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Optimisation and Implementation of a Vibrational Induced Energy Based Sensor System Using PVDF Cantilever

Chayanika Sharma[1]
chayanika114@gmail.com

Babak Montazer[1]
babakmont1212@gmail.com

Utpal Sarma[1]
utpal.sarma.in@ieee.org

[1] *Department of Instrumentation & USIC ,Gauhati University, Guwahati, India*

***Abstract*—This paper addresses the optimization and implementation of a PVDF based flow sensing system. A chamber with six cavities arranged in an array has been simulated and the response of the sensing element at different locations are studied and verified experimentally. Some geometric parameters such as the dimension of the channel and the distance of the holes from the cantilever are varied and the response of the cantilever is monitored. The experiment is performed for different velocities of the air flow.**

***Index Terms*—PVDF film, flow sensor, energy harvester, ambient vibrational energy.**

I. INTRODUCTION

A self-sustained flow sensing system requires a flow sensor that converts the environmental parameters (e.g. fluid flow, wind flow etc.) into suitable electrical form. The vibration produced by a flowing fluid offers a continuous source of energy for low power applications [1]. The first prototype of flow induced vibration as a form of renewable source of energy was developed by Bernitsas et al. in 2008 [2]. The use of renewable sources of energy such as, solar energy, wind energy etc. in the field of electronics provides a permanent solution for power that does not require periodic replacement [3]. Over last few years, the development of low power devices and self-powered techniques with renewable sources of energy become very important as the need and use of power electronics increase rapidly. The movement produced in a slender beam because of mechanical vibrations can be converted into a suitable electrical form [4], [5], [6]. The use of micro-electromechanical systems (MEMS) provides efficient ways for generating operating energy from these renewable sources of energy [7]. Piezoelectric energy harvesting system has been investigated by many researchers [8]. The vibrations produced by flowing fluid can be converted to an electrical signal by a piezoelectric thin film sensor. The piezoelectric sensors provide outputs as a function of deformation caused by the flowing fluid surrounding it. The polymer-based piezoelectric materials have advantages such as higher mechanical strength and flexibility, lower fabrication cost and faster processing over other piezoelectric materials [9]. However, harvesters from air flow can be extensively developed because of the availability of wind flow around us. The present work aims at developing a piezoelectric vibrational energy harvesting system which uses a fluid stream inside a small channel. In this Finite Element Analysis (FEM) -based simulation study, a fluid (air) is surrounding a piezoelectric PVDF cantilever. Fluctuations of fluidic parameters (pressure and velocity) cause a deformation of the piezoelectric cantilever. The deformation of the piezoelectric beam produced an equivalent electrical signal as a function of this deformation [10]. The piezoelectric material properties are kept unchanged throughout the study, but the fluidic parameters and the channel properties are systematically varied to attain the optimum design parameters for the highest sensitivity of the developed harvesting system. An experimental prototype is designed and investigated based on the simulation-based model.

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A. Principle

A piezoelectric cantilever (shown in Fig.1) vibrates due to the pressure difference between the upper and lower parts of it. The cantilever generates a piezoelectric voltage which is a function of this deformation. The generated charge Q is given by equation (1).

$$Q = \frac{d_{31} E_p M}{\sum_i E_i (l_i + A_i {Z_i}^2)} Z_p w dx \tag{1}$$

where d_{31} is the piezoelectric coefficient, M is the bending moment applied to the cantilever at each point . w is the width,E_p and E_i are youngs modulus of each layer,Z_p and Z_i are the distance between the center of each layer and bending neutral plane respectively, l_i is the second moment area and A_i is the cross-sectional area of each layer. [11]

When the pressure difference $\triangle P$ in the direction of the thickness of the cantilever is uniform, the bending moment M on the beam at location x is expressed as follows:

$$M = \frac{w \triangle p (l-x)^2}{2} (0 < x < l) \tag{2}$$

where l and w are the length and width of the cantilever respectively (shown in Fig.2).

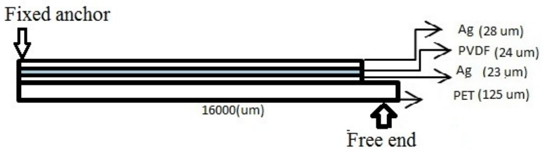

Fig. 1. PVDF cantilever

Substituting equation (2) in equation (1) and integrating from 0 to l, the total charge can be obtained as:

$$Q = \frac{(d_{31} Z_p E_(p.) \triangle p w^2 l^3)}{(6 \sum_i E_i (l_i + A_i {Z_i}^2))} \tag{3}$$

From these two equations, the piezoelectric voltage can be calculated as:

$$V = \frac{(d_{31} Z_p E_(p.) \triangle p w^2 l^3)}{(6 \sum_i E_i (l_i + A_i {Z_i}^2))} \frac{1}{C_p} \tag{4}$$

where C_p is the capacitance of the PVDF layer and is given by

$$C_p = \epsilon \epsilon_0 \frac{A_{UE}}{t} \tag{5}$$

where ϵ and ϵ_0 are the dielectric constant for vacuum and relative dielectric constant of the PVDF film, respectively; A_{UE} is the area of the upper electrode; and t is the thickness of the PVDF film.

II. NUMERICAL MODEL OF THE HARVESTER

Simulation using Finite Element Analysis shows that any change in fluid flow velocity creates a pressure difference, as a result of which vibrations occur in the piezoelectric beam. In a fluid-structure interaction (FSI) module [12], the fluid (air) is surrounding a solid object (piezoelectric beam). The flow channel [11] consists of three parts, as shown in Fig.3.

- The top part of the channel is for the flow of air consisting of inlet and outlet.
- The middle part contains a piezoelectric cantilever and the holes for pressure propagation.
- The last part is a bypass channel.

An array of holes are constructed. As the position of the holes is varied, the pressure surrounding the cantilever changes. The differential pressure is measured inside the flow channel and from this mass flow rate is calculated using the equation (6).

$$R = \frac{(C_d A Y F_a \sqrt{2 \rho \triangle P})}{\sqrt{(1 - \beta^4)}} \tag{6}$$

Here, $C_d, A, , \rho, \triangle P$ represent the discharge coefficient, Area of inlet, Density of air and differential pressure between the inlet and outlet, respectively. The thermal effect (Y) is ignored and the flow is considered as incompressible (hence, $F_a = 1$).

The dimensions of the 2D domain are:

- length L=120 mm;
- height H1=60mm; H2=40mm;
- hole diameter=8mm

The pressure difference between the inlet and outlet was recorded. A time-dependent analysis was performed to observe the response of the beam due to the fluid flow inside the channel. FSI model provided the deflection of the cantilever with the change in mass flow rate inside the flow channel. Table1 shows the material properties of the piezoelectric cantilever shown in Fig.1.

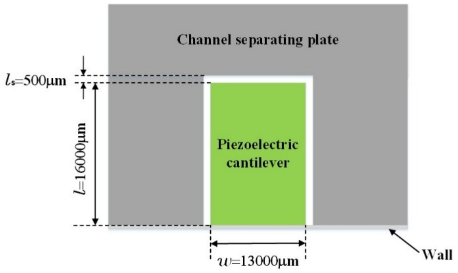

Fig. 2. Design of piezoelectric cantilever

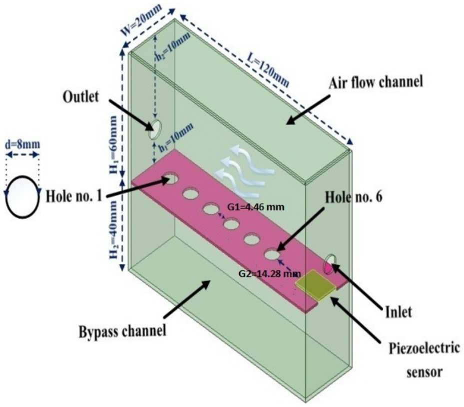

Fig. 3. 3D schematic of flow channel

TABLE I
MATERIAL PROPERTIES OF PIEZOELECTRIC AND SUBSTRATE MATERIALS OF PVDF CANTILEVER

Material	**Density** kg/m^3	**Elastic modulus** (GPa)	**Poissons ratio,** ν	**Relative permittivity,** ϵ_r	**Piezoelectric strain constant** PCN^{-1}	**Dynamic Viscosity** (Pas)
PVDF	1780	2.04.0	0.3	1213	23	
PET	1400	2.02.7	0.37-0.44	–	–	–
Ag	10500	$83E9$	0.37	–	–	–
Air	1.225	–	–	–	–	$1.98E-5$

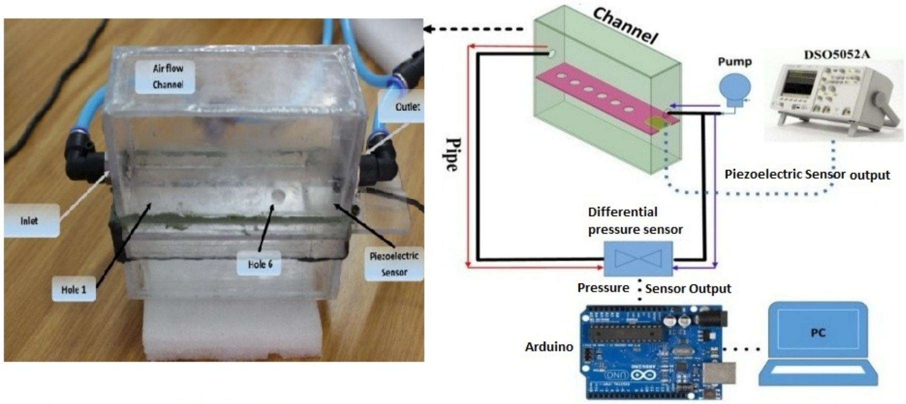

Fig. 4. Block diagram of the proposed experimental setup of the system

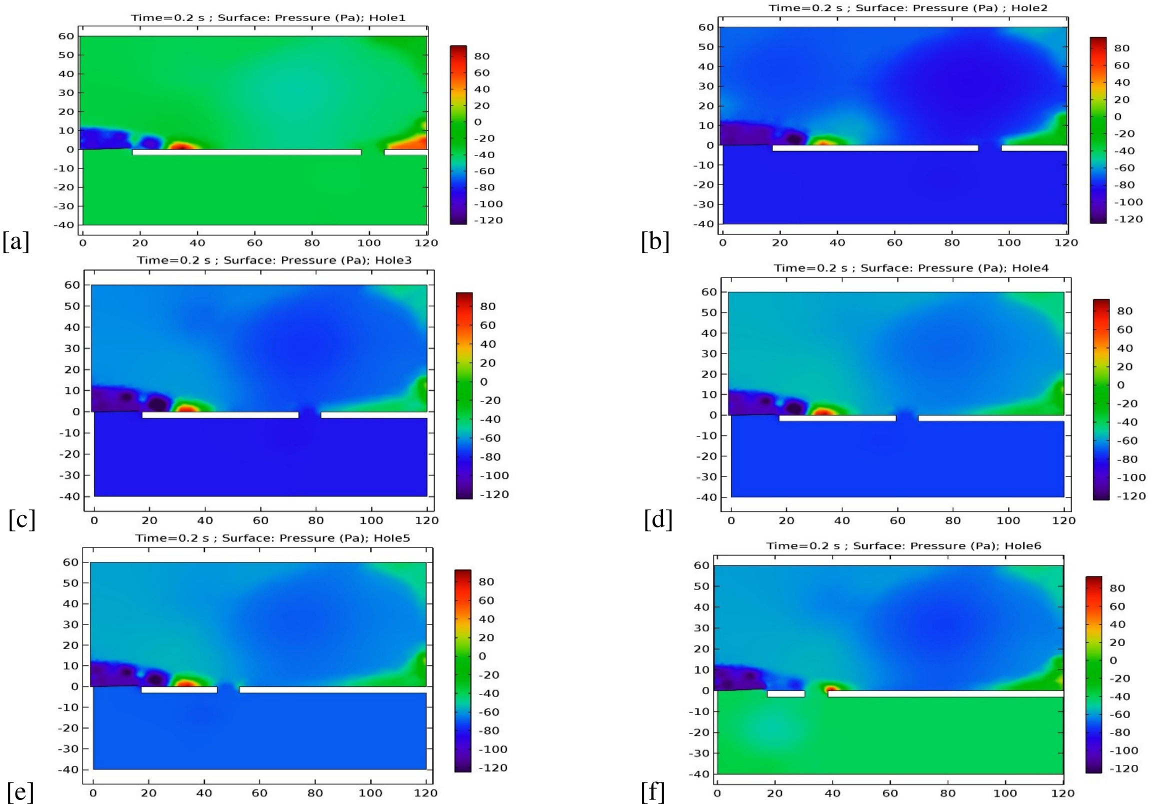

Fig. 5. Simulation results for for pressure difference at the upper and lower portion of the cantilever for six different positions of the holes

III. EXPERIMENTAL SETUP

In Fig.4, the block diagram of the complete experimental arrangement of the proposed system is shown. The piezoelectric sensor is placed on the same plane at which the holes are located. An air pump is used to provide the airflow inside the flow channel. The velocity of the flowing fluid and the positions of the holes are systematically varied to monitor and record the voltage generated by the piezoelectric cantilever. A pressure sensor is used to measure the differential pressure inside the flow channel and the response of the cantilever is recorded by an oscilloscope.

IV. RESULTS AND DISCUSSIONS

Based on the mathematical model developed, the voltage generated due to the deflection of the cantilever under certain air flow velocity can be obtained. In this section, we studied the sensitivity of the system with different geometric shapes of the flow channel and varying the flow parameters. The vibrational energy harvester driven by fluid flow provides electrical outputs in the millivolts range. The analysis was performed to study the sensitivity of the harvester. In the simulation, the

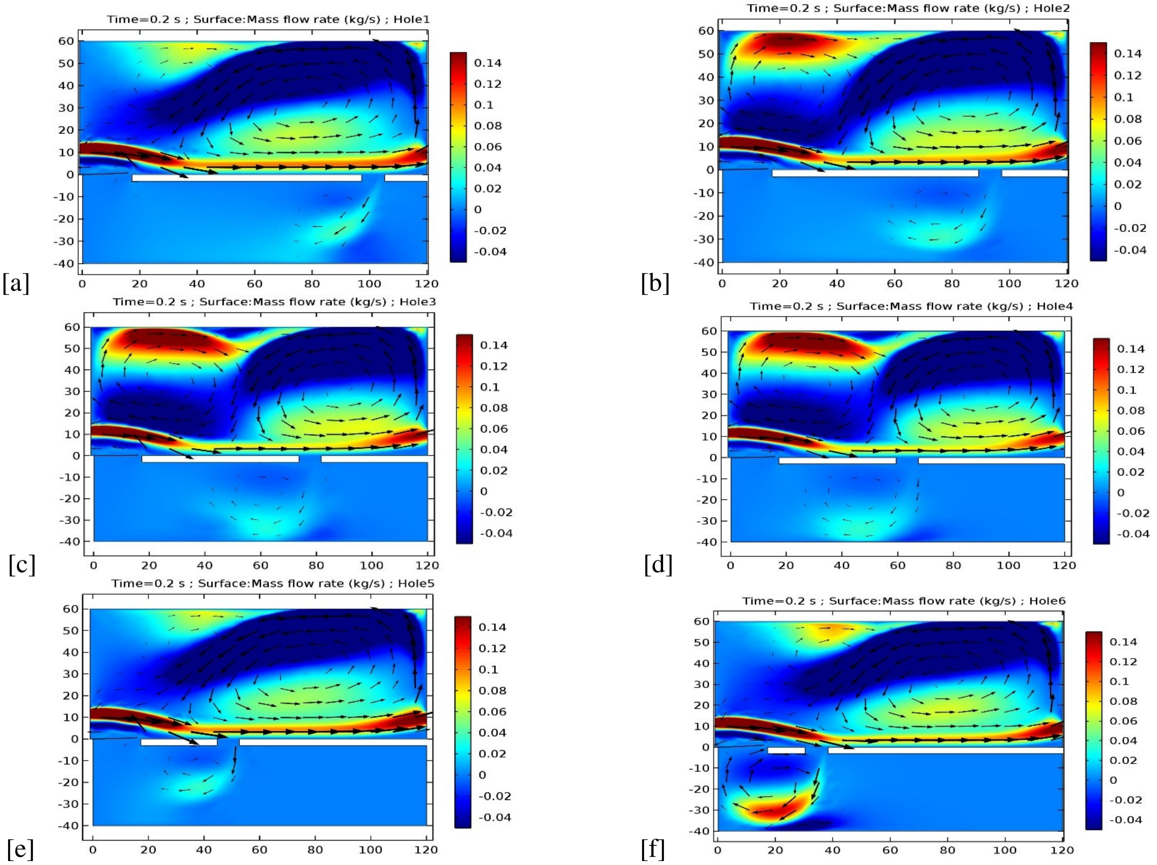

Fig. 6. FSI Simulation result for mass flow inside the flow channel for different holes

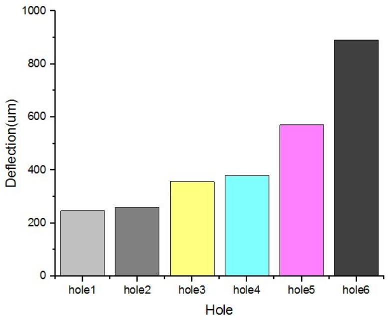

Fig. 7. Tip displacement of the cantilever for each hole in simulation

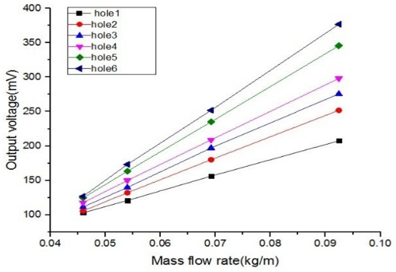

Fig. 8. Output voltage for different mass flow rates with different holes in experiment

model was optimized by varying the positions of the holes inside the model keeping the material properties unchanged. The simulation results for the generated pressure difference between the upper and lower parts of the cantilever and mass flow rate inside the flow channel respectively are shown in Fig.5 and Fig.6 . From Fig.7, we can conclude that the tip displacement of the beam for hole-6 is maximum. Hence output voltage is maximum for this situation. To validate this result, we can say that the upward pressure produced on the cantilever from the lower side due to the bypass cavity (hole) is changed, as the positions of the cavity change. The location of the sixth hole is near to the cantilever beam. Hence the upward thrust produced by the pressure through this bypass hole is maximum. Fig.8 gives the experimental results for different positions of the holes. The output voltage is maximum for hole6 which agrees to the simulation results. Fig.9 gives the comparison of the experimental and the simulation results. The simulation and experimental results are slightly different because a static analysis technique is used in the simulation. In Computational Fluid Dynamic (CFD) model, one end of the beam is kept fixed. The other end of the cantilever is displaced

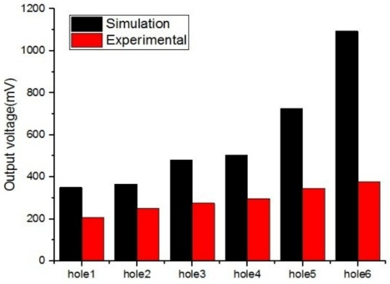

Fig. 9. comparison between experimental and simulated results

to respond to the flow of air inside the channel. However, in the CFD model, nonlinearity increases along the cantilever due to the pressure differences at the upper and lower parts of the cantilever. Again the piezoelectric constant in the experimental model might change with the applied stress [13]. During the experiment, the position of the cantilever that is kept fixed may shift. Due to these reasons, the difference between the experimental and the simulation results increases with time.

V. CONCLUSION

A FEM (Finite element method) Fluid-Structure Interaction model is developed to investigate the impact of the surrounding air to the damping nature of a MEMS cantilever. In this work a vibrational energy harvesting system is presented. The positions of bypass cavities inside the channel are varied to record the effectiveness of the harvester. The optimization of the flow channel is also done using a computational fluid dynamics method of analysis. This technique is promising for ambient energy harvesting for highly sensitive applications. The sensor responded with several millivolts when the mass flow rate of air is varied inside the flow channel. Different output voltages for different positions of the holes are obtained. Experimental set up is also made using piezoelectric cantilever to compare the simulated behavior of the model. With the optimized position of the cavity, the cantilever produces the maximum output voltage, which is desirable. Hence, these results showed the potential to apply the flow sensor to many applications in the future.

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REFERENCES

[1] S.-D. Kwon, “A t-shaped piezoelectric cantilever for fluid energy harvesting,” *Applied physics letters*, vol. 97, no. 16, p. 164102, 2010.

[2] M. M. Bernitsas *et al.*, “Vivace (vortex induced vibration aquatic clean energy): A new concept in generation of clean and renewable energy from fluid flow,” *Journal of offshore mechanics and Arctic engineering*, vol. 130, no. 4, p. 041101, 2008.

[3] M. M. Hassan *et al.*, “Vibration energy harvesting in a small channel fluid flow using piezoelectric transducer,” in *AIP Conference Proceedings*, vol. 1754, no. 1. AIP Publishing, 2016, p. 050041.

[4] N. Wu *et al.*, “Wind energy harvesting with a piezoelectric harvester,” *Smart Materials and Structures*, vol. 22, no. 9, p. 095023, 2013.

[5] Y. Su *et al.*, “Wind energy harvesting and self-powered flow rate sensor enabled by contact electrification,” *Journal of Physics D: Applied Physics*, vol. 49, no. 21, p. 215601, 2016.

[6] B. Montazer and U. Sarma, “Design and optimization of quadrilateral shaped pvdf cantilever for efficient conversion of energy from ambient vibration,” *IEEE Sensors Journal*, vol. 18, no. 10, pp. 3977–3988, 2018.

[7] M. Rezaee and N. Sharafkhani, “Electrostatically frequency tunable micro-beam-based piezoelectric fluid flow energy harvester,” *Smart Materials and Structures*, vol. 26, no. 7, p. 075008, 2017.

[8] B. Montazer and U. Sarma, “Modeling and analysis the effect of pzt area on square shaped substrate for power enhancement in mems piezoelectric energy harvester,” *Journal of Circuits, Systems and Computers*, vol. 26, no. 09, p. 1750128, 2017.

[9] K. S. Ramadan *et al.*, “A review of piezoelectric polymers as functional materials for electromechanical transducers,” *Smart Materials and Structures*, vol. 23, no. 3, p. 033001, 2014.

[10] H. Takahashi *et al.*, “Differential pressure sensor using a piezoresistive cantilever,” *Journal of micromechanics and microengineering*, vol. 22, no. 5, p. 055015, 2012.

[11] Y. Tomimatsu *et al.*, “A piezoelectric flow sensor for wake-up switch of wireless sensor network node,” in *2012 Second Workshop on Design, Control and Software Implementation for Distributed MEMS*, April 2012, pp. 53–57.

[12] G. Hou *et al.*, “Numerical methods for fluid-structure interactiona review,” *Communications in Computational Physics*, vol. 12, no. 2, pp. 337–377, 2012.

[13] D. Vatansever *et al.*, “Voltage response of piezoelectric pvdf films in vacuum and at elevated temperatures,” *Smart Materials and Structures*, vol. 21, no. 8, p. 085028, 2012.