RESTRAIN THE EFFECTS OF VEHICLE-GUIDEWAY DYNAMIC INTERACTION: BANDSTOP FILTER METHOD

No.117

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ABSTRACT: To restrain the effects of vehicle-guideway dynamic interaction, a bandstop filter is introduced into the maglev levitation controller. To compensate these phase-lags in some particular band produced by the bandstop filter, an allpass filter is designed, which can not only attenuate the amplitude at the resonance frequency, but also decrease the phase-lag in relative-wide band. The simulation results show that the proposed filter can restrain the vehicle-guideway vibration at the desired frequency.

1 INTRODUCTION

As the maglev vehicle has to adapt to the variance of guideway, the difficulty of levitation control should be influenced by the condition of the guideway. In practice, the unmoving load would induce the vehicle-guideway interaction oscillation. This can influence the ride quality directly, and even make the levitation system to be unstable [1-5]. In the past, increasing the rigidity of guideway is an effective method to restrain the effects of vehicle-guideway dynamic interaction [6]. However, it can decrease the difficulty of levitation control in the price of heavier guideways, and more cost for manufacture and installation. Obviously, it is significant to reduce the system cost and improve the ride quality by improving the adaptability of maglev vehicle to guidways. Therefore, the vehicle-guideway dynamic interaction problem has been analyzed for years. One of the difficulties of these methods is how to get the vibration information of the vehicle and guideways. Since the gap signal refers to the distance between the levitation magnet and guideway, and it is measured by the onboard-gap-sensor. Thus it can be seen that the gap signal include the vibration information of guideways.

Based on the digital filtering technology, this paper extracted the vibration content of the vehicle from the gap signal, and used as another input of levitation controller to suppress the vibration. The designed filter compromises of a bandstop filter cascaded by an all-pass filter. The bandstop filter is used to filter the frequency component of coupled vibration, and the full-pass filter is used to compensate the phase-lag caused by the band-stop filter. The simulation results show that the presented filter can decline the specific frequency component, and minimize the phase-lag in the relative broad frequency domain.

2 MODEL OF THE MAGLEV SYSTEM CONSIDERING THE VEHICLE-GUIDEWAY INTERACTION

Fig. 1 is the schematic of the mono-electromagnet magnetic levitation system, and its model can be expressed as [3]:

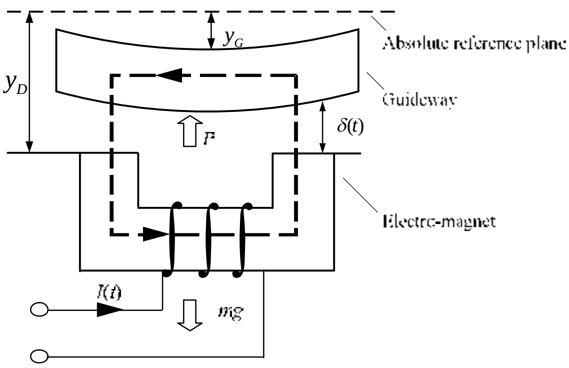

Figure 1. Schematic of mono-electromagnet magnetic levitation system in absolute reference plane

$$\ddot{\delta} = g - \frac{k}{m} \cdot \left(\frac{I}{\delta}\right)^2 \quad (1)$$

$$\dot{I} = -\left(\frac{\delta}{2k} R - \frac{\dot{\delta}}{\delta}\right) I + \frac{\delta}{2k} u \quad (2)$$

For simplicity, we will only consider the effects from first-order model of guideway vibration to the vehicle. By assuming the vehicle is levitated at the middle of simply supported beam, the dynamic model of guideway can be expressed as [3,6]:

$$\ddot{y}_G + b_G \dot{y}_G + \omega_{G0}^2 y_G = \Phi_0^2 P \quad (3)$$

Where, the definitions of these variables are shown in Table 1:

Table 1: definitions of variables

Variables	Definition
δ	Gap between the electromagnets and guideways
y_D	Vertical displacement of electromagnets
y_G	Vertical displacement of guideway
P	Electromagnetic lift force
I	Current in coils
R	Resistance of coils
Φ_0	Zero-order modal function
b_G	Damping coefficient of guideway beams
x_0	Position of the center of mass of the vehicle on guideway

Up to this point, we have derived the model of the maglev system considering the vehicle-guideway interaction.

3 DESIGN OF NOVEL BANDSTOP FILER

3.1 *Motivation*

Typically, in the magnetic control system, there are displacement sensor, acceleration sensor and current sensor, which is used to measure the gap between the electromagnets and guideways, the acceleration of levitation mass, and the current in electromagnet coils, respectively.

Apparently, the gap between the electromagnets and guideways δ equals the sum of the vertical displacement of guideway y_G and the vertical displacement of electromagnets y_D . When the vehicle-guideway interaction oscillation occurs, the frequency components in the signals of δ and y_G are different. If we could filter out y_G, which is the undesired component in measured signal $\tilde{\delta}$,

$$\tilde{\delta} = y_D + y_G$$

Then, the desired gap $\bar{\delta}$ has the relationship with y_D:

$$\bar{\delta} = y_D$$

Considering the ride quality of maglev vehicle, the levitation controller should maintain the $\bar{\delta}$ as constant, and it should be one of the input of controller. In order to suppress the vehicle-guideway dynamic interaction, the control law should be in the form below:

$$v = f(\tilde{\delta}, \bar{\delta}, a, I) \quad (4)$$

In practice, the frequency of guideway vibration is fixed, and is higher than the frequency of the vehicle vibration. So, it is natural to suppose that a bandstop filter could be used to filter the high frequency component (y_G).

3.2 *Basic bandstop filter*

According to the filter theory, the second-order band-stop filter can be expressed as:

$$H(s) = \frac{s^2 + 2\varepsilon_1 \omega s + \omega^2}{s^2 + 2\varepsilon_2 \omega s + \omega^2} \quad (5)$$

When $\varepsilon_1 / \varepsilon_2 \le 1$, the filter can attenuate the amplitude of input.

For example, if we choose ε_1 =1.25, ε_2 =2.125, and ω =1, the transfer function is:

$$H_1(s) = \frac{s^2 + 2.5s + 1}{s^2 + 4.25s + 1} \quad (6)$$

Its bode plot is shown in Fig.2.

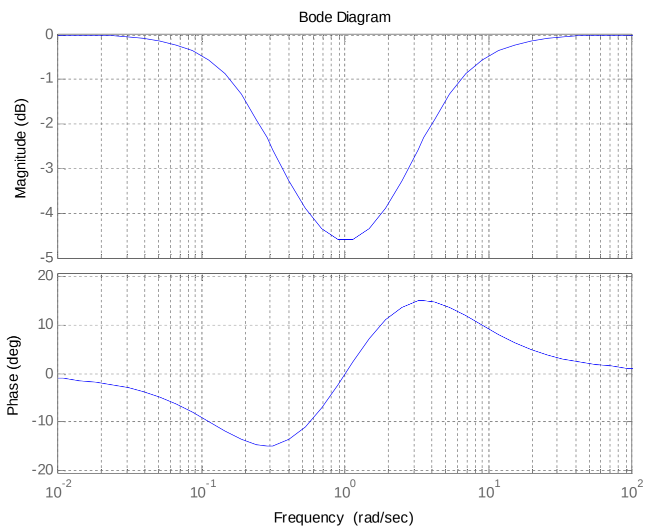

Figure 2. Example of bode plot of band-stop filter

Fig.2 shows that the band-stop filter may influence the phase characteristic of input signal. Especially, the phase-lag maybe destroy the stability of the magnetic levitation control system, and it must be compensated.

3.3 Improved band-stop filter

Based the analysis above, we need a filter, which can compensated the phase lag at a frequency, and has a fixed magnitude. The all pass filter is a good choice.

For example, the transfer function of all- pass filter is:

$$H_2(s)=1+0.2*\frac{s-1}{s+1} \tag{7}$$

and its bode plot is shown in Fig.3:

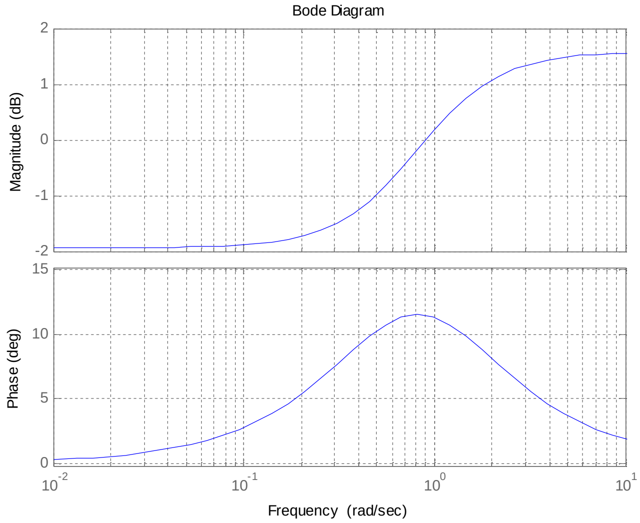

Figure 3. Example of bode plot of band-stop filter $H_2(s)$

If we cascade the all pass filter and band-stop filter, they can not only attenuate the amplitude at certain frequency, but also decrease the phase-lag in the relative-wide band of frequency.

4 SIMULATION RESULTS

The simulation tests are worked on the Simulink platform and the simulation configurations is shown in Table 2.

Table 2: Configurations of simulation

Item	Value
Input signal	sin(10t) + sin(100t)
$H_1(s)$	$\frac{s^2+1.25s+10000}{s^2+50.12s+10000}$
$H_2(s)$	$1+0.2*\frac{0.01s-1}{0.01s+1}$

The simulation results are shown in Fig.4.

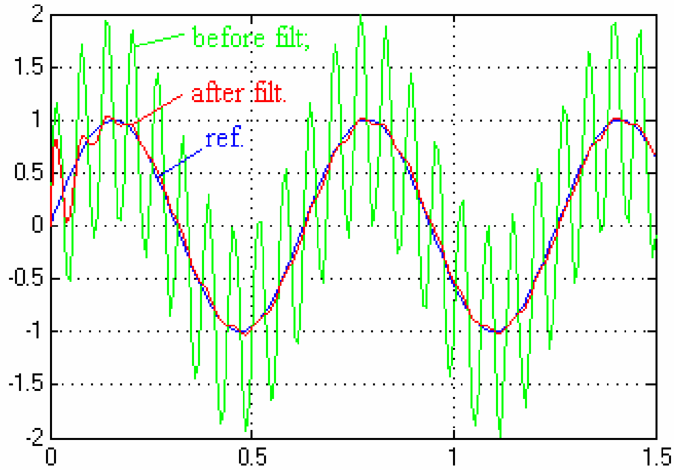

Fig.4 Simulation results

5 DISCUSSION

The presented filter consists of two parts. The band-stop filter is used to decline the specific frequency component, and all-pass filter is used to compensate the phase-lag near the center frequency of band-stop filter. As shown in the simulation results, the designed filter can effectively restrain the specific signal, and nearly do not influence the phase of input signal. However, as shown in Fig.4, there is some distortion in the filtered signal. Although this can be improved by optimal the parameters of filter, it will introduce more phase-lag as well. So, the parameters of the all-pass filter have to be modified. It shows that the two part is coupled, which will increase the design difficulty. Furthermore, in the practical levitation control systems, the high frequency has to be declined in order to increase the signal noise ratio. So, we maybe need another low-pass filter, and this will increase the complexity of design!

6 REFERENCES

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