BLADE PERFORMANCE ON THE EFFECT OF WHALE WAVY LEADING-EDGE BY USING MESHFREE ANALYSIS

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DEDICATION

Thank you for being with me.

All the time.

Through thick and thin.

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ABSTRACT

This study investigates the application of a wavy leading edge (WLE)—based on the flipper of a humpback whale—on a water turbine blade and its effect on blade performance. The analysis was conducted using a numerical tool known as MeshFree. Focusing on the blade application in a water turbine, a wavy leading edge was applied and adapted to the blade due to the proven capability of this feature in reducing turbine cut-in speed. The approach utilises a meshless method (MeshFree), which has been claimed to result in higher accuracy output compared to other well-known numerical tools such as the Finite Difference Method (FDM) and Finite Element Method (FEM). In this study, the subject was considered as a thin-plate element, and the formulation was made in MeshFree, with the processing conducted in MATLAB software. A number of outputs were obtained from the MeshFree method and then applied in a parametric study. A few sets of parameters were identified consisting of radius, number of nodes, and number of Gauss points, where all values were fixed prior to observing the effect of the wavy pattern on the maximum deflection of the blade. Then, the wavelength, amplitude, and curve at the corner of the blade were varied to observe their effect on blade deflection. The results show that the wavelength parameter had no significant effect on the blade deflection compared to the normal design of the blade unlike the amplitude and curve parameters. In sum, although the WLE factors can increase the turbine's effective energy production, it could also contribute to higher maximum deflection on the blade when amplitude is increased. However, this increment could be controlled by increasing the curve at the corner edge of the blade.

ABSTRAK

Kajian ini menyelidik aplikasi plat berombak tepi (WLE)—berdasarkan sirip paus humpback—pada bilah turbin air dan kesannya ke atas prestasi bilah. Analisis ini dijalankan menggunakan penilaian berangka yang dikenali sebagai jaring bebas (MeshFree). Memfokus kepada aplikasinya dalam turbin air, WLE diaplikasi dan diubahsuai pada bilah disebabkan keupayaan bentuk in yang telah terbukti dapat mengurangkan laju potongan turbin. Pendekatan dalam kajian ini menggunakan kaedah MeshFree yang telah terbukti menghasilkan ketepatan hasil yang lebih tinggi berbanding dengan pendekatan berangka yang lain seperti kaedah beza terhingga (Finite Difference) dan kaedah unsur terhingga (FEM). Dalam kajian ini, subjek diambil kira sebagai elemen plat nipis, perumusan dibuat menggunakan MeshFree, dan pemprosesan kira-kira dilakukan menggunakan perisian MATLAB. Hasil dapatan daripada MeshFree dibentangkan dan kemudian digunakan dalam kajian berparameter. Beberapa set parameter telah dikenal pasti terdiri daripada jejari, bilangan nod, dan bilangan titik Gauss di mana semua nilai ini telah ditetapkan sebelum analisis hubungan antara corak WLE dengan pesongan maksimum bilah dijalankan. Kemudian, panjang gelombang, amplitud, dan lengkungan di sudut bilah diubah untuk memerhati kesan perubahan parameter tersebut ke atas pesongan bilah. Keputusan menunjukkan bahawa parameter panjang gelombang tidak memberikan kesan yang nyata kepada pesongan bilah; hal ini berbeza dengan amplitud dan lengkungan. Kesimpulannya, walaupun faktor WLE mampu meningkatkan keberkesanan pengeluaran tenaga turbin, ia boleh juga menyumbang kepada pesongan maksimum yang lebih tinggi apabila amplitud dinaikkan. Walaubagaimanapun, kenaikan ini boleh dikawal dengan menaikkan lengkungan di sudut tepi bilah.

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LIST OF ABBREVIATIONS

WLE	-	Wavy Leading-Edge
FEM	-	Finite Element Method
EFG	-	Element Free Galerkin
MLS	-	Moving Least Square
PDE	-	Partial Differential Equation
PIM	-	Point Interpolation Method
RPIM	-	Radial Point Interpolation Method
CPT	-	Classic Plate Theory

LIST OF SYMBOLS

A	-	Area of the plate
b	-	Body force vector
D	-	Flexural rigidity
E	-	Modulus of elasticity
F	-	Force vector
I_0	-	Mass per unit area of the plate
I_2	-	Mass moments of inertia
K	-	Global stiffness matrix
K^{α}	-	Penalty stiffness matrix
M	-	General moments
M_n	-	Moment
M_{nt}	-	Torsional Moment
Nh	-	Number of nodes
n	-	Normal of the problem domain boundary
t_{Γ}	-	External traction on the plate edge
U	-	Vector of the displacements
u	-	Deflection at x direction
V	-	General shear forces
V_n	-	Shear force
v	-	Deflection at x direction
w	-	Deflection at z direction
w_{Γ}	-	Deflection on the essential boundaries
α	-	Diagonal matrix of penalty factors
∂	-	Differential operators
σ	-	In-plane stress
σ_p	-	Pseudostress
ε	-	In-plane strains
ε_p	-	Pseudostrain
ν	-	Poisson’s ratio

φ_n	-	Rotation on the boundary
S_n	-	Set of nodes in the support domain
ϕ_I	-	MLS shape function
Γ_t	-	Natural boundary

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CHAPTER 1

INTRODUCTION

1.1 Introduction

The wavy leading edge (WLE) of the humpback whale has become the focus of research interest nowadays due to the presence of tubercles on the whale's flipper. The tubercles generate unique flow control mechanisms, offering the humpback exceptional manoeuvrability (Aftab et al., 2016), evident in the turning radius of the whale and its movement through water.

The study of whale WLE, however, is not recent. The idea has been proposed by numerous studies since the early 1970s, with focus on the mechanical features and capabilities of the whale flipper (Edel & Winn, 1978). Since then, a number of theoretical studies have been conducted on the whale's underwater locomotion, flipper movement, flow separation, and the hydrodynamic design of the whale WLE.

Whale WLE has been shown to influence laminar separation bubbles, tonal and broadband noise, and dynamic stalls, leading to its application in marine wind turbines and exhaust fans. Out of all these applications, the rotating blade of the water turbine was selected as the main focus of this study. The rotating blades in the water turbine are exposed to a huge load variation, which induces blade fatigue. This is because the blade has a tendency to experience time-dependent flow separation during operation.

A number of researches have been done to prove the capabilities of whale WLE in reducing dynamic stall, which influences load variation. However, the studies conducted did not focus on structural adaptions. Therefore, an extension to these previous studies is proposed. This time, the whale WLE shape will be adapted to the blade and its structural performance observed using a MeshFree method, a new numerical technique, which is an alternative to the Finite Element Method (FEM). According to Mohd Noor (2013), the technique differs from FEM in that it does not impose limitations on the predefined shape function. The method also uses a set of nodes instead of a set of predefined meshes.

1.2 Research Background and Rationale

Continuous advancement in the field of research involving whale WLE has attracted interest in its development as well as encouraged detailed modelling of the WLE for the purpose of its application in design practice. Nevertheless, improvement in modelling approaches is still imperative since the existing models might lack accuracy and/or computational efficiency (Zainal Abidin, 2013).

Because of the complexity of modelling the WLE, simplified modelling, which in this case refers to the Finite Element Method, will always suffer from a low-quality set of meshes (Liu, 2010). This will result in low accuracy and less acceptable predictions.

Since whale WLE is a 2-dimensional problem, the numerical method using MeshFree will still be less established compared to 1-dimensional problems. Whilst numerous formulations have been proposed, recent works on the WLE blade have focused only on flow measurement, dimension optimisation, and hydrodynamic performance of the mechanism, as was the case of Shi et al. (2017; 2016a; 2016c). The same researchers also conducted cavitation observations and noise measurement (Shi et al., 2016b). Although there are related studies in the field, recent interests have been focused more on the tidal turbine instead of the water turbine. Therefore, this study aims to formulate a 2-dimensional problem in MeshFree as well as expand on existing knowledge by considering the structural performance of whale WLE when applied in water turbine blade design.

1.3 Purpose and Objectives of The Study

The purpose of the study is to conduct a numerical method using MeshFree that can predict the performance of the WLE blade by considering its displacement distribution.

The objectives of this study are listed below:

a. To design a WLE blade using Element-free Galerkin (EFG)

b. To obtain the optimum MeshFree parameters for solving the research problem

c. To study the effect of the whale WLE shape on the performance of the blade

1.4 Scope of The Study

EFG approach is being employed in solving the WLE blade problem. In order to ensure the study conducted to be more focused, the scopes of the study are outlined below:

a. Materials are assumed to be linear elastic

b. The blade is subjected to the function of the water turbine

c. The problem is analysed as a 2-dimensional element

d. Transverse shear deformation of the blade is negligible

1.5 Outline of The Project Report

This thesis comprises five chapters, which are the introduction, literature review, MeshFree formulation, parametric studies, and conclusion.

Chapter 1 is the introductory chapter and explains the details of the present states, its purpose, and the scope of the study. The rationale of the study is further explained in this part in order to obtain good understanding of the research overview before going deeper into the subject matter.

Chapter 2 provides an extensive review of previous related research that has been done in the area of study. This includes the features of the whale flippers, its flow behaviour, application in turbine blade, and the numerical method chosen, which is MeshFree. The application of MeshFree in various engineering problems is also briefly mentioned.

Next, Chapter 3 explains the formulation of the plate element in MeshFree. The applied theory is shown and described before the formulation procedure is outlined and how the equations are derived. At the end of the chapter, the validation and verification of the source code used in the study is explained before proceeding to the next level.

Chapter 4 details out the parametric studies conducted in this work, using the Element-free Galerkin (EFG) method. This is to determine the optimal values of the parameters implemented and how they influence the result. After that, the identified parameters are utilised to find the effect of displacement by changing the wavy shape at the edge of the blade.

The last chapter, Chapter 5, concludes the results of the study while at the same time summarises the findings for every chapter. It also proposes enhancements for future research as a continuation to the plate analysis subjected

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