Figure-3. Step reference response.

Table-2. Numerical results for step reference response.

Controller	**Transient Response**			**Steady-state Error (e_{ss})**	**RMSE**
	OS (%)	***T_r (s)***	***T_s (s)***		
PID	4.1238	0.1602	0.5240	$4.5979\text{x}10^{-04}$	8.0325
FO-PID	$4.69\text{x}10^{-08}$	0.2113	0.4833	$4.0146\text{x}10^{-13}$	7.1596

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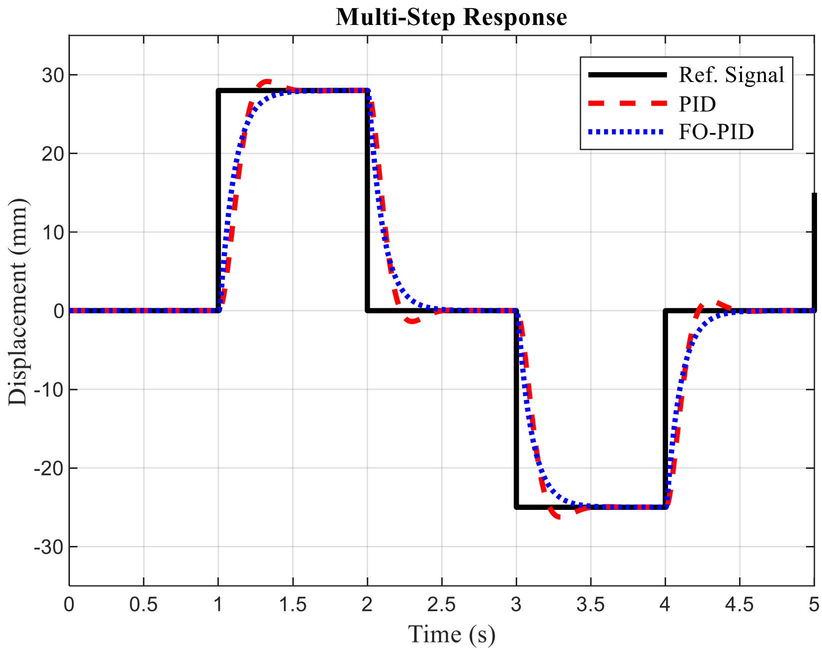

Figure-4. Multiple-step reference response.

For the performance evaluation of the designed controller, either they are able to handle the different set points that represent for example, a shape of a product, or disturbances, multiple-step response inspection is a great choice. Based on Figure-4, both control strategies capable to handle the multiple set points overtimes.

Referring to the RMSE analysis of the multiple-step response, FOPID controller achieved lower error compared to the PID controller. This indicates the PID controller required more effort in order to produce the required performance based on the desired response. At the end of the result, this situation usually leads to higher cost and energy loss. Therefore, according to the performance in the step and multiple-step responses, it can be inferred that the precision and robustness characteristic of the FOPID is greater than the PID controller

Table-3. Root mean square error for multiple-step reference response.

Controllers	RMSE
PID	11.0043
FOPID	9.8920

4. CONCLUSIONS

Transient response and steady-state analyses consist of great indicator that very useful in the control system design. In this paper, step and multiple-step responses have been implemented in the EHA system with the assistant of the PID and the FOPID controllers. Optimal parameters of both controllers have been obtained using PSO algorithm. Based on the output response on step and multiple-step reference response, FOPID controller achieved lower error compared to the PID controller. More effort is needed to achieve the desired response by PID controller compared to the FOPID controller, which concurrently leads to higher cost and energy loss.

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