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Analysis of Rectangular Flexible Horizontal Piezoelectric Cantilever Beam Base on ANSYS

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Abstract. This paper presents the analysis of energy harvester by using rectangular flexible piezoelectric cantilever beam in which applied on sea wave. The limitation of blade design is it only focus on single direction flow of sea wave motion. The finite element model is constructed by using ANSYS to optimize the blade design to maximize the output power. The analysis of rectangular flexible piezoelectric design shows the ability to generate variable of electric power from minimum 20 μW up to 141.30 μW, with dimension of width, length, height of piezo is 10 mm, 30 mm, 0.10 mm and amplitude of sea wave surface of 1.5 m respectively.

1. Introduction

Nowadays, various study of energy harvesting are being conducted to produce electrical power in order to supply the continuous electricity demand to the population in the world. The increasing demand of oil every year has made the application of energy harvester under research. Based on BP Statistical review of World Energy June 2017, the demand for oil consumption is growing with the average of 1.6 million barrels per day (Mb/d), or 1.6% increase above 10 years average (1.2%) which has stated the largest increment [1]. Specifically, in Asian countries, the previous year result as collected from 2005 until 2015, the fuel consumption was only 3.9% instead of 2.1% on 2016.

Various design of piezoelectric energy harvester has been studied according to transverse motion [2] by using ocean wave. Nonetheless, the maximum output power can be achieved up to 30 W if the length and thickness are 1.2 m and 0.01 m [3]. Qian Zhao et al. [4] implemented a design method using cantilever beam structure with low frequency by using ANSYS to generate the output power. PZT-5H piezoelectric material was selected as it has high volume dielectric constant and coefficient. Taylor et al. [5] designed an eel like device which is made from a flexible material by using polyvinylidene fluoride (PVDF) to convert mechanical energy to electrical energy in flowing water such as ocean or river. It is capable to produce 1.0 W output power for an eel of the size of 52 inch long × 6 inch wide × 400μ thickness. Zurkinden et al. [6] uses the bending of sea plants to convert the depth of ocean wave into electrical power from the fluid pressure and viscous of wave movement, however, the result was not improved. Another flexible piezoelectric harvester was designed by Mutsuda et al. [7] which is the orientation of piezo device position in horizontal and vertical directions. The power would increase from the phenomena of wave breaking known as breakwater. The maximum output power could reach up to 25 mW/m² as the result of horizontal plate, which is larger than the vertical. X.D. Xie et al. [3] states that there are two main vibration categories of the ocean wave source by using piezoelectric material, the first is small longitudinal wave motions caused by bluff body or vortex and second is vibration from the heaving of sea wave surface.

ANSYS used to create the modelling of finite element by produced the vibration with different size of design. Furthermore. ANSYS software can be applied in order to pre-estimate the characteristics of piezoelectric devices as by comparing those two results, the calculation value made by ANSYS is very close to the theoretical results[8]. Cui Yiliang et al. [9] study the flow domain and piezoelectric using ANSYS and create output voltage up to 117.65 V with 100 mm length.

In other words, transverse wave motions are efficient to be used as energy harvester under the ocean or on floating structures. Furthermore, the resonance frequency of piezoelectric matches the ambient frequency of sea wave, where it would produce maximum output energy, otherwise the output energy would drop once the resonant frequency is slightly away from the ambient frequency. Hence the operation of piezo energy harvester need to be suitable with the environment to operate energy harvesting [10].

The aim of this paper is to study the resonance output to produce electrical power using ANSYS. The increase number of blade design will be analysed to optimize the energy harvester. The paper is organized as follows: Section II describes the operation of flexible horizontal piezoelectric, Section III designing flexible horizontal piezoelectric, Section IV represents the simulation result in ANSYS. Finally, the conclusion is in Section V of the paper.

2. Principle operation of Flexible Horizontal Piezoelectric

Piezoelectric cantilever beam (Piezo-leaf) looks like a spring leaf [3] produces isolation frequency from transverse ocean or flexible sea wave to convert wave energy into electrical energy by considering the influence coming from different angle such as free surface wave. The leaf concept of the cantilever structure and the fixed end of cantilever will create the flow disturbance in between the upstream and downstream position of the sea wave surface. This phenomena is called Von Karman's Vortex [11]. Using the micro electromechanical system (MEMS), the vibration is created and it produces higher output power with small dimension of piezo required [4]**.** Piezoelectric materials are divided into four categories based on the characteristics of polymers, single crystal, ceramics and composite (combinations of piezo ceramics or single crystal with polymers).

Piezoelectric material contains positive and negative charges in which the centre area would not overlap with those charges. During vibration, the mechanical strain was applied to the material and lead to the production of electrical charges and it will be stored in batteries or capacitors as off grid system. Piezoelectric will generate maximum power of resonance frequency depending on the efficiency and power density of vibration produced [11]. Although the transverse wave are quite inconsistence, the power output is still forecastable and smoother as compared to wind and solar [12].

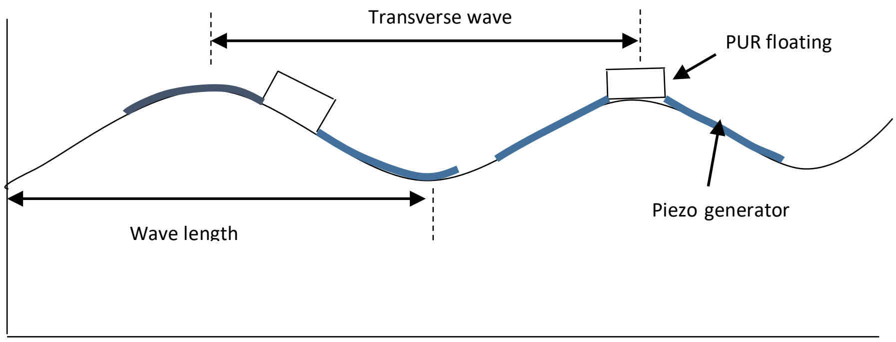

Figure 1. Application flexible horizontal piezoelectric on sea wave.

Figure 1 illustrates the schematic of piezo generator (PZT- Lead Zirconate Titanate) attached on sea wave surface, while it floats on ocean wave surface. Several blades of piezo generator are attached to Polyurethane (PUR) to increase the efficiency of output power. When the motion between flexible piezoelectric and the transverse wave are induced, the electrical power is generated by piezo effects [13].

3. Designing Flexible Horizontal Piezoelectric

The flexible piezoelectric can be easily deformed with the surface of sea wave, vortex, and transverse wave [7] due to vibration process. This kinetic energy will transform from mechanical vibration into electrical energy from the effect of positive piezoelectric. The positive piezoelectric effect is an electric charge on the surface as the result from the deformation of an object under external forces. Furthermore, the flexible piezoelectric was coupled between electrical fields and structure in piezo materials.

The vibration of piezo material will generate the voltage and by applying a voltage into piezo material, it will create the displacement. The structural equations for piezoelectric effect is as mention in equation (1).

$$\begin{bmatrix} N = s^E S + e^t B \\ M = \ f^T + \varepsilon^T B \end{bmatrix} \tag{1}$$

where S is the stress vector (N/m^2), N is the elastic strain vector (m^2/N), s is the elastic stiffness, e is the electric strain constant, M is the electric flux density, B is the electric fields density (V/m), ε^T is the dielectric permittivity (m/F) at T = 0, and t is the piezoelectric matrix (Vm/N or m^2/C).

3.1 The finite element model in ANSYS

In ANSYS mode, the PZT material of the piezo elastic matrixes are as follow [14];

$$\begin{bmatrix} 12.1 & 7.54 & 7.54 & 0 & 0 & 0 \\ 7.54 & 11.1 & 7.52 & 0 & 0 & 0 \\ 7.54 & 7.52 & 11.1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 2.11 & 0 & 0 \\ 0 & 0 & 0 & 0 & 2.11 & 0 \\ 0 & 0 & 0 & 0 & 0 & 2.11 \end{bmatrix} \text{X } 10^{10}\ \text{N/m}^2$$

The material parameters of PUR and PZT are shown in table 1. Young's modulus, Density and Poisson's ratio is inserted into ANSYS property [15] [14].

Table 1. FHP material properties for PUR and PZT in ANSYS.

Parameters	**Float (PUR)**	**Flexible Piezo beam (PZT)**
Young's modulus (Gpa)	0.0075	2.1
Density (kg/m^3)	60	7800
Poisson's ratio	0	0.3

All materials in table 1 will be inserted into engineering data before running the mesh analysis as shown in figure. 2. Meshing in ANSYS consists of mapped meshing and free meshing. The mapped meshing contains the pattern of the mesh whereas the free meshing has no specific pattern applied. In addition, it should be noted that the mesh sizing could be controlled by inserting new sizing to get the value of resolution.

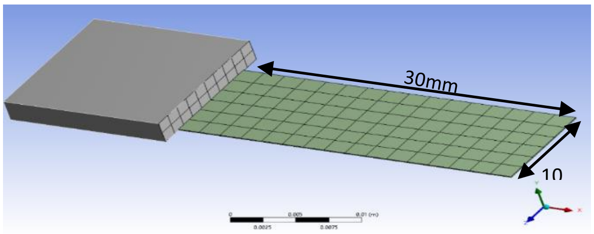

Figure 2. Mesh analysis on flexible horizontal piezoelectric cantilever beam.

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In this project, the element size of global mesh sizing is set to free meshing to get the minimum of resolution as shown in table 2.

Table 2. Parameter setting for global mesh sizing in ANSYS.

Sizing	Parameters
Adaptive sizing	Yes
Resolution	Default
Element size	0
Transition	Fast
Span angle centre	Coarse
Element order	Program controlled

Increasing number of resolution and element size give effect on the mesh quality and inflation. By default, the value of mesh inflation used for growth rate is 1.2 cause to generate thin cells adjacent to boundaries.

4. Result and discussions

The effect of thickness and length of the rectangular cantilever beam of resonance frequency of the blade are studied. By controlling the variable and parameters, the self-frequency are drawn from figure 3 to figure 4.

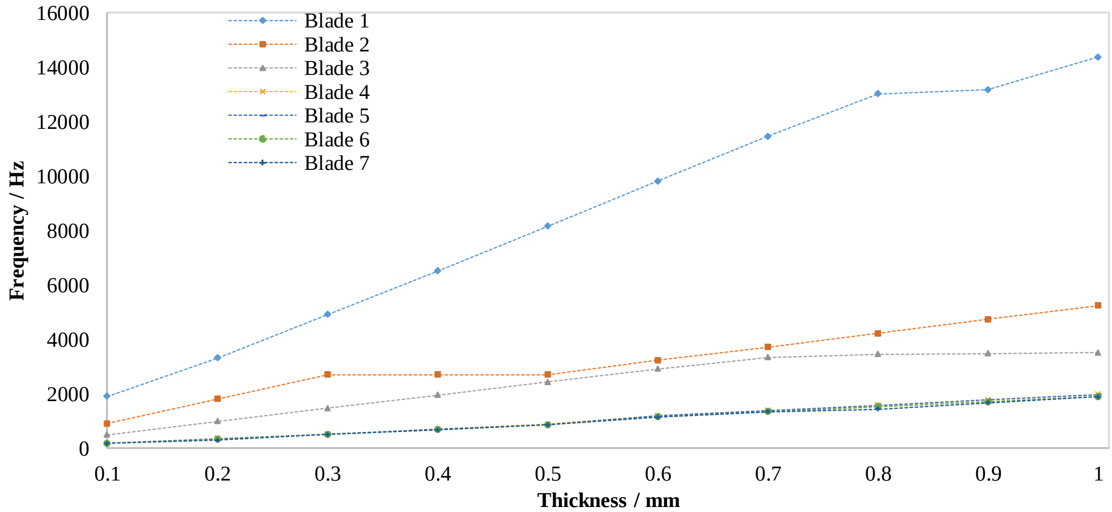


Figure 3. The displacement of resonance frequency on piezo thickness.

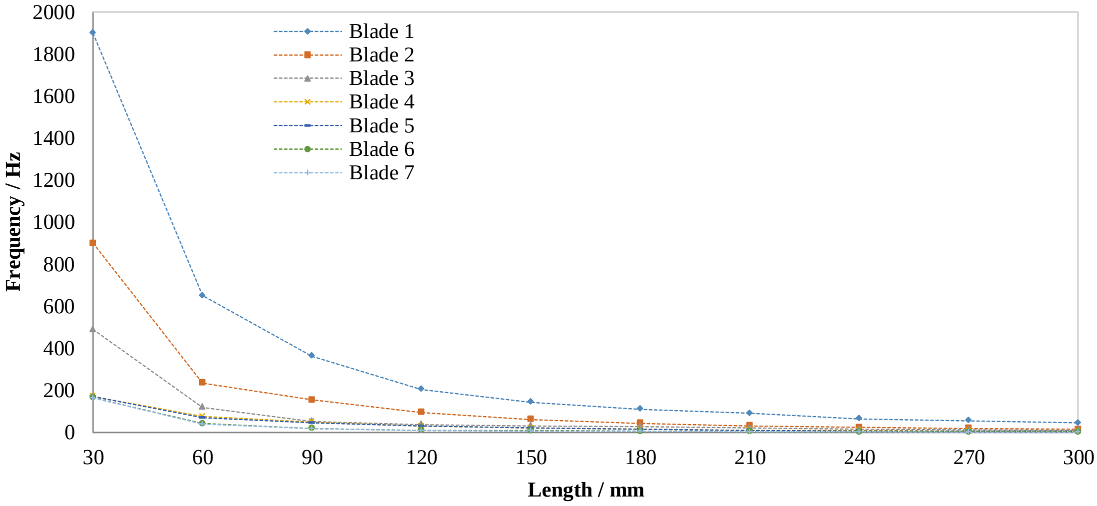
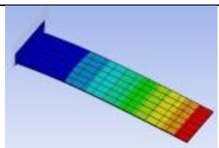
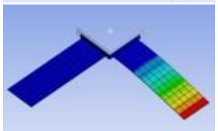
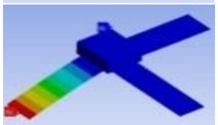
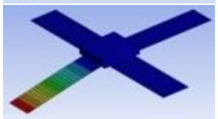


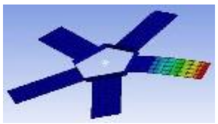
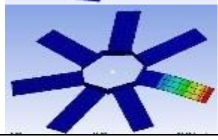
Figure 4. The displacement of resonance frequency on piezo length.

By observations, the increasing of thickness are significant to the increasing of the frequency. Furthermore, the increasing number of blade also affect self-frequency. The increasing number of blade will reduce the self-frequency. Even though the minimum value of thickness is set to 0.1mm, it is verified that the trend remain sensible towards the number of blade design. According to figure 4, the relationship between length and frequency is reduced by the blade design. Self-frequency becomes lower once the number of blade and size of length are increasing.

The summary of design properties for flexible horizontal of piezoelectric obtained is in table 3. This paper applied the reference voltage of 220V as the boundary condition on piezoelectric body in ANSYS.

Table 3. Summary of design properties for FHP using different blade obtain from ANSYS simulation.

Design	Rectangular	Power
1		20.0 µW
2		32.9 µW
3		46.9 µW
4		59.3 µW

5		94.3 µW
6		117.2 µW
7		141.3 µW

The output power of piezoelectric energy is found by;

$$P = \frac{{V_i}^2}{2R_o} \tag{2}$$

where P is the output power, Vi is the voltage from every blade and R_o is the constant value of external resistance. The value of resistance is chosen as 1k Ω to reduce piezo resistance. As result, the output power increase by the number of blade, which recorded 141.3 µW for 7th blade. Nevertheless, the transverse motion of sea wave affected the self-frequency for individual blade.

5. Conclusion

The proposed for rectangular, piezoelectric cantilever beam is developed using ANSYS software. The electrical energy is proportional with the number of blade used and self - frequency. The length and thickness of blade affected the frequency as the impact of sea wave height. Flexible horizontal piezoelectric is floated above the sea wave relatively generates electric power. In this research, the optimum blade design to produce electric power is 141.3 µW, with the width, length, height of piezo is 10 mm, 30 mm, 0.10 mm. The improvement on blade design and material selection with higher efficiency is another solution to increase the electrical power. Besides, actual experiment can be tested to compare the result.

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