An energy harvester combining a piezoelectric cantilever and a single degree of freedom elastic system

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Model of combined energy harvester

A type of vibration energy harvester combining a piezoelectric cantilever and a single degree of freedom (SDOF) elastic system (M+ K_1+ C_1) is presented and the mathematical model of the combined energy harvester is developed to analyze its electrical output performance. An finite element model of the combined energy harvester is developed in ANSYS software to validate the accuracy of the numerical results obtained from the mathematical model.

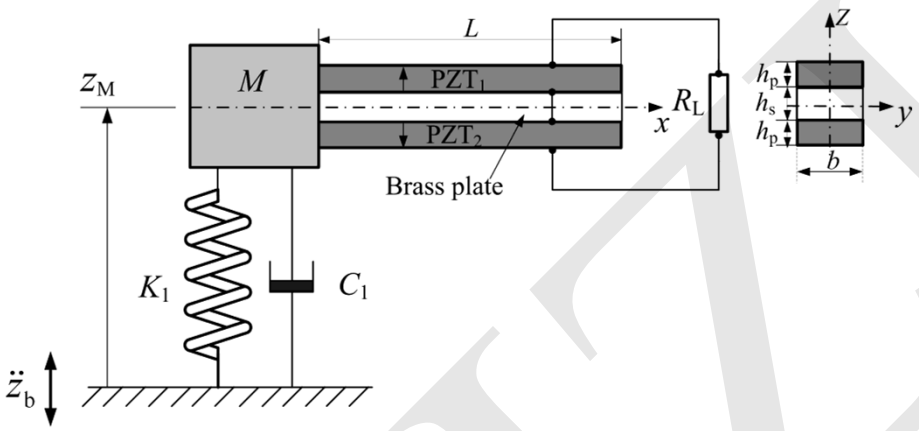

Fig. 1 Model of energy harvester combining a piezoelectric cantilever and an SDOF elastic system

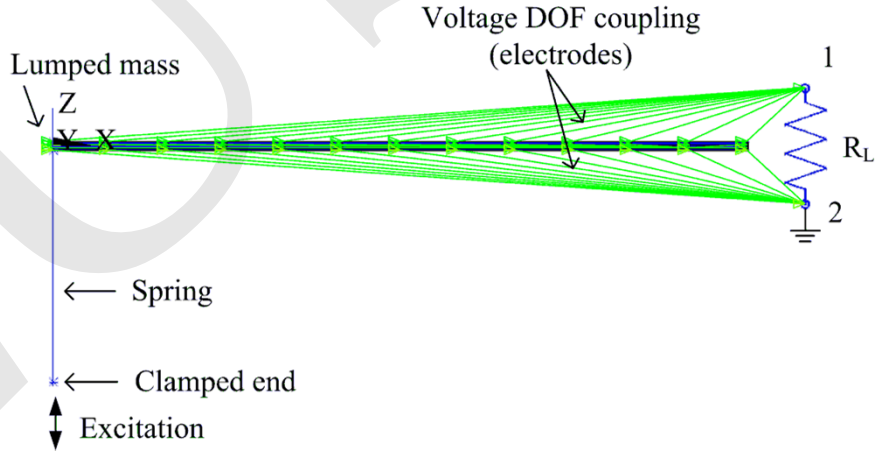

Fig. 2 Finite element model of the energy harvester combining a piezoelectric cantilever and an SDOF elastic system

Effect of mass ratios on electrical outputs

The smaller mass ratio u leads to a higher output power and a closer peak distance. As the mass ratio $u \to \infty$ ($u=1\times10^{10}$) and the natural frequency ratio $g \to 0$ ($g=1\times10^{-10}$), the relative motion curve of the combined piezoelectric energy harvester is nearly identical to that of the single piezoelectric cantilever. The FEA results are in good agreement with the numerical results. The validity of the mathematical model is validated by the FEA method.

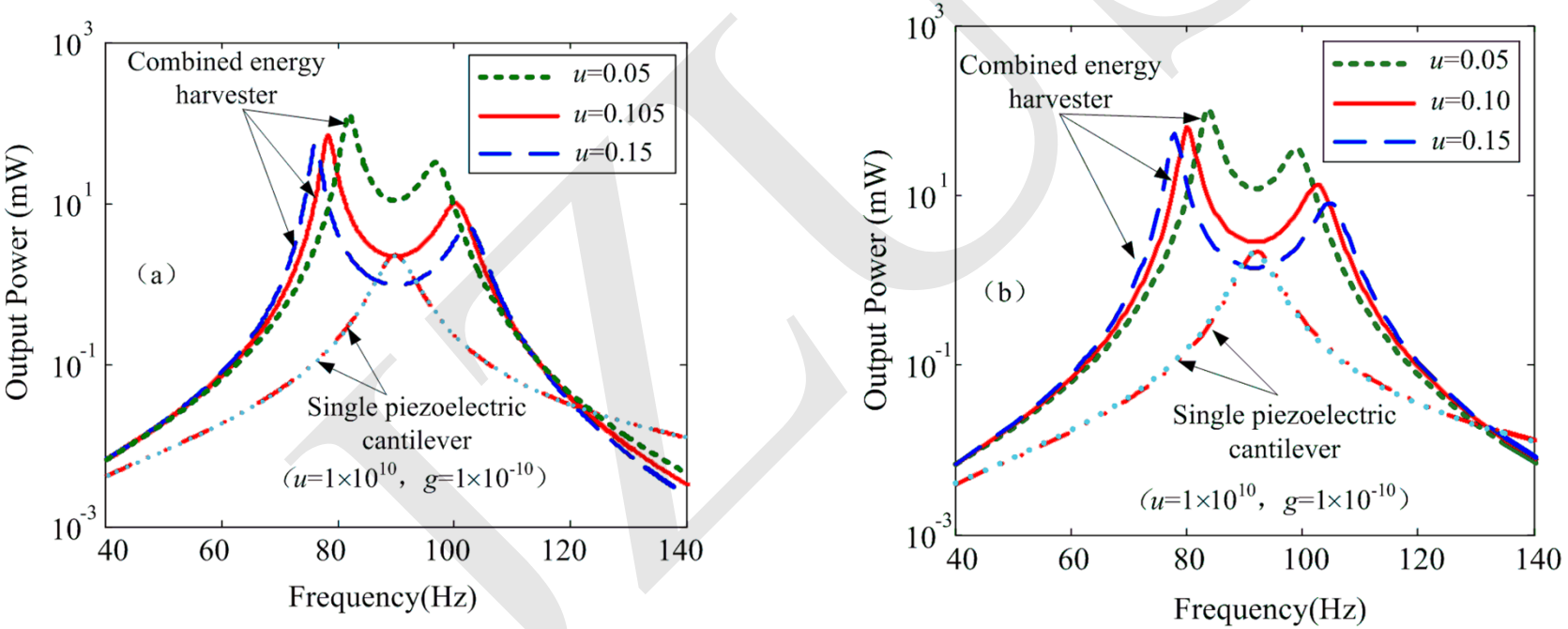

Fig. 3 Output power for single and combined energy harvester with different mass ratios *u*. (a) from numerical calculation; (b) from system-level FEA

Effect of damping ratios on electrical outputs

An increase in the damping ratio (ξ_1) of the SDOF elastic system leads to a decrease in the peak power of the combined energy harvester. The maximal power output of the combined energy harvester is lower than that of the single piezoelectric cantilever for a larger damping ratio (e.g. $\xi_1=10\xi_2$). The FEA results are in good agreement with the numerical results.

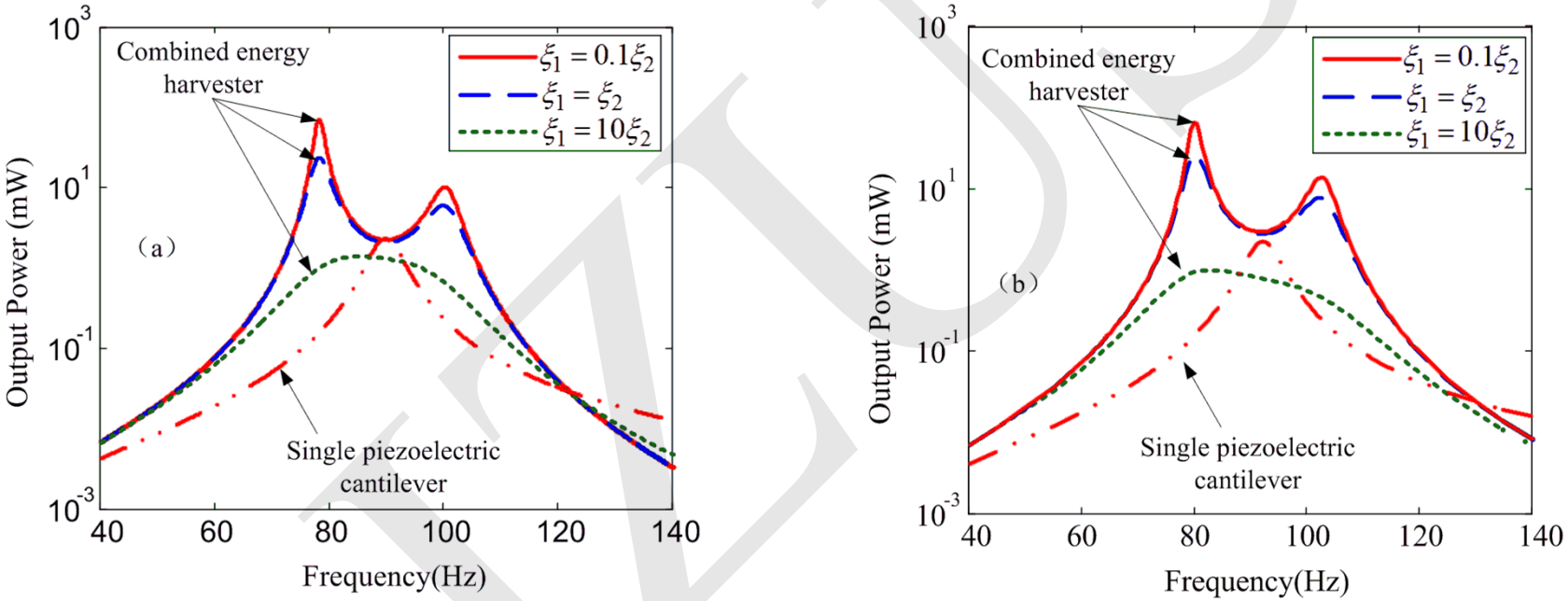

Fig. 4 Output power for single and combined energy harvester with different damping ratios. (a) from numerical calculation; (b) from system-level FEA

Effect of load resistors on electrical outputs

Two matching resistors (9.8 kΩ and 73.3 kΩ) of the single piezoelectric cantilever at resonance frequency (f_r) and anti-resonance frequency (f_{ar}) are used to calculate the electrical outputs of the combined energy harvester. A larger peak voltage is generated at the load resistor of 73.3 kΩ (Fig. 5a). A larger peak current is generated at the load resistor of 9.8 kΩ (Fig. 5b). The two load resistors have almost the same amount of maximum power output (Fig. 5c) although they have different voltage and current outputs.

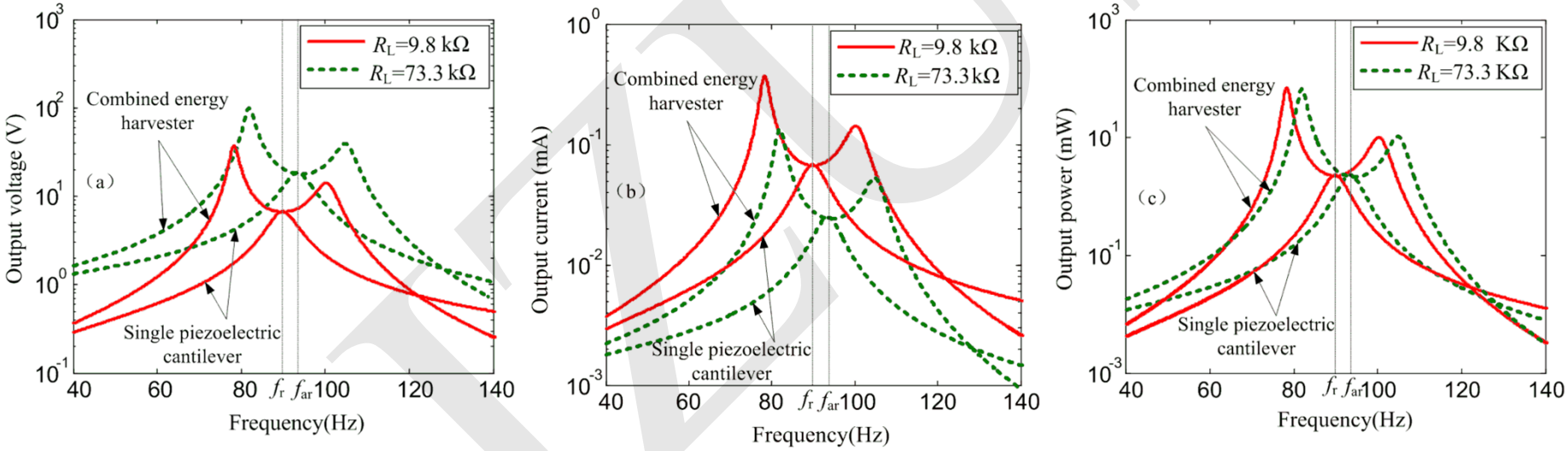

Fig. 5 Electrical outputs vs. vibration frequency for two different load resistances. (a) output voltage; (b) output current; (c) output power

Conclusions

- The additional SDOF elastic system can increase the power output of the piezoelectric cantilever and improve the frequency bandwidth when the mass ratio of the piezoelectric cantilever to the lumped mass of SDOF elastic system is below 0.105.

- A larger damping ratio seriously weakens the function of the SDOF elastic system as a displacement magnifier and decreases the power output. Hence, a proper damping ratio for the additional SDOF elastic system should be determined to improve the power output of the piezoelectric cantilever.

- Two matching load resistances under short circuit and open circuit resonance conditions can obtain the same amount of maximal power. However, a matching load resistance under short circuit resonance condition can obtain higher output current and hence is more suitable for applications requiring a high current, such as a piezoelectric energy harvester.