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Factors Affecting the Behaviour of Piezoelectric Ceramic Membrane Systems

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ABSTRACT

Energy harvesting is a top research topic right now, as the entire world seeks green energy as an alternative source. The power (voltage) extracted from the piezoelectric system was optimized. Several factors influence the creation of electric energy when a load is applied to the sensors, either directly (strain) or via ambient vibration. These variables include the kind of Piezoelectric elements, the frequency of applied stress, the distance from the rotating axis, stiffness, and inserting a chamber beneath the piezoelectric elements .The most affected factor was increasing the distance from the rotating axis since the maximum voltage was 7.02 volt at 106 r/m and the distance is 25 mm. when connecting Piezoelectric elements with cavities below it harvesting a voltage of Vmax equal 26.3 volt at 106 r/m and distance of 25mm. Increasing the stiffness of spring from 360.5 N/m to 522.4 N/m results in increased energy harvesting. Increasing the Piezoelectric elements diameter from 35 mm to 35mm with cavity under it has a significant effect on the gathered voltage.

1. Introduction

The sun is the most important source of energy for life on Earth, either directly or indirectly. Dependence on nonrenewable resources is diminishing them day by day, and they may be completely gone in the not-too-distant future [1]. As a result, we must seek alternative energy sources and our reliance on renewables. This will save nonrenewable resources while simultaneously providing clean electricity. Renewable energy sources include solar cells (Solar energy), wind turbines (Wind energy), geothermal power plants (Geothermal energy), and tidal turbines (Tidal energy). Solar power produces a substantial amount of energy per unit of area and volume, but it is limited to applications that are directly exposed to the sun [1],[2]. The process of gathering energy from natural sources and accumulating and storing it for a useful purpose is known as energy harvesting (EH) [3]. Capturing energy from natural sources is not a new concept; it dates back to the invention of the windmill and the waterwheel [4],[5]. For decades, researchers have been investigating techniques to capture energy from heat and other ambient sources. [6],[7]. Piezoelectric materials have emerged as a potent platform for energy harvesting applications. They now provide long-term solutions for high-performance, low-power electronic devices used in a variety of industries, including aerospace, automotive, and biomedical devices [8]. Ceramics, polymers, and composites are the three primary kinds of materials with piezoelectric characteristics. These materials can be found naturally (for example, quartz, cane sugar, collagen, topaz, and Rochelle salt) or chemically synthesized (for example, perovskites, synthetic polymers,

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or piezoelectric composites). These materials have distinct individual advantages that can be advantageous in certain applications [8]. The usage of conventional piezoelectric buzzers helps us to cut fabrication costs. Energy harvesters work similarly to power generators, gathering energy from their environment indefinitely. Thus, harvesting solutions alleviate concerns associated with batteries such as limited lifespan, big size, environmental degradation, and high maintenance costs [9]. Piezoelectricity Constitutive Equations Piezoelectric materials are a subset of the ferroelectric family of materials. The molecular structure of ferroelectric materials is orientated in such a way that the material exhibits local charge separation, which is known as an electric dipole. Two linear constitutive equations may be used to describe the mechanical and electrical behavior of a piezoelectric material. These equations have two mechanical variables and two electrical variables. The following matrix equations can be used to simulate the direct and inverse effects.

Direct piezoelectric effect:

$$\{D\} = [e]^T\{S\} + [\propto^S]\{E\} \quad (1)$$

Converse piezoelectric effect:

$$\{T\} = [C^E]\{S\} - [e]\{E\} \quad (2)$$

The electric displacement vector is {D}, the stress vector is {T}, the dielectric permittivity matrix is [e], the matrix of elastic coefficients at constant electric field strength is $\{C^E\}$, the strain vector is $\{S\}$, the dielectric matrix at constant material strain is $[\propto^s]$, and the electric field vector is E [10],[11].

Voltages and currents, in contrast to electric displacement and electric field measurement, are simple to measure. As a result, the above equations may be formally stated as follows:

$$V = \int_0^X \vec{E}.\overrightarrow{dx} \quad (3)$$

$$I = \frac{\partial}{\partial t}\int \vec{D}\,\overrightarrow{da} \quad (4)$$

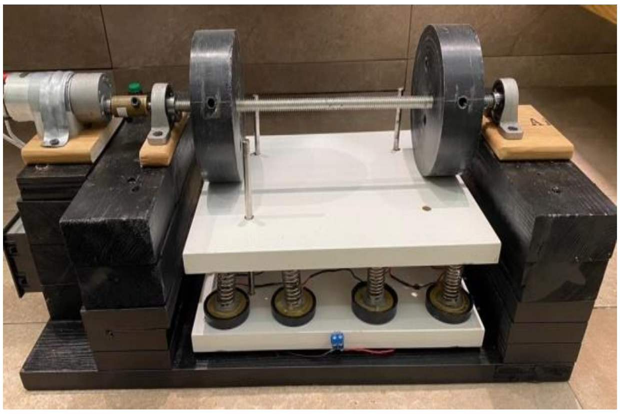
where V is the voltage, I is the current, X is the thickness of the piezoelectric material, and A is the area of the piezoelectric material [12].

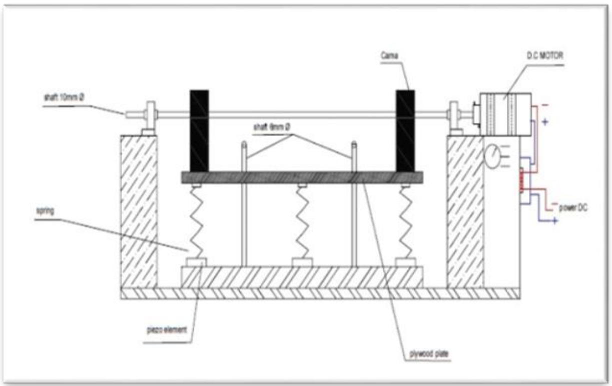
Prabaharan et al. A mechanism for harvesting electrical energy using a piezoelectric crystal is proposed. When the system was subjected to footstep pressure, an alternating current voltage (AC voltage) was generated; a rectifier circuit was used to convert the AC voltage to direct current voltage (DC voltage). The output DC voltage and current were increased using a boost converter, and the output was then stored in a battery [13]. Varsha and colleagues proposed a system design capable of storing mechanical energy generated by footsteps during the day in batteries and then utilising this energy for numerous uses during the night.

Stepping on the system put mechanical stress on the piezoelectric micro generator, causing the piezoelectric sensors to produce energy. The voltage is then stored in a lead acid battery with a capacity of 1 V and 1.3 A. The developed system is safe, clean, does not hurt the environment, and is less expensive [14]. Naresh et al carried out a study and analysis in order to determine the best piezoelectric material for energy harvesting purposes. The most popular piezoelectric materials available are PZT and PVDF. The best was chosen based on the output voltage achieved after applying different weights of pressure. When the output voltage was measured and plotted, it was discovered that PZT produced 2Volt while PVDF produced 0.4Volt. As a result, the PZT was chosen since it produced more [15].

2. Methodology

An investigation into the parameters that influence energy harvesting the vibration energy produced by the movement of humans while walking on roads. A device has been designed that simulates the footsteps of a person walking on the road. The system consists of a DC motor linked with a shaft that contains an eccentric cam and a U-shaped wooden structure with a Playwood panel below it springs. It consists of three groups that are replaced for each case. and the piezoelectric elements also consist of two groups, one of which has a cavity underneath. shown in Figure (1) A and the illustrative drawing of Figure (1) B The technical characteristics listed in Table [1, a, b, c] are (a) Piezoelectric sensor specifications(b) DcMotor specifications (c) Spring specifications. The working technique of this system can be summarized when the eccentric cam rotates, and periodic pressure a Playwood panel on will be generated and transmitted through the springs to the piezoelectric elements, which leads to the deformation of the piezoelectric elements as a result of mechanical stress, and produce the output voltage that can be measured using a voltmeter with time and taking the highest output voltage.





(a) (b)

Figure1. Energy harvesting system

Table:[1, a] Piezoelectric sensor specifications

Parameters	Values	Units
Resonant frequency	4000±500	Hz
Resonant impedance(max)	350	Ohm
Max input voltage	30	V
Capacitance at 1Khz	2500±30%	pF
Plate material	Brass	-
Operating temperature	-20~+60	℃
Storage temperature	-20~+70	℃

Table:[1, b]Motor specifications

Parameters	Values	Units
Reduction Ratio	1:90	-
Voltage Range	6-18	V
Rated Voltage	12	V
No Load Current:	less than 1A	A
Rated Load Current	less than 2.5A	A
Stall Current	6	A
No Load Speed	250	rpm
Rated Load Torque	4.5	kg.cm

Table: [1, c] Spring specifications

Parameters	Values	Units
Wire diameter	1, 1.2, 1.5	mm
Outer diameter	16.75	mm
Free length	480	mm
No. of active coils(n)	10	-
K for spring	522.4,428.48, 360.5	N/m

3. Results and discussion

Studying harvesting energy from unwanted vibration has been explored, considering the affected factors. In most cases, vibration in structural elements is unwanted [16]. Some of them can be performed as: -

3.1 Varying the spring constant k

Three sets of springs made of stainless steel were used, with the same diameter and length and differing in wire diameter and spring constant k. The three groups consist of a spring constant of 260.25 N / m, 428.48 N / m and 605.75 N / m. It was placed over a piezoelectric consisting of six cells. Pressures at different frequencies were applied to them each time for each group. It was noted that the output voltage increases as the spring constant increases, and this increase is in a direct relationship, as shown in Figure (2).

Table 2: Relation between frequency and output voltage

Frequency (Hz)	Vmax(K1)	Vmax(K2)	Vmax(K3)
0	0	0	0
8.75	2.93	7.44	27.7
12.73	4.24	7.76	28.1
16.87	4.69	8.32	31.3
21.46	4.28	7.1	27.2
24.19	4.52	6.62	26.7

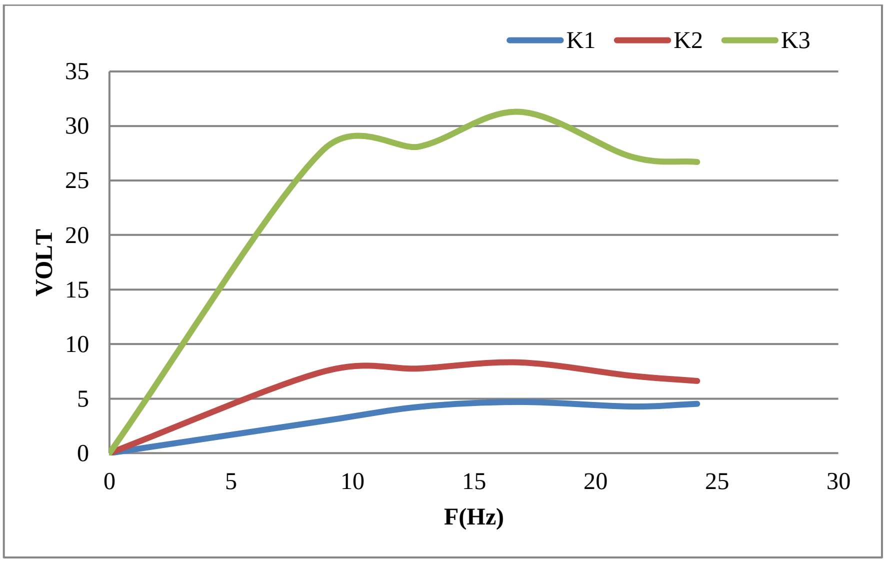


Figure 2. Varying the spring constant k

It can be seen that the highest output voltage was obtained with a frequency of 16.87, and in all cases where the relationship is direct between the stiffness of the spring and the output voltage.

3.2 The presence of a cavity under the piezoelectric elements

In order to obtain the best energy harvesting results, the stresses on the surface of the electrostatic films should be increased as much as possible. It was observed that the best way to obtain a greater energy harvest is by designing a cavitation under the piezoelectric elements to obtain a curvature in the piezoelectric films .When a load on it, and this curvature leads to more stresses than the absence of these .Where piezoelectric elements with a diameter of 35 mm were used, and they were compared by the output voltage, where the above cells were used without cavitation and reading the output voltage, and then the same piezoelectric were used, but a cavitation was placed below them. The output voltage was read and a difference was observed between the two problems. This is indicated in the following cases.

a. In the first case, the eccentric cam rotation axis 10 mm away from the axis of rotation was used at different speeds. The output voltage was calculated for this case for both cavity-containing and non-cavity piezoelectric element, as shown in table[3] and Figure (3).

Table 3: Relation between speed and output voltage with eccentric cam 10 mm

Speed(r/m)	Piezo D35mm	Piezo & Cave D35 mm
0	0	0
55	0.139	1.69
80	0.123	1.82
106	0.253	1.69
135	0.182	1.53
152	0.258	1.15
174	0.176	1.24
195	0.089	1.04
216	0.104	1.14

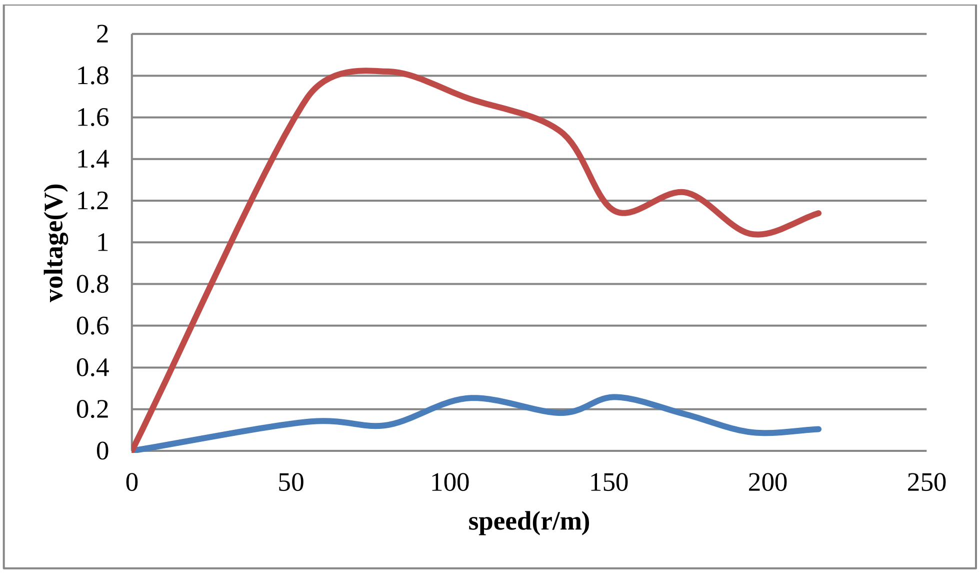


Figure 3. Varying the piezoelectric design with eccentric cam 10 mm

Figure (3) show linear increase of v_{max} as the speed of cam applying load increase up to 50 r /m then a quick increase in voltage with a steady increase in rotate speed is noticed. That behavior could be attributed to the cumulated strain response of piezoelectric elements with different positions.

b. In this case, to increase the pressure on the surface of the piezoelectric element, the distance between the axis of rotation and the eccentric cam center will be increased to 15 mm. That leads to an increase in the output voltage for the difference types of piezoelectric elements with and without cavitation, as shown in figure (4).

Table 4: Relation between speed and output voltage with eccentric cam 15 mm

Speed(r/m)	Piezo 35	Piezo 35 & Cave
0	0	0
55	2.76	9.7
80	2.65	10.6
106	2.65	10.7
135	2.38	10.4
152	2.32	10.1
174	2	9.6
195	1.02	7.8
216	1.66	7.9

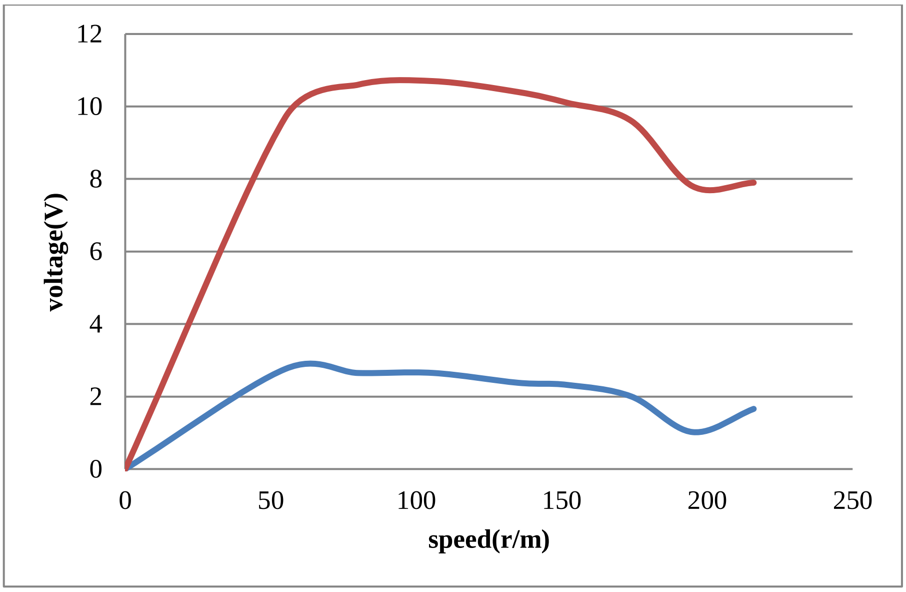


Figure 4. Varying the piezoelectric design with eccentric cam 15 mm

c. In this case, the pressure was increased more than the previous case by increasing the distance to 20 mm from the x axis and observing the behavior of the piezoelectric elements through the figure (5). The increase in output voltage will be high compared to the previous case.

Table 5: Relation between speed and output voltage with eccentric cam 20 mm

Speed(r/m)	Piezo 35	Piezo 35 & Cave
0	0	0
55	4.94	17.5
80	5.13	21.1
106	4.93	22.1
135	5.06	20.9
152	4.9	20.3
174	4.12	17.7
195	3.98	17.4
216	5.56	15.7

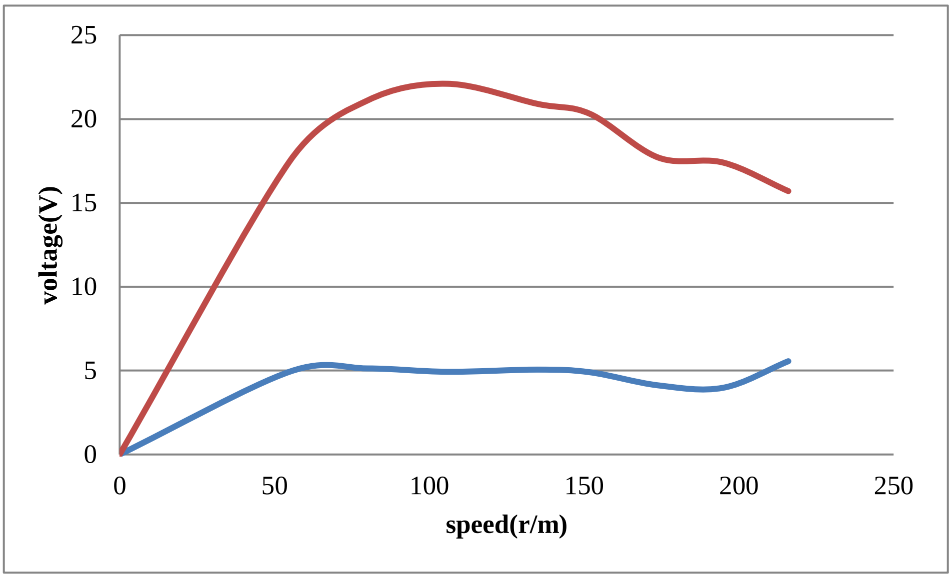


Figure 5. Varying the piezoelectric design with eccentric cam 20 mm

d. In this case, it was observed that the piezoelectric elements gave the highest value of the output voltage at a distance of 25 mm, as well as the difference between the output voltage of the elements with a cavern in it and the elements that did not contain it, and this was shown through the graph in Figure (6).

Table 6: Relation between speed and output voltage with eccentric cam 25 mm

Speed(r/m)	Piezo 35	Piezo 35 & Cave
0	0	0
55	5.02	12.7
80	6.27	22.7
106	7.02	26.3
135	6.9	23.6
152	6.14	20.3
174	5.95	23.4
195	5.05	22.1
216	8.8	28.1

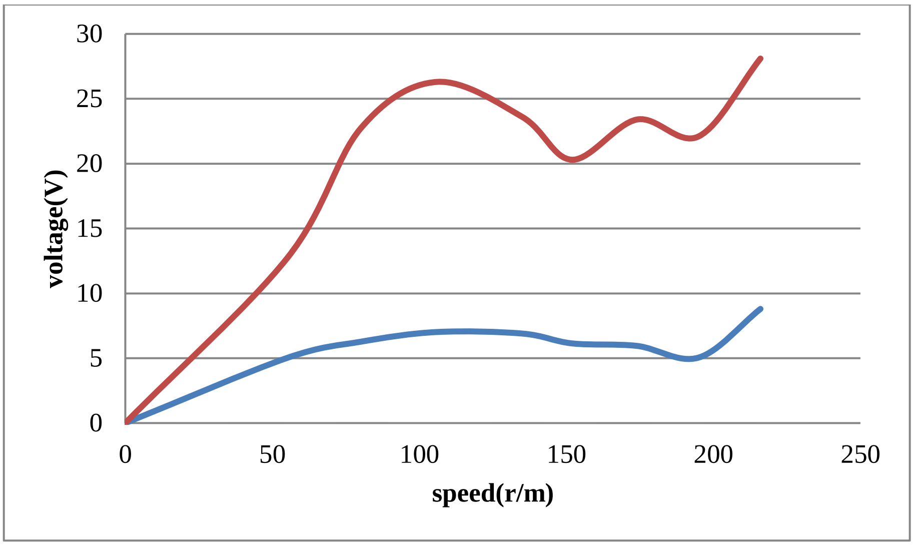


Figure 6. Varying the piezoelectric design with eccentric cam 25 mm

4. Conclusions

Study of energy harvesting of vibrations from the surrounding environment introducing a new electricity producing source or method taking into account many factors. Some are less affected than others.

1. The distance between the eccentric cam shaft and its center, which increases the stress on the piezoelectric elements.
2. The cavity below the element, is one of the most influential factors as it allows the piezoelectric element to bend, which in turn increases the deformation in the surface of the piezoelectric elements.
3. When changing the constant K of the springs, this leads to an increase in pressure on the surface of the piezoelectric elements and an increase in distortions on their surface. We note this by increasing the output voltage.
4. In this experiment, the power produced is proportional to the weight applied to the piezoelectric sheet.
5. The project's operating costs are insignificant because no specific fuel is required, as is the case with conventional power generating facilities.
6. This technology produces no pollution as compared to other power generation technologies, making it environmentally beneficial.
7. Untapped the mechanical energy generated by footsteps is used to generate electricity.
8. Increased pressure is required for more electricity generation, so the project can be successfully performed in congested locations.

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