PARAMETRIC STUDY OF CAVITATION EFFECT ON 3D HYDROKINETIC TURBINE BLADES USING CFD

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by

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June 2021

ENDORSEMENT

I, Nhgantiran A/L Nanthakumar Kawendar hereby declare that I have checked and revised the whole draft of dissertation as required by my supervisor.

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(Signature of Student)
Date: 25 June 2021

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(Signature of Supervisor)
Date: 25 June 2021

____
(Signature of Examiner)
Date: 6 July 2021

DECLARATION

This whole thesis is the work and investigation of my own, except where it is stated otherwise, this work has not previously been accepted in substances for any degree and is not being concurrently submitted in candidature for any other degree.

(Signature of Student)
Date: 25 June 2021

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PARAMETRIC STUDY OF CAVITATION EFFECT ON 3D HYDROKINETIC TURBINE BLADES USING CFD

ABSTRACT

This project's work discusses about the parametric study of cavitation around the horizontal axis turbine blade. This work mainly focusses on the case study of cavitation and how it affects the performance of the blade in terms of lift, drag and pitching moment. Cavitation is the phenomenon where it damages the surface of turbine blade when the cavities collapse. The objectives of this work are to study the effect of Artificial Cavitation Generator (ACG) installed on turbine blade and twisting angle of turbine blade on the blade performance while observing the changes in behaviour of cavitation. The optimal design of turbine blade with ACG and twisting angle is then suggested based on the finding. The analysis is done using Computational Fluid Dynamics (CFD) simulation software, ANSYS FLUENT. This research focuses on 3-dimensional case study of a single blade which uses the profile NACA 4418. The modification of twist angle and also the installation of ACG were done using Computational Aided Design (CAD) software, SOLIDWORKS and Design Modular. The simulations were conducted using parameters from the literature review for validation purpose and also to compare the result of modified blade with original blade. The simulation was conducted at fluid velocity 1.9 m/s with multiphase viscous model, Re-Normalisation Group k-ε model, cavitation model, Schnerr-Sauer model to simulate the cavitation phenomenon. From the simulations, it was found that the twisting angle changes the lift coefficient and also drag coefficient while the installation of ACG disrupts the cyclic behaviour of cavitation phenomenon. The optimal design for the blade is with the twisting angle of 4° and also with the installation of Artificial Cavitation Generator (ACG).

KAJIAN PARAMETRIK PENGARUH KAVITASI TERHADAP BILAH TURBIN HIDROKINETIK 3D MENGGUNAKAN CFD

ABSTRAK

Projek ini membincangkan mengenai kajian parametrik kavitasi di sekitar bilah turbin paksi mendatar. Karya ini terutamanya fokus pada kajian kes kavitasi dan pengaruh kavitasi kepada prestasi bilah turbin dari segi pekali angkat, pekali seret dan pekali momentum nada. Kavitasi adalah fenomena di mana ia merosakkan permukaan bilah turbin ketika rongga runtuh. Objektif kerja ini adalah untuk mengkaji kesan Penjana Kavitasi Buatan yang dipasang pada bilah turbin dan sudut putaran turbin terhadap prestasi bilah turbin sambil memerhatikan perubahan tingkah laku peronggaan. Reka bentuk bilah turbin yang optimum dengan Penjana Kavitasi Buatan dan sudut berpusing kemudian dicadangkan berdasarkan temuan. Analisis dilakukan menggunakan perisian simulasi 'Computational Fluid Dynamics' (CFD), ANSYS FLUENT. Penyelidikan ini memfokuskan pada kajian kes 3-dimensi dari bilah turbin tunggal yang menggunakan profil NACA 4418. Pengubahsuaian sudut putar dan juga pemasangan Penjana Kavitasi Buatan dilakukan dengan menggunakan perisian reka bentuk berbantu pengkomputeran (CAD), SOLIDWORKS dan 'Design Modular'. Simulasi dilakukan menggunakan parameter dari tinjauan sastera untuk tujuan pengesahan dan juga untuk membandingkan hasil bilah turbin yang diubah dengan bilah turbin asli. Ini adalah pendekatan untuk menghasilkan perbandingan dan hasil yang lebih berpengaruh. Simulasi dilakukan pada kecepatan bendalir 1.9 m/s dengan model multiphasa, model 'Re-Normalisation Group k-ε' peronggaan, model Schnerr-Sauer untuk mensimulasikan fenomena kavitasi.

Dari simulasi ini, didapati bahawa sudut berpusing mengubah pekali angkat, pekali seret dan pekali momentum nada sementara pemasangan Penjana Kavitasi Buatan mengubah tingkah laku kitaran fenomena kavitasi dan mengurangkan fenomena kavitasi. Apabila sudut berpusing berubah, pekali angkat, pekali seret dan pekali momentum nada juga berubah. Reka bentuk optimum untuk bilah turbin adalah dengan sudut putaran 4° dan juga dengan pemasangan Penjana Kavitasi Buatan.

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LIST OF SYMBOLS

$C_{1\epsilon}$	Constant with value of 1.44
$C_{2\epsilon}$	Constant with value of 1.92
$C_{3\epsilon}$	Constant with value of 0.09
C_d	Drag coefficient
C_l	Lift coefficient
C_l/C_d	Ratio of lift coefficient to drag coefficient
C_p	Pressure coefficient
F_D	Drag force, N
F_L	Lift force, N
G_b	Generation of turbulence kinetic energy due to buoyancy
G_k	Generation of turbulence kinetic energy due to the mean velocity gradients
k	Turbulence kinetic energy
n	Bubble density numbers
P	Local far-field pressure, Pa
P_B	Bubble surface pressure, Pa
P_{local}	Local fluid static pressure, Pa
P_{ref}	Reference hydrostatic pressure, Pa
P_v	Saturation vapor pressure, Pa
R	Mass transfer rate, m/s
R_B	Bubble radius, mm

R_c	Mass transfer source terms connected to the collapse of the vapor bubbles
R_e	Mass transfer source terms connected to the growth of the vapor bubbles
S_{ij}	Strain rate tensor
S_k	User-defined source terms for k
S_ϵ	User-defined source terms for ϵ
V	Free stream flow velocity, m/s
$\vec{V_v}$	Vapor phase velocity, m/s
Y_M	Contribution of the fluctuating dilatation in compressible turbulence to the overall dissipation rate
α	Vapor volume fraction
ρ	Fluid density, kg/m3
ρ_l	Liquid density, 998.2 kg/m3
ρ_v	Vapor density, kg/m3
σ	Cavitation number
σ_k	Turbulent Prandtl numbers for k with constant value 1.0
σ_ϵ	Turbulent Prandtl numbers for ϵ with constant value 1.3
v	Vapor phase
π	Pi number, constant value 3.142
ϵ	epsilon
τ_{ij}	Viscous stress tensor
μ	Effective molecular viscosity
δ_{ij}	Kronecker delta function

LIST OF ABBREVIATIONS

ACG	Artificial cavitation bubble generator
CAD	Computer-aided design
CFD	Computational Fluid Dynamics
GIT	Grid Independent Test
RE	Renewable energy
RNG	Renormalization group
2D	2-Dimensional
3D	3-Dimensional
USM	Universiti Sains Malaysia

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Appendix A	The Sample Graphs From Ansys Simulation Of Twisting Angle Of 10º

CHAPTER 1

INTRODUCTION

1.1 Malaysia's Current Energy Background

Renewable energy (RE) has been the eye of focus of Malaysian government over the past decade. The 10 years' plan, Malaysia Energy Supply Industry 2.0 (MESI 2.0) was launched by Malaysian government as an initiative to rev up the country's RE capacity. The government has planned to rev up the RE capacity by 20 percent by the year 2025. Malaysian government resort to this initiative as a result of increase in emission of carbon dioxide, carbon monoxide, greenhouse effect and other pollutions such as acid rains. Thus, the government decided to be less dependent on fossil fuels, petroleum and other pollution friendly fuel sources. Looking into statistics, until 2016, up to 86.7% electricity generation in Malaysia were solely dependent on non-renewable energy resource which consists of coal, natural gas and petroleum. Whereas, the remaining 13.3% of electricity generation depends on renewable energy resource which consist of solar, wind and hydro (Suruhanjaya Tenaga, 2017, p. 34). Amidst of all the renewable energy, hydro energy has the most potential to be efficiently and massively implemented due to the geographical terrain and certain climate occurrence of Malaysia. For instance, Malaysia have many large rivers and also have monsoon climate which improves the potential of hydro energy implementation. To be precise, Malaysia consist of 189 rivers with the length of 57300 km. (Abdullah et al. 2019).

1.1.1 Hydro Energy

Hydro energy is a form of energy where it refers to the conversion from the motion of water into electrical energy. Hydro energy is under the category of renewable energy because water is continuously renewable throughout the water cycle. This hydro energy is commonly generated by devices called generators and turbines where the potential energy in the water converts into mechanical energy when it moves or spin the turbine blade and this mechanical energy turned into electrical energy due to the mechanism of the turbine or generator. Moreover, hydro plants can be specified into 3 types, which is Pump storage facility, Run-of-river facility and Impoundment facility (U.S. Department of Energy, 2003, p. 4). Usually the Impoundment facility is the typical hydro plant that will be implemented where dam is built to create a man-made reservoir, then the water from the reservoir will be directed through the large scale turbine to generate electricity. However, this method has its own drawback where the construction cost is high for the dam to be built, whereas the failure of the dam system will have massive impact on the surrounding ecosystem and landscape. On the contrary, the Run-of-river facility shows promising result which does not require large construction cost. Thus, the hydrokinetic turbine shows large potential which may change Malaysia's future electrical energy generation system.

1.2 Hydrokinetic Turbine

Hydrokinetic turbines are the new backbone of hydro energy harnessing system. These devices are recently developed which can convert the kinetic energy from the water current into electrical energy. The concept of hydrokinetic turbine is similar to wind turbine where the water is used to turn the turbine blades which generates electricity. The difference is just that a denser fluid, water moves the turbine blade instead of air. The most crucial components for a hydrokinetic turbine are briefly explained below (Oblas, 2016):

a) Diffuser: The diffuser is the structural member which connects the leading components which consist of front shaft, runner hub, nose supports with trailing components which consist of rear components, mooring supports and nacelle. This component features to increase the available pressure drop across the turbine by drawing more fluid through the turbine.

b) Gearbox: The gearbox serves to speed up the rotation rate of rotor when functioning.

c) Generator: The generator converts the mechanical energy produced from the rotor to electrical energy.

d) Nacelle: The nacelle act as a housing space for the turbine components and prevent the breach of water from affecting them.

e) Runner: The runner consists of the blades mounted to the central hub. The design of runner is to mainly change the fluid flow power into rotary motion.

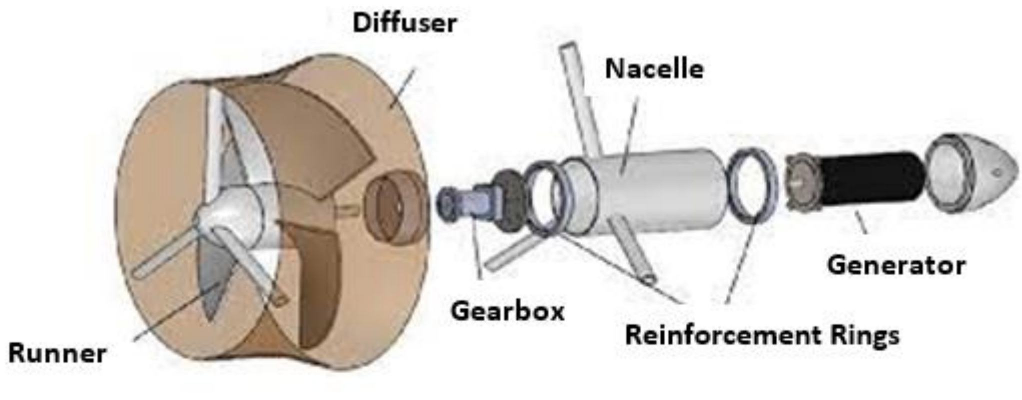


Figure 1.1 Labelled diagram of horizontal axis hydrokinetic turbine

1.2.1 Classification of hydrokinetic turbine

There are several types of hydrokinetic turbine which can be classified into 2 categories. The first category is the horizontal axis hydrokinetic turbine while the second category is the vertical axis hydrokinetic turbine. The first category, horizontal axis turbine has central axis of blades rotating normal to the vector of flowing water direction. The second category, vertical axis turbine has central axis perpendicular to the flowing water direction. While the vertical axis turbine does not need complicated blade design, the horizontal axis turbine needs a well-designed turbine blade to achieve desired performance. The classification of all the hydrokinetic turbines are as shown below:

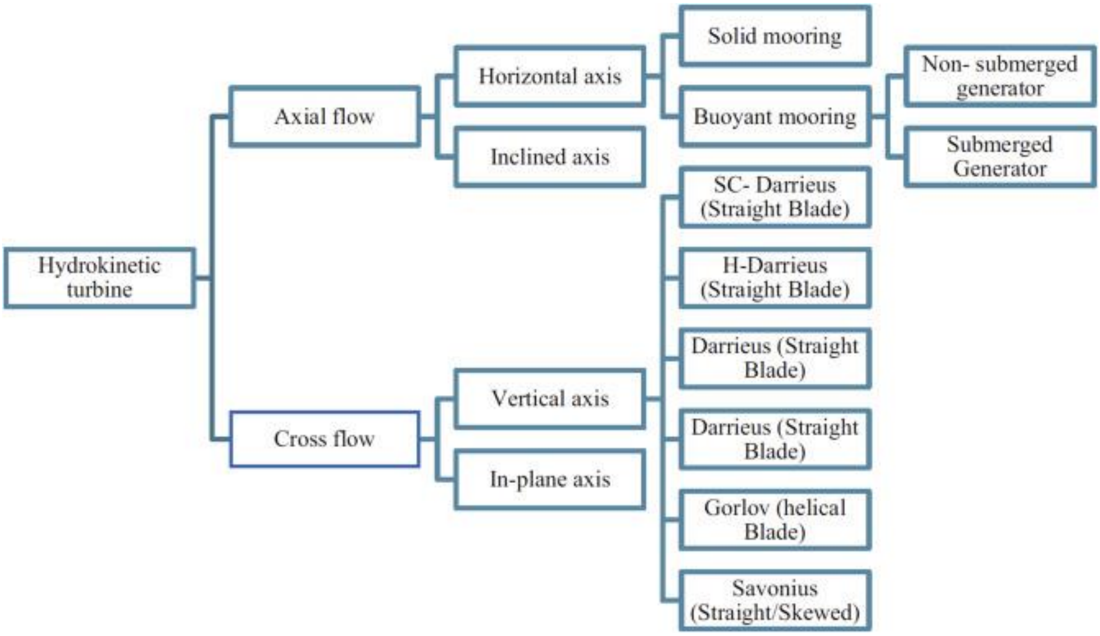
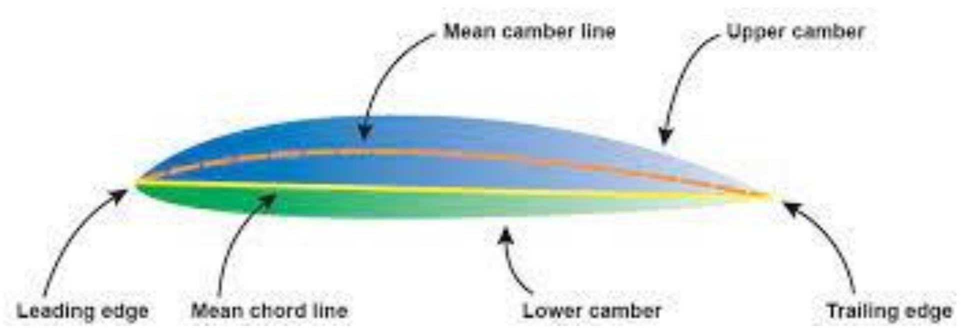


Figure 1.2 Classification of hydrokinetic turbines

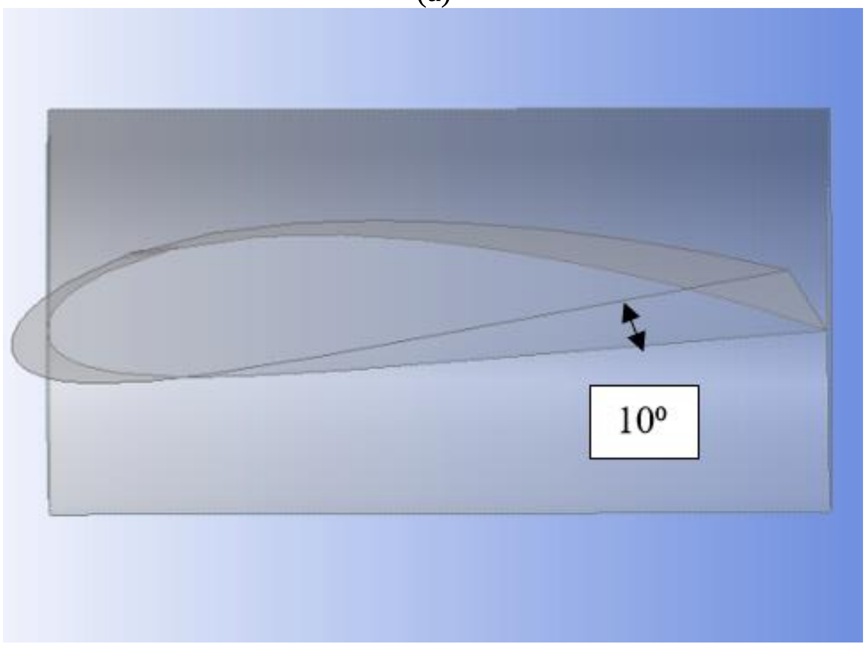
1.2.2 Blade Design of Hydrokinetic Turbine

The main critical criterion of a well performing hydrokinetic turbine is the turbine blade design. The turbine blades produce lift force which allows the rotor to rotate continuously. Thus, the design of the turbine blade has larger impact on the performance of the hydrokinetic turbine. The blades are usually constructed using hydrofoil shape. The hydrofoil shape technically has more curvature shape on the top surface than the bottom surface. The top surface and bottom surface has a flat line connecting both of it which is known as chord line. Then, the locus of mid-points between top surface and bottom surface known as the camber line. The front point intersecting the top surface and bottom surface known as the leading edge while the rear point of intersection known as trailing edge.

Little variation in twist angle has more effect on the performance of hydrokinetic turbine blade. The twist angle is very sensitive to the fatigue life of the blade than the chord length and the blade length (Liu et al., 2017). The fatigue life increases exponentially with the increase in twist angle, while there is parabolic relation between the fatigue life of the blade and the chord length. The fatigue life decreases with increase in the blade length linearly. Due to increase in fatigue life of the blade, the cost of the hydrokinetic turbine plant gets reduced with more reliability. Hence the care should be taken about the twist angle of the hydrokinetic turbine blade while manufacturing. There should always be an optimum twist angle to get optimum power output.



(a)



(b)

Figure 1.3 (a)Labelled diagram of hydrofoil, (b) Top view of turbine blade showing twist angle of 10º

1.3 Cavitation Phenomenon

There is another critical aspect that influences the performances and the lifespan of hydrokinetic turbine blade which is cavitation. Cavitation is a phenomenon where the rapid fluctuation in pressure of flowing water causes the formation of vapor bubbles or known as cavities. To be precise about this phenomenon, when the local static pressure drops below the vapor pressure of liquid, this condition leads to the formation of the vapor bubbles. The vapor bubbles have tendencies to move to higher pressure region as water flow through the turbine blade passage. Then, when the local static pressure rises above the vapor pressure of the liquid due to, the vapor bubbles which present at the region collapse and cause an implosion. The vapor bubbles collapse because it could not withstand the high pressure. The implosion caused by the collapsing vapor bubbles will imitate a supersonic fluid micro jet which hits the surface of the turbine blade. This occurrence will cause surface erosion of the turbine blade. Thus, this affects the performance and lifespan of the turbine blade. Reduction of cavitation impact must be an important aspect taken into consideration when design hydrokinetic turbine blade. Figure 1.5 shown below is the image of erosion damage caused by cavitation phenomenon.

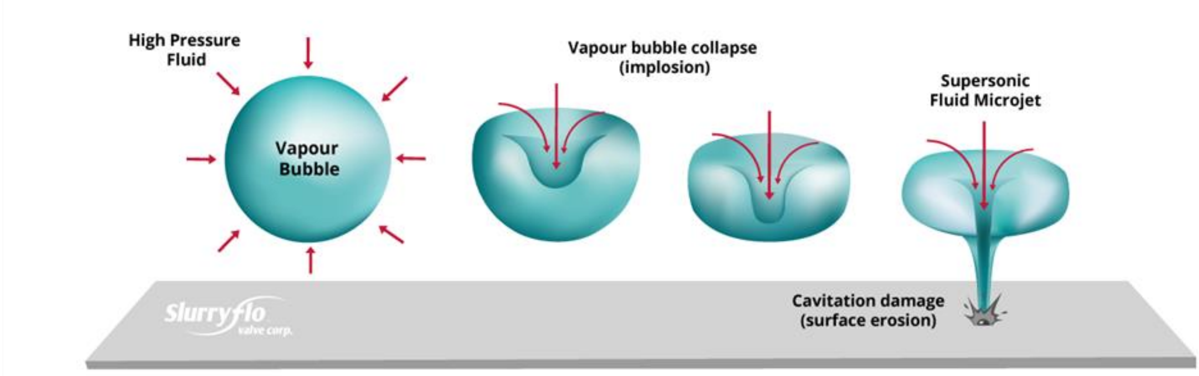


Figure 1.4 Illustration of cavitation phenomenon (Slurryflo 2020)