DESIGN OF A CLOSED CHANNEL FLUID FLOW SYSTEM FOR PIEZOELECTRIC ENERGY HARVESTING

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Abstract – *A significant growth has experienced in the field of energy harvesting using piezoelectric material from fluid flows over the last decade. Inspired by the growing demand and unique capability of the piezoelectric material to convert the mechanical vibration or pressure into electrical energy; the authors present an efficient dynamic model of piezoelectric energy harvester in the paper. This paper includes the design and development of the model of piezoelectric energy harvesting system using hydro-dynamism and conversion of dynamic fluid flow pressure of waste water into electrical energy using a single piezo-patch made from a piezoelectric material i.e. PZT (Lead Zirconate Titanate). The flowing water is made to strike on the piezoelectric patch of PZT for the conversion of pressure energy of water into electric potential on the basis of piezoelectric effect.*

Key Words: Energy harvesting, Fluid flow, Piezoelectric patch, Energy generation, Full-Bridge rectifier circuit and Voltage doubler circuit.

1. INTRODUCTION

Energy harvesting is the process of extracting the available ambient energy from the environment, conditioning it in a convenient manner and stored it for future use. This energy can be stored as the electrical energy (the most used form of energy) which can be readily used for various applications. It is an easy way to generate electrical energy from the unused or untapped energy. So, interest of the researchers increase rapidly in this field. The piezoelectric materials are the best alternatives for the escalating demand to provide moveable and wireless electronic devices with extra life span. Therefore, many researchers have been done to harvest energy using these materials and developed it as self-powered source (that does not require replacable power supplies) for portable devices and wireless sensors at micro-level. The technology of energy harvesting at micro-level is capable of producing mW or µW level power. The capability of piezoelectric materials to produce electric power from mechanical vibration makes them attractive for harvesting energy from various sources such as light, wind, waves, flowing water etc. The Researchers focus in this field is to make less dependency on the external sources to power for initiation. The main aim of this research area is to power the portable electronic devices by using the available ambient source in their environment that can minimize the use of the apparent sources. The purpose of the work in this paper is to provide a renewable energy source at micro-level which can power the portable devices. So, in this paper, a dynamic model is presented for energy harvesting to create a self-powering device using piezoelectric material from fluid-flow dynamism.

1.1 Material Selection

In the present study, PZT (Lead Zirconate Titanate) is used for the purpose of harvesting energy from the dynamic flow of water. PZT is a metallic-oxide based ceramic piezoelectric material. It shows a greater sensitivity as compare to its predecessor i.e. Barium-Titanate. As PZT is physically strong and flexible so it can work against high pressure and forces applied by the flowing water. PZT has high piezoelectric constant and quality factors which make it suitable for piezoelectric energy harvesting. Figure 1 shows the piezoelectric patch made from PZT that used for energy harvesting.

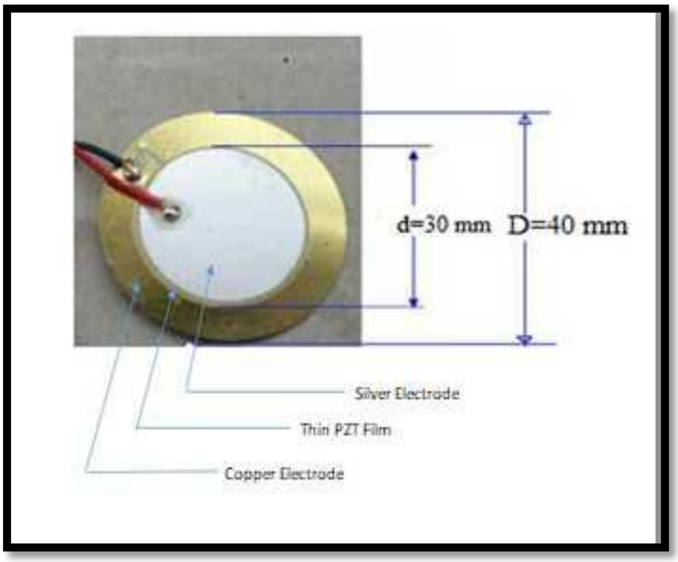


Figure 1 PZT Piezo-patch

Table 1 shows the basic properties of the PZT piezo-patch used for energy production.

Property	Value	Units
Compound Formula	$O_5PbTiZr$	-
Molecular Weight	426.49	g/mol
Density	7.75-8.0	Kg/m^3
Young's Modulus	49	GPa
Curie Temperature	360	Deg.C
Dielectric Constant	1700	-
Coupling Coefficient (k_{33})	0.69	K^2
Dielectric Strength	8-16	MV/m
Strain Coefficient (d_{33})	3.6e-10	m/V
Voltage Coefficient (g_{33})	0.025	V*m/N
Thermal Expansion Constant	11e-6	/K

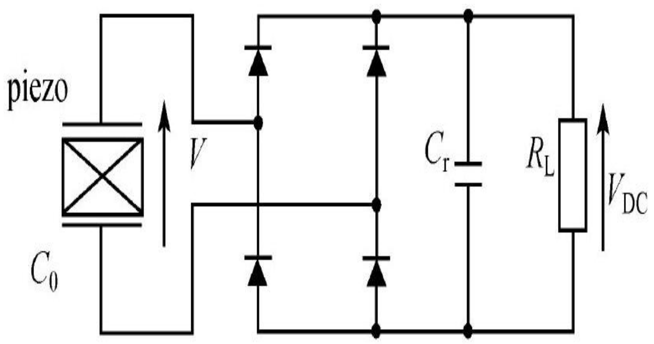
Table 1: Properties of PZT material used

1.2 Description of the smart electrical circuit

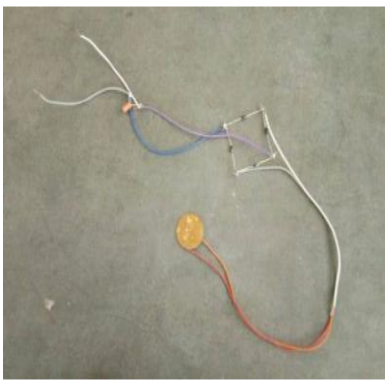
The piezoelectric patch circuit produce output in AC (alternating current) which can be converted into DC (direct current) by using full-bridge rectifier and voltage doubler circuit.

Full-Bridge Rectifier Circuit:

This circuit consists of a diode rectifier and filter capacitor or four diodes in full-bridge configuration and AC source. This circuit converts the whole AC input into constant polarity DC and generate a higher average voltage. Figure 2 shows the schematic and actual circuit of PZT patch with full-bridge rectifier circuit.



(a)

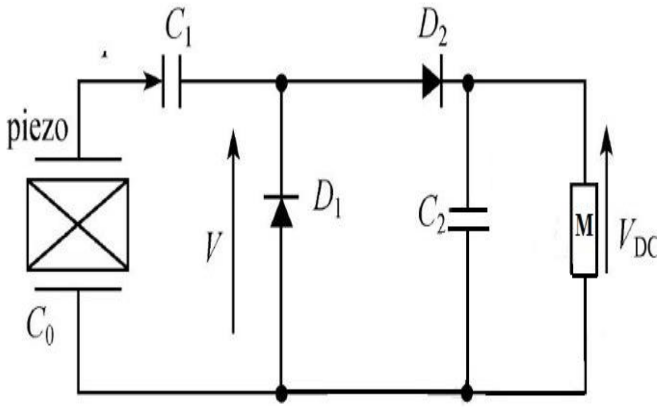


(b)

Figure 2 (a) Schematic of Full-Bridge Rectifier Circuit (b) PZT-Patch with Full-Bridge Rectifier Circuit

Voltage Doubler Circuit:

This circuit converts the AC input voltage into doubled DC output voltage. This circuit consists of two capacitors, two diodes and a multimeter used to measure the output. It is applicable where high power is required for a high resistance load. Figure 3 shows the schematic and actual circuit of PZT patch with voltage doubler circuit.



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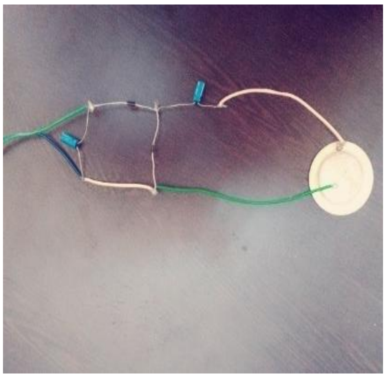

(b)

Figure 3 (a) Schematic of Voltage Doubler Circuit (b) PZT patch with actual Voltage Doubler Circuit

1.3 Description of the Model

The proposed mechanical model is composed of a water tank, an electric motor, pipe to circulate the water flow, PZT patches, flange coupling to provide housing to piezo-patch and water flow measuring system to control the flowing rate of fluid flow. The model is made from a PVC (Polyvinyl Chloride) pipe which is connected to a flange coupling due to cut from the middle of pipe and tightened by means of nuts and bolts. Meshing in the flange coupling is used to provide housing to the piezo-patches. These patches are further connected to the circuit and covered by tape to increase their durability when the flowing water strikes at its surface to produce electrical voltage. This voltage is measured by using a multimeter which is attached to the rectifier circuit. Figure 4 depicts the experimental model of apparatus and the housing of PZT-patch inside the flange coupling. This working model can be used to extract maximum energy from the circuit connected to a multimeter from the flowing water strikes to piezoelectric patches.

Figure 4 (a)
Experimental Model of Apparatus

Figure 4 (b)
Housing of PZT-patch inside the flange coupling

Here, the water tank is used to store and supply water to the system. The electric motor is used to re-circulate the flow of water. The electric circuit is used to store the extracted energy for future use. This energy harvesting model can be used where the water supply is continuous, ranging from low flow water discharge as in homes kitchen drains, brook etc. to high flow water discharge sources like bridge, lakes, rivers, industrial waste disposal etc.

2. DISCUSSION

There are various methods of energy conversion which can be utilized to harvest energy from ambient sources. But from every bit we have seen that their use is limited for a particular case of ambient condition. Electrostatic system requires the initial voltage. In electromagnetic system, there is no generation of a high frequency response due to the hardly movement of coil arrangement. The solar system is applicable only for the conversion of solar energy into usable form. Among all of these we can see that the piezoelectric energy generation or energy generation by piezoelectric material is more beneficial than others due to its reliability and wide range of excitation. Also the power requirement for initiation is very low as compare to other available options and they can be easily integrated with other systems. Thus, we can see that the piezoelectric material can be effectively used for energy harvesting as compare to other harvesting systems. In order to specify this purpose, the authors present the model of piezoelectric energy harvesting system which can convert the dynamic fluid flow pressure of water into electrical energy using piezoelectric patches made of PZT (Lead Zirconate Titanate) with different configuration of circuit that can be extracted maximum energy.

3. CONCLUSIONS

- An effective and efficient model has been developed for piezoelectric energy harvesting from closed channel fluid flow system to convert the dynamic fluid flow pressure of water into electrical energy using PZT as piezoelectric material.
- A feasible and potential source of renewable energy is presented to reduce the dependency on non-renewable energy sources such as batteries made up of harmful chemicals i.e. lead, cadmium, lithium and mercury.
- This system can be used to generate power from the flowing water which can be the wasted water from households, industries, power plants etc.
- This system can be utilized to produce bio mimetic motion such as the motion of fish, jelly fish, eel etc. to build the underwater robotic device for the production of constant electrical energy.
- The model presented here can be used to provide power for running portable electronic devices such as bulbs, mobiles etc.

- This can help us to develop bio-sensors for regular check-up of patient's vitals such as blood pressure, sugar level etc. and also used in other medical applications.

- The model can likewise be used where the quantity of water is scarce and this is an environmental-friendly and cost-effective energy source for both urban and rural areas.

REFERENCES

1) P. Dhingra, J. Biswas, A. Prasad & S.S. Meher, " Energy harvesting using piezoelectric material, Special Issue of International Journal of Computer Applications", International Conference on Electronic Design and Signal Processing, 2012.

2) H.D. Akaydin, "Piezoelectric energy harvesting from fluid flow", CITY UNIVERSITY OF NEW YORK, 2012.

3) A. Erturk & D.J. Inman, "Piezoelectric energy harvesting", John Wiley & Sons, 2011.

4) H.A. Sodano, G. Park & D.J. Inman, "Estimation of electric charge output for piezoelectric energy harvesting", Strain, 40, pp. 49-58, 2004.

5) S.R. Anton & H.A. Sodano, "A Review of power harvesting using piezoelectric materials (2003-2006)", Smart Materials and Structures, 16(3), R1, 2007.

6) S.P. Beeby, M.J. Tudor & N.M. White, "Energy harvesting vibration sources for micro-system applications", Measurement science and technology, 17(12), R175, 2006.

7) H.D. Akaydin, N. Elvin & Y. Andreopoulos, "Energy Harvesting from Highly Unsteady Fluid Flows using Piezoelectric Materials", Journal of Intelligent Material Systems and Structures, 21(13), pp. 1263-1278, 2010.

8) W.G. Ali & G. Nagib, "Design considerations for piezoelectric energy harvesting systems", In Engineering and Technology (ICET), 2012 International Conference, pp.1-6, IEEE, 2012.

9) A. Kumar & D. Chhabra, "Fundamentals of piezoelectric energy harvesting", International Journal for Scientific Research and Development, 4(5), 2016.

10) S.D. Kwon, "A T-shaped piezoelectric cantilever for fluid energy harvesting", Applied Physics Letters, 97, 164102, 2010.

11) K. Narwal & D. Chhabra, "Analysis of simply supported plates for active vibrations control by piezoelectric sensors and actuators", Journal of Mechanical and Civil Engineering, 1(1), 2278-1684, 2012.

12) A. Kumar & D. Chhabra, "Study of PEH configurations & circuitry and techniques for improving PEH efficiency", International Journal for Scientific Research and Development, 4(3), pp. 2098-2102, 2016.

13) A. Jbaily & R.W. Yeung, "Piezoelectric devices for ocean energy: a brief survey", Springer International Publishing, 2014.

14) A. Budhwar & D. Chhabra, "Comparison of energy harvesting using single and double patch PVDF with hydraulic dynamism", International Journal of R & D in Engineering, Science and Management, 4(1), pp. 56-67, 2016.

15) H.A. Sodano, D.J. Inman & G. Park, "A review of power harvesting from vibration using piezoelectric material", The Shock and Vibrations, 36(3), pp. 197-205, 2004.

16) P. Rani & D. Chhabra, "Piezoelectric energy harvesting from fluid flow dynamism using PVDF", International Journal of R & D in Engineering, Science and Management, 4(1), pp. 23-36, 2016.

17) Abrol S. & Chhabra D, "Harvesting piezoelectricity using different structures by utilizing fluid flow interactions", International Journal of R &D in Engineering, Science and Management, 5(7), pp. 24-36, 2017.

18) S. Abrol & D. Chhabra, "Experimental investigations of piezoelectric energy harvesting with turbulent flow", International Journal of Mechanical and Production Engineering Research and Development, 8(1), pp. 703-710, 2018.