Jurnal Ilmiah Teknik Elektro Komputer dan Informatika (JITEKI)
Vol. 8, No. 1, March 2022, pp. 76-82
ISSN: 2338-3070, DOI: 10.26555/jiteki.v8i1.22700

Effect of Continuous Working Fluid Flow Direction on Power Generation from Piezoelectric Sensors

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ARTICLE INFO

Article history:

Received December 31, 2021
Revised February 17, 2022
Accepted April 21, 2022

Keywords:

piezoelectric;
voltage;
current;
vertically;
horizontally

ABSTRACT

This paper presents an experimental study to support the concept of generating energy by a continuous flow of water using piezoelectric sensors. This study is aimed to determine the effect of external force direction of continuous water flow, i.e., vertical and horizontal, on the output of the piezoelectric sensors. The piezoelectric type of ABT-441-RC is used and arranged in parallel. IC MAX471 as an amplifier and Arduino Uno R3 to read the flow rate, voltage, and current were employed. Flow rates with variations of 0.00011 up to 0.00030 m^3/s are set to study the voltage and current of the output. The numbers of piezoelectric sensors used are 4, 6, 8, and 20. As a result, it is found that the pressure in the vertical direction differs up to 68% from the pressure in the horizontal one. The voltage and current in the vertical direction, compared to that of the horizontal direction, differ as much as 85% at a low flow rate and decrease down to 63% at a high flow rate for voltage and 86% to 34% at a low to high flow rate for current. In conclusion, the current generation by the present arrangement is within the micro-ampere range, and the voltage is in a volt range, respectively.

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1. INTRODUCTION

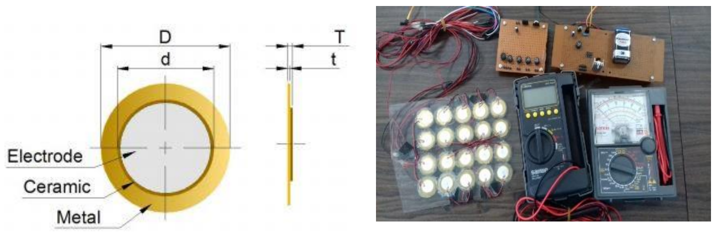
Renewable energy is the energy managed by natural processes that are sustainable and used as alternative energy. Renewable energy is environmentally friendly, thus contributing to overcoming global warming and reducing carbon dioxide emissions. Based on Indonesian government regulation number 79 of 2014 concerning National Energy Policy, Indonesia is targeting the use of new, renewable energy to a minimum of 23% (2025) and 31% (2050) [1]. There is so much research in developing renewable energy sources, both on a large and small scale. A kind of energy currently being developed is the use of piezoelectric technology because piezoelectric does not have a waste substance and is a source of abundant fuel. A piezoelectric sensor is a material that generates a mechanical strain when an external force is applied. The piezoelectric sensor is applied for various purposes in many industries and is used widely. Some applications of the piezoelectric effect are a piezoelectric motor [2][3][4], a piezoelectric screw pump [5], and power generation [6][7]. Piezoelectric technology can be utilized because this technology utilizes mechanical energy even though the energy produced is quite small. The piezoelectric material can convert both mechanical energy and electrical energy, and it is possible to directly apply the bimorph piezoelectric body to the generating power device for energy harvest; however, since its energy efficiency is low, attempt to apply it to the electricity generation was low [8][9].

A review has been done, and it has been found that by using rainwater pressure as an energy source, the amount of energy produced depends directly on the size of the piezoelectric membrane, raindrop size, and frequency [10]. The characteristics of a new wave power generating system have been proposed [11]. They installed a piezoelectric sensor to the seaward position of an existing coastal structure. By installing the sensor that way, waves will hit the piezoelectric sensor to generate energy, while at the same time, the structure acts as a wave breaker. Throughout the experiment, correlations between generation volume and wave conditions have been found. A technical simulation-based system to support the concept of generating energy from road traffic using piezoelectric materials has also been done [12]. The simulation design replicates a real-life system implementation. It investigates practicality and feasibility using a real-time simulation platform (MATLAB-Simulink). Energy harvested by piezoelectric sensors can also be generated by a vehicle that crosses speed bumps [13][14], by the shoe sole [15][16][17], or by unwanted ground vibrations that may cause sound pollution [18]. Power generation by the 3D model-piezoelectric transducer with bending mechanism support has been designed, and the energy can be harvested from walking energy when the piezoelectric tile is placed in that area [19]. Piezoelectric ultrasonic motor (PUM) was proposed, fabricated, and tested with a variation shape [20], high power-density, quick response with high accuracy and resolution [21][22][23], and applied in the field of high-tech and civilian use [24][25]. The use of piezoelectric as a sound vibration sensor to convert vibrations produced by the various object has been tested [26][27][28], which can be applied to a low-power device. Development of the piezoelectric sensors for use in devices with sub-micron-scale dimensions has been reviewed [29]. An overview of piezoelectric for electricity generation has been done [30]. The paper mention that three points should be considered, such as choosing piezoelectric material, assembling piezoelectric power generation equipment, and charge collector and energy storage equipment.

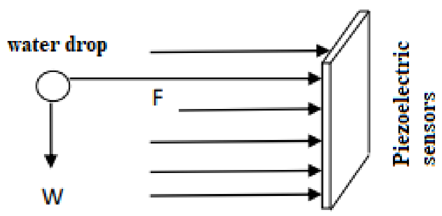
Rainwater, motor vehicle pressure, and noise as energy-input sources for piezoelectric sensors cannot last continuously. Thus, the pressure input for the sensors is limited. Therefore, a continuous source of input is an interesting topic to be studied. The present research contributions are analyzing the effect of flowrate variations in continuous water flow on the piezoelectric sensor and the number of piezo-sensors to the output for power plants in the form of voltage, current, and power. In theory, the stress generated in the vertical direction will be better than in the horizontal direction. However, in this study, qualitative data will be shown.

2. METHOD

The test section components in the experiment consist of a piezoelectric disk bender up to 20 pieces, flowmeter, IC MAX471 to read current and voltage output, buffer (LM741) to maintain the output signal, digital multimeter, Arduino Uno R3, and LCD to read the current and voltage generated by the system. The arrangement of the test section and input testing can be seen in Fig. 1. Piezoelectric sensors are arranged in a parallel circuit on an acrylic plate and separated from the other components. Flow rate measurement is made digitally by using a flow meter sensor as a measuring tool and Arduino Uno for displaying measurement data. The measurement is carried out to obtain the volume of water that hits the test section. The water flow rate is set with variations from 0.00011 to 0.00030 m^3/s to get the pressure variation.



(a)



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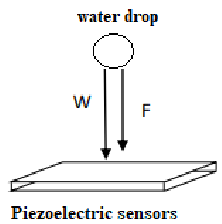

(c)

Fig. 1. (a) The arrangement of 20 pieces of parallel piezoelectric sensors as a test section (Piezo Disc Bender (PZT), D=27 mm, d= 20 mm, T=0.52 mm, t=0.3 mm) (b) Schematic diagram for horizontal flow, W is the force due to gravity and F is the force due to mass multiplied by its acceleration (c) Schematic diagram for vertical flow.

Flow velocity measurement is made by measuring the flow distance from the end of the pipe to the test section divided by the time required for water to arrive section. The distance between the flow source and the test section is 50 to 60 cm. The present study studied two kinds of inputs, i.e., horizontal and vertical directions of continuous water flow. The pressure (P) experienced by the piezoelectric sensor can be calculated hypothetically as follows [31]:

$$P = \frac{F_{horizontal}}{A} = \frac{\rho Q v}{A} \quad (1)$$

where ρ is the density of the water, Q is the water flow rate, v is the velocity of the water, and A is the surface area of the test section. For the vertical pressure, we use the following relation:

$$P = \frac{F_{vertical}}{A} = \frac{\rho Q (v + gt)}{A} \quad (2)$$

where g is the Earth's gravitational acceleration, and t is a traveler time water to the test section surface. Measurement of voltage and current is made manually by digital multimeter and digitally by Arduino Uno, LCD, and PLX acquisition data application. Electric power values are then obtained by multiplying the voltage with the current in the average value after the steady-state condition is reached.

3. RESULTS AND DISCUSSION

The influence of the number of piezoelectric sensors on the output voltage and current has been investigated. The numbers of piezoelectric sensors used are 4, 8, 12, 16, and 20. Fig. 2 depicts the behavior of the test section to voltage and the current value of the present design arranged with a buffer. The test was done with the input of flowing tap water horizontal as far as 60 cm from the nozzle with a flow rate of 0.00011 m^3/s. Fig. 3 shows average voltage, current, and power values in the present testing. The gradients of voltage and current were 51 and 1.07, respectively. The summaries of the measurement based on the number of piezo sensors are tabulated in Table 1.

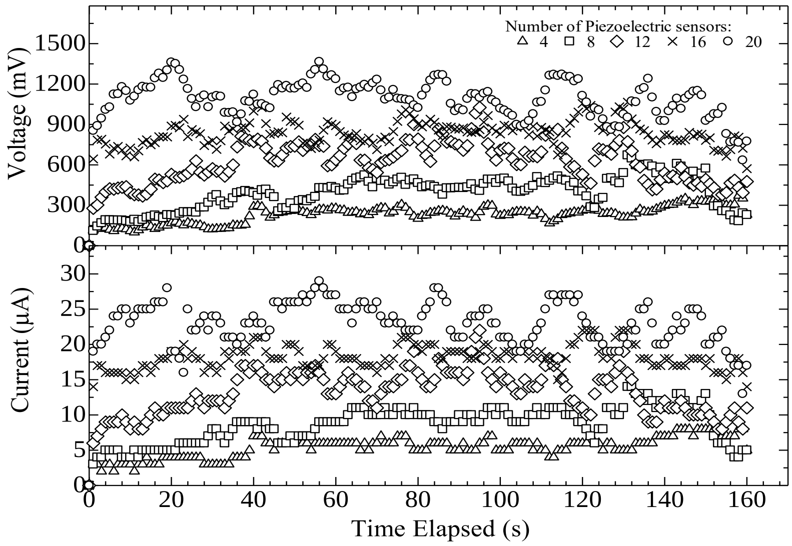

Fig. 2. Voltage and current characteristics of 4, 8, 12, 16, and 20 piezoelectric sensors

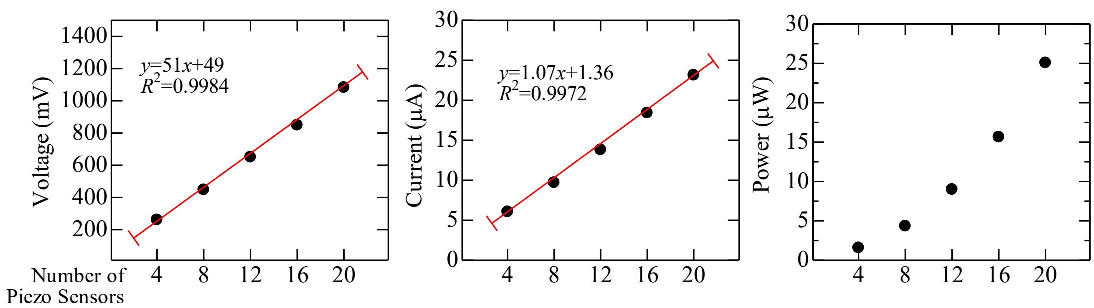

Fig. 3. Rate of the voltage and the current to the number of sensors

Table 1. The measurement result of the number of piezo sensors to the output

Number of sensors	Averaging Voltage (mV)	Averaging Current (□A)	Power (□W)
4	261.02	6.06	1.58
8	447.84	9.70	4.35
12	650.50	13.82	8.99
16	849.18	18.42	15.64
20	1082.78	23.15	25.07

Fig. 4 shows characteristics of velocity, force, and pressure in this experiment. It was shown that the water flow velocity in the horizontal direction has a lower value than that of the vertical direction for about 31% on average. The vertical flow velocity is in the same direction earth's gravitational acceleration, while the horizontal direction is perpendicular to the earth's gravity. This is assumed to be the cause of the difference in velocity. The maximum pressure obtained from the present study is about 13 to 72 Pa for vertical direction and 4 to 49 Pa for horizontal direction, as shown in the figure.

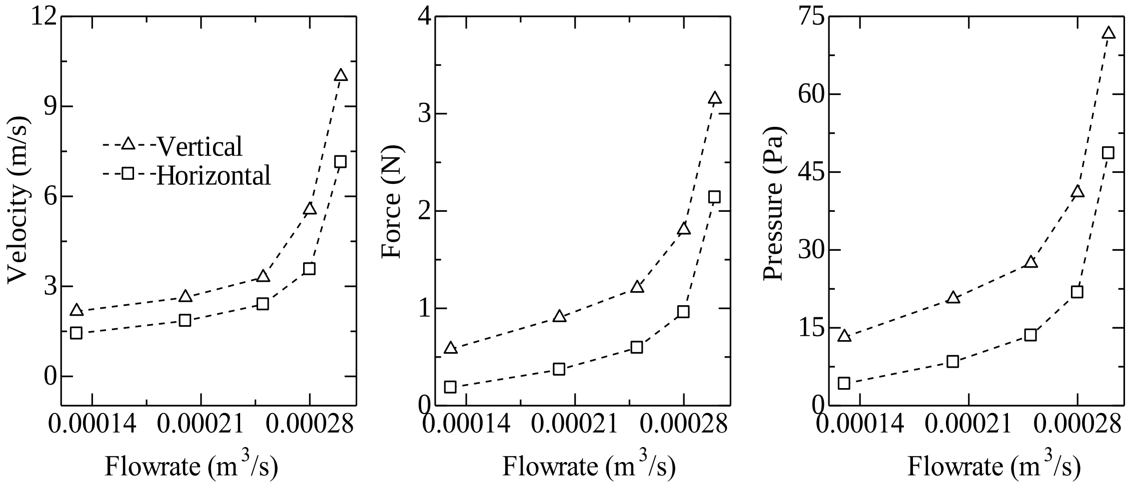

Fig. 4. Relation between velocity, force, and pressure to the flowrate

Fig. 5 and Fig. 6 show the voltage and current measurement data recorded by Arduino Uno using PLX software. The steady-state condition gets started at the 80th s due to parallel circuit arrangement. The voltage difference between the low and the high flow rate is around 2.58 V on vertical and 1.26 V on horizontal. In the case of current, we found that the current difference between the low and the high flow rate is about 72.58 μA in the vertical direction and about 64.88 μA in the horizontal direction. Fig. 7 shows the average calculation of voltage, current, and power to flowrate. The tabulated data is shown in Table 2.

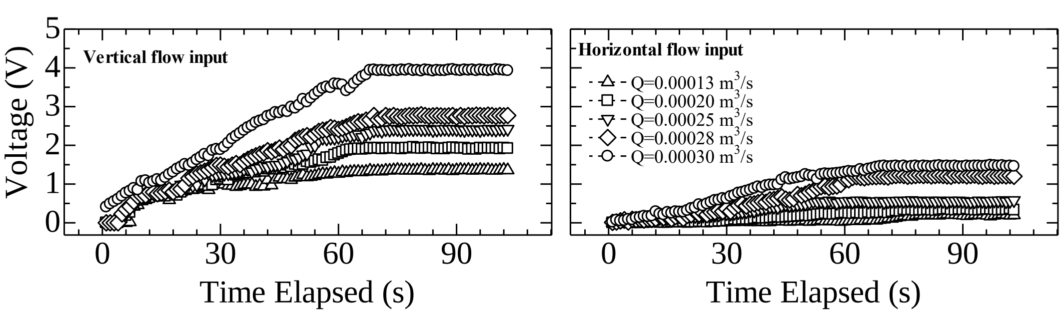

Fig. 5. Voltage measurement versus time

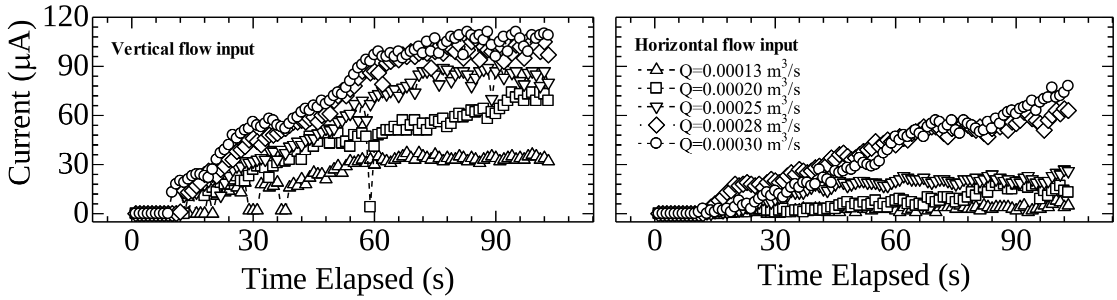

Fig. 6. Current measurement versus time

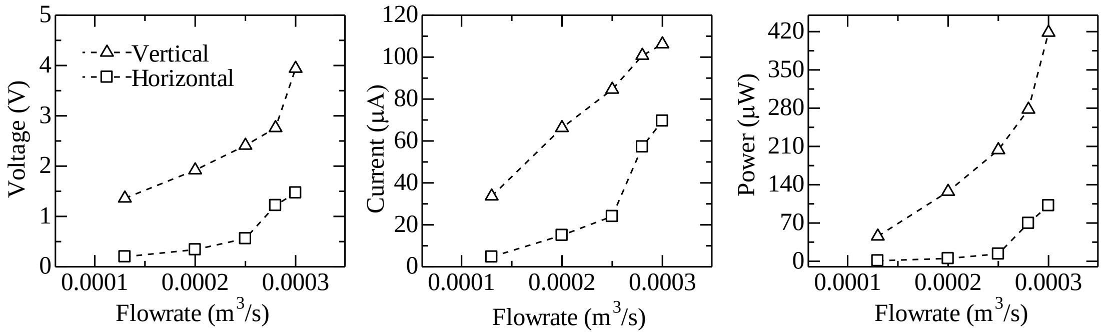

Fig. 7. Voltage, current, and power measurement versus flowrate

Table 2. The measurement result of the variation of flow rate and flow direction to the output

Flowrate (m^3/s)		0.00013	0.0002	0.00025	0.00028	0.0003
Flow velocity (m/s)	Vertical	2.17	2.63	3.30	5.55	10.00
	Horizontal	1.43	1.85	2.40	3.57	7.14
Force (N)	Vertical	0.58	0.91	1.21	1.81	3.15
	Horizontal	0.19	0.37	0.60	0.96	2.14
Pressure (Pa)	Vertical	13.20	20.59	27.44	41.04	71.59
	Horizontal	4.23	8.41	13.52	21.81	48.63
Average Voltage (V)	Vertical	1.35	1.92	2.41	2.76	3.94
	Horizontal	0.20	0.34	0.56	1.22	1.47
Current (μA)	Vertical	33.63	66.25	84.58	100.75	106.21
	Horizontal	4.72	15.03	24.06	57.25	69.59
Power (μW)	Vertical	45.65	127.43	203.60	277.68	418.37
	Horizontal	0.95	5.12	13.52	69.65	101.98

4. CONCLUSION

An experimental study shows the measurements of electric voltage and current in the direction of vertical and horizontal. The electrical voltage generated by the instrumentation system built of piezoelectric sensor-based power plants in the vertical direction is higher than that generated in the horizontal direction with the same flow rate. The voltage, as well as the current, in the vertical direction, differs with the voltage in the horizontal direction as much as 85% at low flow rate and decreases to 63% at the high flow rate, for voltage, and 86% to 34% at low to high flowrate, for current. In conclusion, the current generation by the present arrangement is within the micro-ampere range, and the voltage is in a volt range, respectively.

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