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Analysis of Piezoelectric Buzzers as Vibration Energy Harvesters

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***Abstract* – This paper studies the energy harvesting capability of piezoelectric buzzer elements which are primarily used in electro-acoustic applications. Two commercially available piezo buzzer elements were analysed for their vibration energy harvesting capabilities under mechanical preload condition. A maximum power of 220 uW across a (resistive) load of 126 kΩ was obtained for a 35mm piezo buzzer with a preload of 57gms whereas for a 27mm buzzer the maximum power delivered to a load of 133 kΩ was 86 uW with a preload of 25gms. Resonance frequencies for the two buzzers were found to be 22Hz and 24Hz respectively at an acceleration of 2 m/s^2. The buzzer elements were used to successfully charge a supercapacitor up to 5 volts which was used to power a microcontroller. Results show that piezo buzzers are viable as vibration energy harvesters, capable of powering low-power microelectronic devices.**

Keywords* – *buzzer; diaphragm; harvesting; microcontroller piezoelectric; vibration; energy harvesters; super capacitor.

I. INTRODUCTION

Vibration energy harvesting has caught the attention of researchers in recent years due to a number of reasons. Vibrations are the second most abundant source of ambient energy available in nature after solar energy. Advances in microelectronics and semiconductor technology have resulted in reduced power consumption of devices. Progress in the field of wireless sensor networks has given rise to the need for self-sustained power sources with practically unlimited life and minimum maintenance.

Piezoelectric materials have been extensively researched and used for vibration energy harvesting. In particular, piezocomposites in the form of cantilevers and discs have been used. Coated on a cantilever beam, piezoceramics allow simple energy harvesting without additional mechanical structures. Relatively small external excitations result in output of several volts [1]. The cantilever configuration offers large average strain in the piezoelectric material for a given applied force and low resonant frequencies can be achieved due to the low stiffness of the structure [2]. Another type of piezocomposite harvester is the diaphragm harvester which has been studied by researchers under various excitation profiles. The circular diaphragm structure is commonly used for fabrication of sensors such as pressure sensors. Usually an external force applied on the pressure sensor stands for a long time [3]. From engineering mechanics, it is known that the highest stresses occur in the plane of a bent composite structure [4]. Owing to these reasons, circularly shaped piezoelectric energy harvesters are suitable for high/ low stress applications in a wide frequency range.Table 1 [5-13] gives a comparison of these harvesters. Table 2 [5] lists the various anthropogenic ambient sources of vibration.

A piezoelectric element can be modelled mechanically as a spring mass damper system represented mathematically by a linear, time-invariant second order differential equation [15] as

$$m\frac{d^2z(t)}{dt^2}+b\frac{dz(t)}{dt}+k\,z(t)=m\frac{d^2y(t)}{dt^2} \qquad (1)$$

Under an applied force, the open circuit output voltage (V) of the ceramic is given as

$$V=E.t=\ -g.x.t=\ -g.F.\frac{t}{A} \qquad (2)$$

where E is the electric field, t is the thickness of the piezoceramic, x is the stress, A is the area and g is the piezoelectric voltage coefficient.

The power available under cyclic excitation is given by

$$P = \frac{1}{2}.CV^2f \qquad (3)$$

where f is the frequency of excitation [16].

TABLE I. PIEZOCOMPOSITE ENERGY HARVESTERS

Type of Piezo harvester	Power/ Energy	Frequency (Hz)	Force/ Acceleration/ Pressure	Load at Resonance (kΩ)
Cantilever [5]	0.375 mW	120	2.5g	-
Cantilever [6]	1.5 – 2 mW	0 - 250	2g	1
Cantilever [7]	0.0325 mW	150	4.8g	98
Cantilever [8]	0.003 mW	80	-	333
Circular diaphragm [9]	12 mW	113	1.2 N	33
Circular diaphragm [10]	1.7 mW	1710	80 N	5.6
Circular diaphragm with roller support [11]	1.3 mW	1	10 N	-
Clamped circular diaphragm [12]	29 uJ	0.3	10 kPa	-
Circular diaphragm [13]	1.08	0.96	(0-24.5) N	1.2

TABLE II. AMBIENT ENERGY VIBRATION SOURCES

Vibration Source	Acceleration (m/s^2)	Frequency (Hz)
Car engine compartment	12	200
Base of 3-axis machine tool	10	70
Blender casing	6.4	121
Clothes dryer	3.5	121
Person nervously tapping their heel	3	1
Car instrument panel	3	13
Door frame just after door closes	3	125
Small microwave oven	2.5	121
HVAC vents in office building	0.2 – 1.5	60
Windows next to a busy road	0.7	100
CD on notebook computer	0.6	75
Second story floor of busy office	0.2	100

II. EXPERIMENTAL PROCEDURE

Piezoelectric buzzer elements are available in various sizes. Two commercially and commonly available buzzers measuring 27 mm and 35 mm in diameter were chosen for the present work. An electro dynamic shaker (Type SP2 by Spranktronics Bangalore) was used as the excitation mechanism. Customized holders were fabricated for each buzzer element so that it could be screwed on to the central shaft of the shaker and allow transmission of vibrations vertically to the elements. The holders (fig 1) were circular in shape and the buzzers were adhered to them by means of an adhesive. Care was taken to properly insulate the holders electrically as they were metallic and could electrically short the buzzer elements. As shown in fig 1, the holders were screwed onto the shaft of the shaker. A function generator was used together with a power amplifier to provide sinusoidal excitation input to the shaker. Mechanical weights from a standard weight box were attached on top of the buzzer elements.

Fig. 1. The fixture with the piezo buzzer and mechanical load attached

The weights and frequency were varied to get the peak AC voltage output at resonance for both the buzzers. The AC output of the buzzers was fed to a standard interface circuit (fig 2) consisting of a schottky bridge rectifier and capacitor.

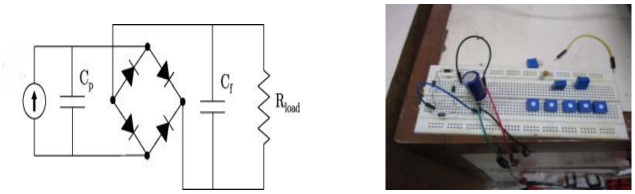

Fig. 2. The standard interface circuit

A resistive load was connected across the capacitor and the peak DC voltage was achieved and measured by varying the resistance. The resistance and electrolytic capacitance were replaced by a 5 V zener diode and a supercapacitor (Cornell Dubilier 5.5 V/ 0.1 F) and the charging of the supercapacitor was studied. The charging of the supercapacitor was recorded using a digital multimeter and data logger (Rishabh 16S and SI 232).

The acceleration of the arrangement (shaker+holder) was measured using a 3-axis accelerometer (ADXL335). Real time values from the accelerometer were recorded on a laptop using Data Acquisition Card (NI-9174) and LabVIEW.

III. RESULTS AND DISCUSSIONS

A. Effect of mechanical preload on output voltage

The output voltages of the piezo elements with and without mechanical preload were studied. Figure 4 (a & b) gives plots of AC voltage output (V) vs frequency (F) for the buzzer elements without mechanical loads.

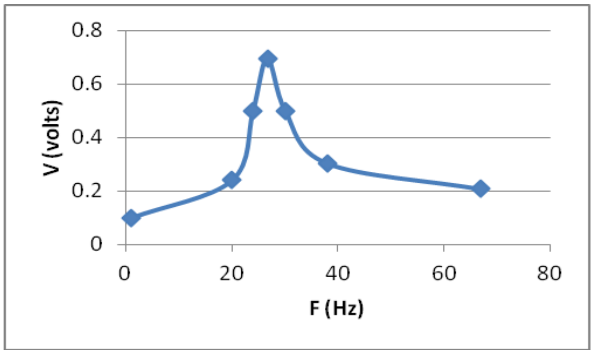

Fig. 3. Voltage output without mechanical preload for 35mm buzzer

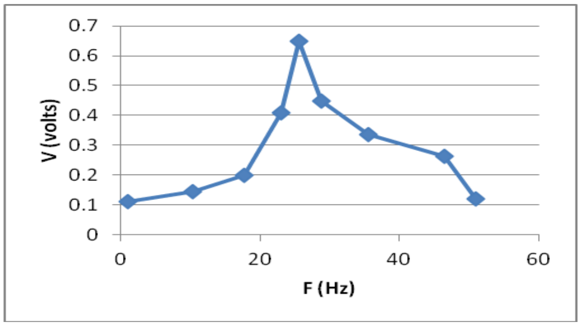

Fig. 4. Voltage output without mechanical preload for 27 mm

As can been seen from the figures, the output voltage without mechanical preload is very low. The highest voltages obtained at resonance were 0.7 and 0.65 volts for the 35 mm and 27 mm buzzers respectively.

The piezoelectric elements were then subjected to mechanical preloads. The preload was increased in steps of 5 gms and the corresponding output voltages were measured. Figures 5 & 6 give plots of output voltage (V) vs preload (W).

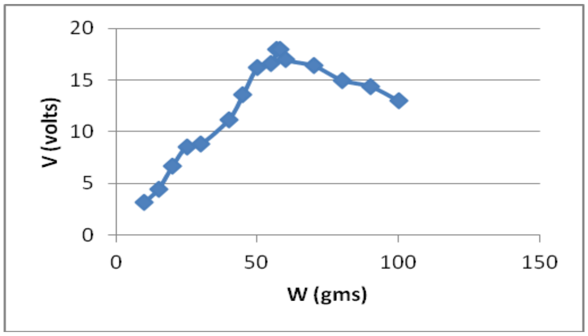

Fig. 5. Voltage output with mechanical preload for 35 mm buzzer

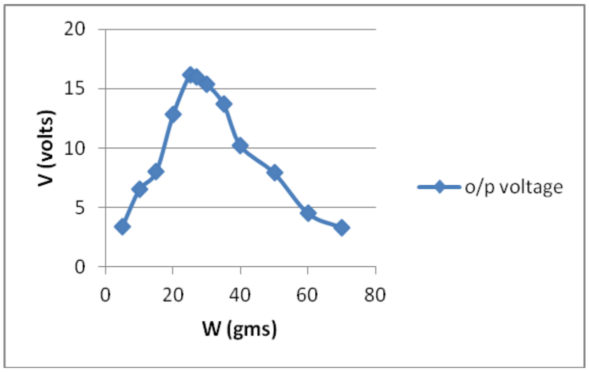

Fig. 6. Voltage output with mechanical preload for 27 mm buzzer

B. Effect of mechanical preload on resonance frequency

Increasing the mechanical preload had the effect of reducing the resonance frequency of the piezo elements. Without the preload, the resonance frequencies were 26.7 Hz and 25.6 Hz for the 35mm and 27mm piezo elements respectively. After application of preload, the resonance frequencies reduced to 22.6 Hz and 24.2 Hz for the 35mm and 27mm piezo elements respectively. Figures 7 & 8 give a plot of frequency (F) vs weight (W) for the two buzzer elements.

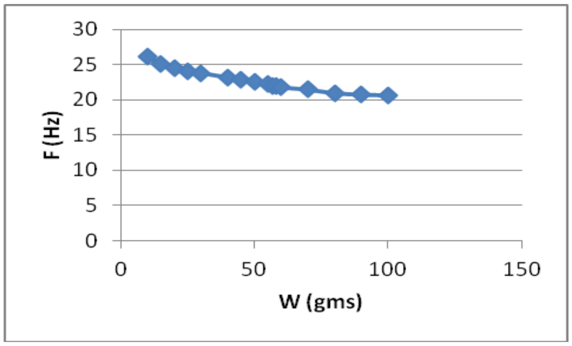

Fig. 7. Frequency vs weight for 35mm buzzer

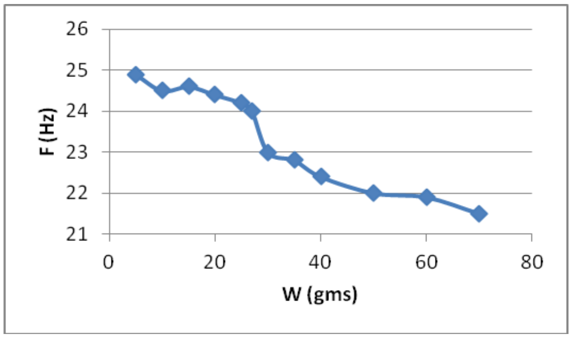

Fig. 8. Frequency vs weight for 27mm buzzer

C. *Power delivered to a resistive load*

Figures 9 and 10 below shows plots of power (P) vs resistive load (R), for the two buzzer elements. Peak powers obtained were - 223 uW across a 126 kΩ resistive load for the 35 mm buzzer and 86 uW across a 133 kΩ resistive load for the 27 mm buzzer at resonant frequencies mentioned earlier.

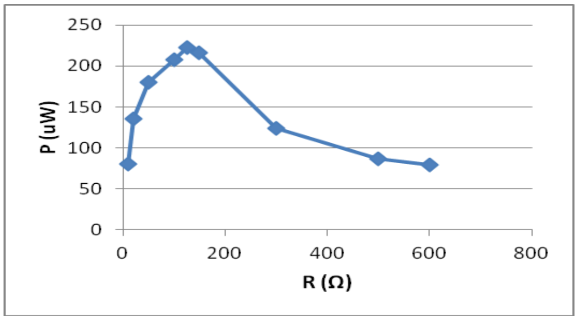

Fig. 9. Power vs load plot of 35mm buzzer

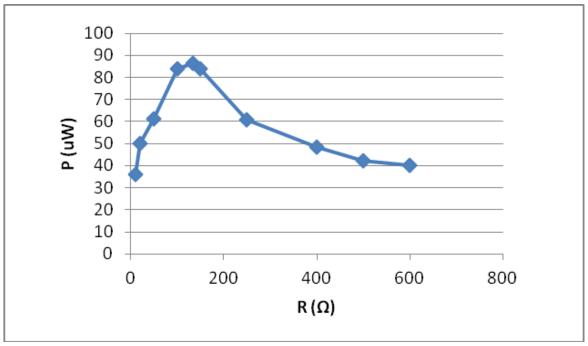

Fig. 10. Power vs load plot of 27mm buzzer

D. *Charging of a supercapacitor*

The piezo buzzers were operated at resonance and used to charge a supercapacitor (Cornell Dubilier 5.5 V/ 0.1 F). Fig 11 gives a plot of supercapacitor voltage (V) vs time (T) for the two piezoelectric buzzers. As seen in the figure, the 35 mm buzzer was able to charge the supercapacitor faster as compared to the 27mm buzzer. The times taken to charge the capacitor to 5 volts were 153 min and 167 min for the 35 mm and 27 mm buzzers respectively. The charged supercapacitor was used successfully to power a Arduino microcontroller board for 10 seconds (fig 8b). The Arduino board was preloaded with a program to flash an on-board LED using a PC. The supercapacitor which was previously charged using the buzzer element was then connected at the power input of the Arduino board. As the voltage of the supercpacitor fell below 3 volts, the Arduino board stopped working. . This can be attributed to the minimum voltage required to power the Arduino board.

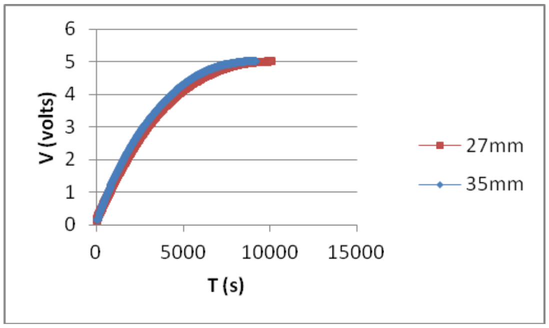

Fig. 11. Power vs load plot of 35mm buzzer

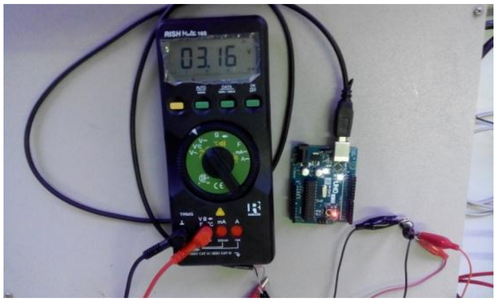

Fig. 12. Arduino board powered by the charged supercapacitor

The acceleration of the arrangement measured using the setup mentioned earlier was found to be 2 m/s^2.

IV. CONCLUSIONS AND FUTURE SCOPE

Commercially available piezoelectric buzzer elements were used as energy harvesters in an experimental vibration setup with mechanical preloads. Optimum preloads were found to be 57 gm and 25 gm for the 35 mm and 27 mm buzzer respectively. Peak powers of 220 uW across an optimum resistive load of 126 k for the 35 mm buzzer and 86 uW across an optimum resistive load of 133 k for the 27 mm buzzer were observed. Resonance frequencies under optimum mechanical preloads were found to be 22.6 Hz and 24.2 Hz for the 35 mm and 27 mm buzzers respectively. The acceleration was 2 m/s^2. A supercapacitor was charged to 5 volts using the buzzer elements operated at resonance and was used to power a microcontroller.

These buzzer elements are cheap, robust, commercially available and due to their thin form factor, are easily integrable into a variety of vibrating structures to generate useful electrical energy which can be used to power microelectronic devices like Bluetooth, GPS modules, microcontrollers and low power sensors, wireless sensor nodes, etc. Results also indicate that these piezo elements are capable of generating sufficient power even at low frequencies and accelerations.

Future work would include studying power output under higher force profile, designing and fabricating arrays of these energy harvesters and using the energy harvested to charge rechargeable batteries and power low-power microelectronic devices.

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