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International Journal of Pavement Research and Technology xxx (2017) xxx–xxx

www.elsevier.com/locate/IJPRT

A preliminary study on the highway piezoelectric power supply system

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Received 9 September 2016; received in revised form 23 August 2017; accepted 25 August 2017

Abstract

Pavement piezoelectric energy harvesting technique is to use a Piezoelectric Energy Harvester (PEH) to convert the mechanical energy of vehicles into electrical energy. A lot of research has been done on the technology of piezoelectric energy collection, but it is mainly focused on the theoretical model and the laboratory tests and lacks the on-site performance evaluation. In this paper, a stacked array type PEH is designed with protection package, which can improve the performance and the service life of the PEH. The demonstration project is also carried out to test the field performance. It is found that under the actual vehicle loading, the obtained piezoelectric energy can successfully light LED signs.

Keywords: PEH energy harvester; Energy collection; Sustainable development; Engineering application; Actual axle load

1. Introduction

The transportation systems require a considerable amount of energy to maintain their regular operations. With the rapid development of society, the increasing energy consumption leads to the shortage of non-renewable energy resources. To solve this problem, many countries pay attention to the collection and use of renewable energy. Pavement will bear millions of times of the axle loadings from traveling vehicles in its service life, resulting in deformation and vibration. Great mechanical energy is wasted during this process. It will be a breakthrough for energy conservation and emission reduction if the mechanical vibration energy is transformed into electric energy.

The piezoelectric energy harvesting technology has been studied for many years. Priya (2005) invented a pocket piezoelectric windmill which was attached to a rotating cam [1]. When the cam rotates, the motivated piezoelectric material will convert the mechanical energy into electric energy. Alexander et al. (2010) developed a system to collect vibration energy generated by pedestrians walking on the roads [2]. Yoshiyasu (2008) developed an energy collection device which was embedded in the pavement [3]. It had been tested at subway entrance, shopping malls, etc. An Israel company INNOWATTECH (2010) announced that they had developed a pavement energy harvesting systems: Innowattech Piezo Electric Generator (IPEG), which is based on a piezoelectric transducer. According to reports, when traffic volume of vehicles is more than 500 in the

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Peer review under responsibility of Chinese Society of Pavement Engineering.

http://dx.doi.org/10.1016/j.ijprt.2017.08.006
1996-6814/

Please cite this article in press as: H. Yang et al., A preliminary study on the highway piezoelectric power supply system, Int. J. Pavement Res. Technol. (2017), http://dx.doi.org/10.1016/j.ijprt.2017.08.006

single lane per hour, up to 250 kW of electrical energy can be collected per kilometer per lane [4].

Guan et al. (2010) studied the cement-based piezoelectric materials for road power generation, where the cement-based piezoelectric composites are manufactured by pre-embedding piezoelectric ceramics [5]. Zhao et al. (2011) designed the piezoelectric materials using the finite element analysis [6]. Xiong et al. (2012) show that the pavement deformation by vehicle processing and the vibration caused by moving vehicles on the road can be used for the collection of electric energy, and the best power acquisition system is discussed in the study [7]. Xiang et al. (2013) considered the piezoelectric road model as the Bernoulli–Euler beam model with pavement damping [8]. Yuan et al. (2014) studied the use of piezoelectric transducers in the collection of track vibration energy for railway safety driving and found that the piezoelectric energy harvester could generate 30 mW power [9]. Zhang et al. (2014) studied the performance of a concrete-piezoelectric cantilever beam transducer in a single vehicle using ANSYS simulation [10].

In all, most of the research on the piezoelectric harvesting technology in pavement engineering is still in the exploratory stage. Although the previous studies have conducted preliminary theoretical analysis and laboratory tests, lack of engineering practice still limits the promotion of this new innovative green technology. In this paper, the stacked array piezoelectric energy harvester (PEH) is applied to the actual road and its performance is tested.

2. Design of PEH for asphalt pavement

Since the PEH will be loaded millions or even billions of times during the service period, the PEH must have good compressive ability, fatigue resistance, waterproof and anti-corrosion performance. There have been many researches done in pavement materials' area but few about PEHs [11,12]. In this study, the PEHs were prefabricated and embedded in the pavement of a test site. Considering the contact area of tires, the PEH was designed to be 30 cm wide and 30 cm long. PEHs in such dimension will have better contact with the wheels of traveling vehicles. The thickness of the PEH is 8 cm, which is slightly thinner than the surface layer of the pavement from test site (9–10 cm). The PEH consists of 12 piezoelectric units, an internal rectification circuit, and two power output cables. Other than a rectangular PEH, a circular PEH was also fabricated with a diameter of 30 cm and a height of 8 cm, containing 12 piezoelectric units.

The PEH consists of four parts: the piezoelectric units, the packaging materials, the internal circuit boards and other sealing fastening components. The inner structure of the PEH is shown in Fig. 1.

The core component of the PEHs is piezoelectric material. This study adopted piezoelectric ceramics PZT-5H (produced by Baoding Hengsheng Acoustics Electric Apparatus Co., Ltd). For each unit, three PZT-5H slices are stacked together and connected in parallel (c.f. Fig. 2). The dimension of the piezoelectric unit size is $\Phi 20 \times 23.2$ mm.

Nylon (model: PA66 with 30% glass fiber) is selected to be the protective packaging material of the piezoelectric energy harvester. It has high strength, high load resistance, high toughness and high resistance to repeated shocks. The protection structure contains three layers: the upper, the middle and the lower layer. The upper layer directly undertook the vehicle load and the lower supported with the ground reaction force. The middle layer reserved the holes for 12 piezoelectric units and desiccant positioning, and grooves for wires and the internal circuit board (as shown in Fig. 3).

After connecting each of the piezoelectric units to the circuit board, the power output will be rectified and extracted by the cable. The rectifier bridge is sealed with electronic glue to prevent the short circuit caused by water leakage. The sealing methods were as follows: applying silicone gasket between the upper and the lower encapsulation structure; putting the stainless steel gasket with a diameter of 40 between piezoelectric materials and wrapping it using protection package, to prevent stress concentration. Therefore, the piezoelectric energy harvester has good compression performance, fatigue resistance and waterproof performance.

The LED demonstration board (Fig. 4) consists of four Chinese characters, meaning "piezoelectric demonstration," which adopted the high power LED yellow lamp bead with condenser cover. The working voltage of LED lamp bead is 3 V, and the working current is 10 mA. Each character on the board is organized with different numbers of lights' series, respectively, 41 lights' series, 50 lights' series, 40 lights' series, 50 lights' series. There are a total of 181 lamp beads, and the working voltage of each character was 123 V, 150 V, 120 V, and 150 V respectively. Every character had two power supply lines, one for the positive and the other for the negative. There are eight wire lines in total, and all of the cables are connected to the output of the PEH through the connection chamber.

3. Demonstration project

The demonstration project of our piezoelectric power supply system is located at K90 + 700 of Ma-Zhao Highway near Zhaotong City, Yunnan Province, where the total length of trial pavement section is about 50 m. 20 fabricated PEHs are installed in real pavement, including 10 rectangular and 10 circular ones. Ma-Zhao Highway is a two-direction six-lane highway. PEHs are installed in the main lane near the emergency lane and along the wheel path of the vehicles. The layout of the installation is illustrated in Fig. 5. To reduce the damage from road construction, the spacing is 2.5 m between two PEHs along the road and the horizontal spacing is 1.875 m, which is consistent with the axle structure of trailer trucks. A cable room is built in the middle position of the demonstration road.

Please cite this article in press as: H. Yang et al., A preliminary study on the highway piezoelectric power supply system, Int. J. Pavement Res. Technol. (2017), http://dx.doi.org/10.1016/j.ijprt.2017.08.006