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A VIBRATION SUPPRESSION METHOD ON FLEXIBLE BAR BASED ON SEMI-ACTIVE CONTROL

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Abstract: Large flexible bar appears obviously low frequency vibration characteristics, for its light damp and feeble rigidity, caused by large scale. Meanwhile, this vibration cannot decay fast in a short time. Traditional passive control method are mainly used the damping material, implement the control by increasing damping, and the effective of vibration control problem on flexible bar is limited. The vibration suppression problem on flexible bar is researched. Piezoelectric elements are used as transducer and actuator, respectively, by sticking on the surface of flexible bar. Vibration control on flexible bars is achieved, by using piezoelectric actuator drove by semi-active control method, based on asymmetric switch damping technology. A test platform of switch damping semi-active control on large flexible bar, is built, we design and manufacture the control circuit. A semi-active control algorithm is implemented by dSPACE. Piezoelectric elements are layout rationally, aimed at the first-order bending mode of the objective bar. Proceed to do the control test, on a 3 meter flexible bar with different excitation condition vibration. The results show that the methods have good inhibition to flexible bar vibration problem, the system damping ratio rise from 0.467% to 4.2%, observably. The amplitude decay cycle decline 9 times. It has immense application prospect in large flexible structure.

Key Words: semi-active control, flexible bar, vibration abatement

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1. Introduction

Large flexible bar structure appears obviously low frequency vibration characteristics, for its large size and small rigidity. Traditional passive control is mostly using increase the damping material to control, the effect is generally limited.

Piezoelectric semi-active control method is developed on the base of piezoelectric active vibration control and passive vibration control. Semi-active control applies the energy on semi-active control loop, but not piezoelectric actuator. It changes the system characteristics by controlling the parameters of the ends of the piezoelectric element circuits, to achieve the control aim.

Semi-active control method based on synchronized switch damping technique derive from France, proposed by D. Guyomar, Claude Richard, etc[1-4], and had got great development. SSD method has stable vibration control effect, so that be fit for multi-mode vibration control without using the accurate structural modes, in complex external environment change. There are varieties kinds of SSD, it's been firstly presented as SSD technique based on short circuit (SSDS) [2]. In order to further enhance the control result, Richard, C. proposed the SSD technique based on inductance (SSDI) [4]. He uses a series inductance L, to make a LC resonant circuit with piezoelectric element capacitance, which increases the control voltage of the piezoelectric elements, and promote the control effect. In order to amplify the voltage on piezoelectric elements, Lefeuvre, E. proposed SSD technique based on voltage source (SSDV) in 2006 [5], which cascade an extra power supply in SSDI loop. Because of extra power supply, the voltage is further improved, which enhance the control effect. In the research of large flexible structure control, Huang Wenhu [6] point out intelligent structure, such as piezoelectric elements, is especially suit the large flexible bar structure vibration require. Onoda, J. from Japan research the vibration control on the truss structure featured, make semi-active control experiment on truss structure by electrorheological fluid, obtain good results of control [7]. In his follow-up study, a piezoelectric stack method is used to carry out the semi-active vibration control on truss structure [8-11]. According to the vibration and control require of truss structure, a variety of piezoelectric stack is pasted on some arthrosises that have large displacement, on truss structure. A semi-active control method based on synchronized switch damping technique can successfully implement the multi-mode vibration control, and work well on control.

2. Semi-active vibration control method based on synchronized switch damping technology

The basic principle of semi-active vibration control method based on Synchronized Switch Damping technology (SSD) is that, connecting the inductance and switch between the poles of piezoelectric elements to make oscillation control circuit, then close the switch, which would shock when the structural vibration displacement reaches extreme. And the switch should be turned on again after the voltage reversing to keep the opposite direction of the structure relative to the controlling force produced by the voltage from the piezoelectric element. Namely, the power always hinder the vibration of structure to achieve the purpose of vibration control. In addition, according to the theorem of conservation of energy, under the premise of the total input energy remaining, the improvement of the power of electromechanical conversion can reduce the energy of the mechanical vibration to achieve the vibration control.

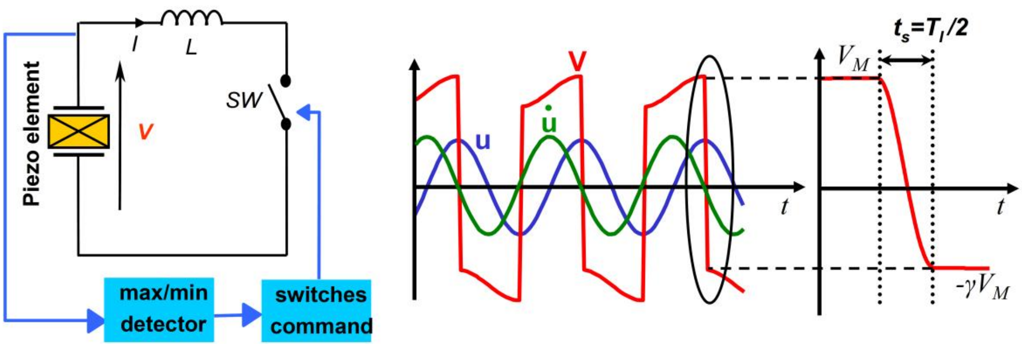


Figure 1. The basic principle of semi-active vibration control method based on SSD

In order to improve the control effect, voltage source can be inserted in the switching circuit to improve the voltage at the both ends of the piezoelectric devices, resulting in more effective control (SSDV method, Synchronized Switch Damping on Voltage).

The series of polar opposite voltage source group in the piezoelectric element loop can supplement the energy caused by the switch network consumption of piezoelectric capacitance. Due to the effect of applied voltage source Vcc, which increases the voltage on the piezoelectric element and enhances the control effect of damping.

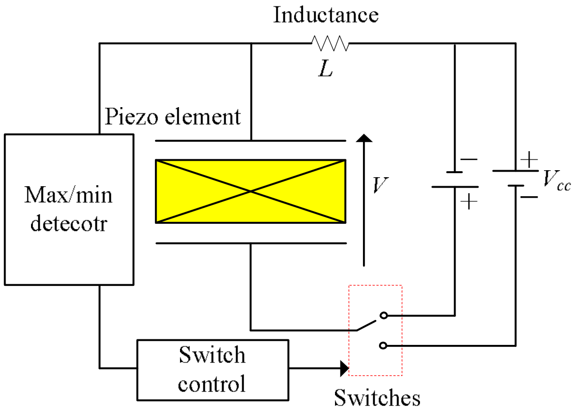


Figure 2. The principle diagram of SSDV

When the displacement of piezoelectric element reaches maximum, making the switch closed, the LC oscillator circuit resonance will occur at this time. When this resonance movement through half a cycle t_i, quickly disconnecting the switch, the voltage on the piezoelectric element will flip. When the voltage on the piezoelectric element reaches the positive maximum value, the switch is made to attach a power -Vcc to the voltage on the piezoelectric element after the voltage reversing; when the voltage on the piezoelectric element reaches the negative maximum value, the switch is made to attach a power +Vcc to the voltage on the piezoelectric element.

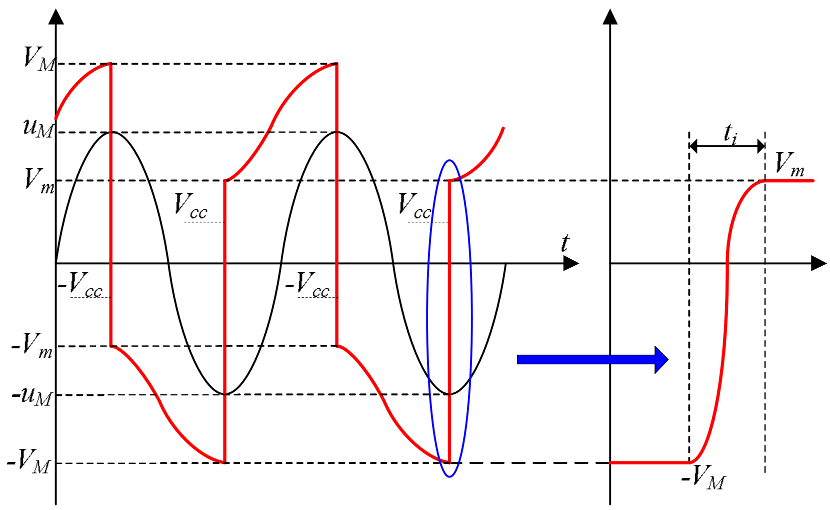


Figure 3. SSDV displacement and voltage curve

SSDV electromechanical conversion in one period:

$$E_t = \int \alpha V du = (\frac{4\alpha^2}{C_0}u_M^2 + 4\alpha u_M V_{cc})\frac{1+\gamma}{1-\gamma} \quad (1)$$

3. System test validation

For vibration suppression test of 3 meters length flexible bar, the large flexible bar switch damping semi-active control experiment platform has been established and the switch control circuit has been made, semi-active vibration control algorithm is implemented by dSPACE, as shown in Fig. 4. Bar roots fixed supported, in view of the need of controlling the bar first-order bending mode to arrange the piezoelectric element sensors and drives, and then we verified the effectiveness of the system vibration suppression effect in the transient and steady state incentives.

Figure 4. Semi-active control circuit and dSPACE control panel

3.1 The transient load (amplitude 4 mm) vibration suppression test

Applying 5 mm initial displacement at the end of the structure, and then release, free damping structure ends moving curve was shown in Fig. 5, the system damping ratio is 0.467%. Carrying out the semi-active vibration control to structure, the vibration amplitude attenuates to 0.1 mm in a short time. Structure ends moving curve after control is shown in Fig. 6. System damping ratio reaches to 4.2%. Flexible bar system vibration damping cycle shorten nine times. Voltage amplitude between both ends of the piezoelectric element of A and B channels in the process of control is about 300V, curve as shown in Fig. 7.

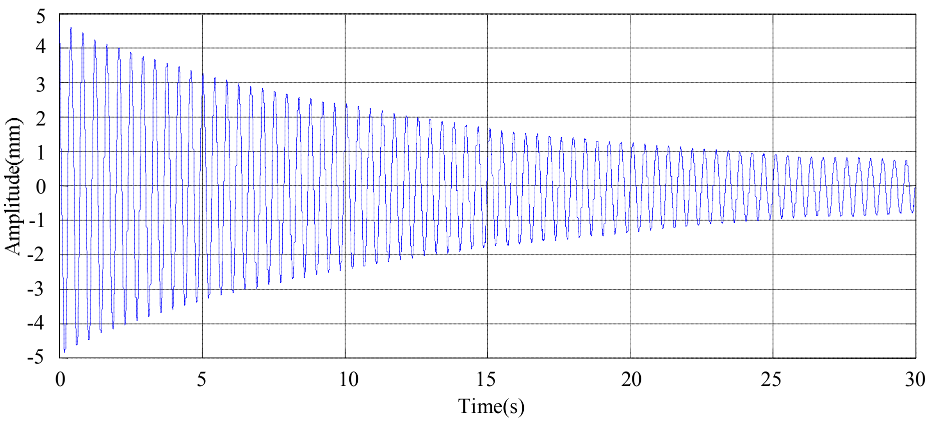


Figure 5. Structure free attenuation ends moving curve after 5mm the initial displacement (Before control)

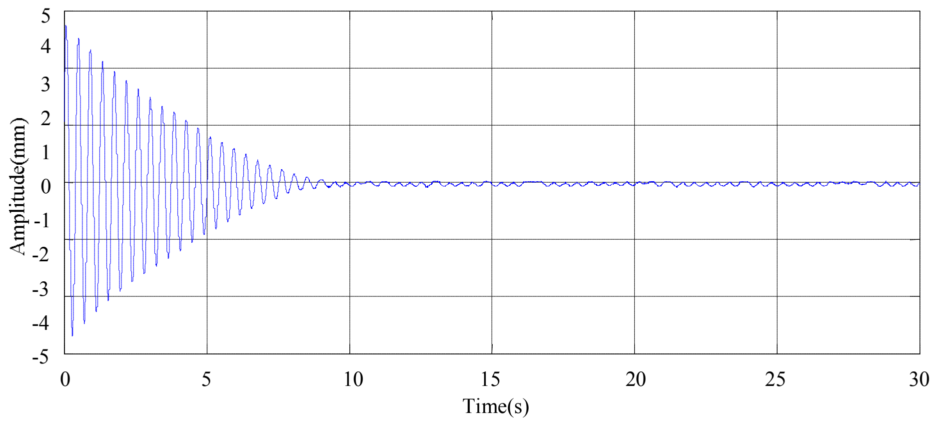
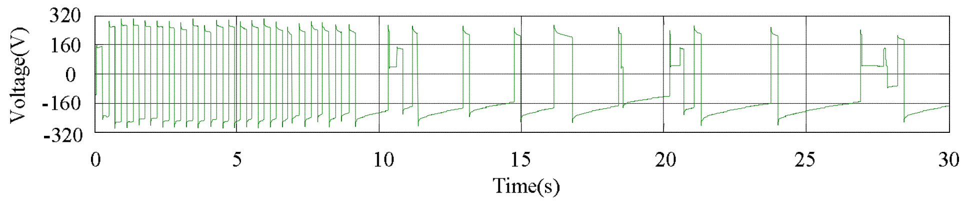
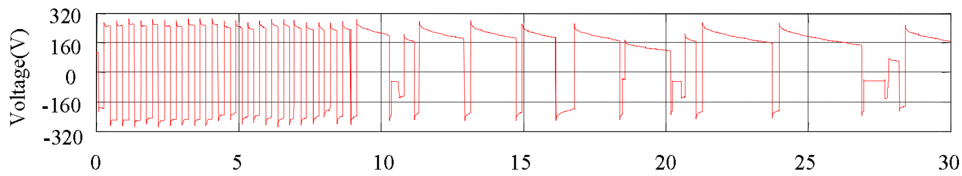


Figure 6. Structure ends moving curve after 5mm the initial displacement (After control)



(a) A channel



(b) B channel

Figure 7. The piezoelectric element voltage curve of A and B channels in controlled process

3.2 The steady-state load (amplitude 4 mm) vibration suppression test

Placing a steady-state excitation of flexible bar root to produce 4 mm amplitude, before and after controlled structure ends moving curve as shown in Fig. 8. Before the control, structure of the steady state vibration amplitude is 4 mm, and after the control, the structure vibration amplitude is reduced to 0.4 mm. Applying FFT analysis to the captured displacement signals, before and after controlled structure ends moving curve as shown in Fig. 9. Amplitude decreased 19.758 dB compared with before and after control. Voltage amplitude between both ends of the piezoelectric element of A and B channels in the process of control is about 224V, curve is shown in Fig. 10.

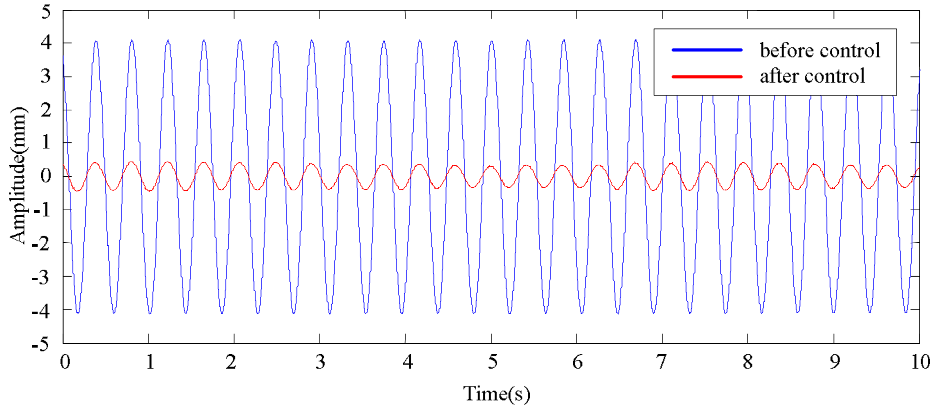


Figure 8. Under steady-state incentives(amplitude 4mm)structure ends moving curve before and after control

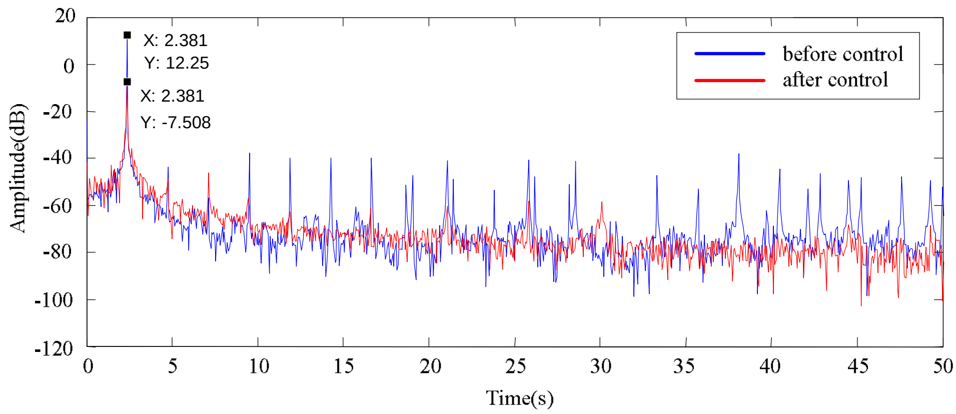
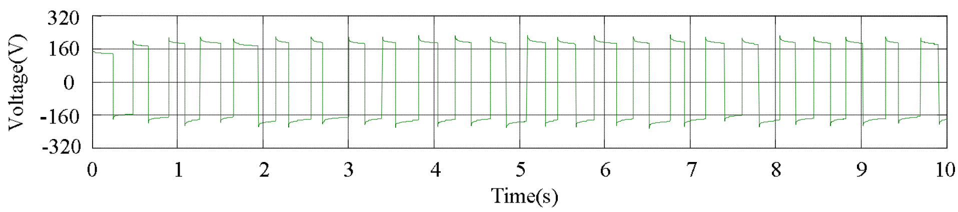
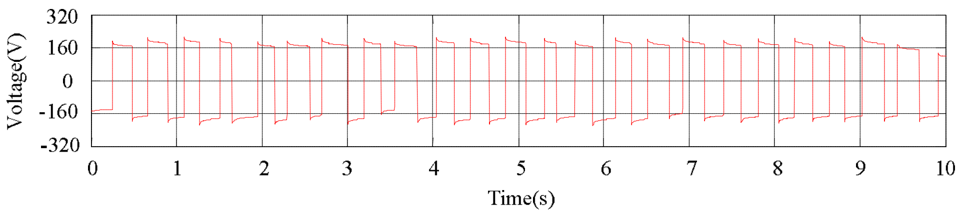


Figure 9. Under steady-state amplitude 4mm amplitude-frequency characteristic curve before and after control



(a) A channel



(b) B channel

Figure 10. Voltage amplitude curve between both ends of the piezoelectric element of A and B channels in the process of control

4. Conclusion

A vibration suppression of flexible bar problem, based on synchronized switch damping semi-active vibration control method and the piezoelectric element, is studied. A large flexible bar switch damping semi-active control experiment platform was established for test validation. The results show that the method has good inhibition effect on the flexible bar vibration in transient and steady-state load excitation. The damping ratio of flexible bar system increased from 0.467% to 4.2%, and the amplitude decay cycle shorten nine times.

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