Position Tracking Performance with Fine-Tuned Ziegler-Nichols PID Controller for Hydraulic Actuator Model

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ABSTRACT: Electro-Hydraulic Actuator (EHA) is widely used in heavy load-handling applications due to its versatility and durability. However, it is susceptible to various plant variation such as noise, physical factors and internal factors that greatly reduce the productivity of the system. Therefore, the implementation of a systematic control system for the EHA system is crucial to enhance its performance and productivity. This paper presents the design of PID controller with two different tuning method which is trial-and-error tuning and Ziegler-Nichols with fine-tuning. The performance evaluation of the designed PID controllers will be based on transient response, steady-state response and error analysis via root mean square error. Results show that ZN with fine-tuned PID leads to a system with better performance and robustness.

Keywords: *PID; Ziegler-Nichols; EHA*

1. INTRODUCTION

An electro-hydraulic actuator (EHA) is a self-contained actuator powered solely by electrical power signal. EHA leads to reliable and simple system architecture due to components such as hydraulic pumps and tubing is constructed together as a package [1].

PID control is the most common control algorithm used in industrial process control due to its simplicity and robust performance. With the closed-loop feedback control, it will make the system variable close to the setpoint [2]. There are three parameters in the PID controller that need to be tune or adjust to achieve desired performance.

Ziegler-Nichols has proposed a fast-tuning method that performs on the closed-loop system which is known as the frequency-domain method. The PID controller can be tuned based on information of ultimate period (Pu) and ultimate gain (Ku) from sustained oscillatory response [3].

2. METHODOLOGY

2.1 Modelling of system with MATLAB Simulink

The EHA system is modelled in MATLAB Simulink software which comprises of an actuator with a 4-way directional valve. It operates a double-acting hydraulic cylinder that is connected to mass, force, spring, and viscous friction that represent the external disturbances in real working condition. Figure 1 shows the EHA system in Simulink using SimScape model.

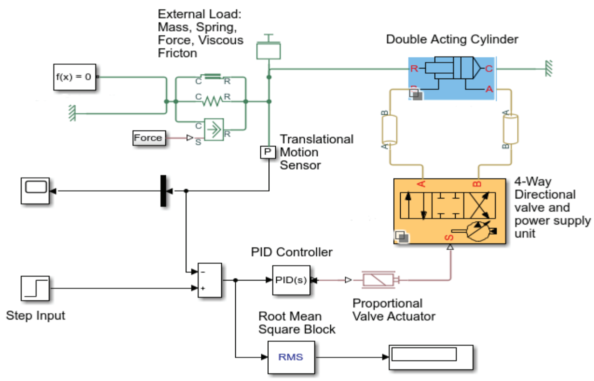

Figure 1 EHA model in MATLAB Simulink

2.2 PID (Proportional-Integral-Derivative) controller design

PID controller is widely used in industrial control application to regulate the parameters such as temperature, pressure, speed, and flow. The structure of a PID controller in the parallel algorithm is illustrated in Figure 2. The control signal or controller output is the summation of proportional, integral, and derivative paths after multiplication with the error signal (e).

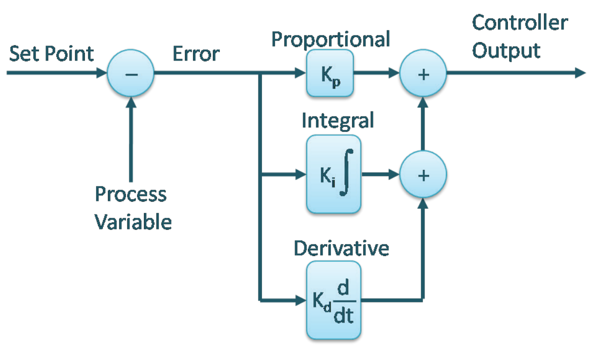

Figure 2 PID controller in parallel algorithm

The overall formula of PID control is summarized as in equation (1).

$$u(t)=K_P*e(t)+K_I*\int_0^t e(t)\,dt+K_D*\frac{d\,e(t)}{dt} \qquad (1)$$

2.2 *Ziegler-Nichols Tuning method*

The tuning method used is via the second classical method proposed by Ziegler-Nichols (ZN). This method is performed on the closed-loop system based on the initial adjustment for the gain of proportional (P) element only. The value of K_P, K_I, and K_D can be obtained from the formula in Table 1.

Table 1 Ziegler Nichols continuous cycling formula

Controller	K_P	K_I	K_D
PID	$0.6*K_u$	$2K_P/P_u$	$K_P*P_u/8$

3. RESULT AND DISCUSSION

The parameters of the PID controller with the trial-and-error tuning method and Ziegler-Nichols with fine-tuning method are summarized in Table 2. The performance evaluation of each designed system is conducted with transient and steady-state analysis. The step signal with a step time of 1s and amplitude of 0.1m is used as the reference input.

Table 2 PID controller parameters

Tuning Method / PID Gain	Trial-and-Error Tuning	ZN with Fine-Tuning
K_P	0.02	0.0162
K_I	0.00005	0.0214
K_D	0.0001	0.0003776

The output response of both systems is plotted in Figure 3 to evaluate the performance. Based on the output of each system, the control performance indexes such as rise time, percentage overshoot, settling time and steady-state error is recorded in Table 3 along with the root mean square error (RMSE) value from error analysis. From the results obtained in Table 3, the PID tuning via ZN with fine-tuning method has the best overall performance. The tuning method has the fastest response based on the shortest step time and it also has the smallest RMSE value which is only 6.585×10^{-9} m. However, the overshoot of this system is relatively high, and this reflects the longer settling time as compared with PID (trial-and-error) system. The PID (trial-and-error) system also has satisfactory transient and steady-state performance. Nevertheless, the error signal of the system is larger by a huge margin which indicates poor setpoint tracking. The RMSE value in PID (trial-and-error) is higher due to the higher steady-state error of 8.259×10^{-6} m.

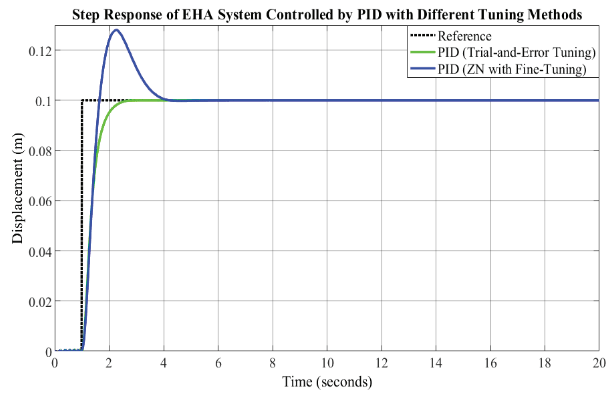

Figure 3 Step response of designed PID control systems

Table 3 Control performance indexes of each designed PID control system

Tuning Method / Control Performance Index	Trial-and-Error Tuning	ZN with Fine-Tuning
Rise Time (s)	0.679	0.444
Settling Time (s)	2.247	3.734
Percentage Overshoot (%)	0.505	25.564
Steady-State Error (m)	8.259×10^{-6}	4.171×10^{-11}
Root Mean Square Error (m)	8.26×10^{-6}	6.585×10^{-9}

4. CONCLUSION

The PID controller is designed with two different heuristic tuning method which is trial-and-error and ZN with fine-tuning. The tuned PID controller is then implemented into the EHA system that modelled in MATLAB software to evaluate the actual displacement of the actuator. Based on the various control performance indexes and error signal analysis, the ZN with fine-tuned PID controller has the best performance in term of response time and setpoint tracking. Therefore, the ZN with fine- tuning method is proposed as the best method in this project with the highest weightage among the control performance indexes.

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