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Research Article

Effect Of Fins Addition to The Performance of a Gravitational Water Vortex Turbine

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Abstract— Hydroelectric power generation falls under power plants that use renewable energy sources to function. With the advent of strict environmental regulations surrounding fossil fuels and coal, the race to improve and maximize the harnessing of renewable energy has never been this essential. With both technology and businesses leaning towards renewable energy, it provides hydroelectric power generation relevancy and a seemingly endless avenue for innovation and refinement. With this in mind, the researchers designed a volute that simulates a whirlpool to be outfitted in the irrigation channels present in the agricultural sector of the Philippines. Furthermore, a comparison was conducted between the performance of a turbine with and without finned blades. The data gathering process was done in the Xavier University Hydraulics Laboratory and under varying flow rates, categorized as Low, Medium, and High. A total of 60 trials were performed, 10 for each category with 2 sets corresponding to the conventionally designed turbine (no fins) and the turbine with fins, under which the rotational speed of the turbine was recorded. The corresponding power input and power output were calculated afterward, as well as the mechanical efficiency of the system under said parameters. Results show that the addition of the fins onboard the turbine blades proved beneficial, as an increase in rotational speed (~10 rpm), power (~0.05 W - 1.5 W), and mechanical efficiency (0.37% - 6%) was observed. Among the three categories, the medium category has the highest increase in efficiency under a volume flow rate of around 0.011 m³/s. On the other hand, the High category has the lowest increase in efficiency under a volume flow rate of around 0.008 m³/s. In conclusion, an improvement in the GWVT was observed when the fins were integrated into the blades.

Keywords— Hydropower, Fins, Water Vortex Turbine, Blade Design

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I. INTRODUCTION

The Gravitational Water Vortex Turbine (GWVT) is a type of turbine designed to harness water energy into electricity under ultra-low head and flow rate, making it ideal for small-scale hydropower systems [5, 6, 7, 8]. Harnessing renewable energy for power generation has never been more pronounced, not only for enhancing human quality of life but also for saving the planet. Ongoing enhancements to hydroelectric turbines remain vital in meeting this pressing need. Many researchers

have extensively examined turbine performance [6] from various perspectives, with numerous prior studies exploring both the performance and design aspects [7] of the Water Vortex Turbine. Such studies typically fall into the category of experimental and analytical, often supplemented by a software simulation and the fabrication of prototypes to assess the feasibility of the pilot model [5].

One way to generate power using the innate water channels is to outfit it with a GVWT. The parts of a

vortex turbine are the open water inlet passage, a circular basin, a turbine with multiple blades, a generator, its impeller support shaft, and the exit passage [7].

The study aims to simulate the design of a vortex turbine, fabricate a whirlpool turbine set-up, and conduct laboratory testing at Xavier University's Hydraulics laboratory. Furthermore, the performance of a conventionally designed turbine and a turbine modified with fins is to be compared based on power output and efficiency.

II. EXPERIMENTAL

The research design in this study falls under experimental research supplemented by simulation, which is defined as the usage of scientific methods to establish a cause-effect relationship between variables, controlled and independent. The design of the set-up is based on the study by Hidayat M.N., et.al. [2] on the design and analysis of a portable spiral vortex hydro turbine for a Pico hydropower plant. Improvements in

the design were implemented based on the recommendations. Also, the design of the turbine fins is based on the thesis study by Apa-ap K.T, et.al [3]. The specification of the design is made to accommodate the size of the Hydraulics Laboratory of Xavier University where the experimentation and data gathering took place.

II.1. Design of Main Components

The conventional design and its fin modification turbine serve as one of the vital components of this project. The blades used in the study comprise six blades per design, with a total of 12 blades. Each blade is bent at a 30-degree angle to maximize the contact of water, thus ensuring the impeller to spin. The dimension of each blade piece is 12 cm in height parallel to the shaft and around 24 cm in length perpendicular to the shaft. Two types of turbine design were fabricated, the other is fitted with a fin design using welded rebar.

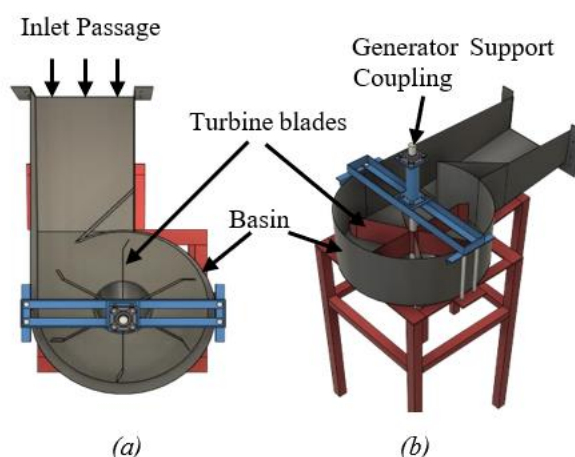


Fig. 1. Design Set-up (a) top view and (b) Isometric view of the Gravitational Vortex Water Turbine

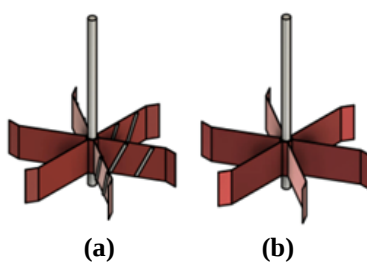


Fig. 2a. Turbine blades (a) with adding fin modification, and (b) without fin or the conventional Turbine



Fig. 2b Fabrication of Turbine blades with welded rebar as fins

The fins were welded at an angle of 60 degrees as presented in the thesis study of Apa-ap K.T, et.al [3], which was also done in the Hydraulics Laboratory, 60

degrees was the angle upon which the highest power generated was recorded.

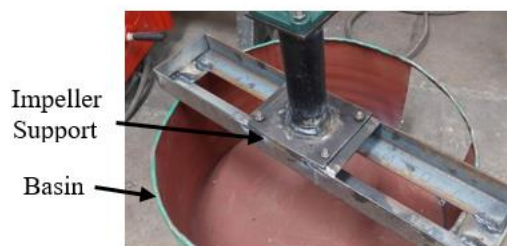


Fig. 3. Fabricated Impeller Support

This mechanism is what keeps the volute from vibrating due to water pressure while also securing the shaft and the turbine as it spins. Four pieces of 14-inch length and

12.5 mm diameter bolt and nut were used to hold the volute into the support structure. It is fitted with two 1-inch flange bearings for added stability.



Fig. 4. Volute Fabrication

The volute casing is designed to guide the flow of water into the impeller, causing it to spin in a spiral vortex flow. As the water spins the turbine, it is then flushed out through a pipe that delivers discharged water back to the hydraulics lab for recycling water. The circular part of the volute is made from a recycled oil barrel drum that measures 57 cm in diameter and 26.6 cm in height.

II.2. Data Gathering

The research aims to compare the overall performance of the turbines. A total of 60 trials were performed, 10 for each category with 2 sets corresponding to the conventional turbine and the turbine with fish fin modification. The varying flow rates are categorized as low, medium, and high, as the equipment could not provide accurate water discharge.

Parameters such as the water velocity, area of inlet, volume flow rate, height, density, gravity, power input, area of blade, shaft radius, mass flow rate, force, angular velocity, torque, power output, and efficiency are vital in this study.

RESULTS AND DISCUSSION

III.1. Simulation

Computer simulations entail employing modeling to generate virtual representations to mimic the behaviors and outcomes of specific systems.

The following illustrations are the fluid flow behavior of a Vortex Turbine using Solidworks software as a medium of simulation.

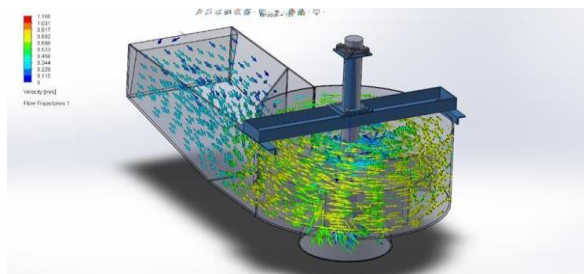


Fig. 5a. Simulation of Conventional Design under low category at a flow rate of 0.015 m³/s

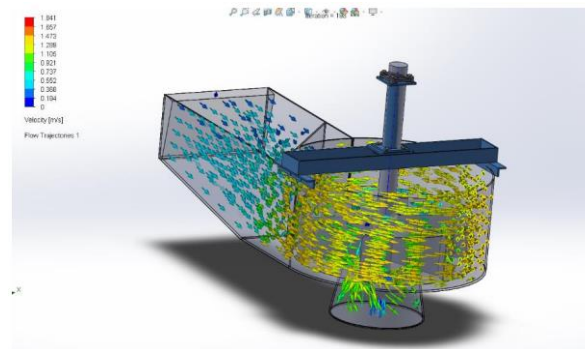


Fig. 5b. Simulation of Conventional Design under medium category at a flow rate of $0.022 \text{ m}^3/\text{s}$

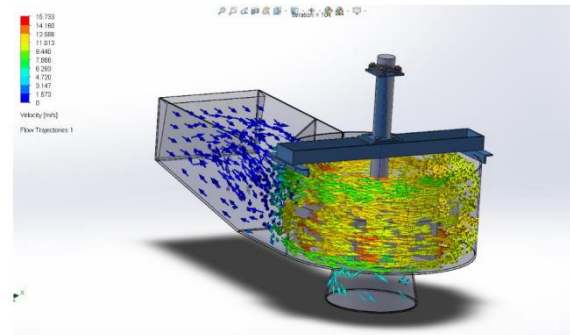


Fig. 5c. Simulation of Conventional Design under high category at a flow rate of $0.027 \text{ m}^3/\text{s}$

In the Conventional Design, the rotational behavior of the fluid inside the volute runs at an average velocity of 0.626 m/s around the entry. As the water creates a whirlpool effect due to the shape of the volute, it

increases the water velocity as well, bumping the maximum velocity of water up to a value of 1.079 m/s near the exit points.

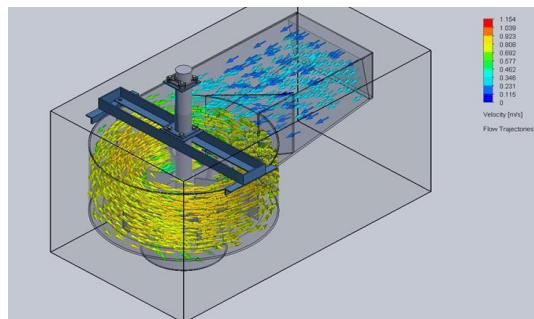


Fig. 6a. Simulation of Modification Design with Fins under low category at a flow rate of $0.015 \text{ m}^3/\text{s}$

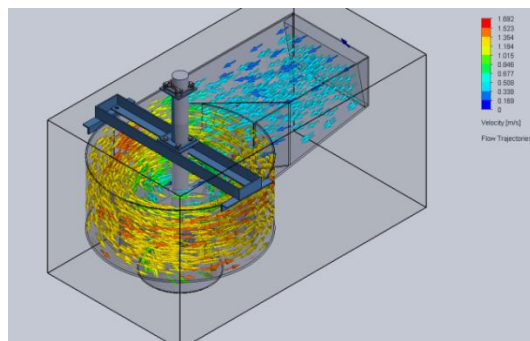


Fig. 6b. Simulation of Modification Design with Fins under medium category at a flow rate of $0.022 \text{ m}^3/\text{s}$

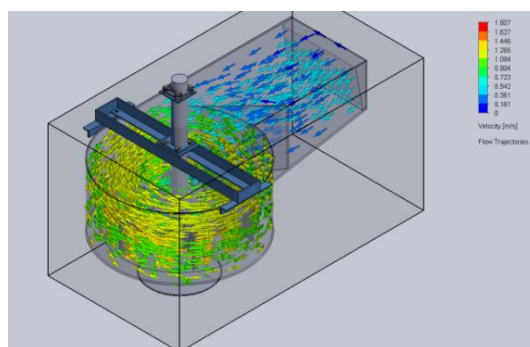


Fig. 6c. Simulation of Modification Design with Fins under high category at a flow rate of 0.027 m³/s)

The average water velocity of 0.506 m/s and the maximum velocity of water amounts to 1.214 m/s were recorded.

III. 2. Volume Flow Rate vs. Rotational Speed

Table 2. Average Rotational Speed

Average Rotational Speed (rpm)						
Category	Volume Rate, m ³ /s	Flow Without Conventional Design	Fins	With Fins	Modification	
Low	0.015	30.6		40.5		
Medium	0.022	45.8		54.1		
High	0.027	65.5		66.3		

The addition of fish fins to the vortex turbine produces an increase in rotational speed which in turn will affect the power generated. Therefore, water discharged, water

velocity, and rotational speed of the turbine have a directly proportional relationship.

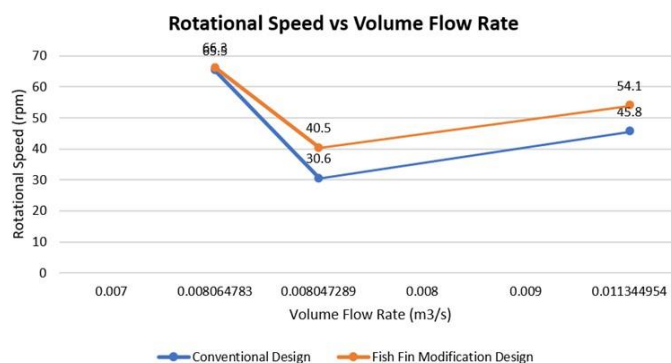


Fig. 7. Volume Flow Rate vs. Rotational Speed

When the amount of water discharged is in the High category, the Float Ball method of collecting data for water velocity becomes unreliable in calculating the velocity of water as it hits the blades. Instead of the ball moving with the flow of the water, it simply floats on the top statically. Logically, when the amount of water increases, discharge increases, and its velocity will also

increase. This was not reflected in the High category, and it is visually represented by Fig. 7. Therefore, in the High category only, the direct proportional relationship between water discharged and rotational speed of the turbine was represented but the same did not occur between water discharged and water velocity due to the Float Ball method becoming inconclusive.

III. 3. Power Input, Power Output, & Efficiency

Table 3. Conventional Design Calculation

CONVENTIONAL DESIGN											
	Water Velocity (Channel) (m/s)	Area of Inlet (m ²)	Volume Flow Rate (Channel) (m ³ /s)	Height (m)	Density (kg/m ³)	Gravity (m/s ²)	Power Input (W)				
Low	0.099	0.15	0.015	0.09	997	9.81	13.730				
Medium	0.173	0.15	0.027	0.09	997	9.81	24.049				
High	0.143	0.15	0.022	0.09	997	9.81	19.829				

	Water Velocity (Blade) (m/s)	Area of Blade (Straight) (m ²)	Volume Flow Rate (Straight) (m ³ /s)	Water Force (Straight) (N)	Area of Blade (Bent) (m ²)	Volume Flow Rate (Bent) (m ³ /s)	Water Force (Bent) (N)	Normal Force (Bent) (N)	Angular Velocity (rad)	Σ Torque (N – m)	Power Output (W)	Efficiency (%)
Low	0.585	0.008	0.00525	3.06	0.004	0.00279	1.63	1.41	3.202	0.869	2.785	20.283
Medium	0.825	0.008	0.00740	6.09	0.004	0.00393	3.24	2.80	4.793	1.728	8.278	34.423
High	0.586	0.008	0.00526	3.08	0.004	0.00279	1.63	1.41	6.855	0.873	5.986	30.192

Table 4. Blade Modification Design with Fins Calculation

FISH FIN MODIFICATION DESIGN											
	Water Velocity (Channel) (m/s)	Area of Inlet (m ²)	Volume Flow Rate (Channel) (m ³ /s)	Height (m)	Density (kg/m ³)	Gravity (m/s ²)	Power Input (W)				
Low	0.099	0.15	0.015	0.09	997	9.81	13.730				
Medium	0.173	0.15	0.027	0.09	997	9.81	24.049				
High	0.143	0.15	0.022	0.09	997	9.81	19.829				

	Water Velocity (Blade) (m/s)	Area of Blade (Straight) (m ²)	Volume Flow Rate (Straight) (m ³ /s)	Water Force (Straight) (N)	Area of Blade (Bent) (m ²)	Volume Flow Rate (Bent) (m ³ /s)	Water Force (Bent) (N)	Normal Force (Bent) (N)	Angular Velocity (rad)	Σ Torque (N – m)	Power Output (W)	Efficiency (%)
Low	0.585	0.008	0.00525	3.06	0.004	0.00279	1.63	1.41	4.239	0.869	3.686	26.445
Medium	0.825	0.008	0.00740	6.09	0.004	0.00393	3.24	2.80	5.662	1.728	9.782	40.675
High	0.586	0.008	0.00526	3.08	0.004	0.00279	1.63	1.41	6.939	0.873	6.060	30.562

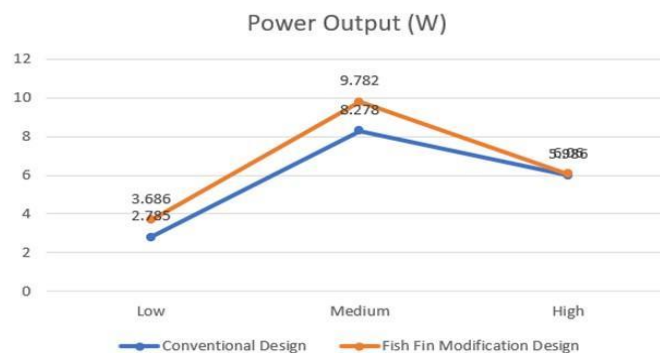


Fig. 8. Comparison of Power Output

With the gravitational water vortex turbine test rig design parameters, the introduction of fish fin modification has significantly increased its power output. For the Low category, the power output of the

turbine increased from 2.785W to 3.686W. For the Medium category, the power output increased from 8.278W to 9.782W. For the High category, the power output increased from 5.986W to 6.06W.

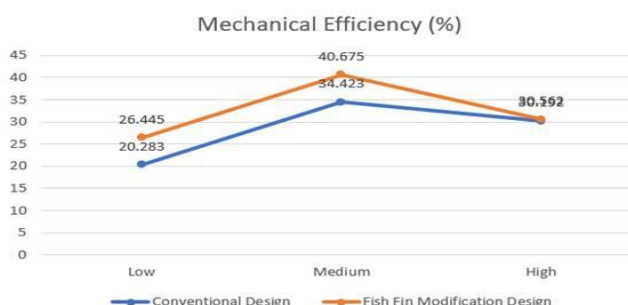


Fig. 9. Comparison of Efficiency

The increase in power output of the turbine incorporated with fish fin modification yielded an increase in efficiency as well. The data shows that for the Low category, the efficiency of the turbine increased from

20.283% to 26.445%. For the Medium category, the efficiency increased from 34.423% to 40.675%. For the High category, efficiency increased from 30.192% to 30.562%.

Conventional Design

Surface Plot of Power Output vs Rotational Speed, Flow Rate

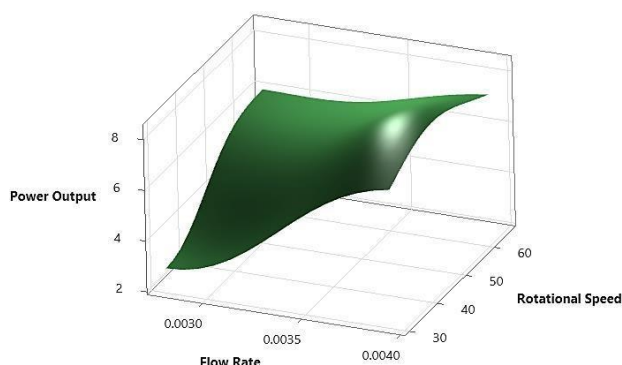


Fig. 9. Conventional Design Surface Plot

Minitab Software visualizes the relationship between flow rate, rotational speed, and power output. The surface plot of the conventional design is represented by the x-axis as flow rate, the y-axis as rotational speed, and

the z-axis as power output. This further supports the researchers' observation that there is a direct proportional relationship between these variables.

Fish Fin Modification Design

Surface Plot of Power Output vs Rotational Speed, Flow Rate

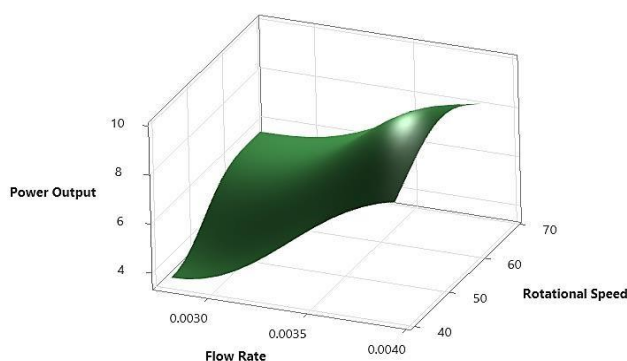


Fig. 10. Fish Fin Modification Design Surface Plot

Comparing the surface plot of the Conventional Design with the Fish Fin Modification, the surface plot shows that the increase in rotational speed brought about by the addition of fish fins leads to an increase in power output.

CONCLUSION

In conclusion, the objectives of the study were fulfilled, and the data gathered were sufficient to be analyzed and interpreted. The first objective of the study was to design a vortex turbine and a corresponding volute that will produce a whirlpool. With the help of Fusion360 and recommendations from professionals, it was able to come to fruition and was fully functional. Another objective was to investigate the performance between a conventional vortex turbine and fish fin modification.

Results show that the addition of the fish fins to the turbine blades proved beneficial, as an increase in rotational speed (~10 rpm), power (~0.05 W - 1.5 W), and mechanical efficiency (0.37% - 6%) was observed. The researchers recommend that the blade design can still be improved as well as the overall design of the volute i.e. longer water channel.

ACKNOWLEDGEMENT

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