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Enlarging Bandwidth of Piezoelectric Vibration Energy Harvesters Using Magnetic Coupling

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1. Introduction

About 85% of tire-induced breakdowns start with slow tire leaks. Drivers usually notice the gradual air loss too late, and serious consequences arise. Tire Pressure Monitoring Systems (TPMS) can indicate the slow leaks and warns the driver in time before the tire risks irreversible damage. However, pressure sensors in TPMS require power and are battery-powered, causing inconvenience and prohibitive cost of replacing battery. Recently, several techniques have been developed for harvesting mechanical vibration energy from a rotating tire to power wireless TPMS for advantage of being maintenance-free [1-6].

In this paper, piezoelectric energy-harvesting devices (EHDs) for gathering the vibration energy of cars running on rough ground are developed to substitute the battery in TPMS. To enhance the practical value, the bandwidth of EHDs are enlarged by introducing the magnetic coupling into the piezoelectric cantilever beam system. The EHD consists of one magnet attached at the end of a cantilever beam as mass. First, a finite element software, COMSOL multiphysics, is utilized to calculate the resonance frequencies and output power of the EHDs. Based on the simulation results, piezoelectric EHDs for TPMS are designed and fabricated. Finally, the prototype is tested for evaluating the bandwidth. The experimental result shows that single piezoelectric cantilever beam successfully increases the bandwidth by 33%, and the system of two piezoelectric cantilever beams in series with magnetic coupling shows a flatter passband. The results of this paper can provide important guidelines for designing piezoelectric vibration energy harvesters integrated with a wireless sensor system as well as the TPMS.

2. Results

2.1 CPC-FEM modeling and simulations

A commercial finite element software, COMSOL multiphysics, was used to develop a 3D numerical model of piezoelectric EHDs connected directly with a load resistor. As shown in fig. 1, the considered EHD is a piezoelectric sandwich structure with a central brass substrate layer and one piezoelectric material layers. The piezoelectric material was chosen to be the default PZT-5A in COMSOL. The dimensions are listed in Table 1. The vibration amplitude and quality (*Q*) of the piezoelectric plate were set to be 25 μm and 65, respectively. Results show that when the external resistance is 175 kΩ, the output power of the designed EHD is about 100.1 μW at 47 Hz, fulfill the power requirement of TPMS.

2.2 Experimental results and discussions

Based on the simulation results, two piezoelectric EHDs for TPMS was designed to match the external vibration frequency, around 45 to 55 Hz, and fulfill the power requirement of TPMS, 100 μW. The cantilever beams, which consist of commercially available pizeoceramic PZT-KA2 plates, were fabricated. Especially, broadband EHDs were developed by introducing the magnetic coupling into the piezoelectric cantilever beam system. The EHD consists of one magnet attached at the end of a cantilever beam as mass. As shown in fig. 2, the prototype was clamp-mounted on a mechanical shaker, which is used to generate mechanical vibrations. The vibration amplitude was set to be 25 μm by adopting an accelerometer. Figure 3 shows one of the fabricated EHDs and the clamp-mounted configuration on a mechanical shaker.

Figure 4 is the frequency response of the cantilever beam subjected to the repulsive magnetic force at different separation distances. The peak voltage of the piezoelectric beam, as the pitch of the magnet decreases, is gradually increased, and its bandwidth is also increased from 6 Hz to 8 Hz and by 33%. Magnetic coupling indeed enlarges the bandwidth of EHDs. Figure 5 is frequency response of two piezoelectric cantilever beams connected in series and in parallel with/without the coupled repulsive magnetic force. When the magnetic force is not coupled, whether in series or parallel output, the voltage output is small at the midpoint between the resonance frequencies of the two piezoelectric beams. Under the mutual repulsive magnetic coupling, the output voltage of the two piezoelectric beams increases at the passband.

3. Conclusions

This paper aims at developing a piezoelectric EHD for gathering the vibration energy of cars running on rough ground to substitute the battery in

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TPMS for advantage of being maintenance-free. To enhance the practical value, broadband EHDs were developed by introducing the magnetic coupling into the piezoelectric cantilever beam system. The EHD consists of one magnet attached at the end of a cantilever beam as mass. The experimental result shows that single piezoelectric cantilever beam successfully increases the bandwidth by 33%, and the system of two piezoelectric cantilever beams in series with magnetic coupling shows a flatter passband. The results of this paper can provide important guidelines for designing piezoelectric vibration energy harvesters integrated with a wireless sensor system as well as the TPMS.

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References
1. S. Meninger, J.O. Mur-Miranda, R. Amirtharajah, A.P. Chandrakasan, and J.H. Lang: IEEE T. VlSI Syst. 9 (2001) 64.
2. C. Shearwood and R.B. Yates: Electron. Lett. 33 (1997) 1883.
3. C.T. Pan and T.T. Wu: J. Micromech. Microeng. 17 (2007) 120.
4. R. Amirtharajah and A.P. Chandrakasan: IEEE J. Solid-State Circ. 33 (1998) 687.
5. S.-J. Jeong, M.-S. Kim, J.-S. Song, and H.-K. Lee: Sens. Actuat. A 148 (2008) 158.
6. N.M. White, P. Glynne-Jones, and S.P. Beeby: Smart Mater. Struct. 10 (2001) 850.

Table 1 The dimensions of EHD

Components \ Dimensions	Length (mm)	Width (mm)	Thickness (mm)
Stainless steel	55.4	15.2	0.2
PZT-KA2	25.4	15.2	0.35
Mass	20	15.2	1.2

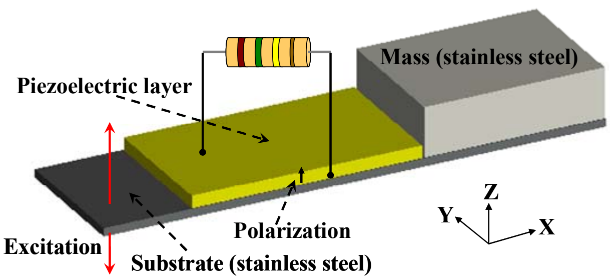


Fig. 1 Modeled geometry of piezoelectric cantilever with a seismic mass.

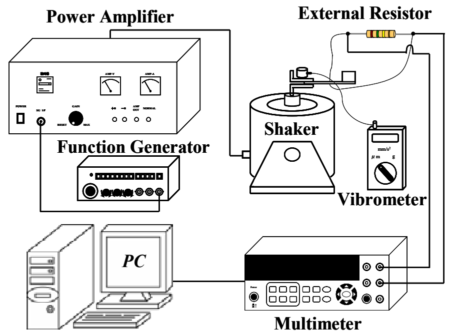
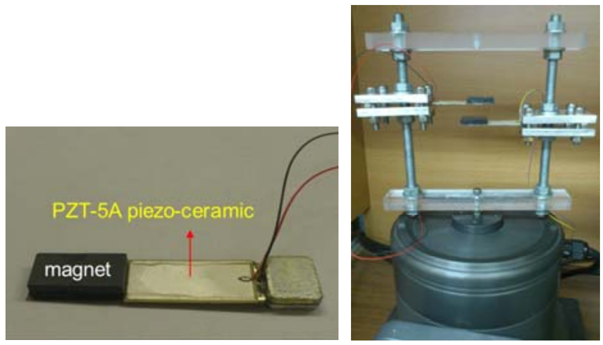


Fig. 2 Experimental setup of power generation testing.



(a) (b)

Fig. 3 (a) The fabricated piezoelectric energy-harvesting device and (b) the clamp-mounted configuration

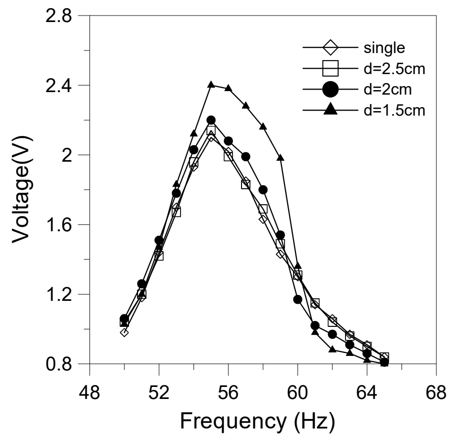


Fig. 4 Voltage output of the EHD while EHDs repel each other.

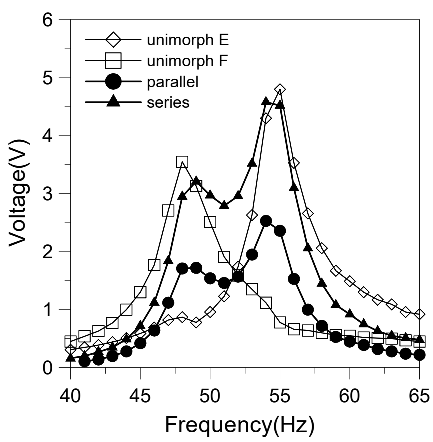


Fig. 5 Voltage output of two EHDs while EHDs repel each other.