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Optimization of The Slope Angle of a Submerged Piezoelectric on a Laboratory Scale

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***Abstract*– Piezoelectrics are materials that can produce electrical voltage when subjected to mechanical stress. This unique property makes piezoelectrics widely used in various applications, such as sensors, actuators, and transducers. One important factor that can influence piezoelectric performance is the tilt angle. The tilt angle is defined as the angle between the piezoelectric surface and the direction of the applied force. This research aims to optimize the tilt angle of immersed piezoelectrics on a laboratory scale. Using the experimental method, this research was carried out using piezoelectric PVDF. Piezoelectric PVDF was chosen because it has good piezoelectric properties and is easy to obtain. Experiments were carried out by applying mechanical force to the piezoelectric PVDF with various tilt angles. Experimental results show that the optimal tilt angle for submerged piezoelectric PVDF is 90 degrees with a value of 7.46196 milliVolts at a flow speed of 1.2m/s. At this tilt angle, the piezoelectric PVDF produces the highest electrical voltage. The results of this study indicate that the optimal tilt angle for sunken piezoelectrics is 90 degrees. This could provide a basis for the development of more efficient and high-performance piezoelectric designs.**

Keywords– piezoelectric, tilt angle, experimental, PVDF, laboratory scale

I. INTRODUCTION

In this modern era, electrical energy has become a fundamental need for humans to carry out their activities. However, meeting the need for electrical energy still relies heavily on the use of fossil energy such as coal, natural gas, and oil According to the Central Statistics Agency (BPS), coal reserves in Indonesia can only last for around
62 years, natural gas for 35 years, and petroleum for 20 years [2]. Apart from that, conventional power plants that use fossil energy are one of the main contributors to air pollution (greenhouse gas emissions) which results in air pollution and the global climate crisis. In Indonesia itself, the scarcity of this energy source has become a fundamental problem, especially in big cities [6].

Ocean energy generators are an innovative technology that harnesses the natural forces of the ocean, including waves, currents, and differences in water temperature, to produce clean, sustainable electricity. This technology has great potential to diversify renewable energy and help reduce dependence on fossil fuels. As research develops and technological efficiency increases, marine energy generation is expected to make a significant contribution to meeting global energy needs while minimizing environmental impacts and supporting the sustainability of marine ecosystems [7].

Piezoelectricity is a material that can produce electrical energy when it experiences deflection [10]. Piezoelectricity has previously been widely used as a source of renewable electrical energy using several experiments, such as stepping on human feet in places that are busy with human mobility, speed bumps that are busy with public transportation, or shoes that are used every day which are modified using piezoelectric devices. Low- power energy generation generated by vibration has attracted significant attention [4][8].

Even though it produces low power, this piezoelectric generator has the advantage that energy is obtained naturally from undersea currents which have never been utilized, considering that Indonesia is a maritime country. Another advantage is that the power plant can be used to create a hybrid power plant with other power plants. Optimizing the tilt angle of piezoelectric immersed in water is important research in the development of new energy conversion technologies [1].

This research aims to find the optimal tilt angle that can maximize the electrical output of piezoelectric in submerged conditions, using a laboratory scale model for testing. The results of this research are expected to make a significant contribution to increasing the efficiency of piezoelectric-based renewable energy conversion systems, which have the potential to be applied on a larger scale in natural aquatic environments [11].

In this study, currents are used as the source of pressure to be applied. Ocean currents are the movement of seawater masses both vertically (upward and downward) and horizontally (sideways) from one location to another [3]. One factor influencing this phenomenon is the Coriolis effect, which causes the

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direction of ocean currents to be deflected by the Earth's rotation. In the Northern Hemisphere, ocean currents curve to the right, whereas in the Southern Hemisphere, they curve to the left [5].
The piezoelectric materials used in energy harvesting devices utilize the phenomenon of the direct piezoelectric effect. To understand and model the response of piezoelectric materials to applied mechanical loads, constitutive equations are required [9].

II. METHOD

A. Literature Study and Previous Research
This research begins with a literature study stage. At this stage, this is done by searching for literature or references regarding the modeling of the mechanism used, angles, current energy, and other references related to the topic of piezoelectricity. The literature sources for this research were obtained from books, final assignments, international journals, and previous research that has been carried out on land and in the air.

B. Identify the Problem
This research was conducted to answer existing problems, namely optimizing the tilt angle of submerged piezoelectrics on a laboratory scale to improve the performance and efficiency of the energy produced. To answer this problem, mechanism modeling is used by utilizing the current speed which will then hit the piezoelectric cantilever directly so that the piezoelectric will receive mechanical energy which can be converted into electrical energy. Another variable is the angle variation of the piezoelectric used. Problem identification involves several tools and materials for testing the mechanism. Problem identification involves several tools and materials for testing the mechanism.

1. Flume Tank
The mechanism that has been modelled and designed will be tested in a testing pool on a laboratory scale. The pool used is a Flume tank-type pool located in
the Marine Machinery System (MMS) Laboratory.

Figure 1. Flume Tank

2. Digital multimeter
A digital multimeter is a multipurpose tool used to measure various electrical parameters such as voltage (volts), current (amperes), and resistance (ohms). With a clear digital screen, this tool allows you to read measurement results quickly and accurately. Digital multimeters have basic functions such as measuring DC and AC voltage, DC and AC, and resistance. Additionally, it can test diodes and transistors and save live measurement data. However, unfortunately, this tool cannot be connected directly to a computer for further analysis.

3. Arduino Uno
Arduino Uno is an open-source platform-based microcontroller designed to facilitate the development of interactive electronics projects. The main function of the Arduino Uno is to read input, such as light on a sensor or touch on a button, and convert it into output, such as turning on an LED, driving a motor, or sending a signal to another device.

C. Mechanism Modeling
Making a prototype design in this case will be carried out after the outline design of the prototype has been realized in real form. This was done to avoid overbudget considering that this research uses pieces of piezoelectric material which are quite expensive. The prototype design can be seen in the following image:

Caption
1. Angle variations
2. Vertical support made of iron
3. Custom horizontal supports made of wood

After modeling a type of mechanism has been carried out, the next step is to turn it into a real model so that it can later be tested in a testing pool (flume tank). The test is said to be successful if all the modeling materials used can withstand the current speed and produce an electrical voltage output.

D. Mechanism Modeling Data
The initial mechanism modelling was carried out by making a 3D model. The dimensions of the modelling can be seen in the following table:

Caption
1. Example of piezoelectric placement at one of the angle variations (90º).
2. Vertical stand (Model A).
3. Horizontal stand (Model B).

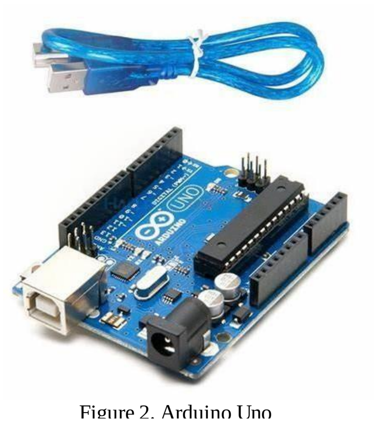

Figure 2. Arduino Uno

Figure 3. Digital Oscilloscope Multimeter

E. Data Collection

After realizing the modeling design, the next step is to collect data variations. Each variation in angle or current speed will be tested for 30 seconds to obtain the voltage value. Later it will be processed to obtain the most optimal electrical voltage value per angle variation.

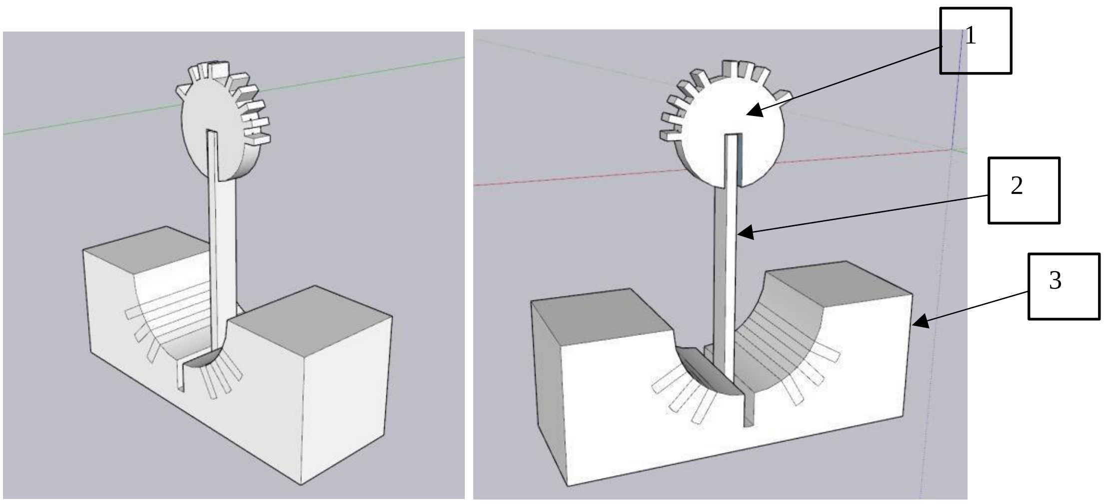

Figure 4 3D Mechanism Modelling

III. RESULTS AND DISCUSSION

A. Effect of Angle Variations on Average Stress

This subchapter presents a graphic analysis of test results that focuses on the effect of angle variations on the average generated voltage from piezoelectric. In this test, angle variations of 0º, 15º, 30º, 45º, 60º, 90º, 105º, 150º were used, with current speeds of 0.8 m/s and 1.2m/s. Electric dipole moment changes will produce an electric voltage on the surface of the material. It can be concluded that angle variations have a significant influence on the average voltage produced by piezoelectricity. The smallest average stress is produced at an angle variation of 150º because of its long distance from the flow source and minimal exposure to current flow. Meanwhile, the largest voltage is produced at a 90º.

Analysis of Figure 8 shows that there is a positive relationship between the piezoelectric surface area exposed to current pressure and the amount of voltage produced. This can be explained based on the working principle of piezoelectric materials which have an asymmetric structure that produces a permanent electric dipole moment. When this material is subjected to mechanical stress, its crystal structure is distorted, and its angle variation because the entire piezoelectric surface is directly exposed to current flow and the conversion of mechanical energy into electrical energy is more efficient.

TABLE 1
MECHANISM MODELING DATA

I. Model A (Vertical Support)	
Length	40 cm
Width	3 cm
II. Model B (Horizontal Support)	
Length	25 cm
Width	15 cm
Heighth	15 cm

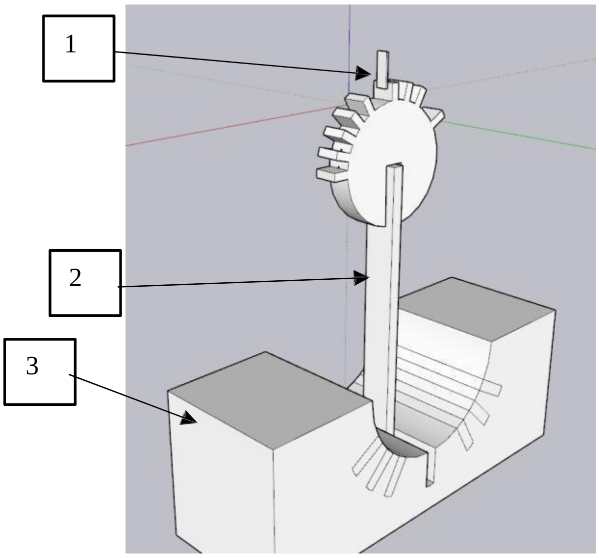

Figure 5. Mechanism Modeling Data

Figure 6. 3D Printing Results with Angle Variations

TABLE 2
TABLE OF MECHANISM TEST VARIATIONS

Angle Variation:	0°, 15°, 30°, 45°, 60°, 90°, 105°, 120°, 150°
Current Speed Variations:	0,8 dan 1,2 (m/s)

B. Effect of Angle Variations on the 10 Highest Average Stresses

This subchapter presents a graphical analysis of test results that focuses on the effect of angle variations on the 10 highest average generated voltages from piezoelectrics. In this test, angle variations of 0º, 15º, 30º, 45º, 60º, 90º, 105º, and 150º were used, with current speeds of 0.8 m/s and 1.2m/s.

Voltage is produced at a 90º angle variation because the entire piezoelectric surface is directly exposed to current flow and the conversion of mechanical energy into electrical energy is more efficient.

Although the average of the 10 highest voltages at flow speed 2 shows an increasing trend, there is a decrease in voltage at the 60º angle variation before finally increasing again at the 90º angle variation. This

TABLE 3
DATA VARIATION TABLE

	Current Speeds	Angle Variations	Voltage (v)
Current Speed 1	1,2m/s	0°	
		15°	
		30°	
		45°	
		60°	
		90°	
		105°	
		120°	
		150°	
Current Speed 2	0,8m/s	0°	
		15°	
		30°	
		45°	
		60°	
		90°	
		105°	
		120°	
		150°	

TABLE 3
COMPARISON OF AVERAGE VOLTAGE VALUES TO FLOW SPEED

	Average Voltage Current Speed 1 (mV)	Average Voltage Current Speed 2 (mV)
0°	2,18970	1,29767
15°	2,43312	1,54103
30°	2,59538	1,62206
45°	3,97415	3,32532
60°	6,27762	4,21754
90°	7,46196	5,35292
105°	3,52813	2,59538
120°	1,05435	0,32439
150°	0,64884	0,24329

TABLE 4
COMPARISON OF THE 10 HIGHEST AVERAGE VOLTAGE VALUES AGAINST FLOW VELOCITY

	Average Voltage Current Speed 1 (mV)	Average Voltage Current Speed 2 (mV)
0°	31,73600	34,17800
15°	48,82700	39,06200
30°	48,82900	39,06000
45°	48,83000	58,59500
60°	63,72000	48,83000
90°	87,89200	63,47700
105°	56,15300	48,82900
120°	31,73600	9,76400
150°	19,53000	7,32300

decreases Analysis of Figure 9 shows that there is a positive relationship between the piezoelectric surface area exposed to current pressure and the amount of voltage produced on the average of the 10 highest voltages at flow speed 1. It can be concluded that at flow speed 1, angular variations have a significant influence on the average voltage. produced by piezoelectricity. The smallest average stress is produced at an angle variation of 150º because of its long distance from the flow source and minimal exposure to current flow. Meanwhile, the largest can be attributed to several factors, one of which is the possibility of water entering the piezoelectric material during the experiment. Water that enters a piezoelectric material can affect the piezoelectric properties of the material and cause a decrease in the resulting voltage. In addition, water can disrupt the piezoelectric crystal structure, change the domain orientation, and reduce its ability to generate optimal electric dipole moments. Environmental factors

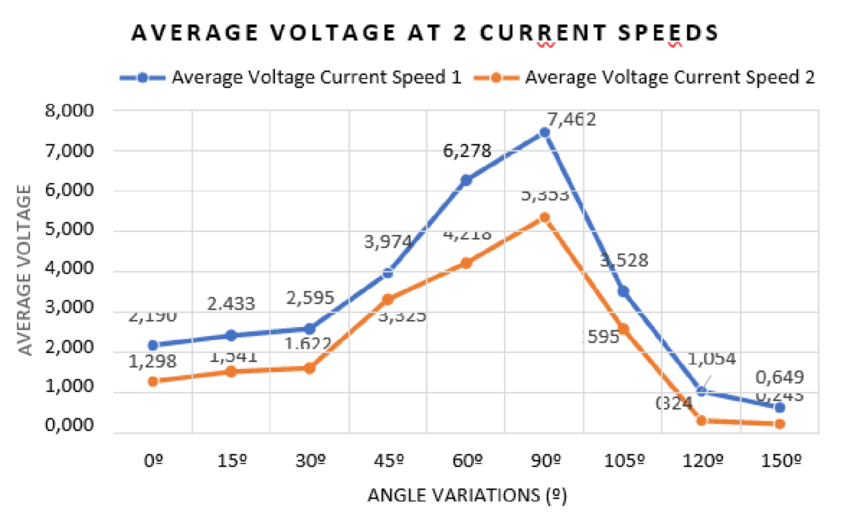

Figure 7. Comparison graph between angular variations and the resulting average piezoelectric voltage generation

such as humidity and temperature can also play a role in influencing the performance of piezoelectric materials. Therefore, it is important to consider environmental conditions and the possibility of leaks when conducting these experiments to ensure more accurate and consistent results. Controlling these variables can help identify and reduce undesirable factors that affect piezoelectric performance, thereby increasing device reliability and efficiency in practical applications.

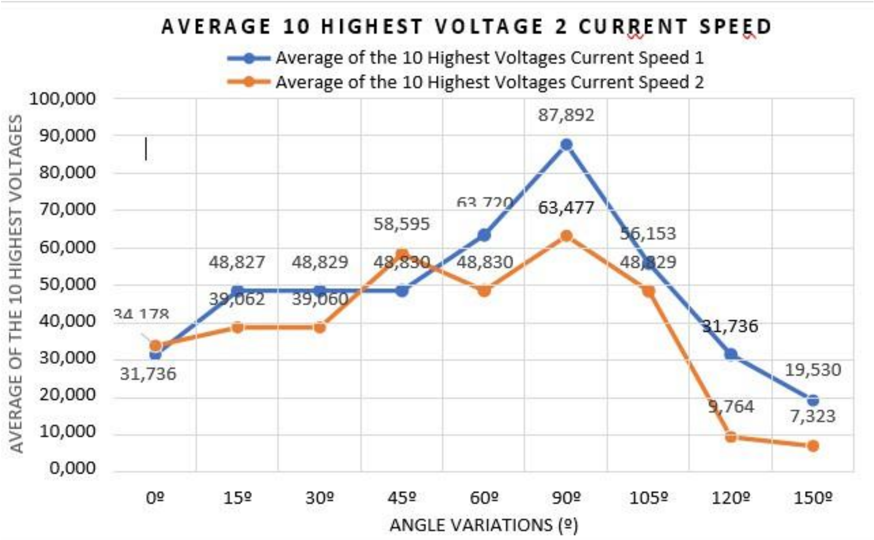

Figure 8. Comparison Graph between Angular Variations of the Average Generated Voltage of the 10 Highest Piezoelectric Voltages Generated

CONCLUSION

Based on the experimental results and mechanical modeling analysis related to marine energy harvesting mechanisms, the following points can be concluded:

1. The analysis results show that the piezoelectric tilt angle has a significant influence on the amount of electrical energy generated. The greater the surface area (in this case the angle of inclination) of the piezoelectric that is exposed to pressure from the water flow, the greater the force acting on the piezoelectric material. This results in greater voltage and the generation of electrical energy produced. In this research, the 90º angle produces the most optimal electrical energy generation for both flow speeds (1 and 2). At flow speed 1, the optimal energy generation is 7.46196 Millivolts, while at flow speed the optimal energy generation is 5.35292 Millivolts. This difference is caused by differences in the force acting on the piezoelectric due to differences in water flow speed.
2. Based on experiments from this research, a mechanism model was obtained to vary the slope angle using 2 supports (horizontal and vertical). The function of the two supports is to support 3D printing at various angles. This design allows the sinking piezoelectric to be subjected to direct current pressure and produces maximum deflection in the piezoelectric, thus producing an electric voltage per angle variation.
3. This research shows that the speed of water flow influences the amount of electrical energy generated by piezoelectricity. This is in line with the working principle of piezoelectricity, where the voltage produced is proportional to the force applied. In this case, the force acting on the piezoelectric comes from the pressure of the water flow. The greater the speed of the water flow, the greater the pressure generated on the piezoelectric. In this research, a variation of 1.2 m/s produces optimal electrical energy generation.

This is because at this speed, the pressure of the water flow acting on the piezoelectric produces a force large enough to produce maximum voltage and electrical energy generation.

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