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STRUCTURAL VIBRATION CONTROL BY USING THE ENERGY FROM DIFFERENT MODES

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Abstract

Abstract: Vibration control based on mechanical energy transfer was recently proposed in a technique called synchronized switch damping with energy transfer (SSDET). In this technique, the mechanical energy, which is extracted from energy source structure is transferred in order to damp another structure. This paper introduces this technique on a multimode vibrating structure. The energy transfer path is from one mode to another. A threshold is set in the control system for the sake of better damping. Experiments are carried out on a clamped plate under harmonic response. Results validate the effectiveness of this technique for multimode vibration control.

Keywords: piezoelectric, vibration control, semi-passive, vibrating mode, energy transfer

1. General Introduction

Among kinds of semi-active and semi-passive vibration control methods, Synchronized Switch Damping (SSD) techniques are proved to be an effective treatment [1-4]. Compared with the passive methods, the system has the immunity against the structure dynamic properties shift due to the environmental change. They are also compact, lightweight which is convenient to apply to specific structure with weight or size restriction. Compared with the active control, the SSD control system is very simple to implement while consumes small energy even self-powered [5]. In these techniques, the switch in the circuit is intermittently switched leading to a non-linear voltage process on the piezo-elements. The piezo-force induced by such voltage always shows an opposite sign with the structure velocity which leading the vibration suppression on the structure. Such behavior is similar with the well-known direct velocity feedback control or bang-bang control. In this paper, a newly developed method so called Synchronized Switch Damping by Energy Transfer (SSDET) [6] was employed to suppress the structure vibration by transferred the energy between different modes of a vibrating structure.

2. Principle of Synchronized switch damping by energy transfer

Be different from the classical synchronized switch damping (SSD) technique which is a type of piezoelectric shunt damping techniques, the SSDET involves two or more vibrating structures or modes. In this paper, the objective is to using the extracted energy from one vibrating mode (source mode) and transfer it to another mode (target mode) in order to improve the damping performance on the latter.

An energy transfer circuit (as shown in Fig.1) is connected between two groups of piezoelectric elements for delivering the energy from one mode to another. These piezoelectric elements could be arranged on one structure or different ones. The subscripts s and t stand for source mode and target mode respectively. The circuit could be considered as two LCR circuits sharing an inductor L and a resistor R, C_0 and V are the capacitance and the voltage on the piezoelectric elements, respectively.

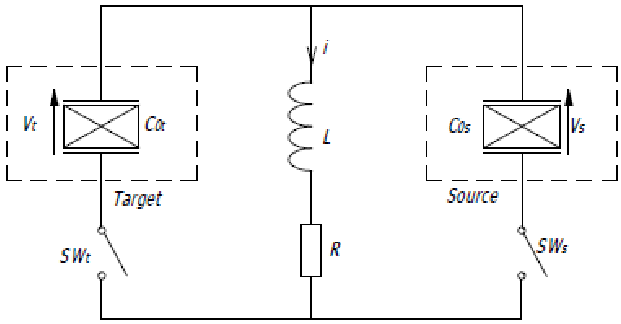

Figure 1 – SSDET circuit

The practical operation of the SSDET namely the control law could be summarized as two consecutive steps. The first step is that, when the displacement of the target mode gets to its extremes values, the switch SWs is closed for a quarter or three quarters of the LC_sR oscillation period depending on the polarity of the piezo-patches, so Vs drops to zero and the energy stored on the capacitor Cs would be totally transferred to the inductor L, and then the switch SWs is re-open. The following step is to immediately close the switch SW_t for about half of the LC_tR period in order to invert V_t to its opposite extreme. Compared with the classical SSDI technique, the SSDET has an initial current in the inductor at the very beginning leading to a stronger inversion so as to get a better damping effect.

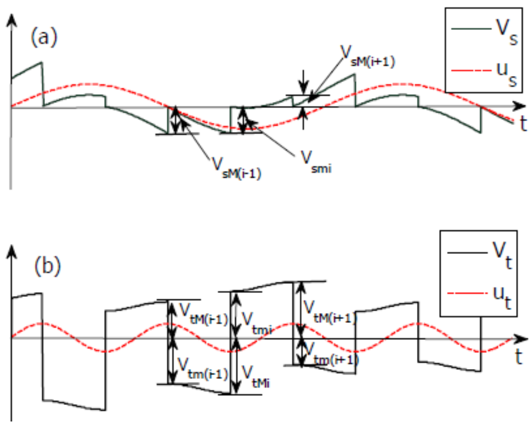

Figure 2 – Voltage and displacement waveforms under SSDET technique

The typical waveforms of the voltage V and displacements u for both source mode and target mode are shown in Fig.2. It is assumed that the displacement of the target mode under SSDET control is sinusoidal. Concerning with the typical SSDET technique, the energy transfer occurs at each extreme of the target displacement. Thus, two transfers would be conducted during one period of the target mode at its maximum and minimum displacement instant respectively. If the operation time is T and the vibration frequency of the target mode is f_t, the transferred times n can be easily obtained.

3. Experiment on a cantilever plate

3.1 Experimental setup

The experiment was carried out on a printed circuit board with one edge clamped as shown in Figure.3 and the schematic experimental setup was illustrated in Fig. 3 (a). The frequencies of its first bending mode and first torsion mode are 23.7 Hz and 82.5 Hz under open circuit condition. Their mode shapes are shown in Fig. 4. As shown in Fig. 3, the plate was clamped on a rigid support and excited under a two-wave mixing signal by an electromagnet in order to simultaneously excite the mentioned bending and torsion modes. Two groups of piezoelectric elements (PZTs) were bonded on the plate surface close to the clamped edge as shown in Fig. 4. The induced electrical charge was also shown in Fig. 4. Note that the electrical charge showing different polarities between different modes. Hence, the PZTs of group 1 can only extract the bending mode energy, and the PZTs of group 2 can only extract the torsion mode energy by connecting the PZTs of group 2 in parallel. The displacement was measured by two laser sensors at two points which were symmetric to the static line of the torsion mode. Assuming that the measured displacements were d1 and d2, thus the bending displacement u_s equals to (d1+d2)/2 and the torsion displacement u_t equals to (d1-d2)/2.

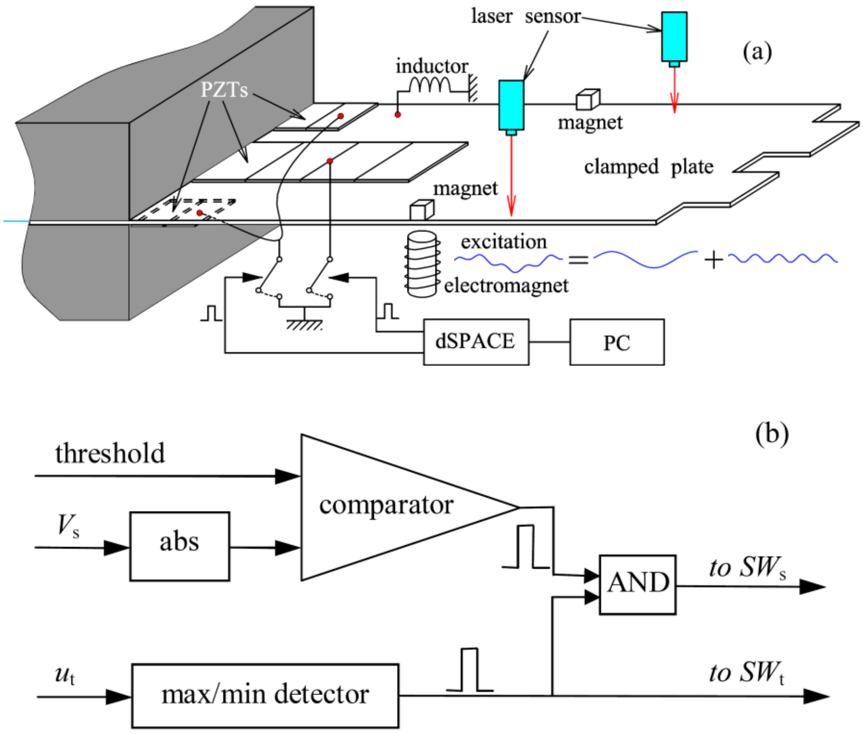

Figure 3 – A schematic diagram of the experiment. (a) The experimental setup. (b) The switching control scheme.

A switching control system, which is showed in Fig. 3(b) was designed by Simulink/dSPACE scheme to control the MOSFET switches. From this scheme, it could be known that switch SW_t will be always closed once u_t reaches to its extremes. However, switch SWs could be closed when two conditions are met at the same instant. One is u_t gets to its extremes. Another one is that the absolute value Vs is greater than the preset threshold.

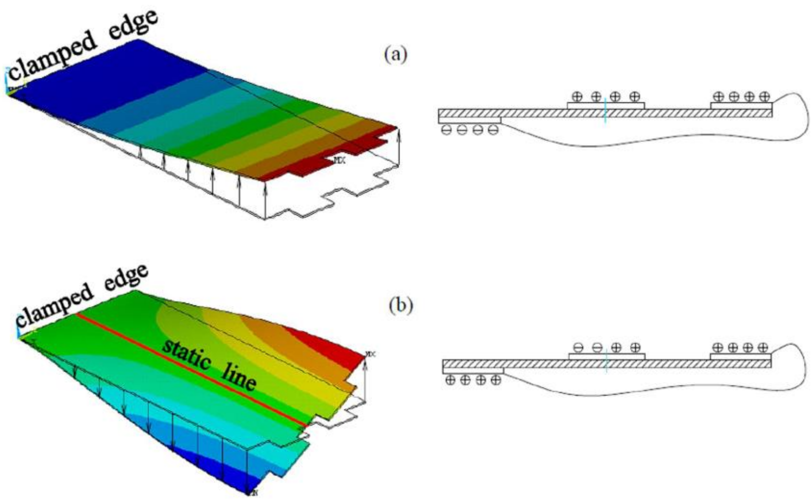

Figure 4 – Mode shapes of the plate. (a) the first bending mode shape(fs=23.5Hz) and the electrical charge distribution (b) the first torsion mode(ft=81.7Hz) and the electrical charge distribution

3.2 Results and discussion

The control effects are shown in Fig.5. The threshold is set to 5V in the experiment. The experiment was carried out as following steps. At first, the structure was excited under both bending and torsion mode without any control. And then, the SSDI control was conducted on the torsion mode from 5 seconds to 10 seconds, which damped the torsion motion. During this time range, the bending mode kept its amplitude since no operation was acted on it. From 10 seconds to 17 seconds, the SSDET control was conducted, and it caused obvious damping to the torsion mode. The source mode was also suppressed because its vibration energy was extracted and transferred during this period.

The details of the displacements and voltages under different control stage are shown in Fig.6. A slight coupling effect could be observed from global displacement in Fig.6(a) and in the piezoelectric voltage of torsion mode. Such voltage waveform represented a clear SSDI waveform under the SSDI operation in Fig.6(b). Fig.46(c) detailed the waveforms with SSDET control. Thanks to the threshold setting, the bending mode energy was transferred when the voltage Vs was larger than the predetermined threshold value. Otherwise, only SSDI is conducted on the torsion mode.

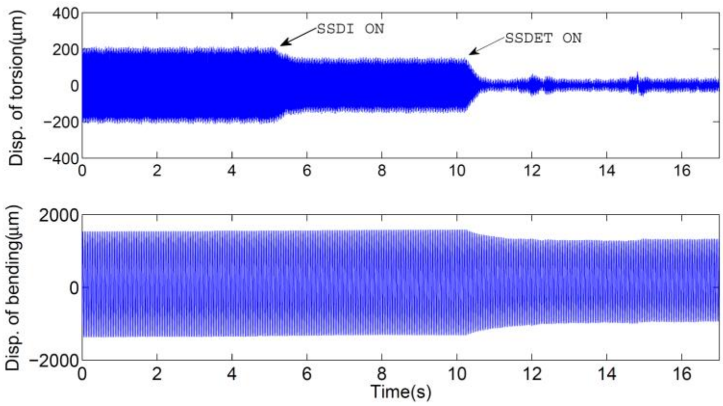

Figure 5 – Control effect in time domain.

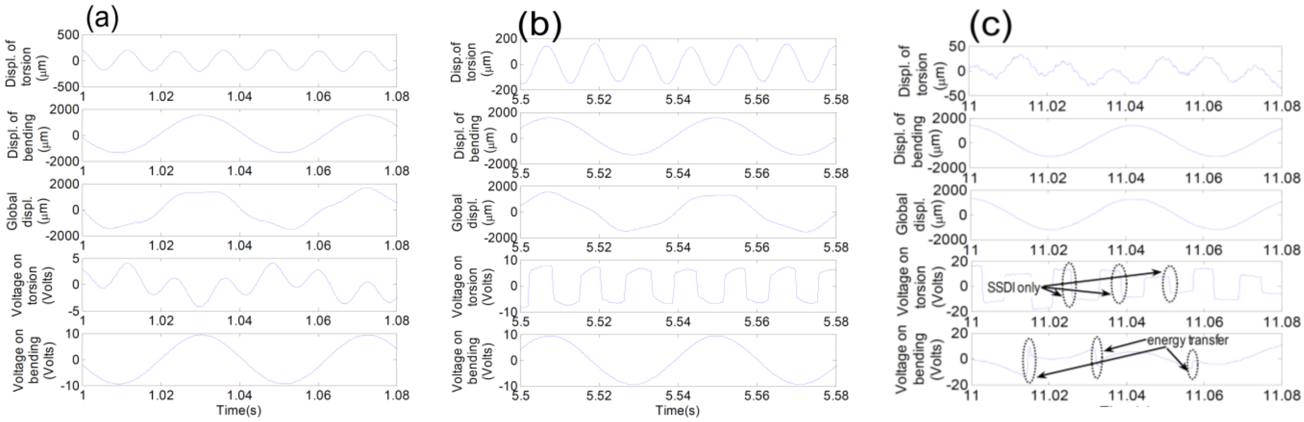

Figure 6 - Details during different control stage. (a) Without control (b) SSDI control (c) SSDET control

Fig.7 shows the transfer function under no-control case and several SSDET with different thresholds as well as SSDI control. The bandwidth range covers the torsion mode (target mode) frequency. Larger threshold would increase the damping, meanwhile the transfer function curve became not smooth any more. In fact, the system would lose its stability if the threshold is larger than a certain value which approximately equals to half of the source voltage amplitude under open circuit condition. Because the fact of threshold setting is to accumulate more energy on the source. However, it is inevitable to decrease the transfer times as we discussed before. If the threshold is set too high, there will be a relatively large time interval between two switching which images unsteady piezoelectric force exerting on target. Moreover, the strong energy transfer leads to a great voltage inversion on the target would excite the residual modes of the structure.

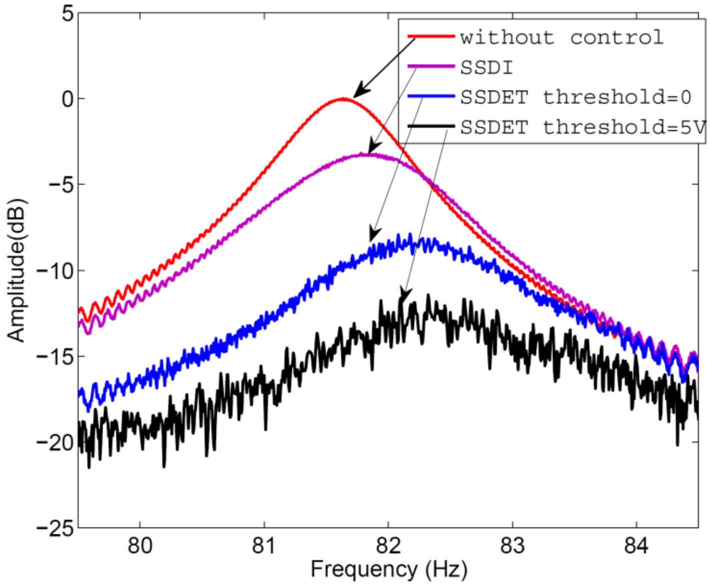

Figure 7 – Transfer function of the plate with different control strategies.

4. Conclusions

This paper introduced a synchronized switch damping by energy transfer (SSDET) method. The principle of this technique is presented. The experiment was carefully designed and carried out on a clamped plate which was excited at both its bending and torsion mode. The results showed that the vibrating energy was successfully extracted from its bending mode to elevate the damping effect on the torsion mode. Therefore, this provides a new thinking of vibration control method.

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6. Copyright Statement

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