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A piezoelectric impact-induced vibration cantilever energy harvester from speed bump with a low-power power management circuit

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ABSTRACT

An energy harvesting system for road speed bumps was proposed, which consists of a piezoelectric impact-induced vibration cantilever energy harvester and a low-power power management circuit. The piezoelectric impact-induced vibration cantilever was used to harvest the energy from speed bump as it is suitable for converting the low-frequency mechanical impact to high-frequency vibrations. Furthermore, considering the characteristics of piezoelectric energy harvester for speed bumps, a high-efficiency and low-power power management circuit was designed to collect the electric energy from the harvester. A buck-boost DC–DC switching converter is used to match the impedance of PZT and so as to obtain the maximum energy from the harvester, and a wake-up circuit is designed to reduce the power dissipation of the power management circuit itself. A prototype of the piezoelectric impact-induced vibration cantilever energy harvesting system was constructed and the experiment results showed that, the controller in the power management circuit consumed only 3% of the ideal energy generated by one tire in the awake mode and less than 1% of it in the sleep mode. The efficiency of the circuit was around 74% at various vehicle speeds. In addition, the total ideal energy generated by one piezoelectric cantilever from one car passing the speed bump was 1.26 mJ. This energy was exhausted by the power management circuit without sleep mode within 25 s, whereas with sleep mode, the energy of 0.82 μJ was delivered to the battery. Therefore, the sleep mode function in the circuit is essential to reduce the energy loss and improve the efficiency of the speed bump energy harvester.

1. Introduction

With the rapid development of the internet of things (IoT), wireless sensor nodes (WSNs) have been widely applied in various fields, such as road traffic monitoring, noise nuisance monitoring, and environmental parameters monitoring [1–3]. Currently, batteries are used for the power supplies in WSNs, but these batteries cannot be replaced frequently in most cases because of environmental limitations. Therefore, the need to provide the alternative power sources for WSNs has been a major concern in both the academic and industrial fields. A lot of research has been conducted to harvest energy from the ambient sources such as solar, wind, vibration, heat and radio frequency radiation [4–8]. These energy harvesters can charge or replace batteries and serve as clean and renewable energy sources for WSNs.

Speed bumps on the road are commonly used to control the vehicle speed and generally slow down the vehicle speed to 5–20 km/h to improve traffic safety. Transforming the kinetic energy generated by a vehicle passing over speed bumps to electric energy may become a promising approach for the alternative power sources for WSNs. Several kinds of speed bump energy harvesters have been reported in the past few years [9–13]. The rack pinion and crankshaft was used to convert translational movement into generator rotation in [9], but the obtained energy by this harvester is limited. Another category of speed bump energy harvester utilizing the electromagnetic mechanism or piezoelectric material was reported in [10–13]. The piezoelectric material converting mechanical strain into electricity has been a focus of recent research due to its relatively simple structure, high power density and lower cost. A piezoelectric energy harvester for road was presented in [14], however the obtained power was as little as micro-watt.

Since the vehicle passing over the speed bump is an extremely low-frequency excitation source for an energy harvester [15,16], a piezoelectric energy harvester for speed bump (PHSB) using impact-induced vibration is proposed in this paper. The impact-

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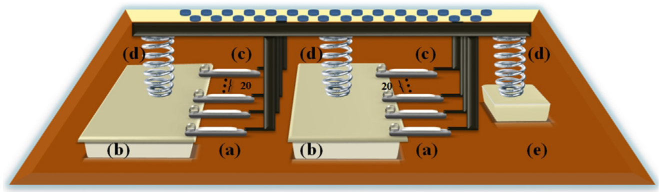

Fig. 1. Cantilever beam-based piezoelectric harvester for speed bump.

induced vibration cantilever energy harvester is a promising method because it can converts a low-frequency input into a high-frequency resonant output and therefore can efficiently harvest the energy from low-frequency excitation. Especially, the impact-induced vibration energy harvester always vibrates under the natural frequency of the piezoelectric materials [17].

The impact-induced vibration harvester converts the mechanical vibration energy into AC electrical power. Since WSN devices and rechargeable battery usually require a DC power supply, a power management circuit is necessary to rectify the AC power to steady DC power. Several kinds of circuit structures for piezoelectric energy harvesters have been investigated to improve the efficiency of the harvester, which can mainly be divided into two types. The first type focuses on dominating the capacitive characteristics of the output impedance of piezoelectric harvester [18,19]. However, the nonlinear control function is very difficult to achieve due to the noise problem and accurate timing requirement. The second type focuses on realizing resistive matching [20–22]. These approaches are reasonable because the impedance of a piezoelectric cantilever vibrating around the resonant frequency is mostly resistive. Generally speaking, the second type is more robust and easy to control. These existing studies on energy harvesting system focus on high-frequency vibration, especially for continuous sinusoidal vibrations. However, the harvesting circuit for impact-induced vibration harvester has rarely been researched and discussed.

In this paper, the low-power power management circuit is proposed for improving the energy harvesting efficiency of PHSB. A buck-boost DC–DC switching converter is used to match the impedance of PZT and so as to obtain the maximum energy from the harvester. In addition, considering that the vehicle passing through the speed bump is random and intermittent, a wake-up circuit is designed to reduce the power dissipation of the power management circuit itself, when no vehicle is passing and the input energy is below a certain value, the wake-up circuit will shut down the power management circuit and thus which works in the sleep mode with ultra-low power dissipation.

The paper is organized as follows: Section 2 presents the structure of PHSB, and explains how to transform the kinetic energy to electricity. Section 3 shows an impact-induced vibration experimental system to simulate the vehicle passing the speed bump, and analyzes the output characteristic of PHSB under impact-induced vibration. Section 4 proposes the prototype circuit for the PHSB with two operation modes. Section 5 presents the experiment results. Section 6 discusses the usage of the energy obtained from proposed energy harvesting system. The conclusions are given in Section 7.

2. Energy harvester for speed bump

The mechanical structure of the energy harvester for speed bump is based on an impact-induced vibration cantilever, as shown in Fig. 1. The harvester, installed inside of a speed bump, consists of 48 piezoelectric unimorph cantilevers marked as (a) in Fig. 1,

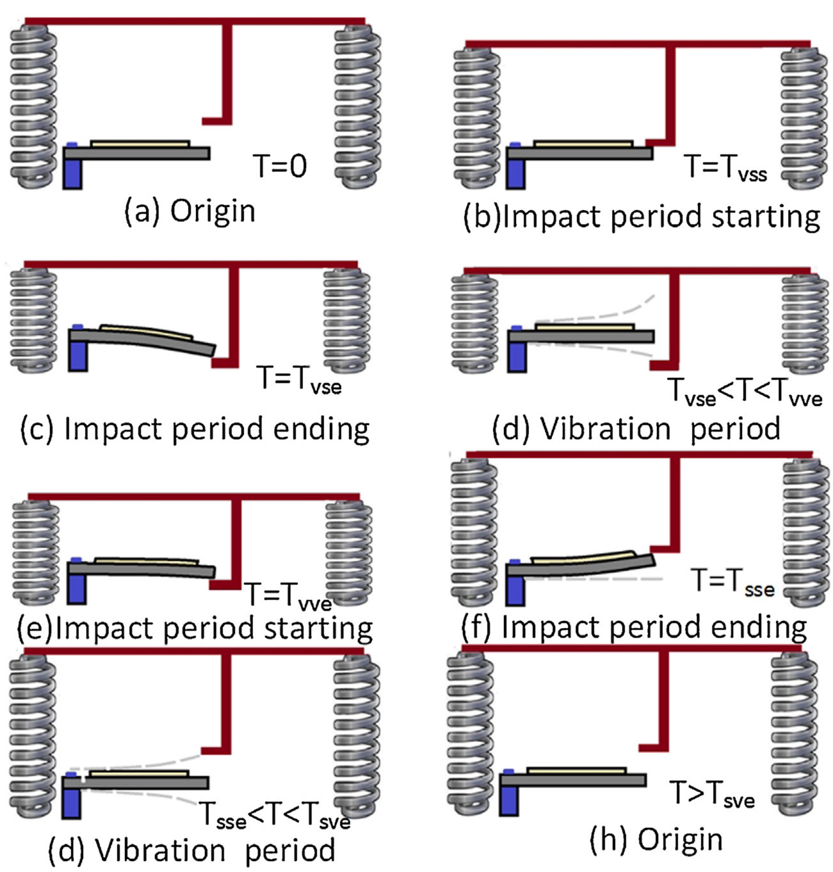

Fig. 2. Operation process of one piezoelectric unimorph cantilever in PHSB.