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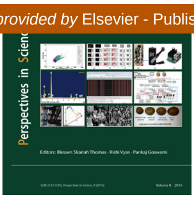

TID and I-TD controller design for magnetic levitation system using genetic algorithm☆

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Summary This article is about the design of controllers for magnetic levitation (Maglev) system in both simulation and real time. Local linearization around the equilibrium point has been done for the nonlinear Maglev system to obtain a linearized model transfer function. In this study, the design of integral-tilted-derivative (I-TD) controller has been proposed for the Maglev system and its performance is compared with conventional tilted-integral-derivative (TID) controller. In this study, TID controller parameters have been optimized through genetic algorithm (GA) and those set of values have been employed for the design of I-TD controller. A performance comparison between TID and I-TD controller is then investigated. The analysis shows the superiority of I-TD controller over TID controller in terms of maximum overshoot, gain margin and phase margin. The settling time remains almost same in both the cases. In future, a detailed study of robustness in presence of model uncertainties will be incorporated as a scope of further research.

Introduction

Maglev is an example of inherently nonlinear and unstable system. Developing a proper control strategy has always been a challenging task for researchers to control this system. Different control techniques have been proposed by researchers which include use of classical to soft computing-based methods (Wai and Lee, 2008).

This article is about to design the TID (Luo and Chen, 2013) and I-TD controller for Maglev system. In this study, an evolutionary algorithm (EA) has been applied to optimize TID controller parameters and those set of values have been employed for the design of I-TD controller.

This article is organized in nine sections. Section 1 is about the introduction of the article. Section 2 is about the schematic diagram and transfer function of Maglev system. Sections 3 and 4 deal with the structure of TID and I-TD controller and the dominant pole calculation. In section 5 and 6, the system with TID controller and objective function optimization through GA has been provided. Section 7 is about

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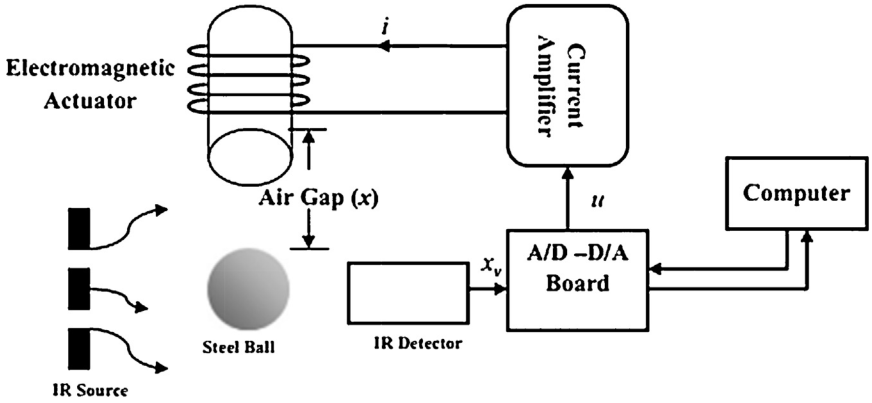

Figure 1 Schematic diagram of Maglev system.

the simulation diagram and response of the system with TID and I-TD controller. Sections 8 and 9 deal with the performance comparison between above-mentioned controllers and the conclusion part of this article respectively.

The Maglev system

The schematic diagram of Maglev system (Ghosh et al., 2014) considered in this article is provided in Fig. 1.

The simplest nonlinear model (Magnetic Levitation, 2011) in terms of ball position *x* and electromagnetic coil current *i* is given by

$$m\ddot{x} = mg - k\frac{i^2}{x^2} \tag{1}$$

where, *m* is the mass of the ball, *g* is gravitational constant and *k* depends on the coil parameters. As *x* and *i* are proportional to x_v and *u*, the linearized model transfer function of Maglev system can be written in the form of $\frac{\Delta x_v}{\Delta u}$ (Ghosh et al., 2014) and is given by:

$$G_p(s) = \frac{\Delta x_v}{\Delta u} = \frac{-3518.85}{s^2 - 2180} \tag{2}$$

TID and I-TD controller

TID and I-TD controller is similar to PID and I-PD controller except from the fact that in TID and I-TD controller, in place of the proportional compensating unit a compensator having a transfer function represented by $k_t/s^{\frac{1}{n}}$ is present. For TID and I-TD controller, the preferable value of *n* is in between 2 and 3. In this article, for simplicity *n* has been taken as 2.

Dominant pole calculation

For this study, the design specifications have been considered as

Damping ratio (ζ) $\le$ 0.8 and settling time (t_s) $\le$ 2 sec.

According to these specifications, dominant poles have been found to be at $s_{1,2} = -2 \pm 1.5i$.

System with TID

Characteristics equation of the system with TID controller for unity feedback is given by

$$1 + G_p(s)G_c(s) = 0 \tag{3}$$

$$i.e.\quad 1 + \left(\frac{-3518.85}{s^2 - 2180}\right)\left(\frac{k_t}{s^{\frac{1}{n}}} + \frac{k_i}{s} + k_d s\right) = 0 \tag{4}$$

Substituting s_1 in equation (4) and separating real (R) and imaginary (I) parts, one obtains

$$R = 1 + 0.3205k_t - 0.5179k_i - .02239k_d \tag{5}$$

$$I = -0.9699k_t - 0.3863k_i + 0.4321k_d \tag{6}$$

The objective function '*f*' considered for obtaining the value of k_t, k_i and k_d has the format

$$f = |R| + |I| + |\theta| \quad \text{where}\, \theta = \tan^{-1}\left(\frac{|I|}{|R|}\right) \tag{7}$$

Objective function optimization using GA

The objective function '*f*', *containing* three unknown variables k_t, k_i and k_d, has been optimized through GA with number of iterations, population size, bit size, crossover probability and mutation probability taken as 25, 40, 10, 0.8 and 0.125 respectively. The decision regarding the range ($-25 \le k_t \le -23$, $-6 \le k_i \le -4$ and $-0.25 \le k_d \le 0$) of these unknown parameters has been made after performing a number of trial runs. After several experiments within the range of these parameters, the final parameters of the fine-tuned GA are run for 10 independent times to get final optimum values of the unknown variables. After optimization, the values of k_t, k_i and k_d are found to be as −24.5768, −4.7597 and − 0.1529 respectively. These values are then utilized for designing both the TID and I-TD controller.

Simulink and real time responses

The input signal considered for this study is a square wave with mean −1.55 V. The input signal has been passed through a prefilter for reducing the steepness of the signal at the

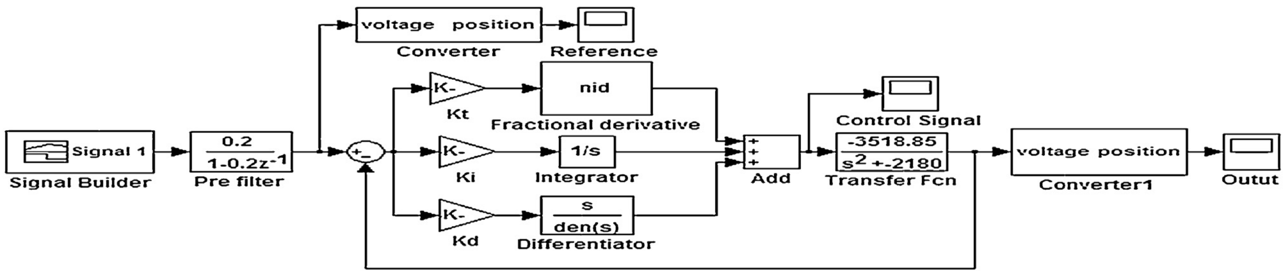

Figure 2 Closed loop Maglev system with TID controller.

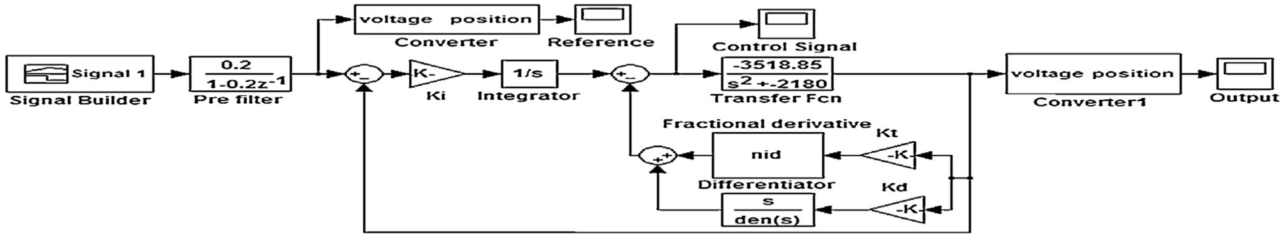

Figure 3 Closed loop Maglev system with I-TD controller.

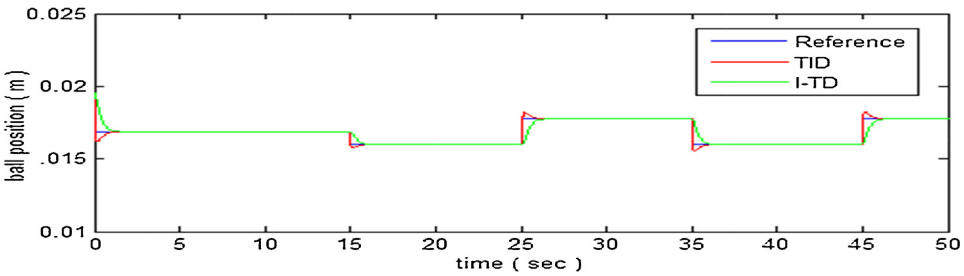

Figure 4 Simulink response of Maglev system with TID and I-TD controller.

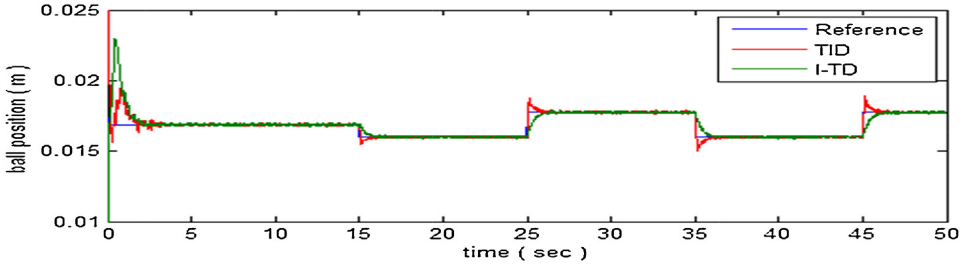

Figure 5 Real time response of Maglev system with TID and I-TD controller.

time of step change. In Simulink diagram, two voltage to position converters can be observed which are used for maintaining the analogy with the real time simulation. The non-integer differentiator (NID) toolbox has been used for fractional integration. The simulation diagrams as shown in Fig. 2 and Fig. 3 with TID and I-TD controller are given below.

The response of simulations with TID and I-TD controller has been provided in Fig. 4 and Fig. 5 which clearly indicates the superior response of I-TD controller compared to that of TID controller.

Performance comparisons between TID and I-TD controller

Investigating the real time response, it can be found that

- For TID controller maximum overshoot is 5.80%, whereas for I-TD controller the overshoot is almost negligible.
- Gain margin (GM) and phase margin (PM) of the system with TID controller is $-12.7\,\text{dB}$ and 89.6°, respectively,

whereas with I-TD controller GM and PM is 42.2 dB and 136° respectively.
- The settling time remains almost same in both the cases.

The above findings are the clear indication of the fact that I-TD controller has the potential to provide better transient response and relative stability as compare to TID controller.

Conclusion

In this study, TID and I-TD controllers have been designed for Maglev system and the performance is compared. The result of comparison shows that I-TD controller provides better response than TID controller in terms of overshoot, gain margin and phase margin. To improve time domain response and relative stability, the applications of I-TD controller can be extended to the other plants. In future, a detailed study of robustness in presence of model uncertainties will be incorporated as a scope of further research.

References

Ghosh, Arun, et al., 2014. Design and implementation of a 2-DOF PID compensation for magnetic levitation systems. ISA Trans. 53, 1216—1222.

Luo, Ying, Chen, YangQuan, 2013. Fractional order motion controls, 1st Ed. John Wiley & Sons Ltd.

Magnetic Levitation: Control Experiments Feedback Instruments Limited, UK, 2011.

Wai, R.J., Lee, J.D., 2008. Adaptive fuzzy-neural-network control for maglev transportation system. IEEE Trans. Neural Netw. 19, 54—70.