EXPERIMENTAL ANALYSIS ON DIFFERENT RUNNER BLADES ON THE VORTEX PERFORMANCE

CHAI SHUN JI

FACULTY OF ENGINEERING
UNIVERSITI MALAYSIA SABAH
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THESIS SUBMITTED IN FULFILMENT OF THE REQUIREMENTS FOR THE DEGREE OF BACHELOR OF ENGINEERING

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DECLARATION

I hereby declare that this project progress report entitled "Experimental Analysis On Different Runner Blades On Vortex Performance", submitted to University Malaysia Sabah, is an original work under the supervision of Madam Fadzlita Binti Mohd. Tamiri, and it is submitted as a partial fulfilment of the requirement for the degree of Bachelor of Mechanical Engineering, which has not been submitted to any other university for a degree. I also certify that the work described is entirely mine, except for quotations and summaries of sources which have been duly acknowledged.

27th June 2022

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DEGREE : **BACHELOR OF ENGINEERING WITH HONOURS**

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ABSTRACT

This thesis writing aim is to design skewed blade profile of the vortex turbine based on the simulation analysis to determine whether it has better efficiency than flat and curved turbine. This is done through experimental analysis for different runner blades on vortex performance. Validation process was first carried out by mesh independent analysis through ANSYS CFX to determine whether there are differences between experimental and simulation results in terms of water vortex height generated. The design of skewed blade is developed by using flow velocity inside vortex that extract from simulation result using horizontal line technique. The data will then convert to a set of coordinates system that will be used to design blade profile. The number of blades used for blade design is 5 blades which will produce the highest efficiency. Experimental analysis was then carried out using three different types of turbine blade which is flat, curved and skewed turbine to determine their vortex performance in terms of power output and efficiency respectively. The final result for this research is that the curved turbine has both the highest power output and efficiency as compared to flat and skewed turbine. This showed that the curved turbine is the best choice for better vortex performance in water generation system.

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ABSTRAK

Tujuan penulisan tesis ini adalah untuk menjalankan reka bentuk turbin vorteks bilah miring berdasarkan analisis simulasi untuk menentukan sama ada ia mempunyai kecekapan yang lebih tinggi berbanding dengan bilah rata dan bilah melengkung. Ini dilakukan melalui analisis eksperimen ke atas prestasi vorteks dengan menggunakan jenis turbin bilah yang berlainan. Proses pengesahan akan dilakukan terdahulu melalui mesh independent analysis dari ANSYS CFX untuk membandingkan ketinggian vorteks air yang dihasilkan dari eksperimen dengan simulasi. Turbine bentuk miring dibuat dengan menggunakan halaju aliran di dalam vorteks yang diekstrak dari hasil simulasi menggunakan teknik garis mendatar. Data kemudian akan ditukar menjadi satu set sistem koordinat yang digunakan untuk merancang profil bilah. Bilangan bilah yang akan menjadi reka bentuk ialah 5 bilah di mana ia mampu memberikan kecekapan yang tertinggi. Analisis eksperimen akan dilakukan ke atas ketiga-tiga jenis turbin bilah iaitu turbin rata, melengkung dan miring untuk menentukan prestasi vorteks dalam keluaran kuasa dan kecekapan masing-masing. Hasil terakhir untuk penyelidikan ini adalah turbin melengkung mempunyai keluaran kuasa dan kecekapan yang tertinggi berbanding turbin rata dan turbin miring. Ini menunjukkan bahawa turbin melengkung merupakan pilihan terbaik untuk prestasi vorteks yang lebih baik dalam sistem penjanaan air.

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LIST OF ABBREVIATIONS

GWVPP	-	Gravitational Water Vortex Power Plant
CFD	-	Computational Fluid Dynamic
h	-	Vortex Height
u	-	Water velocity in x-direction
v	-	Water velocity in y-direction
D	-	Distance

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CHAPTER 1

INTRODUCTION

1.1 Introduction

Nowadays, peoples from all around the world have apply the usage of renewable energy as technologies such as hydro, wind, solar and biomass to generate electricity for daily life usage. Hydropower is the most impactful green energy source since it provides multiple energy security and environmental benefits. Hydropower is defined as the rate where hydraulic energy is collected from a certain amount of falling water, due to the result of its position or velocity, or even both of them. Hydropower is known as the most widely used of renewable energy source, because it has more than 1,295 GW of installed capacity worldwide. This accounts for more than 18% of total installed power generation capacity and more than 54% of global renewable power generation capacity (Power Technology, 2020).

Turbine driven from the release of water from a reservoir, the construction of dams on rivers, and pumped-storage plants are all examples of hydropower generation. However, hydropower projects have been a contentious issue in recently due to the social and environmental implications on human displacement and also biodiversity. In this case, the gravitational water vortex power plant (GWVPP) is a good example of a hydropower application which provide more advantages than drawbacks.

Gravitational water vortex power plant (GWVPP) is a type of micro hydro vortex turbine system that generates electricity from a flowing fluid that comes from a renewable energy source. The water in this plant travels through a huge, straight intake before tangentially entering a round-shaped basin. The water will then produce violent vortex that will exits the outlet at the shallow basin's centre bottom (Rahman et al., 2017).

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Based on (Zotlöeterer, 2014), GWVPP does not work on the differences in pressure but on the dynamic forces created or generated by the vortex due to its ultra-low hydraulic head requirement. In the vortex power plant, water is tangentially fed into a circular basin to generate a free vortex while energy is being extracted from the free vortex using a turbine in it. This type of power plant can be placed in rivers or stream due to its hydraulic head requirement is as low as 1 m. Water can be fed into the vortex turbine by an open channel or a closed conduit or pipe, which is better for smaller systems (Singh, 2019). Although the vortex turbine structure seems to be simple, the operation of analysis is not easy because it involves complex computational fluid dynamics (CFD) modelling.

Based on table of classification hydropower, gravitational water vortex hydro power is classified as micro hydropower because the maximum reported power generation does not exceed 100kW (Iemsomboon et al., 2013). The main advantages of this power plant are the ultra-low head turbine which operates in as low head range of 0.7 - 2m. Besides, the electricity generation is from ultra-low hydraulic pressure and also very environmentally friendly. It can also enhance the evaporation head, allowing water to cool down when the temperature rises in the summer (Rahman et al., 2017). Vortex turbine is one of the methods to utilize the low head hydro energy resources. Besides, Zotlöterer (2016) also states that the advantages of these GWVPP are favourable to aquatic species since the low pressure, low shear and low impeller RPM ensure the fish can enter and exit the turbine without harm.

The capacity of vortex turbine generation systems ranges from 0.2 to 4.0 kW. The open channel water route, vortex pool, and runner are crucial components of the vortex turbine. The vortex pool has a cylinder shape with a circular hole in the middle. The water travels downward in a vortex flow that forms above the hole. Due to vortex movement, the runner which installed above the hole rotates(Haryadi et al., 2020). To increase the intensity of the vortex flow, tangential water flow into the pool. Researchers have used four different types of runners in recent studies which are flat radial, paddle, centrifugal and modified form. A vortex turbine can increase water surface area, reduce disturbance to aquatic species, increase oxygen solubility and improve aeration (Haryadi et al., 2020).

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Currently, there are many past research focused on different parameters to increase the vortex turbine performance in terms of efficiency and power output. Based on study from (Dhakal et al., 2015), when the number of blades of turbine increased from six to twelve, the efficiency of the GWVPP will be reduced. However, (Power et al., 2015) determine that as the number of blades increased from two to four, the efficiency increased. Both groups of researchers came to the opposite conclusion, which indicates that there may be an optimal number of turbine blades. For this project, it aims to determine which type of runner blades is the most suitable to be use in the vortex turbine system by conducting an experiment analysis. The number of blades used also take into consideration in the experimental analysis. After that, simulation analysis was done based on the vortex water flow inside the tank without the turbine to simulate the water flow using SolidWorks and Ansys Computational Fluid Dynamic (CFX) and then compare the vortex height obtained from simulation with the vortex height from experimental results.

1.2 Problem Statement

Gravitational water vortex power plant (GWVPP), a low hydraulic head hydropower plant which also has a very high potential for generating electricity and to be commercialize. Since the vortex hydropower is still new, the turbine efficiency is quite low compared to other conventional hydro turbines and hence its efficiency has been a hot discussion topic for time being. Past research had found that different parameters such as volumetric flow rate, geometry of the basin, turbine position, blade geometry and number of blades will affect the efficiency of GWVPP.

Turbine blade is one of the most vital parts for vortex turbine. The turbine was forced by the hydropower from the water vortex. It is important as it extracts the power from kinetic energy that produce from the water vortex inside the basin.

Since water vortex turbine is dependent to tangential force of water flow, the design of the shape of blade that will match with the tangential flow velocity in every height of the vortex is important. Different types of runner blades will have different impact to the vortex turbine performance. There are lots of factors and parameters that can influence the performance of a vortex turbine. Different parameters' impact on the turbines' performance have been studied by a lot of past researchers. For

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example, (Singh & Nestmann, 2009) had compared the effect of height, angle and number of the runner blades on the axial turbine efficiency.

The aim of this project is to determine which type of runner blade is the most suitable in use to increase the vortex turbine performance in terms of efficiency and power output. There are three types of runner blades which applied for comparison which is flat, curved and skewed blades. In this case, the number of blades will also take into account as it will affect the vortex turbine performance and also its efficiency.

1.3 Research Objectives

1. To simulate the vortex water flow inside the tank without the turbine using Ansys Computational Fluid Dynamic (CFX).
2. To design and fabricate the skewed turbine blade by using 3D printer.
3. To carry out experimental analysis on the vortex turbine with different types of turbine blades and compare their impact on vortex turbine performance.

1.4 Scope of Works

Scope of works are related to the reports, experimental analysis and final product that are expected to receive. The scope of work is performed as stated:

a. Develop a CFD model of the vortex tank without turbine to simulate the water flow using SolidWorks and Ansys Computational Fluid Dynamic (CFX) and then compare the vortex height obtained with experimental results.

b. Design and fabrication of skewed turbine blade by using 3D printer.

c. Experimental analysis using the existing water vortex turbine system with different types of turbine blades which are flat, curved and skewed blades.

d. Experimental analysis using the Prony brake system to measure the torque of the water vortex turbine for different types of turbine blades.

e. Investigate the effect of different types of blades have on the vortex turbine performance in terms of power output and efficiency.

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1.5 Research Methodology

Phase 1: Experimental Analysis

Literature review is done by studying the past research related to the vortex turbine. The theoretical information related and obtained provides a well-strategized planning to design and fabricate the skewed blade of the vortex turbine by using 3D printer. Experimental analysis is done to determine the water vortex performance between three different types of runner blades which is flat, curved and skewed.

Phase 2: Design CFD model and Simulation Flow Analysis

The CFD model of the vortex tank without turbine included is developed to simulate the water flow and compare the vortex height to experimental results. Simulation Flow Analysis on the water flow is done by studying the results made by the Ansys CFX. The data will be presented in the form of tabulation results, graph and software demonstrations.

Phase 3: Design and Fabricate the Skewed Blades of Vortex Turbine

Designing of the CFD model for the vortex turbine will be done using the SolidWorks software to generate the 3D drawing for skewed turbine blade. SolidWorks software also enables any modification and improvement to be done on the model. The CFD model must be in 3D solid model to be able to use in Ansys CFX.

The flow vector of the vortex flow is analysis by using Ansys Computational Fluid Dynamic (CFX). Ansys CFX is helpful in designing the skewed blade. Using simulation result that obtained, the result will be further analyse with related calculations and theory analysis to conduct the performance test on flat, curved and skewed blades. The skewed turbine was design with the number of blades being 5 which is most suitable for the vortex generation system because it will have the highest vortex performance results in terms of power output and efficiency.

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1.6 Research Flow Chart

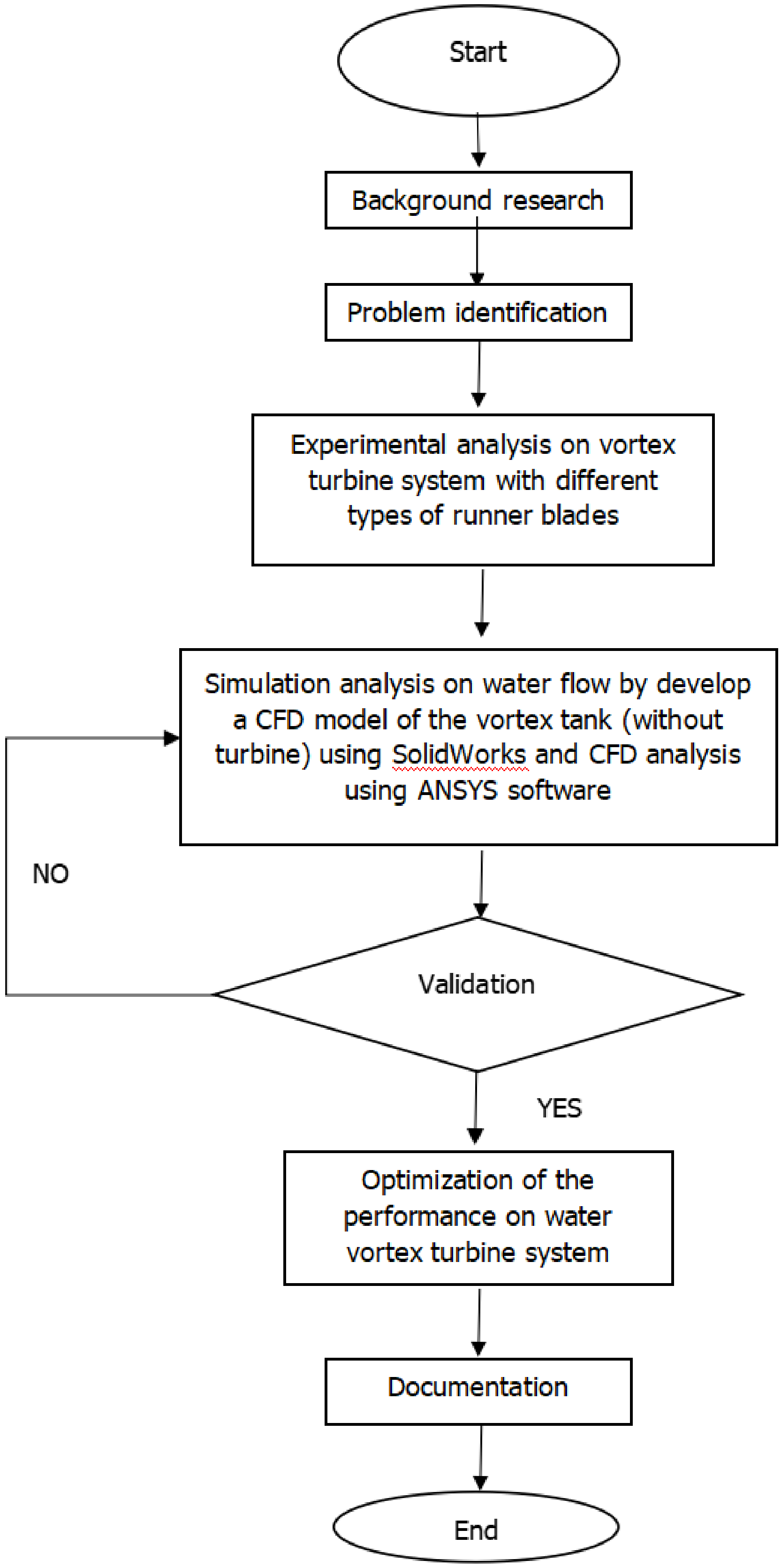

Figure 1.1 : Research Flow Chart

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1.7 Research Expected Outcomes

This research's expected outcome is the improve in the abilities to do literature review, designing and fabricating the skewed blade, theoretical analysis and simulation analysis with the information and knowledge provided from the past research papers. Through this experimental analysis, the expected outcome is to determine among three different types of runner blades which are flat, curved and skewed, which one will have better vortex turbine performance in terms of power output and efficiency.

1.8 Research Contribution

Energy consumption in variety fields have been a hot topic for the world for many years. For power generation system, the application of vortex turbine as new source of electricity generation has lots of advantages and environmentally friendly. It also does not require large space for installation like building a dam which causes damage to ecosystem. It also has less interference with the aquatic life inside the river. It can allow fish to flow in both upstream and downstream directions. The low-speed turbine does not interrupt the natural flow of water and does not harm aquatic and marine species. As a result, the water vortex turbine technology poses no damage to biodiversity and is one of the options for utilising low-head hydropower resources. Lastly, this research paper hopes to be able to help in achieving a better performance for the water vortex turbine system.

1.9 Research Commercialization

The vortex turbine system has good commercialization potential as it is capable of generates electricity from a moving fluid of renewable energy source. The installation of this technology can be used by small business owners or house in the rural area as it is able to provide energy for the running of entire energy appliances. Besides, the vortex turbine system working concept has been proven to be environmentally friendly with lowest carbon footprint and the most inexpensive technologies that will surely contribute more for building an eco-friendly environment.

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CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

Hydropower is a renewable energy source that generates electricity by damming or diverting the natural flow of a river or other body of water. Hydropower applies the water cycle's continuous and unending recharge system to generate energy, with no reduction or elimination of the water source or supply.

Hydropower uses turbines and generators to transform kinetic energy into electrical energy, which is then sent into the electrical grid to power homes, industries and companies. Hydroelectric turbines account for about 17% of the total number of power generating units in the United States and Canada. According to the North American Electric Reliability Council (NERC) Generating Availability Report, the failures of the turbine governor, wicket gate mechanism, lubrication oil system and generator bearings are among the top 25 causes of forced and scheduled outages and deratings of hydroelectric turbines (Pall Corporation, 2006). This means that immediate and substantial work is needed to increase hydroelectric turbine reliability and availability.

Furthermore, hydroelectricity is the cheapest and cleanest form of electricity, far cleaner to the power and water created by fossil fuels, which streams and water that falls have the potential energy. Hydropower utilises a turbine to convert energy into useable mechanical power via water movement, which is then converted into electricity or directly used to operate the milling machine via an electric generator. Due to the differences in elevation that redirected the water through a pipeline for everyday usage in delivering water, the potential energy power can be used right away by altering the process (Gatte & Kadhim, 2012).

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2.2 Classification of turbines

There are various designs for hydroelectric turbines nowadays, but they all work on the same principle where the potential energy of water was converted to kinetic energy by rotating a paddlewheel or propeller-type runner on the turbine. The converted rotational kinetic energy was then used to generate electricity, power up an electric generator and other varieties of related applications. The shaft of a hydroelectric turbine can be oriented vertically or horizontally. In this case, most of the reaction turbines have shafts that are vertically oriented.

There are two types of hydroelectric turbines which are impulse and reaction turbines. For the powering of impulse turbine, one or more water jets are directed tangentially into "buckets" or "paddles" of a wheel-shaped runner which rotating in air. While a stream wheel is powered by the natural flow of water in a stream or river, an impulse turbine is powered by a forceful jet of water generated by a high head of water (Breeze, 2018). They're typically used in low-flow, high-head applications for example like Pelton, Turgo and Crossflow turbine. At very low head, the performance of this type of turbine is weak.

Next, reaction turbines are submerged in water and worked based on the differences in water pressure between the pressure side and the discharge side of the runner blade. This principle is like how the wind propels a windmill propeller. This type of turbine was designed for non-mountainous areas with low heads and high flow rates, for example like Francis and Kaplan turbine. However, Francis turbines are sometimes applied in applications with a high head and low flow rate.

Classification of turbine is low head, medium head or high head machine as shown in the table 2.1 based on size of the machine.

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