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Study of Feedback Linearization Controller for Maglev Trainlevitation

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Abstract: In this paper,the feedback linearization controller is proposed to control the maglev train levitation. The maglev train is simplified as an electromagnet suspension. The mathematical model is presented.The effectiveness of the controller is first verified by simulation. Experimental results show that the magev train can be levitated at any position from 3mm to 9mm.

Keywords: *Feedback Linearization Controller, Maglev Train System, Magnetic Levitation*

Introduction:

Currently the maglev train is the fastest speed train in the world, there are three technologys is used to control the maglev train. They are Electromagnetic suspension (EMS) system of German, Electrodynamic suspension (EDS) system of Japanese and Inductrack techology. In the papper the EMS System is discussed. Modeling and algorithm were implemented on single EMS system. EMS system is nonlinearities and instability, it is difficult to design a controller. Due to inherent nonlinearities of EMS, feedback linearization was proposed. This method makes the nonlinear system in linear system. The experimental result shows that the magev train can be levitate at any position from 3mm to 9mm.

II. Modeling:

There are three subsystems in the maglev train, they are track system, several electromagnet system and propulsion system. In electromagnetic system, the levitation force is generated to attractive force between electromagnets and track and keeps the train levitated at a certain gap distance from the track.The configuration of the EMS system as the follow:

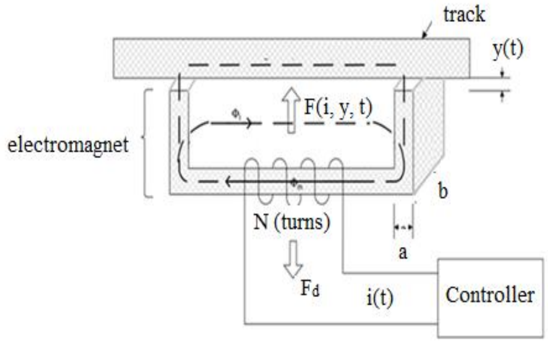

Fig 1. The EMS system configuration

Where,

N is the total turns of the magnetic winding
y(t) is the suspension airgap between track and electromagnet
f_d is the disturbance force
F(i, y, t) is the suspension force
i(t) is the current in the coil of magnet coil

The inductance of the coil is given by the equation (Boudali, 2003[5]):

$$L(y) = \frac{\mu_0 N^2 A}{2y(t)} \qquad (1)$$

When the current is passed through magnet coil, magnetic flux is generated. This flux procedu ces an attractive force between track and electromagnet. The suspension force is given by equation (Shina [7,8]):

$$F(i,y) = -\frac{d}{dy}\left[\frac{1}{2}L(y)i^2(t)\right] \qquad (2)$$

$$F(i,y) = \frac{\mu_0 N^2 A}{4}\left[\frac{i(t)}{y(t)}\right]^2 \quad (3)$$

Where,

A=axb (m^2) is magnet ploe face area
$\mu_0 = 4\pi.10^{-7}$(H/m) is the permeability of air

Following the Newton's second law, the dynamic of the electromagnet is given by:

$$m\frac{d^2y(t)}{dt^2} = mg + f_d - \frac{\mu_0 N^2 A}{4}\left[\frac{i(t)}{y(t)}\right]^2 \qquad (4)$$

Following the Kiffchoff 's voltage , the electrical dynamic of the system is given by:

$$u(t) = Ri(t) + \frac{d}{dt}(L(i,y)) \qquad (5)$$

Where,

R is the resistance of the magnet coil
u(t) is the electromagnet coil voltage input
m is the mass of the magnet, load, bogie
L(i,y) is the inductance of the magnet coil,

$$L(i,y) = \frac{\mu_0 N^2 A}{2}\left(\frac{i(t)}{y(t)}\right) \qquad (6)$$

Replacing (6) in (5) we can get:

$$u(t) = Ri(t) + \frac{\mu_0 N^2 A}{2}\frac{1}{y(t)}\frac{di}{dt} - \frac{\mu_0 N^2 A}{2}\frac{i(t)}{y(t)^2}\frac{dy}{dt} (7)$$

From (4) and (7) , the dynamic equation for single electromagnet suspension system:

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$$\begin{cases} m\dfrac{d^2y(t)}{dt^2} = mg + f_d - \dfrac{\mu_0 N^2 A}{4}\left(\dfrac{i(t)}{y(t)}\right)^2 \\ \dfrac{di}{dt} = -\dfrac{2R}{\mu_0 N^2 A}y(t)i(t) + \left(\dfrac{i(t)}{y(t)}\right)\dfrac{dy}{dt} + \dfrac{2}{\mu_0 N^2 A}y(t)u(t) \end{cases} \qquad (8)$$

III. Feedback linearization control algorithm design:

For a single input single output system, given by:

$$\begin{cases} \dot{x} = f(x) + g(x)u \\ y = h(x) \end{cases} \qquad (9)$$

From equation (8), setting the state variables:

$$\begin{cases} x_1(t) = y(t) \\ x_2(t) = \dot{y}(t) \to \dot{x}_2(t) = \ddot{y}(t) \\ x_3(t) = i(t) \to \dot{x}_3 = \dot{i}(t) \end{cases}$$

Where,

x$_1$(t) is the magnet’s position,

x$_2$(t) is the maget’s velocity

x$_3$(t) is the current in the coil of magnet coil

The state equations of the magnetic suspension system will derived as follow:

$$\begin{cases} \dot{x}_1(t) = x_2(t) \\ \dot{x}_2(t) = g + \dfrac{1}{m}f_d - \dfrac{\mu_0 N^2 A}{4m}\left(\dfrac{x_3(t)}{x_1(t)}\right)^2 \\ \dot{x}_3(t) = -\dfrac{2R}{\mu_0 N^2 A}x_1(t)x_3(t) + \left(\dfrac{x_3(t)}{x_1(t)}\right)x_2(t) + \dfrac{2}{\mu_0 N^2 A}x_1(t)u(t) \end{cases} \qquad (10)$$

$$y = x_1(t) = y(t)$$

Differentiating y with respect to time until the input appears. We obtain:

$$\ddot{y}(t) = \frac{Rx_3^2(t)}{mx_1} - \frac{x_3(t)u(t)}{mx_1} \qquad (11)$$

The equation shows the input/output relation of system:

$$y^{(3)} = a(x) + b(x)u \qquad (12)$$

Where a(x), b(x) are functions of state variables:

$$a(x) = \frac{Rx_3^2(t)}{mx_1} \; b(x) = -\frac{x_3(t)}{mx_1}$$

The state feedback law:

$$u = \frac{1}{b(x)}\left(-a(x) + v\right) \qquad (13)$$

From (13) that makes the nonlinear system in (12) to linear with the new input –output relation is:

$$\ddot{y}(t) = v$$

The equation of tracking control:

$$v = \ddot{y}_d + (k_1\ddot{e} + k_2\dot{e} + k_3 e) \qquad (14)$$

Where

$e = y_d - y$ the error between desired position yd and feedback postion y from sensor

The control aim of feedback linearization controller is used to control the feedback postion y tracks to desired position (yd) at any positions.

IV. Result and discusion:

The parameters of system are choosen in the simulation: m=15 kg, N=1000 turns, A=1750 mm^2. Using Matab/Simulink simulation to simulate and resolve the algorithm. The simulation of system is simulated base on the input signal is step response, constant, sine response.

Fig 2 shows the response of the system when the desired position changes from 3mm to 7mm. With increasing the desired position, the controller signal increases slightly (Fig 3)

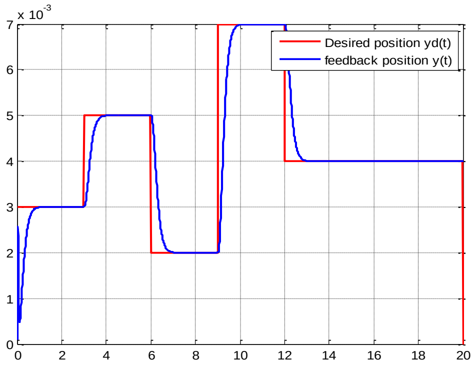

Fig 2. Transient response of the system with changing of desired postion

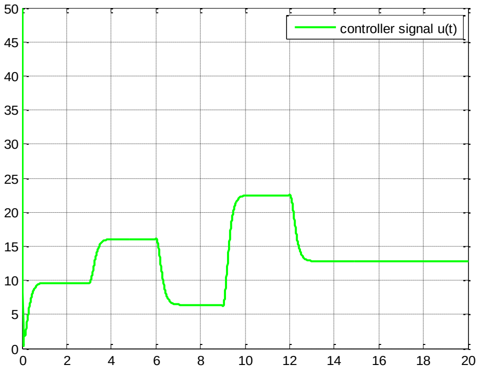

Fig 3. Transient response of controller signal

Step response: Fig 3 and Fig 4 show the transient response and controller signal when the desired postion is the step response. When the output reaches the desired postion, the controller signal is 28 volt.

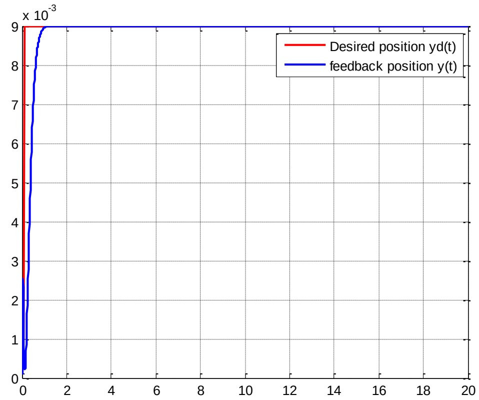

Fig 4: Transient response of the system with step response

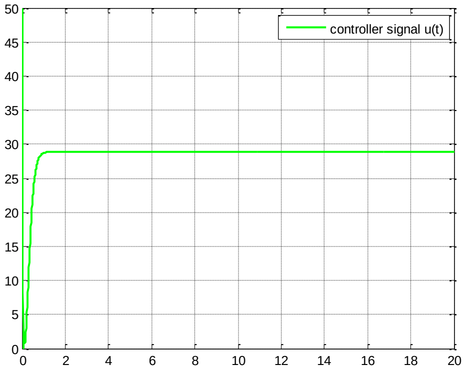

Fig 5. Transient response of controller signal

When m=15 kg, f_d= 50N, Fig 6, 7 show the effect of transient response on out put and cotroller signal

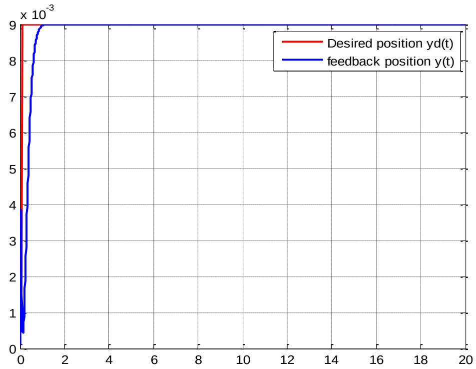

Fig 6. Transient response of the system when have disturbance force

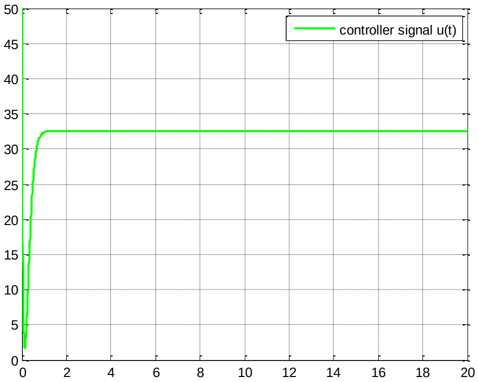

Fig 7. Transient response of controller signal when have disturbance force

Fig 8. 9 show the real result of real mode with changing of position of electromagnet, the voltage will be change.

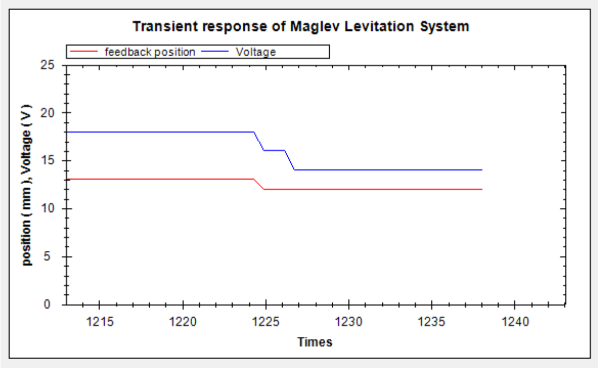

Fig 8: The relation between position of electromagnet and voltage (decreasing of position)

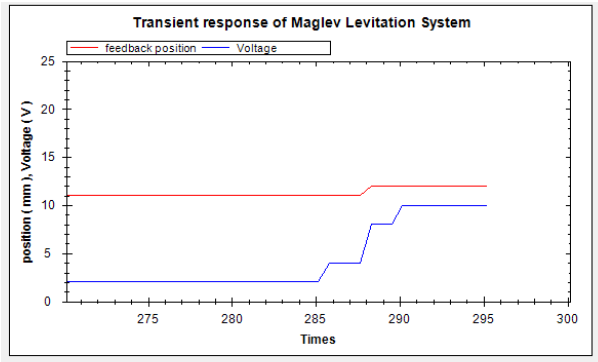

Fig 8: The relation between position of electromagnet and voltage (increasing of position)

Conclusion:

A feedback feedback linearization controller is used to control an electronagnetic suspension system. The experimental result shows that the magev train can be levitate at any position from 4mm to 9mm with many input signal conditions.

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