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ELECTROMECHANICAL SYSTEM DESIGN AND FABRICATION FOR ENERGY HARVESTING

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Abstract - Energy harvesting is an exciting topic of research right now, when the entire world wants green energy as a substitute source. The optimization of power (voltage) extracted from the piezoelectric system was studied. Several variables influence the creation of electric energy when a load is applied to the sensors, either directly (strain) or via ambient vibration. These factors including the No.and type of Piezo elements, frequency of applied load , the distance from rotating axis, stiffness and No. of springs and introducing a cavity below the piezo elements. Increasing the distance from rotating axis was the most affected factor since the max voltage was 7.02v at 16.87 Hz and the distance is 25 mm. while connecting piezo elements with cavity below harvesting a voltage of V_{max} equal 26.3 v at 16.87 Hz and distance of 25mm .Increasing the Piezo elements from 6 to 12 cause an increase in energy harvesting. Changing the Piezo diameter from 20mm to 35 mm have considerable effect on harvested voltage.

Keywords: - energy harvesting, piezoelectric , vibration ,optimization factors

1. INTRODUCTION

The sun, either directly or indirectly, is the most important source of energy for Earth's life. Dependence on nonrenewable resources is depleting these resources day by day, and in the not-too-distant future, they may be fully depleted. As a result, it is necessary to look for alternate energy sources and reduce our reliance on renewables. This will reduce the use of nonrenewable resources while also producing clean energy. Solar cells (Solar energy) , wind turbines (Wind energy) , geothermal power plants (Geothermal energy) , and tidal turbines (Tidal energy) are examples of renewable energy sources. 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 getting energy from renewable sources is known as energy harvesting. natural sources and accumulating and storing it for a useful purpose (EH). The concept of capturing energy from natural sources is not new; it dates back to the invention of the windmill and the waterwheel [3+4]. Researchers have been developing strategies to extract energy from heat and other ambient sources for decades.the research include introducing composite materials to design a harvesting system with optimized [5,6]

Prabaharan et al. (2013). [**7**] Proposed a technique for harvesting electrical energy using a piezoelectric crystal. When a footstep pressure was applied to the system, an alternating current voltage (AC voltage) was created; to convert the alternating current voltage to direct current, a rectifier circuit was used. direct current voltage (DC voltage). A boost converter was used to boost the DC voltage and current output, and the output was then stored in a battery. Varsha et al. (2018). [8] proposed a system design that is capable of storing footsteps mechanical energy that got generated during the day in batteries then use this energy during the night time for some applications. A person stepping on the system caused a mechanical stress on the piezoelectic microgenerator which in result caused the piezolelectric sensors to produce electricity. The voltage is then stored in 1 V, 1.3A lead acid battery. . The designed system is safe, clean, not harmful to the environment and less cost effective. Naresh and others. (2018). [9] A study and analysis were conducted to select the most suitable piezoelectric material for energy harnessing purposes. PZT and PVDF are the most common piezoelectric materials that can be obtained. The best was selected based on the output voltage obtained after applying pressure of different weights. The output voltage was observed and plotted and it was found that PZT produced V while PVDF produced 0.4V. Thus, the PZT was chosen because it generated a higher production.

2. The Constitutive Equations of Piezoelectricity

Piezoelectric materials are a subset of a wider range of materials known as ferroelectrics. Ferroelectric materials have a molecular structure. is oriented in such a way that local charge separation occurs in the substance, It is referred to as an electric dipole. Two linear equations of constitutive may be used to characterize a piezoelectric material's mechanical and electrical characteristics. These equations have mechanical two variables and electrical two variables. The matrix below shows how mathematical equations can be used to calculate direct and inverse effects.

The impact of direct piezoelectricity: $\{D\} = [e]^T\{S\} + [\propto^S]\{E\}$ -------- - (1)

Converse piezoelectric effect: $\{T\} = [C^E]\{S\} - [e]\{E\}$ ---------- (2)

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

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

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

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

Where V denotes voltage, I denotes current, X denotes piezoelectric material thickness, and A denotes piezoelectric material area. [12].

3. **Methodology**

To study factors affecting energy harvesting a designed system was introduced. The system consist of motor ,playwood plate ,springs and piezoelements shown in Figure (1) with technical properties listed in table[1,a,b,c].The technique of this system can be summarized using the figure by

When the motor rotates at a certain speed controlled by the speed regulator, the wheel rotates with an eccentricity from roating center, pressing on the plywood, the object of this movement is to create fluctuated linear vibrations. As a result, there is pressure on the center-mounted spring which in turn press the piezo elements. To focus the applied pressure and prevent the sensor from damage caused by direct overload, the size of each piezoelectric sensor (35 x 0.53) mm.

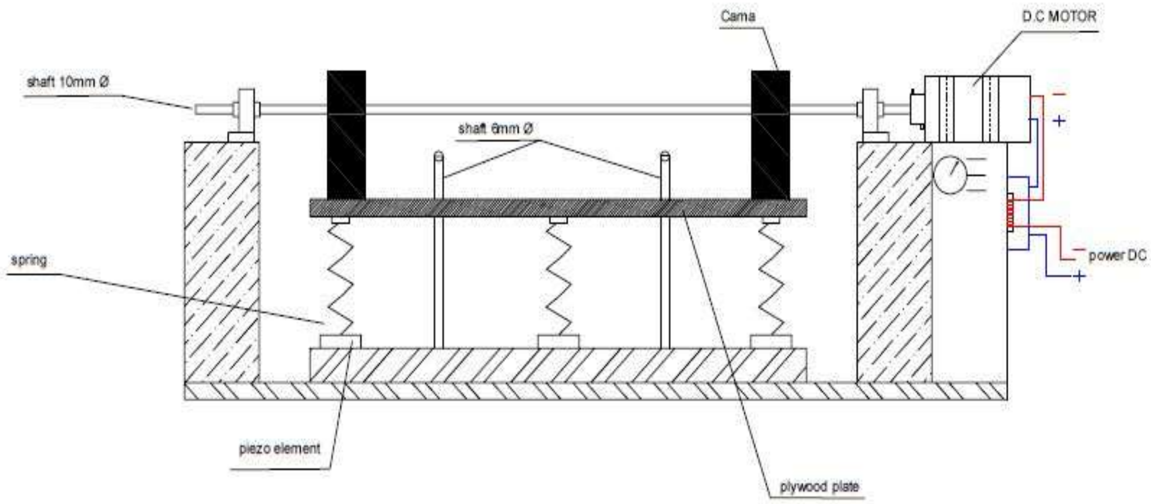

Fig. 1.energy harvesting system elements

Table$[1, a]$ the piezoelectric sensor specifications

PARAMETERS	VOLUME	UNITE
RESONANT FREQUENCY	4000 ± 500	H_z
RESONANT IMPEDANCE(MAX)	350	Ohm
MAX INPUT VOLTAGE	30	V
CAPACITANCE AT 1 KHZ	2500 ± 30%	p^F
PLATE MATERIAL	BRASS	-
OPERATING TEMPERATURE	-20 ~+ 60	$°C$
STORAGE TEMPERATURE	-20 ~+ 70	$°C$

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	1.2	mm
Outer diameter	16.75	mm
Free length	480	mm
No. of active coils(n)	10	-
K for spring	428.48	N/m

Piezoelectric sensors will deform as a result of mechanical stress, resulting in voltage output. The layout is capable of producing the maximum electrical energy. Experience It is accomplished by joining six as an example or more piezoelectric ceramic PZT components below. There are four types of circuit configurations: series, parallel, and parallel. Figure 2 depicts the setup. The circuit layout that generates the most electrical energy is chosen to be used throughout this investigation. [13].

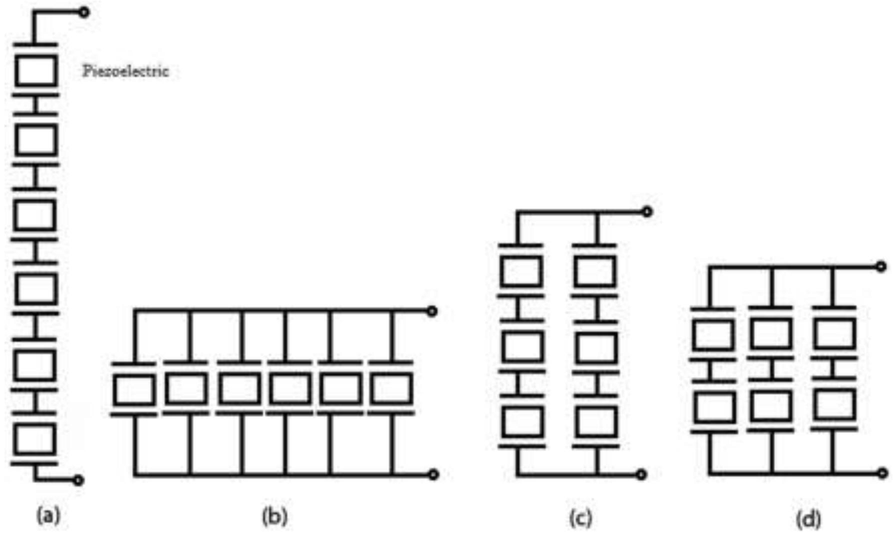

Fig. 2 piezo electric elements connection

4. **Experimental results**

In most cases vibration in structural elements is unwanted [14].Studying harvesting energy from unwanted vibration have been explored considering the affected factors .some of them can be performed as:-

a) Changing the number of piezoelectric elements

The output voltage varied depending on the number of piezoelectric sensors used, As illustrated in Fig. 3, the higher the number of cells used, the higher the production. The layout of six cells was tested initially, and subsequently the total number of cells was raised to twelve. The cells must be positioned in such a manner through which when any type of stress is applied, all piezoelectric cells are crushed. Table [2] show that V_{max} of 12 pieces is greater than of 6 pieces. Increasing the No. of piezo elements means introducing higher strain change which harvesting more voltage [15]

Table [2] Number of piezo element effect on harvested voltage

Test no.	frequency(Hz)	V_{max}(6piezo)	V_{max}(12piezo)
0	0	0	0
1	8.75	12.09	17.5
2	12.73	12.39	21.1
3	16.87	12.13	22.1
4	21.46	11.8	20.9
5	24.19	11.37	20.3
6	27.85	10.45	17.7
7	31	9.94	17.4
8	34.38	9.67	15.7

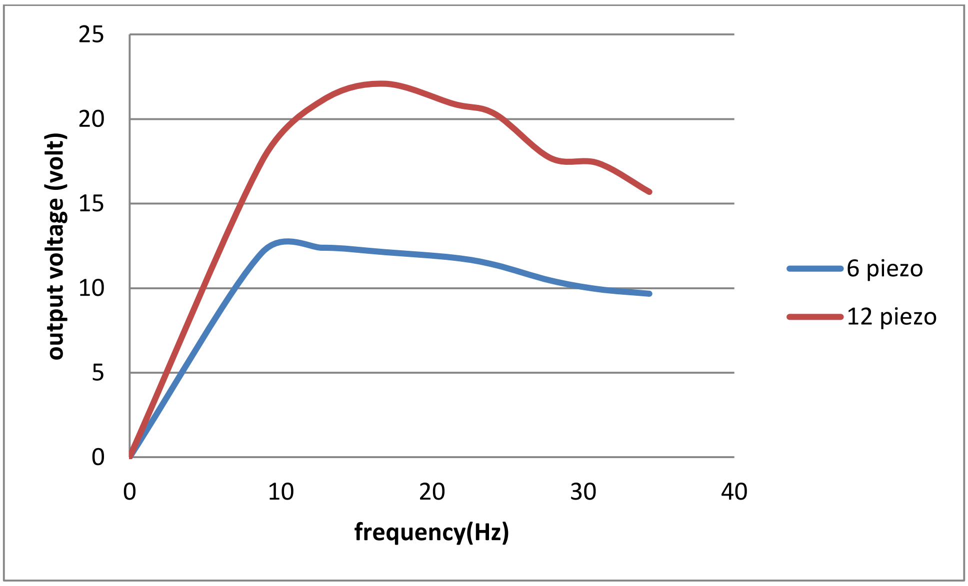

Fig.3 voltage of different No. of piezo elements .

Figure.(3) show linear increase of v_{max} as the frequency of applying load increase up to 10 Hz then a quick increase in voltage with a steady increase in frequency is noticed . that behavior could be attributed to the cumulated strain response of piezo elements with different positions[20 ,16].

b) Change the diameter of piezoelectric elements

when the diameter of the piezoelectric element is changed, it produces different output voltage. The increase in the diameter of the piezoelectric leads to an increase in voltage . A piezoelectric sensor with a diameter of 20 and 35 mm was examined and the same frequencies were applied. It was observed that the output voltage is directly proportional to the increase in the diameter of the piezoelectric sensor [21,17]. As shown in Figure(4).

Table [3]. frequency and voltage output of 6 piezo elements

		Vmax at diameter(mm)	
test.no	frequency	20 mm	35mm
0	0	0	0
1	8.75	0.388	4.94
2	12.73	0.236	5.13
3	16.87	0.294	4.93
4	21.46	0.333	5.06
5	24.19	0.344	4.9
6	27.85	0.312	4.21
7	31	0.28	3.98
8	34.38	0.593	5.56

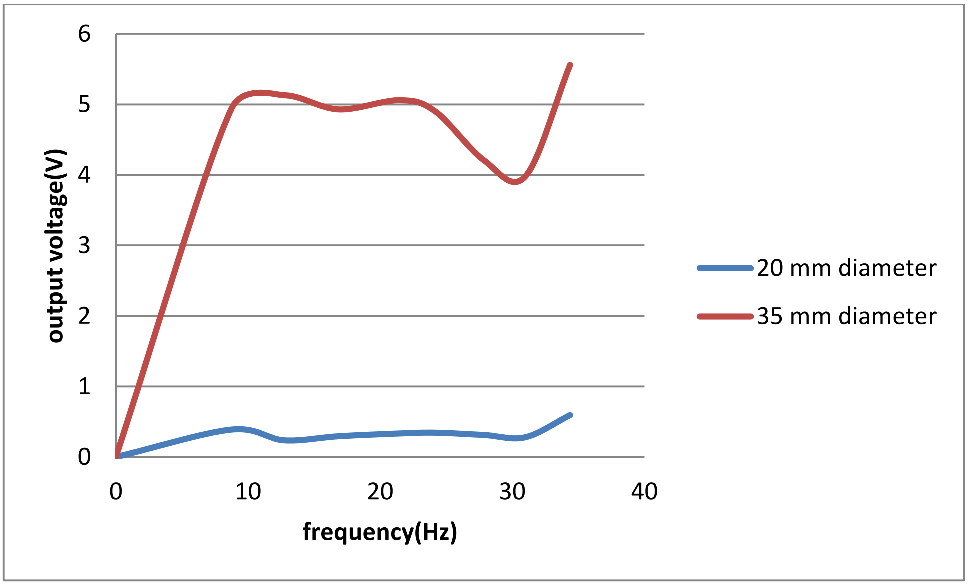

Fig. 4. Varying the diameter of piezoelectric sensors with d=20mm

c) Distance from rotating axis

The applied load was considered according to the source of vibration . since most of vibration sources are due to structural movement(angular or linear). A designed configuration was performed to apply load with different frequencies to simulate the a fluctuated movement .when the distance increases, the increase will lead to more pressure on the spring placed under the playwood board, which is tangent to the board , This leads to greater pressure on the piezoelectric sensor. the increase in pressure on the piezoelectric sensor will generate an increase in stresses in the piezoelectric, which leads to the production of a greater output voltage[18,19]. As shown in Figure(5).

TABLE 4. RELATION BETWEEN FREQUENCY AND VOLTE OUTPUT

Voutput at distance(mm)

frequency	10	15	20	25
0	0	0	0	0
8.75	0.139	2.76	4.94	5.02
12.73	0.123	2.65	5.13	6.27
16.87	0.253	2.65	4.93	7.02
21.46	0.182	2.38	5.06	6.9
24.19	0.258	2.32	4.9	6.14
27.85	0.176	2	4.21	5.95
31	0.089	1.02	3.98	5.05
34.38	0.104	1.66	5.56	8.8

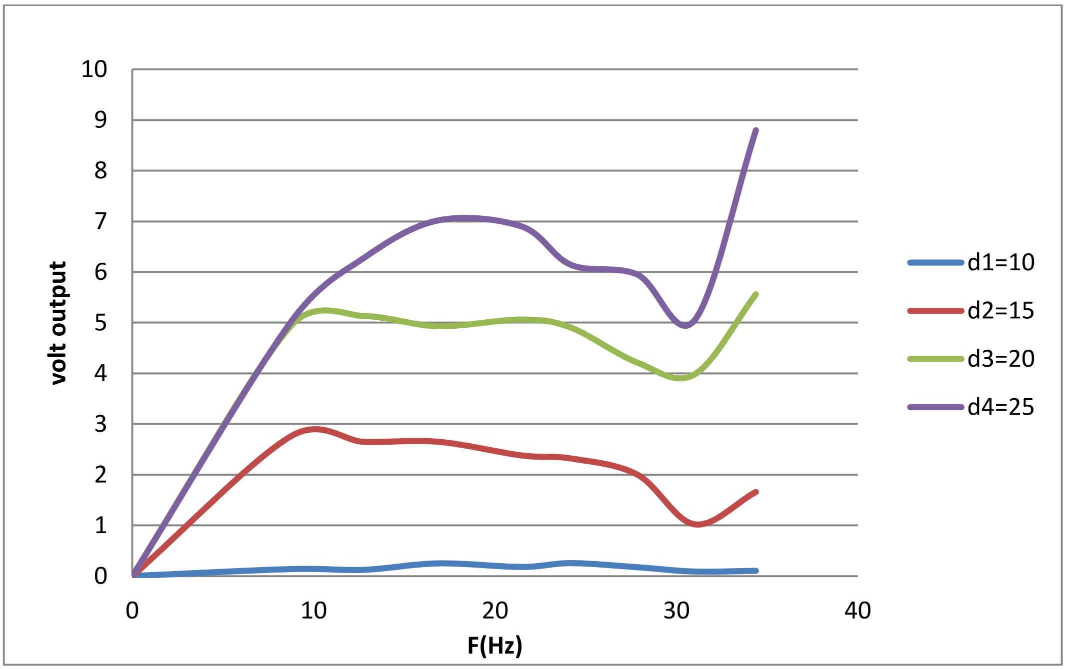

Fig. 5 The distance from rotating axis

Figure 5 above show that a similar behavior of linear relation obtained of voltage harvested with the increase OF frequency till it reach 10Hz. a great converges obtained in d= 20 and 25 at this frequency. Increasing frequency up to 40 Hz led to different output voltage [18].

5. CONCLUSION

study energy harvesting from vibration considering many factors. Some of them are less affecting than others. Distance from rotating axis and cavity below the element are most affecting factors .increasing the piezo pieces and diameter less effect .increasing frequency of applying load have considerable effect with .spring stiffness and No. effect the harvested energy .

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