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EVALUATION OF ROAD TRAFFIC ENERGY HARVESTING USING PIEZOELECTRICITY

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ABSTRACT

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In modern day society, cleaner, more sustainable forms of electrical power are needed to keep costs lower and to ensure a healthier environment for future generations. The use of piezoelectric devices installed within a road would enable the capturing of kinetic energy from automobile traffic. This energy can then be converted into electrical energy and can be used to offset some of the power coming from the main grid. Such a source of power can also be used to operate road lighting and signage systems, or it could be injected to the grid at an appropriate Point of Common Coupling (PCC). This paper discusses investigation of energy harvesting from piezoelectric materials when installed in a road. The work includes conversion of kinetic energy to electrical using piezoelectric materials, the energy harvesting method, and experimental research on piezoelectric materials.

Contribution/Originality: This paper's primary contribution is assessing the energy harvesting from piezoelectric materials when installed in a road. The study documents piezoelectric harvesting from road traffic is one of few published directly relating to road traffic application.

1. INTRODUCTION

The piezoelectric effect is the conversion of mechanical pressure into electric current and voltage. The word "piezoelectric" literally means electricity caused by pressure. Piezoelectric materials can be used as mechanisms to transfer mechanical energy, usually ambient vibration, into electrical energy that can be stored and used to power other devices. A piezoelectric substance is one that produces an electric charge when a mechanical stress is applied. Conversely, a mechanical deformation is produced when an electric field is applied.

Electricity has become a lifeline of present day civilization and thus its demand is enormous and is growing steadily. Similarly, traffic on roads in the UK is increasing day by day and thus, congestion on roads is becoming inevitable with the growing trend for personal transportation systems [1]. Car ownership and road usage is growing alongside the population – All motor vehicle traffic in the UK has increased 6% since 2014. Car traffic also had the largest annual increase since the early 2000s. Provisional 2015 estimates suggest that this trend is continuing.

In support of this evidence, there has been over 311 billion vehicle miles travelled in the UK in 2014 alone, covered within 245,800 miles of road. This data shows that the scope for energy harvesting roads has enormous potential, and the need for green, renewable energy is becoming ever more important. Therefore, attention turns to converting the wasted energy used in automobile travel into green energy. Energy demand and heavy traffic correlation inspire to envision a device in the road that would harvest the energy from the vehicles driving over it.

Piezoelectricity is not a new concept, it was theorized as early as 1880 where the Curie brothers [2] subjected quartz crystals to mechanical pressure and a very small amount of electricity was produced. However, in this paper attempts are being made to assess the functionality of piezoelectricity in roads to utilise energy executed from the moving vehicles, i.e. using piezoelectric material to convert the mechanical energy of vehicles when travelling over a road surface into electrical. This is discussed in detail in section 2. Section 3 describes the prototype energy harvesting rigs and section 4 presents and discusses the results obtained from the test rig with all its associated electronic circuitries.

2. PIEZOELECTRIC INVESTIGATIONS

A piezoelectric generation system is usually composed of a mechanical part; whose role is to collect ambient mechanical vibration and subject the active material to stress and strain variations. Through its electromechanical coupling property, the active material (for instance a piezo disc ceramic) converts the mechanical energy resulting from stress and strain variations into electrical energy. A piezoelectric harvesting system can be represented in its simplest form in Figure 1.

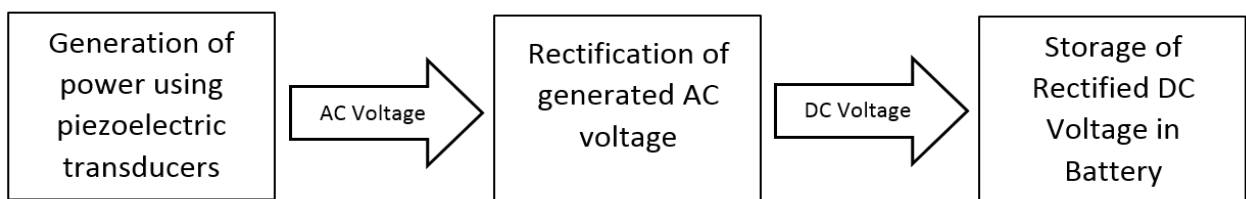


Figure-1. Top level block diagram of proposed system

Source: G. Priestner

Piezoelectric discs are one such material that is relatively cheap and readily available as shown in Figure 2, and its structure in Figure 3.

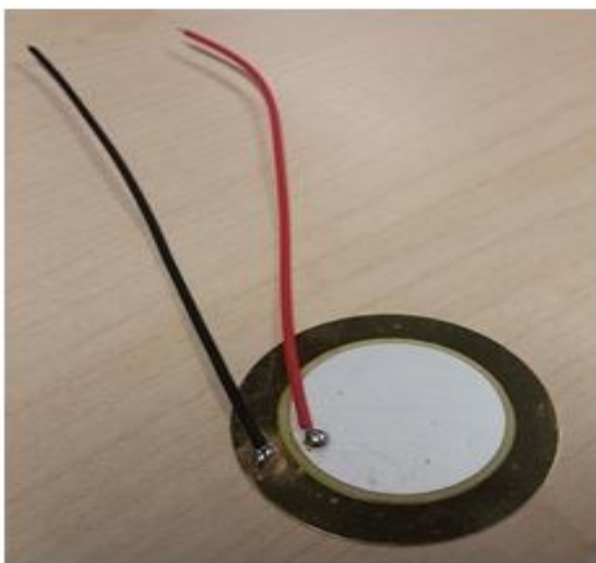


Figure-2. 35mm piezo disc

Source: G. Priestner

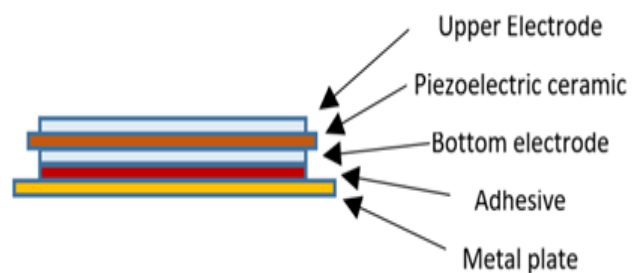


Figure-3. Structure of piezo disc

Source: G. Priestner

When the piezo disc's output is connected to an oscilloscope, with firm tapping from a small hammer the generated outputs are shown in Figures 4 and 5.

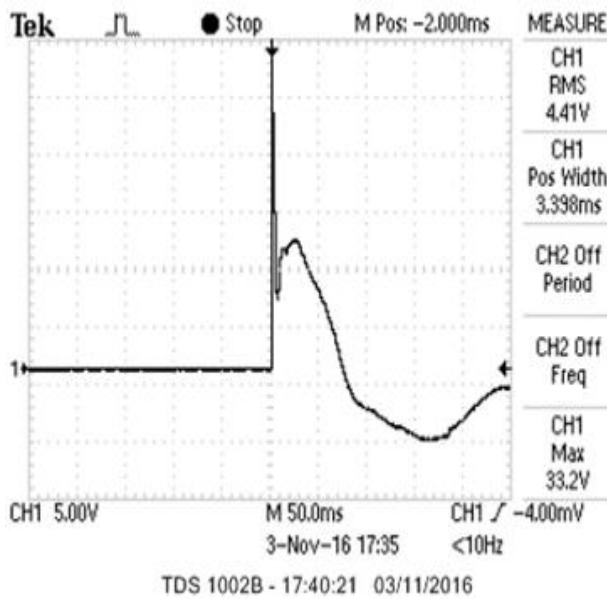


Figure-4. 4-5 rms volts output from piezo disc

Source: G. Priestner

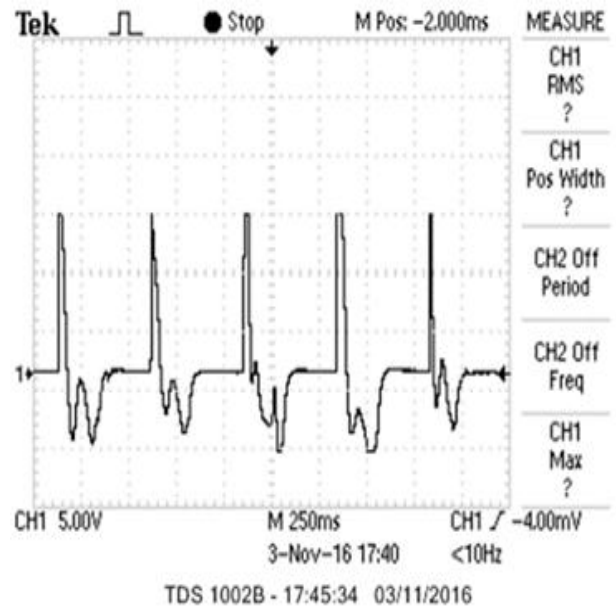


Figure-5. Piezo output from firm tapping

Source: G. Priestner

Tentative inspection of Figures 4 and 5 show that the output of the piezo disc is AC. The transducer produces an initial voltage spike, which then degrades in a linear fashion, before going into the negative cycle and finally settling. In real-world application of vibration power harvesting, a rectifier circuit is necessary to convert AC to DC to charge a battery or to feed directly an electronic device such as road-side lamp posts [3-8].

A very simple and common non-controlled rectifier circuit is the full-wave rectifier with a diode bridge. A full-bridge rectifier is more efficient than a voltage doubler, as a voltage doubler only provides current to the output during the positive half-cycle [9]. The full bridge rectifier is used to convert the AC input from the piezoelectric into DC, and a capacitor can be used to smooth the DC voltage.

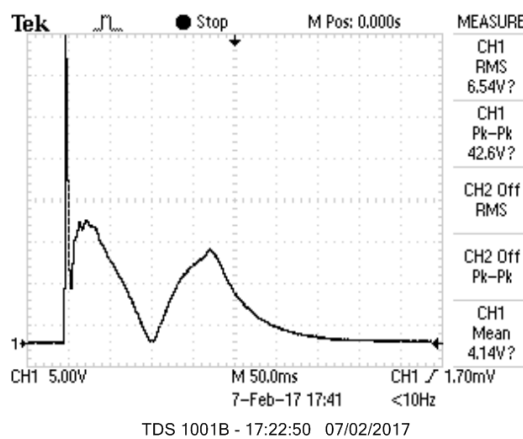


Figure-6. Individual piezo rectified

Source: G. Priestner

Figure 6 shows the piezo output when the negative cycle is inverted to positive through rectifier concept. It should be noted that the V_{rms} value has increased, even though a similar force is applied to the same piezo in Figure 4. This implies a higher V_{rms} is generated when using a full bridge rectifier.

3. PROTOTYPE ENERGY HARVESTER

A method of actuating multiple piezoelectric discs is required to test how piezoelectric materials behave when connected in different configurations, to determine the most efficient solution. A prototype solution is designed in CAD, and laser cut in various thicknesses of MDF.

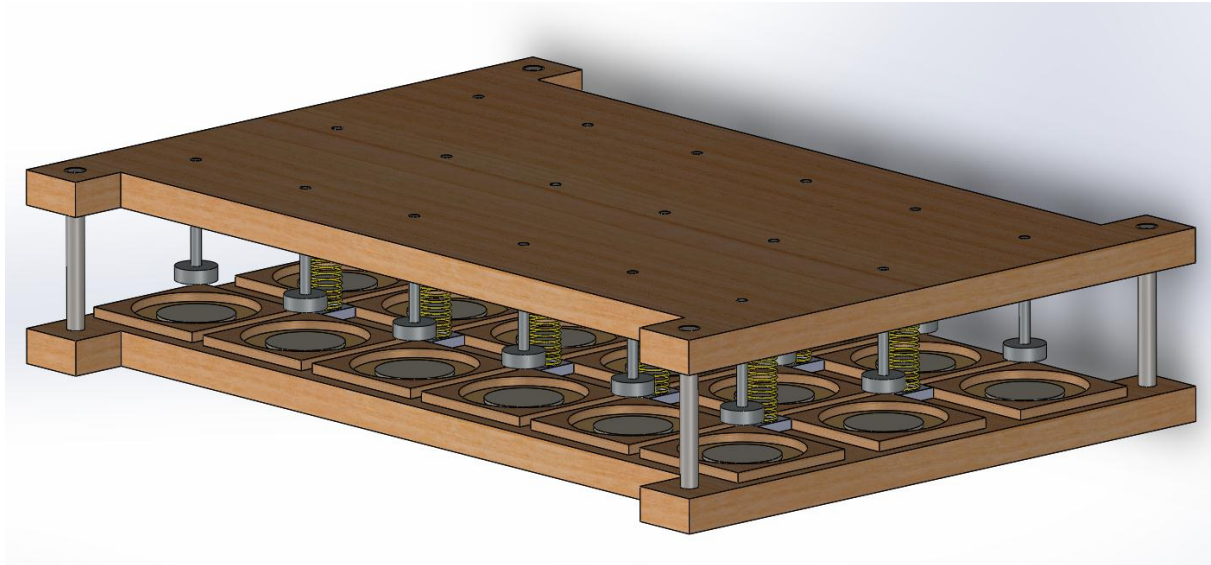


Figure-7. Prototype Harvester isometric view

Source: G. Priestner

As shown in Figure7, the piezoelectric discs are kept in place by square holders with the centres cut out. These ensure the piezo sensors are secured in the harvester. Once the harvester had been designed in CAD, the model is built. The materials chosen are 6 mm MDF for the bottom and top plates, and 3 mm MDF for the piezoelectric disc holders.

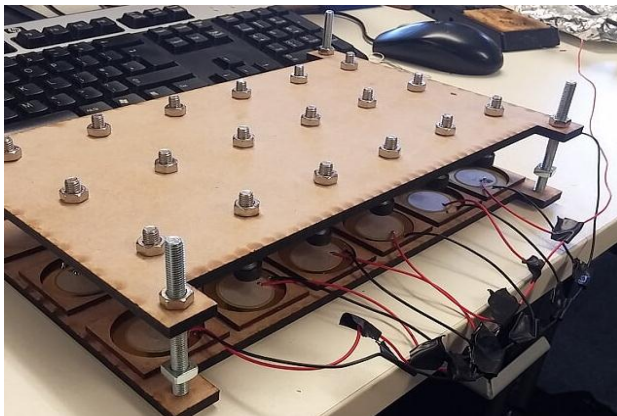


Figure-8. Prototype Harvester with piezo sensors

Source: G. Priestner



Figure-9. Prototype Harvester side-on view with piezo sensors

Source: G. Priestner

With reference to Figures 8 and 9, the harvester should be positioned within the road, under small bumps. As vehicles then travel over the small bump in the road, the piezoelectric harvester actuates the discs causing electrical charge to be accumulated in the temporary capacitor. This energy can be used to charge a battery, or be transported directly to the main grid. The heavier the vehicle, and a higher the rate of traffic and therefore more actuations over time, a higher output voltage can be achieved.

4. SOME RESULTS AND DISCUSSION

All piezo sensors are connected in parallel and then the resultant output terminals are connected to a full bridge rectifier. A 100 μ F capacitor is connected across the output of the rectifier to store the generated energy. The prototype harvester is then actuated by foot multiple times for 60 seconds as shown in Figure 10.

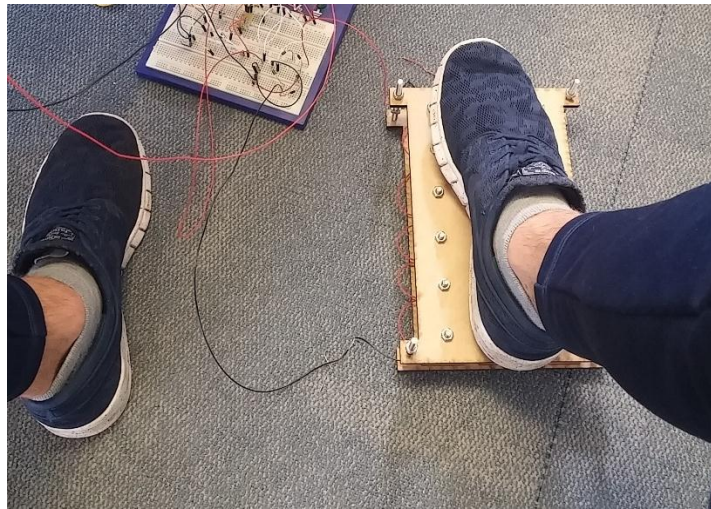
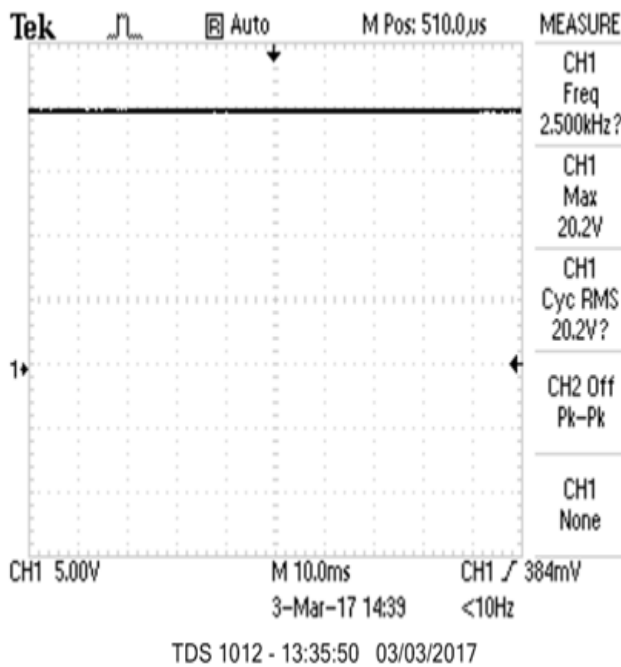


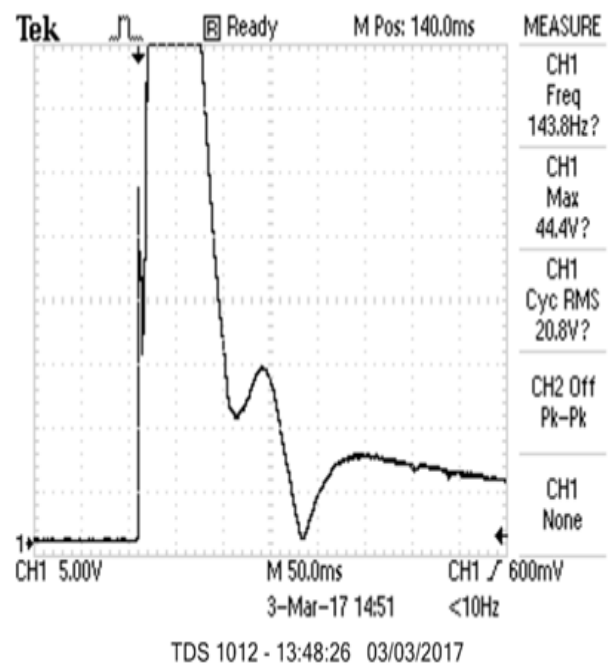
Figure-10. Testing prototype harvester

Source: G. Priestner



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Figure-11. Shows after 60 seconds of stepping 20.2Volts is generated
Source: G. Priestner



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Figure-12. Depicts the Output voltage from one step
Source: G. Priestner

The piezo harvester worked well for actuating all the piezo sensors simultaneously. Analysis of Figures 11 and 12 suggest that a high voltage can be obtained across the capacitor from a short duration of actuating time. As discussed earlier in this paper, the output voltage is proportional to the energy applied to the sensors, so the harder the step, the higher the voltage output. This infers the harvester should ideally be in an area of fast flowing and high frequency traffic. Figures 13 and 14 show the output profile of the harvester under various loads.

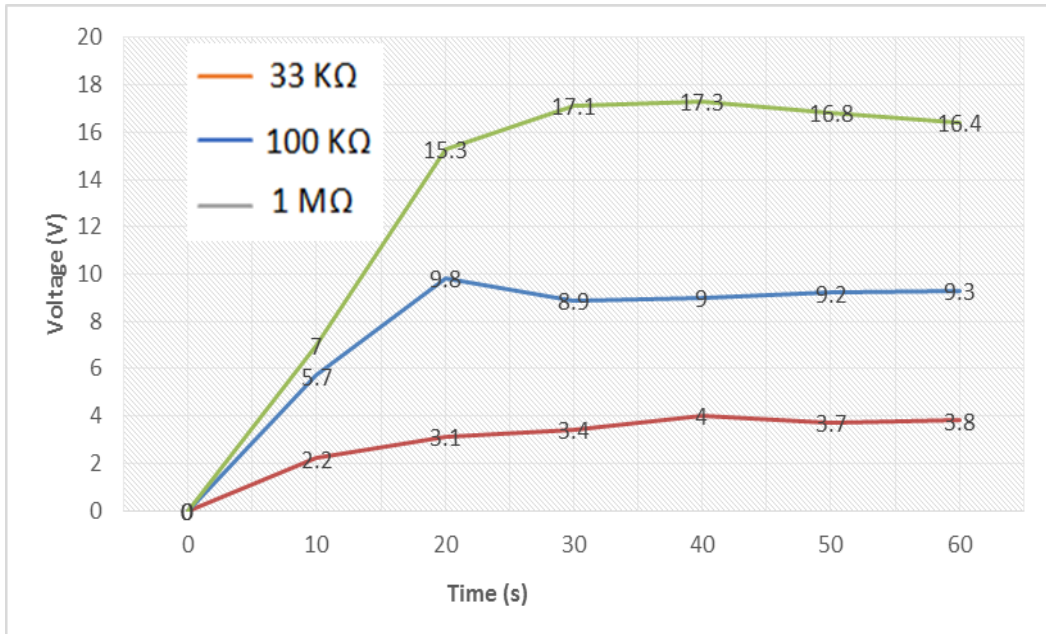


Figure-13. Profile of voltage output with various loads

Source: G. Priestner

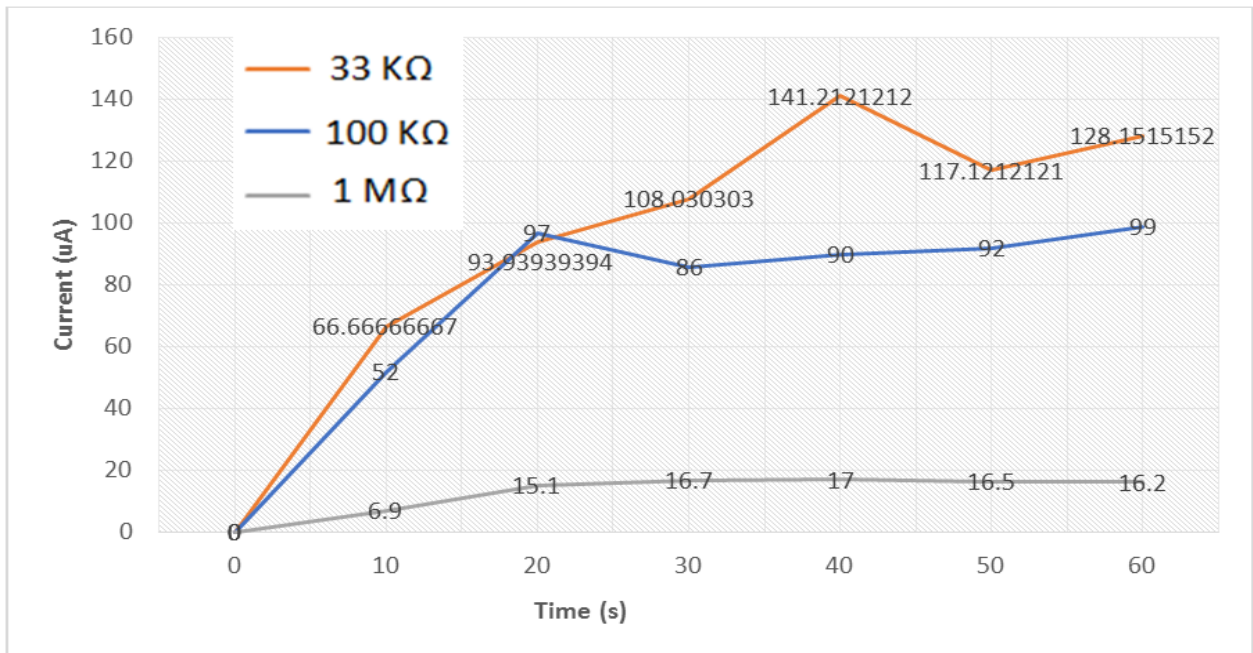


Figure-14. Depicts current output with various loads

Source: G. Priestner

A closer inspection of Figures 11 and 12 reveal that with this approach a high output voltage (multiple of the generated sensors' voltage) can be obtained when the sensors' generated voltage of 20 Volts charge the capacitor over a reasonable period. This in turn depends on the size of the capacitor, its rating and time constant. However, as shown in Figure 13 when the piezoelectric harvester is connected to a load the voltage decreases in a linear fashion. Figure 14 shows that with a 33kΩ load, the maximum current output obtained is ~140µA. Obviously, this is not sufficient to power any semiconductor device. However, if more piezo discs are connected, and a higher input force is applied, such as a vehicle driving over them, the voltage and current output would rise. For roadside applications, the piezo sensors could be used to charge batteries positioned on the road-side. Or, the sensors could feed the the input of a boost converter to power applications directly.

5. CONCLUSIONS

In this study, a prototype piezoelectric energy harvester is designed and tested. Although the current output of the designed harvester is not sufficient to power any semiconductor devices directly, it is feasible that if more piezo harvesters are positioned in the road, with a higher actuation weight and at a higher frequency, more power could be generated. This power can then be used to charge roadside batteries or could be fed to the input of a boost converter in order to power applications directly.

Although the concept of piezoelectricity has been around for decades, with first applications of piezoelectricity developed around 1940 [2] with modern day technology, piezoelectricity has real potential as an alternative renewable energy source.

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Competing Interests: The authors declare that they have no competing interests.

Contributors/Acknowledgement: Both authors contributed equally to the conception and design of the study.

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