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Linear Quadratic Regulator controller for Magnetic Levitation System

Engr. Sadaqat Ur Rehman[1], Engr. Muhammad Junaid[2] and Engr. Obaid Ur Rehman[3]

[1, 2, 3] Department of Electrical Engineering, Sarhad University of Science and IT, Peshawar, Pakistan

[1]sadaqat.ee@suit.edu.pk, [2]junaid.ee@suit.edu.pk, [3]nattest@gmail.com and obaid.ee@suit.edu.pk

ABSTRACT

This paper explains Magnetic Levitation system of a train which comprises of guidance track made with magnets. The main objective is to design a proper controller that can suspend and propelled the train on a guidance track made with magnets. To perform the desired task state space model of Magnetic Levitation system is derived. The response of the system is simulated in MATLAB. The open loop response showed that the derived model is unstable. Linear Quadratic Regulator (LQR) controller is designed to analyze the system in closed loop. The controller showed improved performance for different tracks. Different types of realization techniques (minimal realization, balanced realization, modal realization, observer canonical realization) are compared for minimum fragility in controller implementation. The difference among the different realization controllers has been analyzed in detail for rounding off error or truncation error and an optimal non fragile controller design has been presented. Different disturbances were imposed upon the simulated model. All the results are analyzed in open and closed loops. The closed loop response showed that the train is suspend and propelled on the track and the desired results were achieved successfully

Keywords: *LQR, Magnetic Levitation System, Realization techniques, Bullet Train, MATLAB Simulink.*

1. INTRODUCTION

Magnetic levitation systems have many varied uses such as in friction less bearing, high speed maglev passenger trains, levitation of wind tunnel model, vibration isolation of sensitive machinery levitation of molten metal in induction furnaces and the levitation of metal slabs during manufacture (Laithwaite 1965, Jayawant and Rea 1965) [1]. Here our objective is to design such a controller which can suspend and propelled the Maglev train on the track. The maglev train is based on three type of systems which control the train moves on the track Guidance system, Propulsion system and levitation system [2]. Guidance system refers to the sideward force that requires moving the train on the track. Propulsion system uses an electrically powered motor in the guide way which appears to be the favoured option for high speed Maglev trains. Levitation system keeps the train suspended against the gravity by forces of magnetic field. These systems have unstable open loop response, to make the response of the system stable feedback path was used. Linear Quadratic Controller (LQR) was used to make the closed loop response of the system stable [3].

Valer and Lia build a nonlinear model for magnetic levitation system and proposes systems linearization principle (the expansion in Fourier series and the preservation of the first order terms) in order to linearize the acquired nonlinear model [4, 5]. Our interest here is to design a Non-fragile optimal controller so a linear controller was designed to give safety and ride comfort to passengers inside the cabin of a train. The complete mathematical derivation for the Magnetic Levitation train model in state space form is simulated in MATLAB / SIMULINK [6]. Magnetic levitation is very useful in High Voltage insulation testing [7]. The block diagram of the Magnetic Levitation train is shown in the Figure 1.

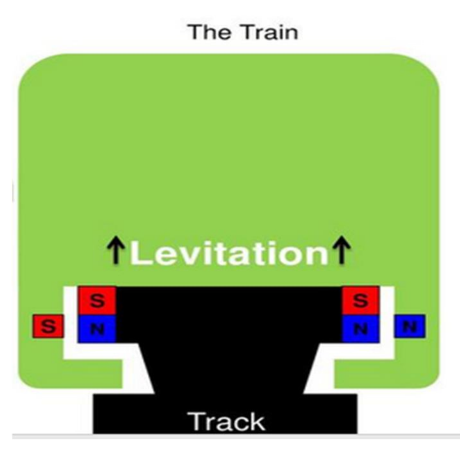

Fig. 1. Block Diagram of Magnetic Levitation System

2. MATHEMATICAL MODEL OF MAGNETIC LEVIATION SYSTEM

State space model of Magnetic Levitation is derived as given in [4].

V= dx/dt (1)
u= Ri + dL(x)i/dt (2)
mẍ = mg-c(i/x)2 (3)

Equation (2) indicates that L(x) is a nonlinear function. Various approximate values are used to determine the value of inductance for the Magnetic Levitation. If we take the assumption that the inductance of the system varies with the inverse of the ball position

L(x) = L + L0x0/x (4)

Where L is the constant Inductance of the coil in the absence of the ball, L0 is the additional inductance contributed by the presence of the ball

u(t)= iR+ d/dt (Lc + L0x0/x)i
u(t)= iR+ Ldi/dt - (L0x0i/x2)dx/dt

Substituting L0 x0 =2C [4], we get
u(t)= iR+ Ldi/dt – C(i/x)2dx/dt (5)

Linear Model of the System is

$$A = \begin{bmatrix} 0 & 1 & 0 \\ \frac{Cx_{03}^2}{mx_{01}^3} & 0 & -2\frac{Cx_{03}}{mx_{01}^2} \\ 0 & 2\frac{Cx_{03}}{Lx_{01}^2} & -\frac{R}{L} \end{bmatrix} \quad B = \begin{bmatrix} 0 \\ 0 \\ \frac{1}{L} \end{bmatrix}$$

$$C = [1 \quad 0 \quad 0]$$

3. METHODOLOGY

By taking the Open loop response of the system, open loop response of the system shows that the system is unstable. Linear Quadratic Regulators are used to overcome the disturbance effect and overcome the disturbing effect and to improve the performance parameter and make the close loop response of the system is stable, realization technique is used to obtain a r educed and non-fragile model [3].

A. Realization Technique

In order to obtain a reduced and non-fragile optimal controller different realization techniques are used. Minimal realization (The realization is known as "minimal" as it defines the system with least number of states). Balanced realization, Modal realization and Observer based canonical realization are the other different techniques used to obtained a reduced and non-fragile model.

4. RESULTS AND CONCLUSION

This work is carried out on considering a magnetic levitation system. The mathematical derivations are done in state space form. For simulations MATLAB software is used. The open loop response in MATLAB shows oscillations, large overshoot and required large settling time to damp. LQR controller/compensator was designed to obtain the desired response. LQR controller improved the performance of the system. The results obtained were satisfactory. Different realization techniques are then used, by applying these techniques the controllers action is made more efficient and the system is made highly stable and non-fragile.

A. Open Loop Response

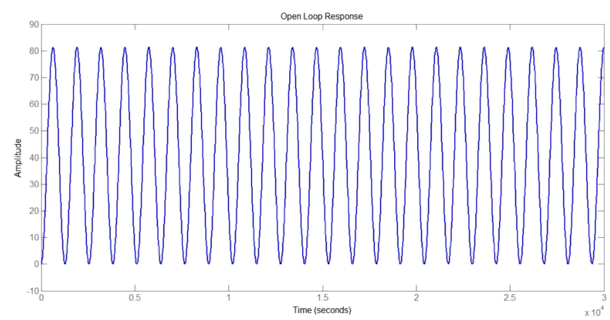

Fig. 2. Open loop Response of Magnetic Levitation System

The open loop response is unstable, thus the open loop response is very uncomfortable for the passengers.

B. LQR Controller Response

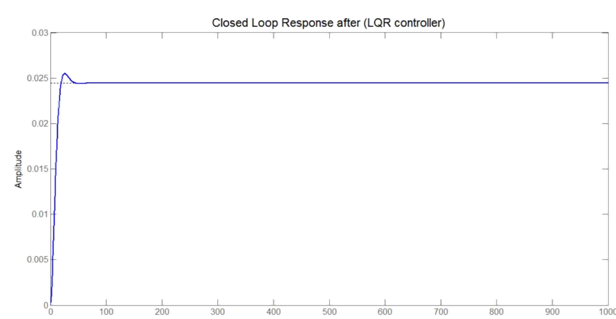

Fig. 3. Closed Loop Response after (LQR Controller)

Thus the LQR Controller gives a better response and settled the oscillations in the vehicle body quickly. After the addition of LQR controller the system becomes stable.

C. Minimal Realization

For LQR controller no state has been reduced, the controlled response has three states and after minimal realization the states remain the same. Difference between the LQR controller and minimal realization response was plotted as shown in Figure 4

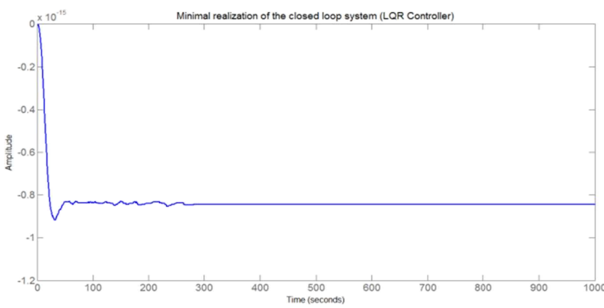

Fig. 4. Minimal Realization of the Closed loop System (LQR Controller)

D. Balanced Realization

Difference between the LQR controller and balanced realization response was plotted as shown in the Figure 5.

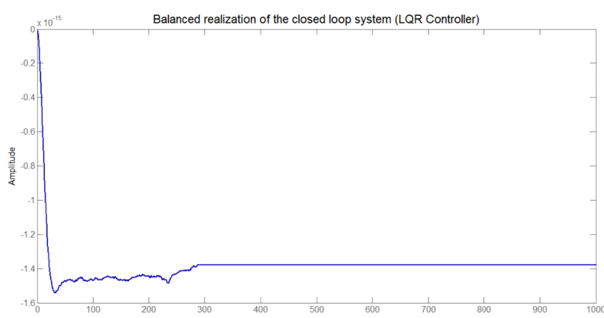

Fig. 5. Balanced Realization of the Closed loop System (LQR Controller)

E. Model Realization

Difference between the LQR controller and modal realization response was plotted as shown in Figure 6.

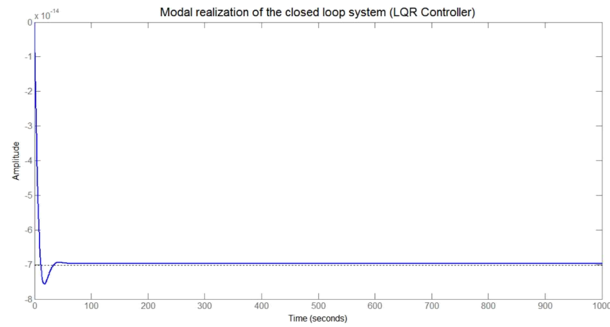

Fig. 6. Modal Realization of the Closed loop System (LQR Controller)

F. Observer Canonical Realization

Difference between the LQR controller and Observer Canonical realized response was plotted as shown in the Figure7.

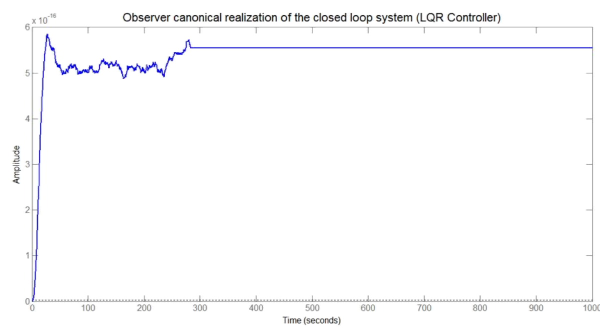

Fig. 7. Observer Canonical Realization of the Closed loop System (LQR Controller)

A brief summary of all types of realization techniques was given below in table 1. This table shows that observer canonical realization gives the least error to controller which represents the most optimal and most non-fragile optimal controller technique.

Table 1: Realization Analysis for different controllers

Realization type	***LQR controller***
Minimal Realization	10^{-15}
Balanced Realization	10^{-15}
Modal Realization	10^{-14}
Observer canonical Realization	10^{-16}

For different input disturbances the LQR controller shows better response. The LQR controller settles the oscillations more quickly, reducing the oscillation and overshoot. The designed LQR controller provides better handling ability for wide range of disturbances and provides better ride comfort for passengers.
Also observer canonical realization gives the least error to controller which represents the most optimal and most non-fragile optimal controller technique.

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AUTHOR PROFILES:

Engr. Sadaqat Ur Rehman is currently serving as a Lecturer & member, QEC at the Department of Electrical Engineering, SARHAD University of Science & IT Peshawar, KPK Pakistan. He has done MS in Electrical Engineering with a Specialization in Electronics & Communication Engineering in 2014 & BSc in Computer Systems Engineering in 2011. His Area of Research is Image/Video Processing. He is an active member of Pakistan Engineering Council (PEC)
Cell: +92-333-9206903

Engr. Muhammad Junaid is currently serving as a Lecturer (Power Engineering) and member/team leader, Quality Enhancement Cell (QEC) at the Department of Electrical Engineering, SARHAD University of Science & IT Peshawar, KPK Pakistan. He is a Power Engineering Specialist having done MS in Electrical Engineering with the Specialization in Power System Engineering in 2015 recently & B.Eng in Electrical Power Engineering in 2011 respectively. His Area of Research is in High Voltage Engineering/ Power System Engineering.He is an active member of IAENG HONG KONG, IEEE PES, IJENS-RPG Researchers Promotion Group, Pakistan Engineering Council (PEC) & Institute of Engineers Pakistan (IEP).
Cell: +92-345-9150634

Engr. Obaid ur Rehman is an Assistant Professor at the Department of Electrical Engineering, SARHAD University of Science & IT Peshawar, KPK Pakistan. He is Currently PhD Scholar at College of Electrical Engineering, Zhejiang University, PR China