Analytical versus optimization PID Tuning for Electronic Wedge Brake Clamping Force Control

Mohd Hanif Che Hasan[1,2,*], Mohd Khair Hassan[2], Fauzi Ahmad[3], Sharil Izwan Haris[3]

[1)] Fakulti Teknologi Kejuruteraan Electrik dan Electronik, Universiti Teknikal Malaysia Melaka, Hang Tuah Jaya, 76100 Durian Tunggal, Melaka, Malaysia
[2)] Fakulti Kejuruteraan, Universiti Putra Malaysia, Serdang, 43400 Seri Kembangan, Selangor, Malaysia
[3)] Fakulti Kejuruteraan Mekanikal, Universiti Teknikal Malaysia Melaka, Hang Tuah Jaya, 76100 Durian Tunggal, Melaka, Malaysia

*Corresponding author's email: hanif.hasan@utem.edu.my

ABSTRACT: This paper presents a series of simulation results for the Electronic Wedge Brake (EWB) clamping force control based on SISO based Proportional-Integral-Derivative (PID) control configuration. The PID tuning is performed using different tuning methods, namely Ziegler-Nichols (ZN), Chien-Hrones-Reswick (CHR), Approximate MIGO (AMIGO), Skogestad Intern Model Control (SIMC) and Gradient Descent (GD) method. The result shows that the GD method is the best with 37% enhancement on the rise time and fulfil actuator limit below 12V. Even though others tuning method is easy to implement compared to GD that need several iterations to get the best value, there are some requirements are not meet.

Keywords: *Electronic Wedge Brake (EWB); Clamping Force Control; PID Tuning*

1. INTRODUCTION

One of the most important aspects of EWB is the control scheme that will dictate the effectiveness of the whole braking ability for the system. With the ideas of electromechanical brake control as a potential influence, force control was introduced to EWBs. Single loop control is a basic method to perform EWB clamping force control as in [1]. In this configuration, brake force or torque is feedback directly to the controller. Besides, classic cascade control also used [2]. The state feedback method was also proposed in EWB such as PI with full or less state feedback, PI-Optimal LQR, Sliding Mode Control (SMC), and Adaptive SMC.

Several methods are used to tune the PID controller in a SISO system. The Skogestad, Cohen Coon, and IMC methods are applied to three tank process model [3]. A comparison between classical technique and optimization algorithm was made and show that the optimization method is the best for PID tuning [4].

The controller designs for EWB that have been studied focus on system robustness when parameter variation and disturbance occur. The performance during transient conditions is less discussed. Therefore, the investigation on PID tuning is examined to look at the best option available.

2. METHODOLOGY

Modelling of original EWB can be described as 5 states state-space linear model [1]. However, model reduction is possible. The reduce order EWB model when the axial damping and wedge mass are neglected [5] is described in Equation(1) as:

$$x = [\theta_m, \omega_m, I_m]^T \qquad (1)$$
$$y = F_c$$

$$A = \begin{bmatrix} 0 & 1 & 0 \\ \frac{K_a{}^2 a_2{}^2}{\eta J_m (a_1{}^2 a_3 + K_a)} - \frac{K_a a_2{}^2}{\eta J_m} & -\frac{D_m}{J_m} & \frac{K_t}{J_m} \\ 0 & -\frac{K_e}{L_m} & -\frac{R_m}{L_m} \end{bmatrix}$$

$$B = \begin{bmatrix} 0 \\ 0 \\ \frac{1}{L_m} \end{bmatrix}, \text{and } C = \begin{bmatrix} \frac{K_{cal}\tan(\propto) K_a a_1 a_2}{K_a + a_1 a_3{}^2} \\ 0 \\ 0 \end{bmatrix}^T$$

Where

$$a_1 = \cos\beta,$$
$$a_2 = \frac{L_a N_a}{2\pi}$$
$$a_3 = K_{cal}\tan\alpha(\tan\alpha - \mu)$$
$$\beta = \begin{cases} 0 & \text{, for Normal Actuation EWB} \\ \alpha & \text{, for Optimized Actuation EWB} \end{cases}$$

The PID control tuned based on 5 different tuning methods is used to evaluate the effectiveness of tuning methods. The tuning methods used are the ZN, CHR, AMIGO, SIMC and GA algorithms. Several design requirements are set. Transient response characteristic is considered with rising time and settling less than 0.2 s and 1 s respectively and limited by 5% overshoot. The actuator constrain is 12V at a maximum 10,000 N clamping force, thus only 0.0012V is allowed during unity step input.

The ZN, CHR, and SIMC assume that a plant is a first-order model with a time delay as Equation (2) before the PID parameters are tuned using their method.

$$G(s) = \frac{ke^{-sL}}{Ts + 1} \qquad (2)$$

The CHR uses a lookup table for 0% overshoot with disturbance rejection to compute controller parameters.

The AMIGO approach, on the other hand, employs open-loop, time-domain, and M-constrained integral gain optimization. The PID parameter tuning based on GD offers a more flexible option when all parameters are set using specified design requirements, rather than a relatively rigid design process via classical methods. The EWB model parameters used in this evaluation is based on [1]. The final value of tuned parameters is summarized in Table 1.

Table 1 PID Tuned Parameters for Each Tuning Method

Tuning Method	K_P	K_I	K_D
ZN	0.000433	0.0020	2.342e-05
CHR	0.000342	0.0013	1.557e-05
AMIGO	0.000181	0.0006	0.908e-05
SIMC	0.000192	0.0004	0.456e-05
GD	0.000289	0.0004	2.970e-05

3. RESULT AND DISCUSSION

The performance of each system response shown in Figures 1 and 2.

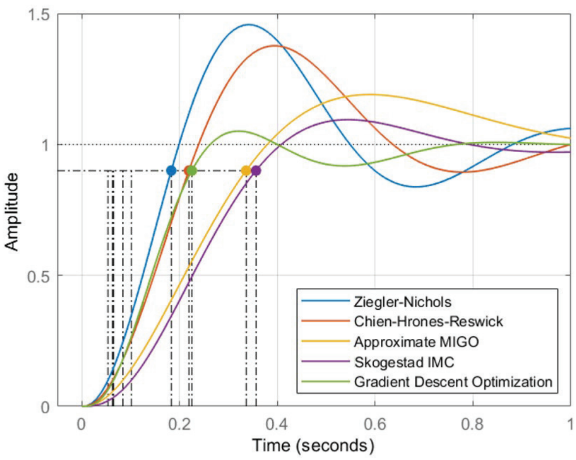

Figure 1 Reference Tracking Based on Various PID Tuning Method

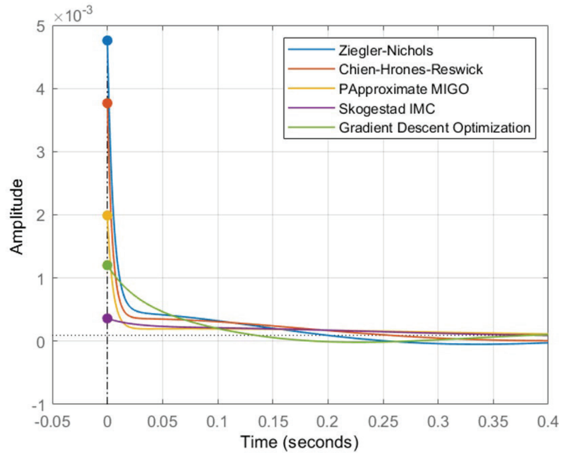

Figure 2 Actuator Effort for Each Tuning Method.

The performance of each controller is compared in Table 2. Only rise time for GD fulfils the requirement. Besides, only SIMC and GD methods produce actuator effort within the allowable range.

Table 2 Rise Time and Actuator Maximum Effort for Each Tuning Method

Tuning Method	Rise Time (s)	Actuator Effort (mV)
ZN	0.129	4.76
CHR	0.219	3.77
AMIGO	0.252	1.99
SIMC	0.255	0.36
GD	0.160	1.20

4. CONCLUSION

EWB clamping force control based on SISO based PID is configured and tuned based on 5 different tuning methods, i.e., ZN, CHR, AMIGO, SIMC and GD. The GD method is the best solution where the rise time is 37% better than the worst time achieved with the actuator optimized at the 12V limit. Even though others tuning method is easy to implement compared to GD, it cannot fulfil all the requirements.

ACKNOWLEDGEMENT

Authors are grateful to Universiti Teknikal Malaysia Melaka for the financial support through Pusat Pengurusan Penyelidikan & Inovasi (CRIM).

REFERENCES

[1] M. H. Che Hasan, M. Khair Hassan, F. Ahmad, and M. H. Marhaban, "Modelling and Design of Optimized Electronic Wedge Brake," in *2019 IEEE International Conference on Automatic Control and Intelligent Systems (I2CACIS)*, 2019, no. June, pp. 189–193.

[2] F. Ahmad, S. A. Mazlan, K. Hudha, H. Jamaluddin, and H. Zamzuri, "Fuzzy fractional PID gain controller for antilock braking system using an electronic wedge brake mechanism," *International Journal of Vehicle Safety*, vol. 10, no. 2, p. 97, 2018.

[3] K. T. Sundari, C. Komathi, S. Durgadevi, and K. Abirami, "Optimal Controller tuning of a PI controller for a three tank non-interacting process," *ICPECTS 2020 - IEEE 2nd International Conference on Power, Energy, Control and Transmission Systems, Proceedings*, pp. 2–6, 2020.

[4] J. M. S. Ribeiro, M. F. Santos, M. J. Carmo, and M. F. Silva, "Comparison of PID controller tuning methods: Analytical/classical techniques versus optimization algorithms," *2017 18th International Carpathian Control Conference, ICCC 2017*, pp. 533–538, 2017.

[5] M. H. Che Hasan, M. K. Hassan, F. Ahmad, and M. H. Marhaban, "Electronic wedge brake model approximation analysis," in *Proceedings of Mechanical Engineering Research Day 2020*, 2020, no. December, pp. 26–27.