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A Piezoelectric Vibration Energy Harvester for Tire Pressure Monitoring Systems

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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 harvesters for gathering the vibration energy of cars running on rough ground are developed to substitute the battery in TPMS. First, a finite element software, COMSOL, was utilized to calculate the resonance frequencies and output power of the piezoelectric energy-harvesting devices (EHDs). Based on the simulation results, a piezoelectric EHD for TPMS was designed and fabricated. Finally, the EHD's damping ratio was measured for comparison of experiment with simulation. The prototype was also tested for evaluating whether the output power is enough to power the TPMS.

2. Results

2.1 CPC-FEM modeling and simulations

A variety of modeling approaches [7-14] have been used to analyze the outputs of piezoelectric EHD, like uncoupled analyses, equivalent electric circuit methods, advanced modeling methods, and. coupled piezoelectric-circuit finite element model (CPC-FEM). In this paper, a commercial FEM software, COMSOL, was used to develop the CPC numerical model of a piezoelectric EHD 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 vibration amplitude and quality (Q) of the piezoelectric plate were set to be 25μm and 65, respectively. Special focus is taken on the effect of the load resistor on output power as well as the influences of the EHD's dimensions on resonance frequency and output power. The results in fig. 2 show that when the external resistance is 175kΩ, the output power of the designed EHD is about 100.1μW.

2.2 Experimental results and discussions

Based on the simulation results, a piezoelectric EHD for TPMS was designed to match the external vibration frequency, around 45 to 50 Hz, and fulfill the power requirement of TPMS, 100μW. The prototype, which consists of a commercially available pizeoceramic PZT-KA2 plate, was fabricated and measured. The dimensions are listed in Table 1. First, the damping ratio of the EHD was measured for comparison of experimental results with simulation ones. The EHD was fixed to a magnetic base, and its free end was beat by a steel ball, causing an oscillation. The damping ratio could be calculated from the oscillation signal and is 0.0194.

As shown in fig. 3, the prototype was clamp-mounted on a mechanical shaker, which is used to generate mechanical vibrations. The vibration amplitude was set to be 25μm by adopting an accelerometer. Figure 4 shows slight inconsistencies of resonance frequency and output power between experiment and simulation caused by the neglect of adhesive layer and different piezoelectric materials used in the simulation and experiment. After considering the adhesive layer and adjusting relative dielectric constant of the piezoelectric plate to be 2250, the resonance frequency and optimized resistance are 47.6 Hz and 175 kΩ, respectively. They are in a good agreement with the experimental results. Moreover, as shown in fig. 5, when the external resistance is 175kΩ, the output power of the designed piezoelectric harvesting device is about 100.4μW, which is sufficient to power the TPMS.

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 TPMS for advantage of being maintenance-free. The EHD was designed and optimized by adopting a finite element software, COMSOL. The prototype, which consists of a PZT-KA2

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plate, was fabricated and measured. The experimental results show that the designed EHD yields a output voltage of 4.2V and output power of 100.4μW. Such output power is enough to power the wireless tire pressure monitoring system. 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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Table 1 The dimensions of EHD

Dimensions / Components	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

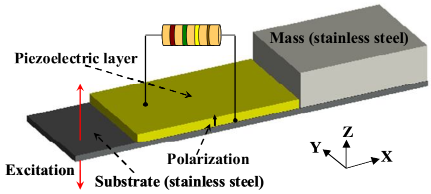


Fig. 1 Modeled geometry of piezoelectric cantilever with a seismic mass.

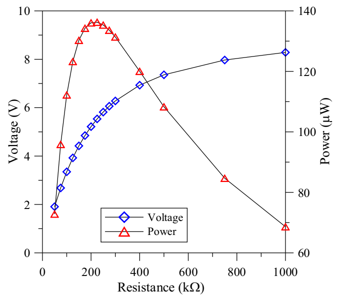


Fig. 2 Calculated electric characteristics of the designed energy-harvesting device

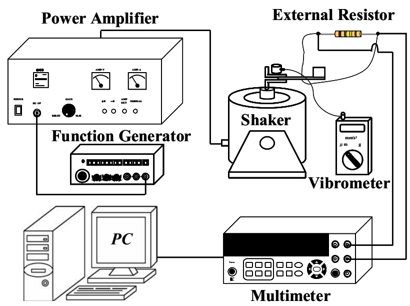
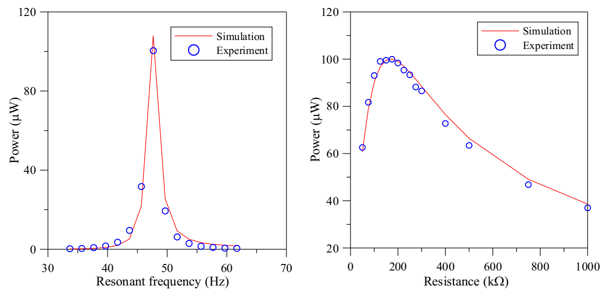


Fig. 3 Experimental setup of power generation testing.



(a) (b)

Fig. 4 (a) Frequency response after considering the adhesive layer and (b) output power after considering the adhesive layer and adjusting relative dielectric constant of the piezoelectric plate.

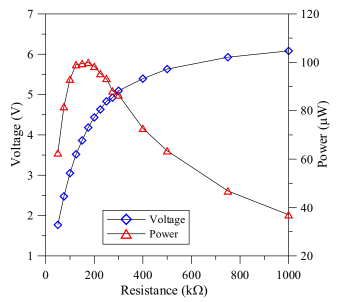


Fig. 5 Measured electric characteristics of the fabricated energy-harvesting device.