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Developing a Hydropower Vortex Induced Vibration System in Slow Stream Water

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Abstract: Energy resources are beginning to replenish and the reliability on renewable energy has increased to 30% as we approach year 2020. However the current sources of renewable energy used for mass generation also have its own drawbacks mainly in terms of costing, maintenance and geographical changes which incur environmental disturbances. Energy harvested from Vortex Induced Vibrations (VIV) in water with a continuous flow of more than 0.3m/s has the ability to replace conventional hydropower methods with a more cost efficient and environmental friendly way. This research managed to produce a prototype focused on using a spring system to maximize oscillations induced by the vortex in flowing water onto a cylinder shaped PVC pipe of a specific diameter. The energy harvesting method adapted in this system is a piezoelectric tape. Upon every oscillation, the designed system is able to flick the piezoelectric tape inducing a certain amount of voltage. Initial design of prototype was to discover the most adequate cylinder PVC pipe for vortex in water to produce oscillations. The best way to design the system was tested to maximize flow induced oscillations. The final prototype of this stage also found the best harvesting method for the transformation process of induced oscillation into electrical energy. At this stage the prototyping is detailed at combining the existing prototype and piezoelectric transducers. The end product successfully produced up to 0.2watts/second of power. However, the unstable flow conditions and small scale testing prototype incurred an inconsistent power generation. From this research, it was brought to conclusion that the prototype has to be of a larger scale for real life applications of vortex induced vibration hydropower system.

Keywords: Vortex Induced Vibration, Piezoelectric Energy Harnessing, Spring Induced Oscillations

I.INTRODUCTION

In the world of electrical power today, renewable energy is the most explored alternative in replacing the conventional coal, diesel and other fossil fuels used to generate massive amounts of electrical power in order to accommodate for current domestic and industrial power demands. Our sole utility company in Malaysia, TenagaNasionalBerhad, generates approximately 85% of their electrical power using non-renewable energy sources [7]. These unrenewable sources are constantly drained at an unsustainable rate and at the same time happen to be the significant contributors towards environmental issues that are out there such as pollution, green house effects and global warming.

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Based on a recent study by University of Michigan and Berkley University, there is going to be a new technology producing clean energy from water using the concept of Vortex Induced Vibration (VIV)[1]. Energy is harnessed using the fish movement concept; a shear layer forms on either side of the body, the shear then separates and curls back behind the body forming multiple alternating vortices, to turn potentially destructive vibrations in fluid flows into clean hydro energy [1].

This VIV technology has yet to be commercially utilized as a power generator. The most challenging part of this new technology is determining how to maximize the power harvested from the vibrations [8]. However, being able to harvest energy as electrical power at low currents allows versatile applications even for home based appliances where no large output is required as to overcome the research gap on determining ways on maximizing power output for larger power generation.

This research focuses on adapting the VIV concept onto a newly designed system to generate flow induced oscillations. From the oscillations, energy is transformed into electrical energy using piezoelectric tape. Literature reviews based on the findings from researches related to VIVACE converters, VIV energy harvesting methods and effective design ideas for VIV in slow and continuous water flow.

II.METHODOLOGY

The new design works on a similar principle of using vortex induced vibration in slow stream water to generate electricity but by using a piezoelectric energy harvester instead. Its vibrating characteristics agree with the typical single circular cylinder VIV [2]. For a pulsating flow field, where the flow velocity fluctuates circularly with a period of several seconds; as well as in the case of a steady flow, when the inlet velocity exceeds the threshold velocity which is slightly smaller than the threshold velocity under the steady flow, resonance is generated [2].

The frequency response analysis indicates that the resonance vibrations at the lock-in frequency occur as long as the maximum flow velocity satisfies the resonance condition [2]. For the case of the first design, a new software was invented by Bern it's as and his team called Vsk [3]. This simulator is able to calculate the lock-in frequency required by the system with different spring constants in order to produce high amplitude oscillations at resonance [3]. However, the software is limited to public which implicates a constraint in carrying out the simulation using this software.

Design of Experiment Setup

i) Materials

The materials and equipment used in the set-up is as follows: (i) PVC Cylinder Pipes, (ii) 12N Spring; OD:20mm, Length: 50mm before extension, (iii) Copper rod; Diameter: 1mm, soldered with 4 thin copper lines, (iv) L-brackets , (v) Closed hooks, (vi) String; 2 pieces with identical length (vii) PC aluminium case; 8x5 inches top cutout, (viii)ARDUINO UNO Microcontroller, (ix) Piezoelectric Grove Film Sensor, (x) 8V Battery, (xi) Arduino UNO Computer Software

ii) Model Design Structure

In the prototype design, the existing VIVACE model was applied at a much smaller scale for the ease of prototype model testing and domestic application in the near future. The most crucial part of the design was the cylinder used to produce the vortex induced oscillation in the water. Five cylinders of different diameters were built from schedule 40 PVC pipes. The PVC cylinders were approximately 140mm in length with nominal diameters of 19.05mm (0.75”), 25.4mm (1”), 31.75mm (1.25”), 38.1mm (1.5”) and (2”). The cylinders were sealed at their ends using PVC end caps as shown in Figure 1. Table 1 shows the mass of each cylinder according to its respective diameters.

Fig. 1 Five PVC Cylinder of Various Sizes

Table. 1 Corresponding mass for different diameter PVC cylinders

Diameter (inches)	Mass (g)
0.75	104
1.00	158
1.25	194
1.50	272
2.00	337

In the middle of both the sides of the end caps, a hole was drilled and small hooks were attached. These hooks are used for the insertion of spring ends used in the prototype. Four springs of 12N each were used in the design to aid the oscillating movement produced by the flow induced vibration. Two springs were attached from the top screws of the cylinder housing in parallel and the bottom part wrapped onto the hooks drilled at the end caps. Same goes to the bottom two springs arranged in parallel, they were attached to the bottom screws of the housing as shown in Figure 2.

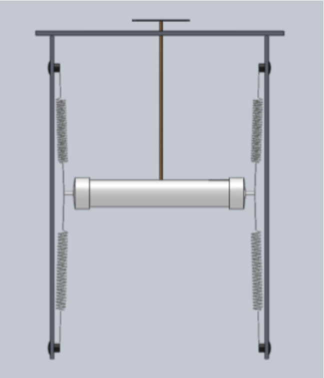

Fig. 2 Cylinder Housing Set-up

Fig. 3 Final mechanical design of prototype

The housing for the PVC cylinder was designed to rest on the grounds of water streams where the prototype is placed. The housing was made using a recyclable aluminium PC cover. An 8 x 5 inches cut out was made on the top part of the PC cover to allow visibility of the entire system and cylinder oscillations after being submerged into the water. The aluminium cover sides were used for the placement of springs and cylinder connected using L-shaped brackets and holes drilled on both sides of the PC aluminium cover. A string was placed in the middle of the springs to keep springs in place avoiding swaying when submerged in water with high current. The swaying in the springs can cause a disturbance in the ideal system functions resulting in no significant results. The mechanical final design is as shown in Figure 3.

A hole was drilled in the middle of the cylinder equidistant to both ends of the chosen PVC cylinders end caps attaching a thin copper rod. This copper rod has four small thin wires connected perpendicular to it to cause a flicking on the piezoelectric tape every time the cylinder oscillates. Based on real data, the flicking action onto a piezoelectric tape generates higher amount of power compared to bending or pressing. On the basis of this finding, the energy harvesting system for this prototype was designed as such. The piezoelectric tape is then connected to a transducer board and the Arduino UNO microcontroller that is programmed to transfer the input onto the computer via a USB cable. The set-up is as shown in Figure 4.

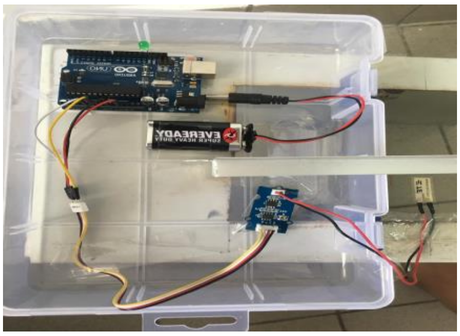

Fig. 4 Energy Harvesting System for Prototype (Top View)

iii) Structure of Operation and Software Simulation

The lightest of the five PVC cylinders was chosen in the finalised design for optimum movement in water when vortex induced vibrations acts on it. The prototype is designed to produce an upward and downward bobbing movement in the PVC cylinder when put in slow stream water. The oscillations will then cause the flicking motion onto the piezoelectric film caused by the copper rod attached to the cylinder.

Each time the piezoelectric film is flicked it will produce AC current. The current produced by the piezoelectric film flicking will then be sent to the Arduino UNO programme for the waves to be generated and the exact current produced to be displayed through the graph. The light bulb attached to the Arduino board will light up when the input voltage is given by the flicking piezoelectric film.

From the data collected a case study on position of cylinder PVC in varying water levels was carried out to find out the best condition of water level for the prototype to produce optimized results. This will help in deducing the best places to fit the functions of this prototype. The parameters used to test out this prototype were natural water flowing areas. The water sources used had a scope of three different levels as shown in Table 2 below;

The oscillations of the cylinder at Level I, Level II and Level III were observed. The flicking of the piezoelectric film occurrence and LED bulb lighting up would indicate the functional level of the prototype at these different heights of water sources. The results of the case study are clearly explained in the following section.

Table. 2 Case Study Parameters

WATER LEVEL	PLACE SETTING	HEIGHT OF WATER SOURCE (mm)
LEVEL I	TNB Research Centre Solar Floating Lake Drain, UNITEN Bangi	115
LEVEL II	College of Engineering Lake, UNITEN Bangi	190
LEVEL III	De Centrum Jacuzzi, Kajang	332

III.RESULTS AND DISCUSSION

Results

The method used in the testing of prototype was to first do a test on the PVC cylinder to be used for the most optimum oscillation in slow stream water. Then, a case study on the water levels necessary for the prototype to fully work and produce an oscillating motion that can flick the piezoelectric film to produce power with parameters as shown in Table 2. The final output from the first and second case study on the mass of PVC cylinder and water level required to optimize functions of the prototype.

i) Mass of Cylinder for Optimized Flow Induced Oscillation

To begin with the mechanical design of the system, the prime mover, in this case the cylinder used in the system to generate flow induced oscillations are extremely important. The mass of the cylinder is a very crucial factor in order for the whole theory of flow induced oscillations top work well with the springs used in the system. This case study will help in choosing the best of the five (5) nominal diameter cylinders to be used in the design referring to Table 3.

Table. 3 Cylinder Type Corresponding to its Mass and Fixed Number of Springs

Cylinder Type	Mass (g)	Number of Springs
TYPE I	337	4
TYPE II	272	
TYPE III	194	
TYPE IV	158	
TYPE V	104	

The tabulation of results for this case study is shown in Table 4 below.

Table.4 Tabulation of Results for Oscillation Test of PVC Cylinders

Cylinder Type	Flicking Motion of Piezoelectric Film	Range of Oscillation (mm)
TYPE I	No	0
TYPE II	No	0
TYPE III	No	Up to 20
TYPE IV	Yes	Up to 30
TYPE V	Yes	Up to 60

ii) Position of Cylinder PVC in Varying Water Levels for Optimized Flow Induced Oscillation

During the design phase, a spring was used to hold the cylinder downwards to aid vertical oscillation movements of the PVC cylinder when vortex in water acts upon it. This case study will focus on the different water levels where the oscillations induced by the flow in water is optimized.

Based on the three (3) case studies carried out, Table 5 is produced,

Table. 5 Tabulation of results from Position of Cylinder PVC in Varying Water Levels for Optimized Flow Induced Oscillation case study

Case Study	Water Level	Water Height from Ground (mm)	Range of Oscillation (mm)	Piezoelectric Tape Flicking	LED	Generated Voltage (V)
1	Level I	115	< 35	No	Off	0
2	Level II	190	</= 35	No	Off	0
3	Level III	332	60-65	Yes but inconsistent	On	3

iii) Power Generation through Piezoelectric Flicking after Optimization

Based on results from previous case study, it is clear that prototype has to be fully submerged in water or water level for testing parameters should be at Level III. From here, the best place setting for optimized readings was in the De Centrum Jacuzzi, Kajang. The output power display from the Arduino software produced an average reading as shown in Figure 5.

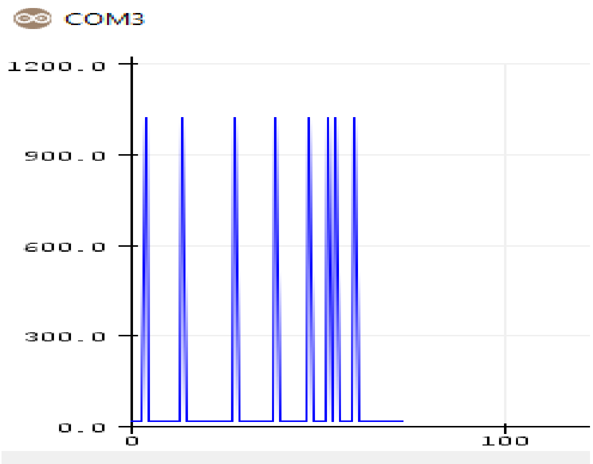

Fig. 5 Average Power Display on Arduino Computer Software

From the depicted graph, on the y-axis is the current output from the oscillation of PVC cylinder and flicking of piezoelectric film produced by the prototype. The x-axis shows the span of flicking in 100 seconds. From the graph it is clear that the output current is always stable however the time taken for each surge differs due to the unsteady flow of water.

IV.DISCUSSION

i) Mass of Cylinder

Based on the case study performed using the oscillation test, it was found that the mass of cylinder used makes a difference in the oscillating range when vortex in the water acts on it. Mass of the cylinder was also found to be very significant in terms of producing a range of oscillation. Range of oscillation described here refers to whether or not the copper rod instilled onto the midsection of the PVC cylinder perpendicular to it causes a flicking motion to the piezoelectric tape placed at the cut-out of the aluminium housing. As the mass of the PVC cylinder decreases, the range of oscillation increases. These findings prove that the best PVC cylinder to be used in this case study is cylinder of Type IV.

After this case study, further testing was done focusing on Type IV cylinder only.

ii) Water Level

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Based on the case study performed using the water level test, it was found that the prototype has to be fully submerged for the prototype to function optimally. This is due to the acts of PVC cylinder in the water. The material type of the cylinder is of PVC and the cylinder is found to require a low mass in order to function optimally. However when placed in water, the cylinder tends to float according to the water level because the cylinder is hollow inside.

When the cylinder is placed on the surface of the water, the cylinder is merely floating inconsistently and does not allow vortex to form in order to produce the oscillations. For this prototype vortex forming is essential in order to produce proper flow induced vibrations.

iii) Power Generated through Piezoelectric Energy Harnessing

Based on the background studies, piezoelectric films produce optimum results when flicked compared to the bending and pressing motion that acts on it. From the results, each oscillation by the cylinder allowed the copper rod to flick the piezoelectric tape. The results obtained were unsteady although parameters to optimize functions of the prototype were put. Average current generated over a period of 100 seconds were not consistent due to the unsteady flow of water in the place setting.

The graph spikes up to 1A of current normally after 5-7 seconds of piezoelectric flicking. However there are inconsistent periods when the current spikes within 2 seconds due to the increased frequency of oscillation. This happens when there is a sudden increase in flow speed since the water source is unsteady. The LED light turn on and off at every spike of current portraying the current induced. The LED bulb in this prototype is controlled by the Arduino microcontroller.

V.CONCLUSION

Harnessing of energy produced from oscillating cylinder using piezoelectric allows a direct conversion of electricity upon oscillation. The flicking of the piezoelectric film produces more electrical energy compared to the motion of pressing or bending. At each oscillation from the cylinder, the piezoelectric film is able to detect and transfer the input into a display of produced current from the system. The output is however unsteady due to the unsteady flow of water.

The Arduino microcontroller used in the prototype was able to show the graph of current produced in period of 100seconds. The current produced displayed a 1A reading at an average period of 5 seconds of stable vibration frequency produced by piezoelectric film. The overall system showed a final power generation of 0.2 watts per second. For future works, the following are recommended.

i) Power Stability

Capacitors can be used for the charge and discharge of current for a more stable output. A step up power module can be used to increase the electrical output and this will help in using the prototype design for real life applications. Tests on power stability should be conducted to produce a more stable graph.

ii) Energy Storage

Once the power output have been stabilized, the energy produced can be stored in an energy storage system or battery as power supply to low amps applications such as backup power supply for IOT security systems which are now becoming a trend in the market. The objective of using renewable energy in homes or offices can be realized.

iii)Improvement in Current Design

Instead of using only one cylinder in the aluminium housing, more identical cylinder and springs can be placed parallel to each other for more power generation at the same time. This will help in producing higher amount of power output with the same flow of water and can be used for higher amps real life application with a reduced cost instead of building another identical system separately.

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