Active Vibration Suppression Scheme of Magnet Girders

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Abstract

Compared with passive vibration suppression scheme, the active vibration suppression provides more frequency response range and software flexibility. It has potential to apply the active vibration suppression to the existing structures or new built ones. The active dynamic vibration system chooses a voice coil motor (VCM) as the actuator. While matching with a suitably designed PID controller, the vibration can be effectively reduced in specific frequency range. This paper presents the simulations and experimental results of the active dynamic vibration absorber applied for magnet girders.

1 Introduction

The beam stability in the electron accelerator, such like a synchrotron storage ring, is related to many factors. Among which the vibration from girders is one of the most crucial. The solutions can be divided into two strategies, mainly, to isolate the vibration sources from the girder, or to improve the girder characteristics resistant to the vibrations.

The vibration absorber is placed in the devices which have the serious vibration. There are two types of absorbers: passives and active. The difference between passive and active absorber is that the later one actively provides powers to suppress the vibrations. The dynamic vibration absorber is adopted in the active vibration suppression system in such way that the system is designed to exercise a force such that the excited frequency is near the natural frequency of the mechanical system. The dynamic vibration absorber is inexpensive and no need to modify the original girder structure relative to the dynamic vibration isolator.

System

The active dynamic vibration suppression system is depicted in *Figure 1*. The dynamic vibration absorber system can be separated into several parts: a computer system, a 16-bits A/D card, a 16-bits D/A card, an accelerometer system and a voice coil motor system. The computer system calculates the value of PID logic with a constant frequency (1KHz). The A/D card translates the vibration of the girder, analog voltages measured by the accelerometer system, into digital outputs and then delivers the digital signals to the computer. The accelerometer system consisting of an accelerometer and Integrated Circuit Piezoelectric which supplies a steady current to an accelerometer, is to measure the magnitude of the vibration. The analog output voltage of the accelerometer is proportional to the amplitude of the vibration source. The D/A card translates the digital signals of the computer system to analog voltage. A voice coil motor system composes a power amplifier and a voice coil motor. The voltage provided by power amplifier to the voice coil motor is directly proportional to the input signal. The main procedure of the dynamic vibration absorber is the computer system seizes the signal of an accelerator system, computes the result with PID logic and outputs the signal to suppress a force whose excitation frequency is not anticipated.

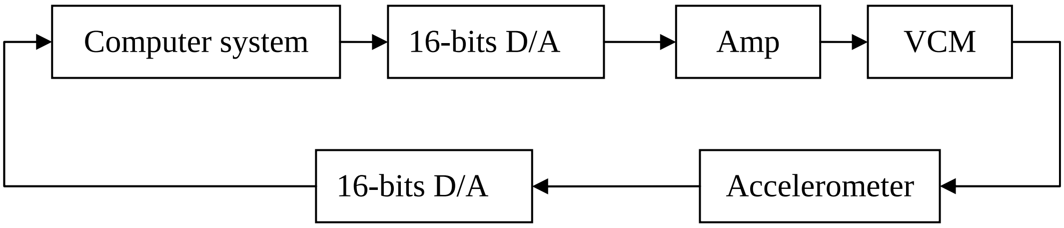


Figure 1

VCM

The voice coil motor is one kind of direct drive motors. It provides a force proportional to the current applied to the coil by a permanent magnetic field and coil winding. Its structure is showed in *Figure 2*. The structure of the voice coil motor is simple and their maintainability is easy. The relations between the current of a VCM and the magnetic field are below.

$$\vec{F} = l\,\vec{I} \times \vec{B}$$

where $\vec{F}$ represent the thrust on the coil, l is the length of a coil placed in the magnetic field, $\vec{I}$ is the current of coil, and $\vec{B}$ is the magnetic flux density. $\vec{I}$ and $\vec{B}$ are vertical to each other in the VCM structure, and the magnitude and direction of $\vec{F}$ is decided. The F can be written as below.

$$\begin{aligned} F(t) &= lIB \\ &= K_f I \\ &= K_f K_i V \\ &= Ku(t) \end{aligned}$$

where K_f is a constant, K_i is a constant between the voltage and the current, K is a constant and u(t) is input voltage signal.

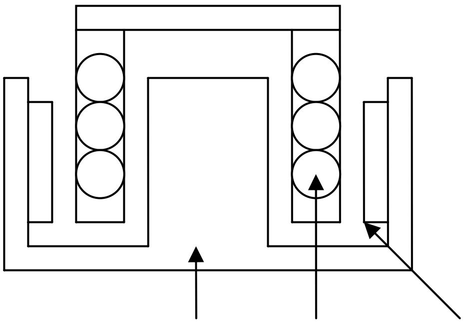


Figure 2

2 Mathematical Model

The voice coil motor are adopt as an actuator to generate the opposite force to the girder vibration. A simplified model is used to analyze the experiment plant shown in *Figure 3*. m_1 and m_2 represent the mass of the girder and the coil of the VCM, respectively. x_1 and x_2 represent the displacements of m_1 and m_2, respectively. The dynamic equations for the entire system are written as (1) and (2),

$$m_1\ddot{x}_1 = F + k_1 x_1 + c_1\dot{x}_1 + k_2(x_1 - x_2) + c_2(\dot{x}_1 - \dot{x}_2) \quad \rightarrow (1)$$

$$m_2\ddot{x}_2 = -F + k_2(x_2 - x_1) + c_2(\dot{x}_2 - \dot{x}_1) \quad \rightarrow (2)$$

The dynamic equations can be re- arranged as below,

$$\dot{Y} = \begin{bmatrix} 0 & 1 & 0 & 0 \\ \frac{k_1+k_2}{m_1} & \frac{c_1+c_2}{m_1} & -\frac{k_2}{m_1} & -\frac{c_2}{m_1} \\ 0 & 0 & 0 & 1 \\ -\frac{k_2}{m_2} & -\frac{c_2}{m_2} & \frac{k_2}{m_2} & \frac{c_2}{m_2} \end{bmatrix} Y + \begin{bmatrix} 0 \\ \frac{1}{m_1} \\ 0 \\ -\frac{1}{m_2} \end{bmatrix} F$$

$$Y = [x_1 \quad \dot{x}_1 \quad x_2 \quad \dot{x}_2]$$

Y represents the displacement and the velocity of m_1 and m_2, respectively. From the matrix, F can control the displacement of m_1.

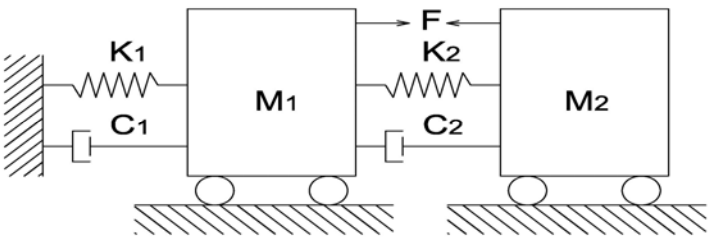
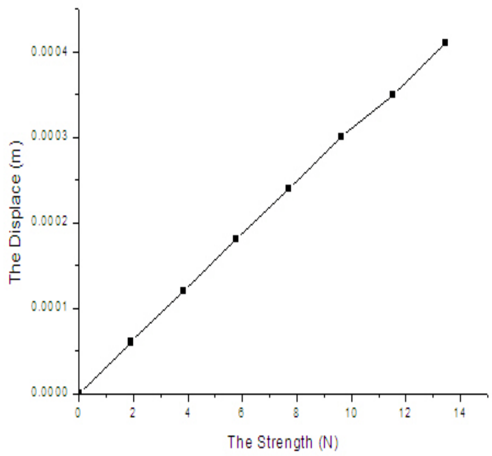


Figure 3

3 System Identification

To order to design the control law exactly, the parameters of the dynamic vibration absorber should be measured and the VCM and the girder should be identified. The *Figure 4* shows the spring coefficient. The properties of the VCM are tabulated in Table I. The girder has a nature frequency at 35 Hz. Its properties are in Table II. *Figure 5* shows the ratio of input voltage signal and output force of the VCM.



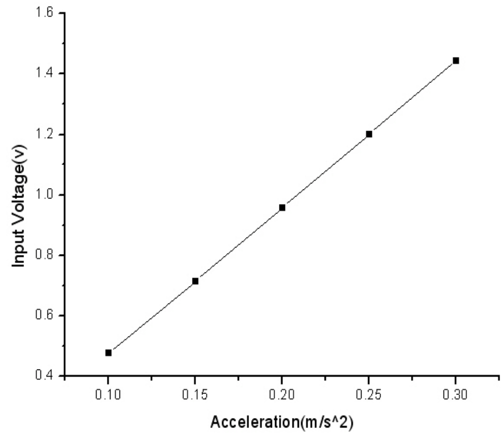


Figure 4 The spring coefficient of voice coil motor *Figure 5*

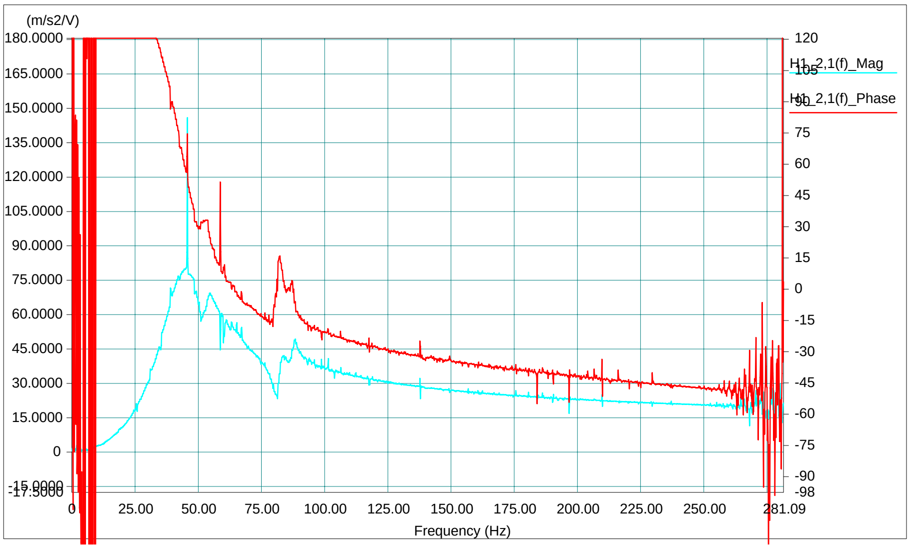


Figure 6 The nature frequency of the VCM

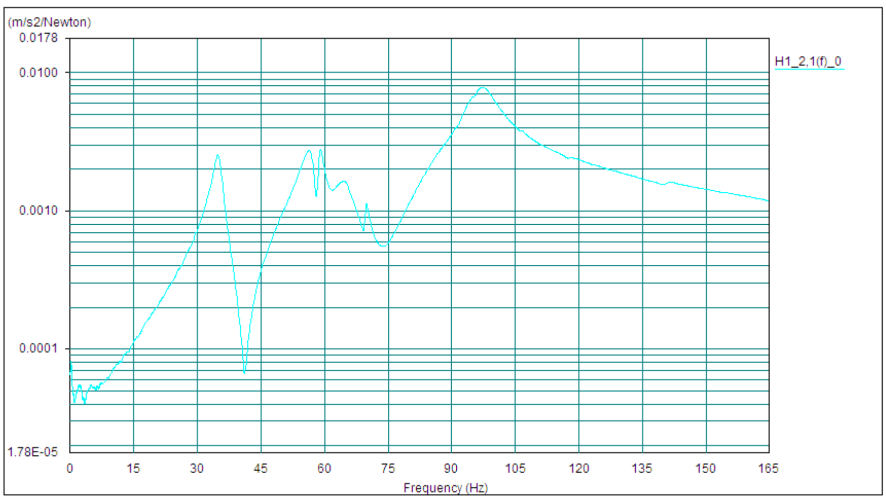


Figure 7 The nature frequency of the Girder

The mass of VCM	12.2
The coil mass of VCM	0.3 kg
The damping ratio	0.158
The spring Coefficient	32000 N/m

Table I

The girder mass	1200 kg
The damping Ratio	0.0068
The spring Coefficient	57700000 N/m

Table II

4 Experiment and Simulation

In order to suppress the vibration at 35 Hz of the girder, the PID is adopted to suppress girder system response. To choose suitable parameters of PID controller, the Routh-Hurwitz method is used to check the system stability. The simulation result shows the magnitude of the girder vibration with a controlled system at the nature frequency is lower than the original girder as in *Figure 9*. In *Figure 10*, the blue line and green line represent the girder vibration for a controlled system and for an uncontrolled system, respectively.

The magnitude of vibration of the girder with a controlled system is two times at 35 Hz lower than the original girder. The nature frequency of the girder is moved from 35 Hz to 34 Hz.

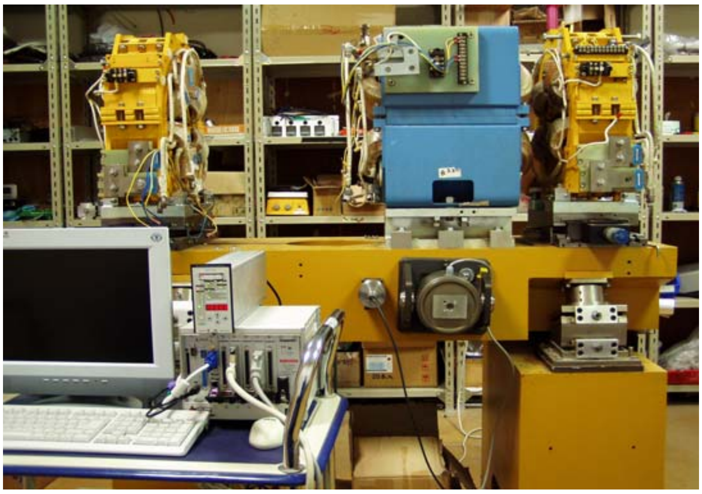


Figure 8

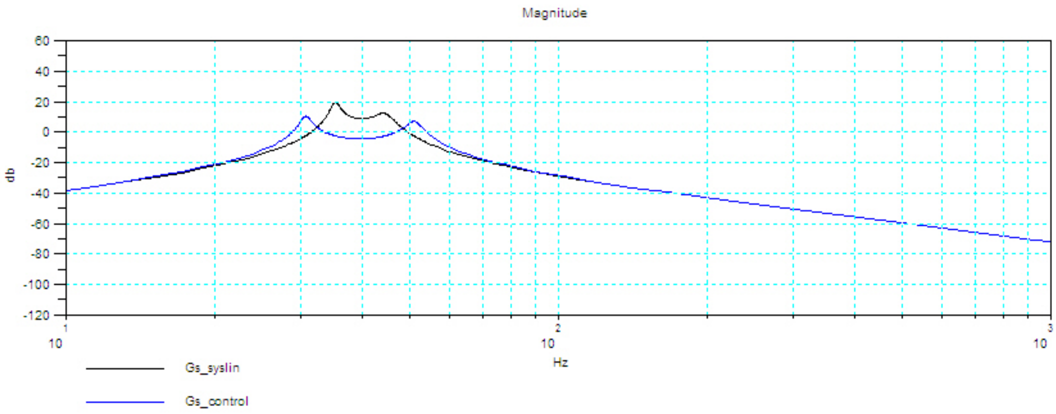


Figure 9

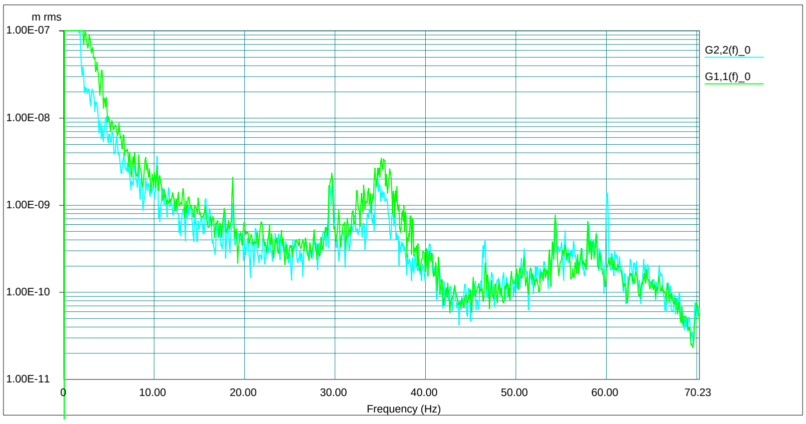


Figure 10 kp = 0.03

5 Conclusion

From the experiments, the girder vibration with a controlled system is suppressed. It is experimentally proved that the dynamic vibration system with the employment of the VCM as an actuator provides an efficient way to suppress the girder vibration. The experimental results however are not as good as expected, mainly because the parameters of girders are not well identified yet. For example the loading of the girder was not well taken into consideration in the experiments. Further experiments concerning more on the dynamic characteristics of the girder and the VCM are in progress.

6 Reference

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