Control of Maglev System in the Presence of Input Constraints

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Abstract

In this study, a robust controller and a robust adaptive controller that can be used to control a magnetic levitation are designed. In the robust controller, the goal is to realize the control of the system without using any of system paramaters and just by using the measurements obtaned from system. The main disadvantage of the robust controller is that it may need high control effort. Robust adaptive controller aims to compensate uncertain system parameters and use these compensations in control design. The convergence of the observation and tracking errors under the closed-loop process and the stability of the closed-loop error dynamics are proved by the Lyapunov based stability analysis. The performance of two different controllers designed is shown by experimental results.

1. Introduction

Magnetic levitation (maglev) systems can hold ferromagnetic materials in the desired position in the air by using electromagnetic force. The electromagnetic force is provided by the electromagnetic field generated by the maglev systems. The ability of these devices to freely move ferromagnetic materials in the air is the basis of many other technologies. This ability eliminates the problem of friction and as a result, minimizes material wear as much as possible.

Maglev systems are used as active suspensions in the suspension systems of land transport vehicles (Goodall and Kortum, 1983; Rote and Cai, 2002). The Maglev system was accepted as the mainstay in the development and improvement of magnetic train applications (Givoni, 2006; Lee et al., 2006). Moreover, Maglev systems can be used for vibration isolation in sensitive environments where vibration is not desired. For example, high-precision positioning of chip plates formed in photolithography (Eroğlu and Ablay, 2016). Maglev systems lay the groundwork for testing linear control systems approaches and nonlinear control systems approaches. Considering these benefits, maglev systems have become a subject of study (Matsumura and Yoshimoto, 1986).

Robust controller (RC) does not need any information about system model and parameters. This controller is used to eliminate parametric and structural uncertainties, which are frequently encountered problems in the control of maglev systems. Their biggest disadvantage is that they have no information about system parameters, so they work in the worst case scenario and spend a lot of effort. Operations of all states (position of ferromagnetic material, velocity of ferromagnetic material and electromagnet current) provide control of these systems. The main purpose of this study is to design nonlinear RC and robust adaptive controller (RAC) that can control the maglev system. Theoretical analysis of the designed controllers is carried out through Lyapunov based arguments. In this analysis, the convergence of the observation and tracking errors under closed-loop operations is mathematically demonstrated.

Error Definitions

The error between the desired ball's position x_d and the measured ball's position x is defined as tracking error while and additional auxiliary error r is needed for both RC and RAC designs

Tracking Error $\quad e \triangleq x_d - x \quad$ (1)

Auxiliary Error $\quad r \triangleq \dot{e} + \alpha e \quad$ (2)

Open Loop Error System

The open loop error system can be obtained as

$$m\dot{r} = N - I^2 - \frac{1}{2}\dot{m}r \quad (3)$$

$$N \triangleq m\ddot{x}_d + f + m\alpha r - m\alpha^2 e + \frac{1}{2}\dot{m}r \quad (4)$$

Control Input Design of RC

$I = \sqrt{u_c + \gamma}$ (5)

$\gamma = \rho_{b1}\tanh(r) + kr$ (6)

$u_c = \gamma \tanh(r)\tanh(\gamma)$ (7)

Control Input Design of RAC

$I = \sqrt{u_c + \gamma}$ (8)

$\gamma = \hat{P}\emptyset + kr$ (9)

$u_c = \gamma \tanh(r)\tanh(\gamma)$ (10)

Stability Analysis of RC

The Lyapunov function candidate is defined as $\quad V(e,r) = \frac{1}{2}e^2 + \frac{1}{2}mr^2 \quad$ (11)

and its time derivative can be upper bounded as $\quad \dot{V} = \dot{e}e + rm\dot{r} + \frac{1}{2}\dot{m}r^2 \quad$ (12)

$$\dot{V} \leq -\beta 1 - \beta 2\|z\| \quad (13)$$

$$\beta_1 \triangleq \min\{(e - \frac{1}{2}r)^2, -r(N_d - \rho_{b1}\mathrm{sgn}(r)), \gamma\tanh(r)\, r\tanh(\gamma)\} \quad (14)$$

$$\beta_2 \triangleq \min\{(\alpha - 1), (k - \frac{1}{4}), \rho_{b2}\} \quad (15)$$

Stability Analysis of RAC

The Lyapunov function candidate is defined as $\quad V(e,r,\tilde{P}) = \frac{1}{2}(e^2 + mr^2 + \tilde{P}) \quad$ (16)

and its time derivative can be upper bounded as $\quad \dot{V} = \dot{e}e + rm\dot{r} + \frac{1}{2}\dot{m}r^2 + \tilde{P}\dot{\tilde{P}} \quad$ (17)

$$\dot{V} \leq -(\alpha - \frac{1}{2})e^2 - (k - \frac{1}{2})r^2 - \beta_1 \quad (18)$$

$$\beta_1 \triangleq \gamma\tanh(r)\, r\tanh(\gamma) \quad (19)$$

2. Results and Discussions

Fig 1. Feedback Instruments Maglev system

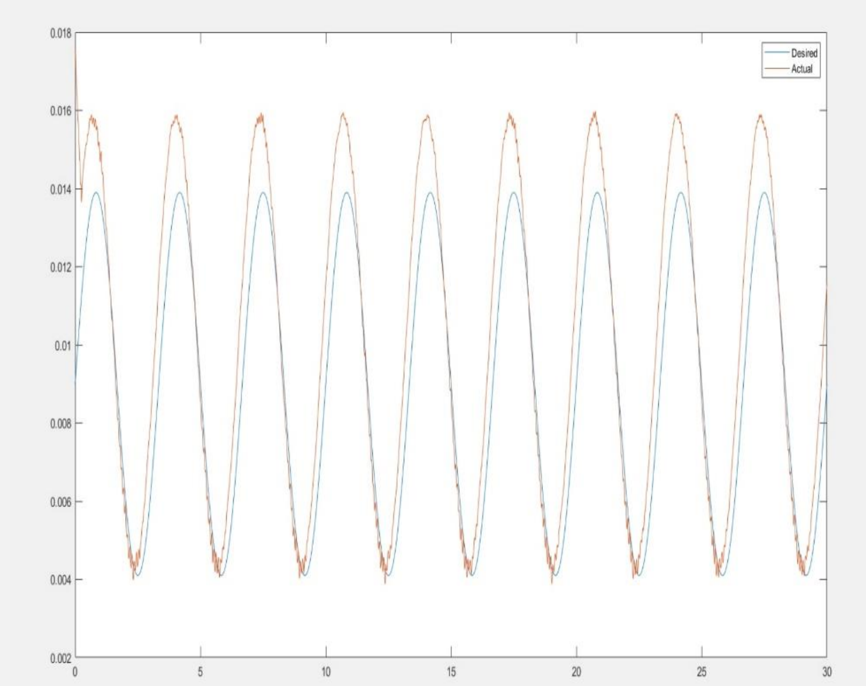

Fig 2. Actual and desired trajectories for the constant desired trajectory. (RC)

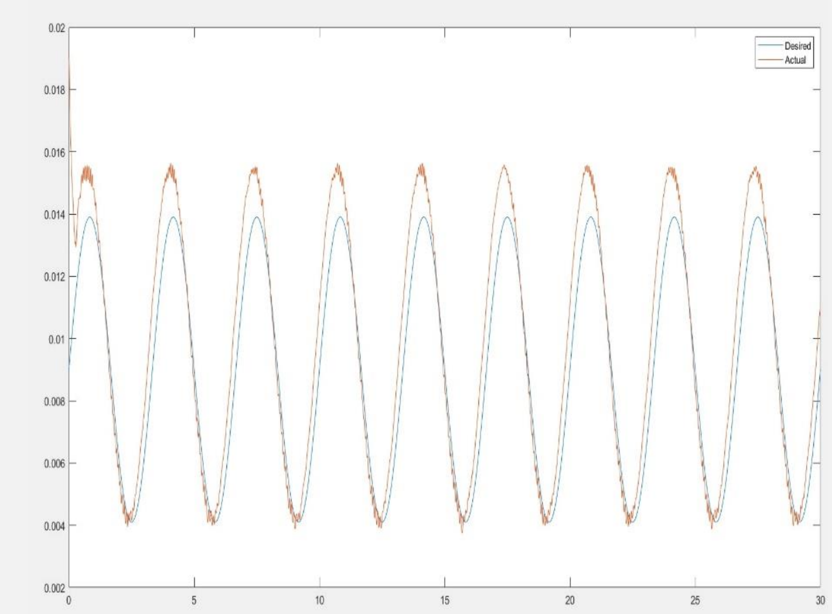

Fig 3. Actual and desired trajectories for the constant desired trajectory. (RAC)

The designed controllers were tested under real-time experimental conditions and the results are shown in Figure 2 and Figure 3. It was observed that the test results of RAC are better than the test results of RC in terms of tracking. RC and RAC are viable controllers for the control of maglev systems, as they can control systems that have no knowledge of the structure and model parameters of the selected system.

References

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