PIEZOELECTRIC SWITCHING TECHNIQUE FOR VIBRATION DAMPING

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1. Introduction

Piezoceramics are widely used as actors and sensors in many technical applications. They offer very precise positioning and high dynamics. It makes them suitable for vibration damping especially at high frequencies. However, they need comprehensive amplifiers and power supply when used as actors. An alternative approach for vibration control and damping is piezoelectric shunt damping cp. Fig.1.

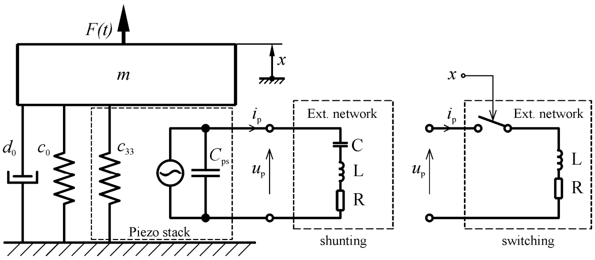

Figure 1. Mechanical structure with piezo element. Shunting and switching principles.

It features an electrical network which is connected to the electrodes of the piezoceramics. The piezoelectric transducer is embedded into the mechanical structure and couples the mechanical and the electrical systems by energy conversion by the piezoelectric effect. The aim of the network design is to cause a dynamical behavior of the piezoceramics which influences the mechanical vibration in the desired way. Typically, a resonant LR shunts are used for vibration damping, which for maximum efficiency, must be tuned to the natural frequency of the mechanical system or to the frequency of excitation [1]. The drawback of this passive solution is the small frequency bandwidth. Therefore, this technique is appropriate for vibration problems with only one dominant invariant frequency known in advance. A negative capacitance network has been proposed to increase the damping performance and the frequency bandwidth. However, a negative capacitance cannot be realized in a passive way and requires power supply for operation [2]. Another solution for vibration damping is switched LR shunt [3]. In this technique, the electrical network is connected and disconnected periodically to the electrodes of the piezoceramics. An electronic switch circuit is needed to connect and disconnect the network at appropriate times. Typically, the switching is triggered by the mechanical vibration itself. It has been shown that these switching shunts are very robust against changes of the system parameters and the excitation frequency.

2. Piezoelectric model

For the calculations, a linear, one dimensional model of the piezoceramics is used, cp. Fig.1. The mathematical model is derived from the constitutive equations [1]. In case of the switching it is necessary to establish the energy amount that may be extracted from the mechanical structure in the quasi steady state by integration of the product of the momentary voltage u_p at the piezo element and the piezo curent i_p over one mechanical vibration period: $\Delta E = \int_t^{t+\Delta t} u_p(t) i_p(t) dt$. The calculations in Laplace domain ($s=j\omega$) are divided into two parts where the switch is open: voltage at the piezo $U_{p,open}$ Eq(1) and closed: voltage at the piezo $U_{p,close}$, and the piezo current $I_{p,close}$ Eq(2).

(1) $$U_{p,open} = E(s) - \frac{U_{p,0^-}}{s};$$

(2) $$I_{p,close} = \left(E(s) - \frac{U_{p,0^-}}{s}\right) \frac{1}{\frac{1}{sC_{ps}} + Z(s)}; \quad U_{p,close} = \left(E(s) - \frac{U_{p,0^-}}{s}\right) - I_{p,close} \frac{1}{sC_{ps}}$$

where: $E(s) = -X_m(s) \frac{c_{33} d_{33}}{C_{ps}}$ is the internal voltage source of the piezo, $Z(s) = R + sL$ is the switched impednce shunt, the parameters of the piezo are: C_{ps} - piezo capacitance, c_{33} - mechanical stiffness of the piezo d_{33} - piezo sensitivity, X_m - external deformation. The variation of the open and close time of the switch influences the amount of the energy being transferred to the shunt.

3. Measurements and the conclusions

The measurements are performed on the single supported beam with a piezo path attached to the structure. The energy dissipated in the system is plotted over a normalized close and open switch time cp. Fig.2.

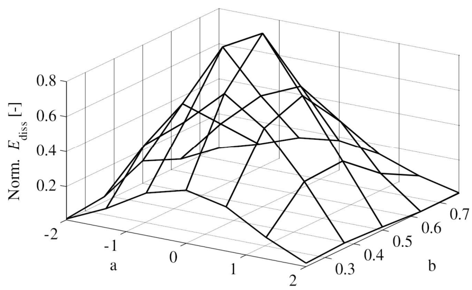

Figure 2. Measured dissipated energy.

It is proven that contrary to the heuristic control law proposed in [3], the switching times should be adjusted to the time constant of the external branch in order to achieve the maximum possible energy extraction.

5. References

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