

Optimal PID Controller Design of a Magnetic Levitation System

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Abstract: The exegesis of the control of Magnetic Levitation (maglev) system is a challenging problem and many control techniques have been tested on this benchmark problem to test the efficiency of the proposed control law. An attempt has been made in the present paper to stabilize the maglev system by designing a PID controller first by using 'PID tuner' tool in Matlab and then by using the Pole-Placement Technique (PPT).

Keywords: Linearization, Maglev system, Magnetic levitation, PID controller, Pole-placement technique.

I. INTRODUCTION

The non-linear system such as the maglev system is an open-loop unstable system with a fast dynamic response, therefore designing the controller is very challenging. Despite, this system has an application in the industries related to maglev based high-speed trains [1-2]. In several works of literature, an attempt has been made by researchers for developing the controller for the maglev system. In references [3-6], linear and non-linear methods were employed to design and analysis the control algorithm for the maglev system which includes linear state and adaptive control or an exact linearization.

Therefore, the present manuscript comprises five sections. Section 2 demonstrates the mathematical modeling of the considered maglev system. The designing of a PID controller using Matlab / Simulink is described in Section 3. The results and discussion are presented in Section 4. Finally, in Section 5 the conclusion is drawn.

II. MAGLEV SYSTEM MATHEMATICAL MODEL

Fig. 1 depicts a maglev system. The system incorporates a magnetic sphere suspension system (an arrangement of the electromagnet, infrared position sensor, and a metal sphere).



Fig. 1: Maglev System Unit

The suspension system further can be represented as a mechanical system where the position of a sphere is controlled by adjusting the electromagnet current. The second is an electrical system, which can be controlled by controlling the electromagnet terminal voltage. Accordingly, the vertical position of the metal sphere is controlled by changing the electromagnet current setting and the input voltage. Hence, due to the electromagnetic force, the metal sphere is suspended in air.

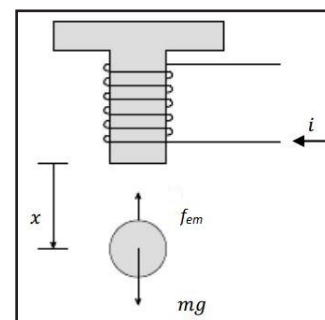


Fig. 2: Sketch of a Maglev System

The acting balance forces on the ball and the coil subsystem [7-9] is described by equation (1) as:

$$m\ddot{x} = mg - f_{em} \quad (1)$$

where, $f_{em} = K_f \frac{i^2}{x^2}$ is an electromagnetic force, m and x are the mass and position of the ball respectively. g is the gravitational constant, K_f is the constant depending upon the parameters of the electromagnet and i is the current in the electromagnet. Therefore, equation (1) can be written as:

$$m\ddot{x} = mg - K_f \frac{i^2}{x^2} \quad (2)$$

Table I present the parameters of a maglev system. Equation (2) implies a non-linear model and for analysis of the system using techniques such as Bode plots, Nyquist plots, root locus (for closed loop system only), the system model has to be linearized. Such a linearization is done at equilibrium point of $x_{ss} = 7$ mm and $i_{ss} = 1$ A.

TABLE I: PARAMETERS OF A MAGLEV SYSTEM

K_f	Magnetic constant	32645 mN-mm ² -A ⁻²
g	Acceleration due to gravity	9810 mm-s ⁻²
m	Mass of metal ball	0.068 Kg

Now, set of shifted variables are defined by equation (3) and equation (4)

$$\hat{x}(t) \triangleq x(t) - x_{ss} \quad (3)$$

$$\hat{i}(t) \triangleq i(t) - i_{ss} \quad (4)$$

Rewriting the equation (2) yield

$$m \frac{d^2 \hat{x}}{dt^2} = mg - K_f \left(\frac{\hat{i} + i_{ss}}{\hat{x} + x_{ss}} \right)^2 \quad (5)$$

$$\frac{d^2 \hat{x}}{dt^2} = \frac{1}{m} \begin{bmatrix} \frac{\partial}{\partial \hat{x}} \left(mg - K_f \frac{(\hat{i} + i_{ss})^2}{(\hat{x} + x_{ss})^2} \right) \hat{x} + \frac{\partial}{\partial \hat{i}} \left(mg - K_f \frac{(\hat{i} + i_{ss})^2}{(\hat{x} + x_{ss})^2} \right) \hat{i} \end{bmatrix} \quad (6)$$

Putting $(\hat{x} = 0, \hat{i} = 0)$ in above equation, we get

$$\frac{d^2 \hat{x}}{dt^2} = \frac{2K_f i_{ss}^2}{x_{ss}^3 m} \hat{x} - \frac{2K_f i_{ss}}{x_{ss}^2 m} \hat{i} \quad (7)$$

Finally, taking the Laplace transform of (7), we obtain

$$G_m(s) \triangleq \frac{\hat{x}(s)}{\hat{i}(s)} = -\frac{a}{s^2 - b} \quad (8)$$

$$\text{where, } a \triangleq \frac{2K_f i_{ss}}{x_{ss}^2 m}, \quad b \triangleq \frac{2K_f i_{ss}^2}{x_{ss}^3 m}$$

III. DESIGN OF PID CONTROLLER

A. Design Using 'PID Tuner' Tool in Matlab

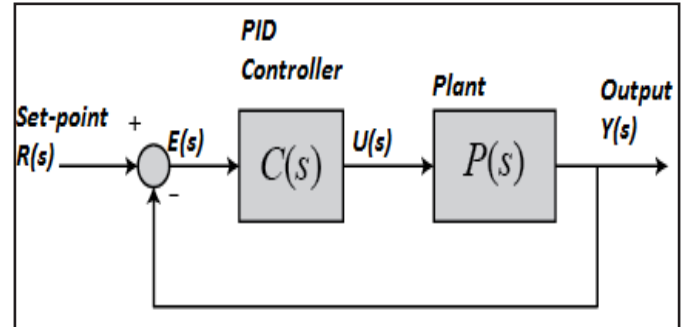


Fig. 3: Schematic of Conventional PID Controller

The block diagram of the PID controller [7] is given in Fig. 3. The PID controller improves dynamic response and decrease or eliminates the steady state error. By adding a derivative controller to the system improves transient response, as it adds a finite zero to the open-loop plant transfer function. Incorporating an integral controller to the system adds a pole at the origin; therefore, system type will increase by one. Also adding Integral controller will decreasing the steady-state error due to a step function to zero. The input / output relationship of a PID controller [5] is expressed by equation (9).

$$U(s) = (K_p + (K_i/s) + sK_d) E(s) \quad (9)$$

The PID controller parameters are updated by 'PID tuner' tool in Matlab software. The control signal is amplified using a gain block to obtain optimum response.

B. Design Using Pole-Placement Technique

The characteristic equation closed-loop transfer function is considered and solved for some assumed poles. The PID Controller thus designed is used to simulate the system. The control signal is amplified using a gain block to obtain an optimum response.

IV. RESULTS AND DISCUSSION

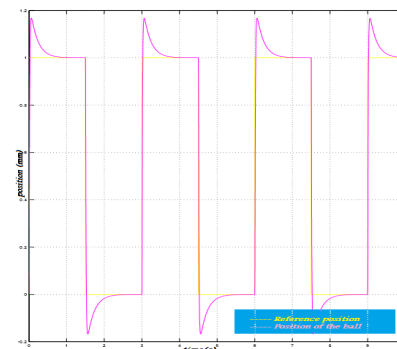


Fig. 4: Pulse Response of the Maglev System Using 'PID

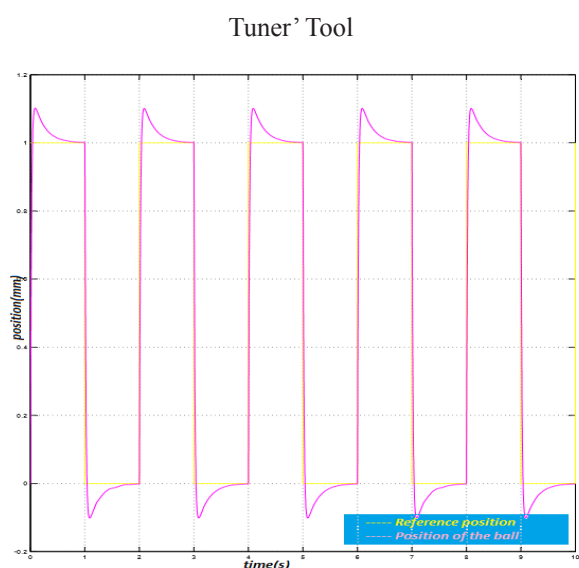


Fig. 5: Pulse Response of the Maglev System Using the Pole-Placement Technique

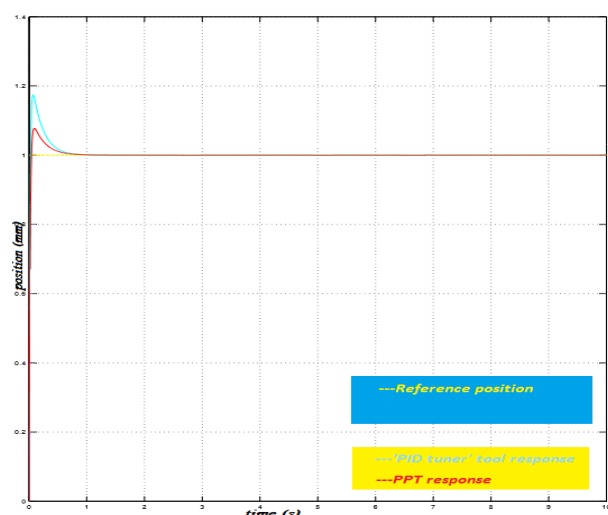


Fig. 6: Step Response Comparison Between Two Designed Controllers

For PID Controller design using 'PID tuner' tool when $K_p = 2.4$, $K_d = 0.03$, $K_i = 10.5$ and Gain = 500, then the pulse response is shown in Fig. 4 and for PID Controller design using Pole-placement technique by assuming poles at -20, -30, -40 and Gain = 10, then the pulse response is shown in Fig. 5. Comparison between step responses of two designed Controllers is shown in Fig. 6. It can be seen that the peak overshoot and settling time is less while using PID Controller designed by pole-placement technique.

V. CONCLUSION

The paper examined control practices that are common in control systems design. A PID controller for the maglev

system is designed and analyzed for the maglev system. The proposed controller is implemented and verified in the Matlab / Simulink environment for the considered maglev system. The results confirm that the output response of the model traces the reference trajectory and therefore, the proposed approach is suitable for such a non-linear system.

REFERENCES

- [1] J. Rao, R. Jian, K. Wang, W. Ke, B. Wang, W. Boyu, Q. Ge, G. Qiongxuan, L. Shi, S. Liming, and Y. Li, "A special excitation system for analysis of coupling characteristics of thrust and levitation force of maglev train," *Transportation Systems and Technology*, vol. 4, no. 2, pp. 45-51, 2018.
- [2] M. Cavagnaro, C. Maurizio, and V. D. Site, "A new concept of modular magnetic levitation train for urban transport," *Transportation Systems and Technology*, vol. 4, no. 2, pp. 107-119, 2018.
- [3] W. Barie, and J. Chiasson, "Linear and nonlinear state-space controllers for magnetic levitation," *International Journal of Systems Science*, vol. 27, no. 11, pp. 1153-1163, November 1996.
- [4] M. Shafiq, and S. Akhtar, "Inverse model-based adaptive control of magnetic levitation system," *5th Asian Control Conference*, 2004.
- [5] F. Zhang, and K. Suyama, "Nonlinear feedback control of magnetic levitating system by exact linearization approach," *Tokyo University of Mercantile Marine, Japan, Proceedings of IEEE Conference on Control Applications*, pp. 267-268, 1995.
- [6] I. Ahmad, and M. A. Javaid, "Nonlinear model and controller design for magnetic levitation system," *Recent Advances in Signal Processing, Robotics and Automation*, pp. 324-328, (n.d.).
- [7] A.-V. Duka, M. Dalau, and S.-E. Oltean, "IMC based PID control of a magnetic levitation system," *Procedia Technology*, vol. 22, pp. 592-599, 2016.
- [8] E. S. Yadav, S. K. Choudhary, and I. Thiruvakarasu, "Design and simulation of a nonlinear control system for magnetic levitation of steel ball," *International Research Journal of Engineering and Technology*, vol. 2, no. 8, pp. 544-549, November 2015.
- [9] A. J. Hajaji, and M. Guldasinge, "Modeling and non-linear control of a magnetic levitation system," *IEEE Transaction on Industrial Electronic*, vol. 48, no. 4, pp. 831-838, 2001.