Research of vibration control based on current mode piezoelectric shunt damping circuit

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Research of vibration control based on current mode piezoelectric shunt damping circuit

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Abstract. The piezoelectric shunt damping circuit using current mode approach is imposed to control the vibration of a cantilever beam. Firstly, the simulated inductance with large values are designed for the corresponding RL series shunt circuits. Moreover, with an example of cantilever beam, the second natural frequency of the beam is targeted to control for experiment. By adjusting the values of the equivalent inductance and equivalent resistance of the shunt circuit, the optimal damping of the shunt circuit is obtained. Meanwhile, the designed piezoelectric shunt damping circuit stability is experimental verified. Experimental results show that the proposed piezoelectric shunt damping circuit based on current mode circuit has good vibration control performance. However, the control performance will be reduced if equivalent inductance and equivalent resistance values deviate from optimal values.

1. Introduction

Aircraft vibration is an important problem of aircraft design. The new intelligent materials has brought a new breakthrough to solve this problem. Piezoelectric material as the mainstream of the new intelligent material has obvious positive and inverse piezoelectric effect [1], and has been widely used in the vibration and noise control. Shunt piezoelectric damping technology is a kind of piezoelectric passive control method. The basic idea of this technology is the use of the positive piezoelectric effect change the mechanical energy to electrical energy, and the resistance of shunt circuit will consume it as heat energy. As result, vibration and noise has been controlled [1, 2].

The typical RL shunt circuit, by connecting the resistor (R) and inductive (L) series or parallel in shunt circuit. In order to get the optimal control effect, the natural frequency of the shunt circuit is generally close to or equal to the natural frequency of the control mode [2, 3]. This means that when the low frequency vibration is controlled, the design of the shunt circuit requires a big inductance to achieve better effect.

In practice, the physical inductance is composed of a pure coil or a cored coil, and its volume increases with the inductance value [4]. The problems cause the physical inductance to be difficult to apply in the shunt circuit of low frequency vibration. In order to solve this problem, the simulation inductance can be realized by using integrated electronic components. The conventional piezoelectric shunt damping circuit is used to simulate the large adjustable equivalent inductance and resistance by voltage mode circuit. Such as using 741 type voltage feedback operational amplifiers designed RLC series piezoelectric shunt circuit[2] (Yang, 2005), such as comparing and analyzed RL series, RL parallel, RL-C parallel shunt circuit by using voltage feedback operational amplifier designed[3] (Mao, 2011). In recent years, the current mode circuit has been widely applied [5, 6], because it is more advantageous than the voltage mode circuit in the processing of high speed, broadband and high accuracy analog signal. It provides a new method for the design of piezoelectric shunt damping circuit.

In this study, piezoelectric shunt damping circuit designed by current mode technology is presented, and through the experiment to test the effects of vibration control. Meanwhile, control system stability by changing the circuit parameters is analyzed.

2. Theory of RL series shunt circuit

As shunt circuit in the study, shunt circuit can be modeled by an equivalent resistance R_{eq} and an equivalent inductance L_{eq} series circuit, the equivalent resistance R_{eq} include theoretical resistance R_t and parasitic resistance R_i. According to the literature [7-9], the optimal inductance value Lopt and equivalent resistance value Ropt are respectively:

$$L_{opt} = \frac{1}{\omega_s^2 C_p (1+K_{31}^2)}, \quad R_{opt} = \sqrt{2}\frac{K_{31}}{\omega_s C_p} \tag{1}$$

Where ω_s is control frequency, C_p is the capacitance value of piezoelectric ceramic chip (PZT), K_{31} is the piezoelectric coupling coefficient:

$$K_{31}^2 = \frac{\omega_{open}^2 - \omega_{short}^2}{\omega_{short}^2} \tag{2}$$

Where ω_{open} and ω_{short} are the piezoelectric structure natural frequency of the open circuit and short circuit respectively.

3. Shunt circuit designed

The second generation current conveyors(CCII) in today's very widely used, and CCII is a three-port device, its voltage current input and output characteristics are represented as:

$$\begin{bmatrix} i_y \\ V_x \\ i_z \end{bmatrix} = \begin{bmatrix} 0 & 0 & 0 \\ 1 & 0 & 0 \\ 0 & \pm 1 & 0 \end{bmatrix} \begin{bmatrix} V_y \\ i_x \\ V_z \end{bmatrix} \tag{3}$$

Where ± 1 represent the same phase CCII and the opposite phase CCII.

Using CCII theory, the shunt circuit can be designed by adding a negative impedance converter in front of the inductance. According to this idea, shunt circuit is designed as Figure 1 shown.

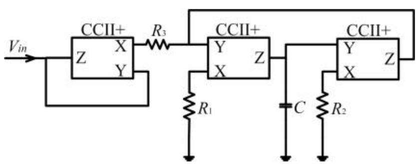

Figure 1. Principle diagram of CCII shunt circuit.

Combining Figure 1 with Eq.(3), input voltage can be written as

$$V_{in} = V_{Y1} = V_{X1} = V_{Y2} - I_{in} R_3 \tag{4}$$

And, $V_{Y2} = V_{X2} = I_{X2}R_1$, $I_{X2} = I_{Z2}$.
Meanwhile,

$$I_{in} = I_{Z1} = I_{X1} = I_{Z3} = I_{X3} \tag{5}$$

And, $I_{X3} = \dfrac{V_{X3}}{R_2}$, $V_{X3} = V_{Z2} = V_{Y3} = I_{Z2}\dfrac{1}{j\omega C}$.
Therefore, Eq.(5) can be rewritten as

$$I_{in} = \frac{I_{Z2}}{j\omega CR_2} \tag{6}$$

Substituting Eq.(6) into Eq.(4), the impedance of circuit can be written as

$$Z_{in} = \frac{V_{in}}{I_{in}} = j\omega CR_1R_2 - R_3 \tag{7}$$

Thus, this circuit equivalent inductance and equivalent resistance are respectively

$$L_{eq} = CR_1R_2, \quad R_{eq} = R_i - R_3 \tag{8}$$

Where R_i is parasitic resistance of shunt circuit.

Notice the Eq.(8), we can find designed shunt circuit can be adjusted equivalent inductance and equivalent resistance parameters independently.

4. Experimental setup

The experiment adopts 6061 aluminum cantilever beam of dimensions 345mm×30mm×5mm. Choose two pieces of piezoelectric ceramics (PZT) counterpoint to paste on the beam near the clamping end roots, and the one PZT as excitation source, another is connected to the shunt circuit as shunt damping system. The vibration testing by using CA-YD-186 type acceleration sensor paste on cantilever beam free end, and the vibration analysis was carried out by TST5912 dynamic testor. The experimental photo is shown in Figure 2.

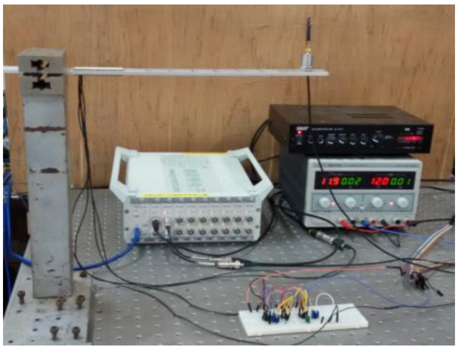

Figure 2. Material photo of experiment

The capacitor of piezoelectric ceramic chip used in the experiment is C_p=90nF. Measured natural frequency of the second modal with open circuit and closed circuit are ω_{open}=2π×181.64rad/s and

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ω_{short}=2π×181.45rad/s respectively. Figure out coupling coefficient K_{31}=0.05, and optimal inductance value and resistance value are L_{opt}=8.51H and R_{opt}=619Ω.

According to shunt circuit shown in Figure 1, using AD844 integrated operational amplifier implementation of the second generation current conveyors, and select the C=100nF, R_1=10kΩ, R_2=8.56kΩ. Because theoretical value has error in practice, we adjusted resistance on line, at last find actual optimal resistance value is R_{ropt}=605Ω. Choosing the second mode as control target, using 181Hz sinusiodal signal to stimulate the structure. The time domain result is shown in Figure 3.

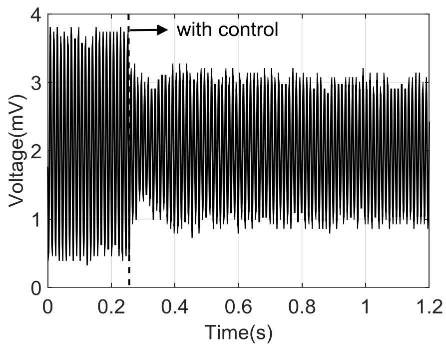
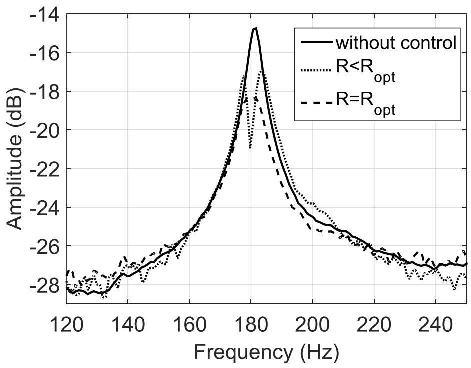
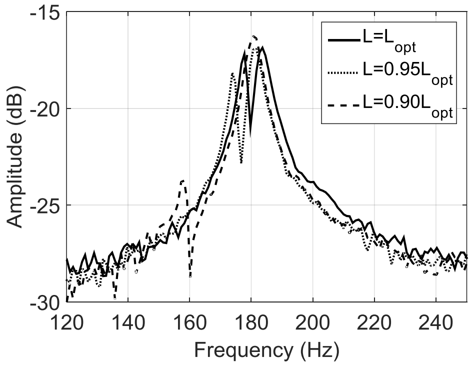


Figure 3. The diagram of accelerometer response with 181Hz

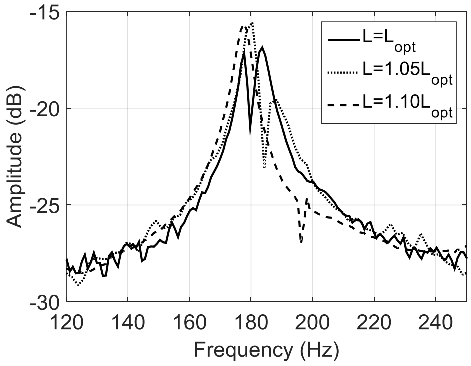
Then, to verify the stability of the system, select sweep signal excitation. Figure 4(a) is the frequency response diagram under different resistance value and optimal inductance value. It can be found that the vibration peak decreases when the optimal equivalent resistance is obtained. When the equivalent resistance is less than the best value, the control frequency peak has declined obviously, and the resistance value is too small to reduce the effective control of shunt circuit frequency range, and produce a new vibration peak on both sides. Figure 4(b) is the frequency response comparison diagramunder inductance value is greater than the optimal value, and Figure 4(c) is the frequency response comparison diagramunder inductance value is less than the optimal value. We can find that if the inductance value is greater than optiamal value, the control frequecy will decrease, and if the inductance value is less than optiamal value, the control frequecy will increase.



(a) The frequency response diagram under different resistance value



(b) The frequency response comparison diagramunder inductance value is greater than the optimal value



(c) The frequency response comparison diagramunder inductance value is less than the optimal value

Figure 4. The second natural frequency response figure

5. Conclusion

The current mode technology provides a new design method for piezoelectric shunt damping circuit. The new shunt damping circuit designed by the current mode circuit can adjust its equivalent inductance and equivalent resistance independently, and the system response speed is fast, and the effect of control cantilever beam vibration is good.

Acknowledgments

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