RESISTANCE PREDICTION OF DOUBLE ACTING TANKER IN ICE CONDITION

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ABSTRACT

An icebreaker ship should have ice bow design at its stem part. It should have ice bow design because a common bow design has high resistance when sailing in open water. In order to solve the problem, previous researchers had introduced a Double-Acting Tanker (DAT) which is able to sail astern on sea surface covered by ice and sailing ahead in open water. The main problems are liaised with hull, ice, and propeller interactions during the DAT ship sailing astern which is very complex and simulation software is unable to simulate. In addition, the model scale test in the towing tank needs a full scale data of ice resistance. The aim of this work was to propose an empirical method to predict the resistance of DAT based on Koto method. The resistance components were water resistance, friction resistance, momentum resistance, immersion resistance and breaking resistance. The dimensionless constants for each resistance component were determined by using multiple regression variables. The forward sailing resistance of a DAT model was simulated at 0.4 m/s, 0.5 m/s and 0.6 m/s to predict the suction force of the propeller disc effect when DAT sailing at 1.8 m/s, 2.4 m/s and 2.7 m/s in iced sea surface condition. DAT resistance was predicted using the Finite Element Method (FEM) in Eulerian-Lagrangian Coupled theory (CEL) to detect the interactions between ship and ice sheets. The results showed that the ice sheet warms up when DAT sails forward and the ice sheet bends when DAT sails astern. The required force to break the ice sheet when sailing astern is less than the one sailing forward because of the critical bended length is shorter than normal bended length. The simulation results using the proposed empirical method show a good agreement with the experimental data. A total of 60% drag decreased when DAT sails backward. The significance of this study is the complexity of the astern sailing was explained clearly when the resistance of DAT was predicted by using empirical method.

ABSTRAK

Kapal pemecah ais harus mempunyai reka bentuk haluan ais di bahagian hadapan kerangka. Reka bentuk haluan ais diperlukan kerana reka bentuk umum kapal mengalami rintangan yang tinggi sewaktu pelayaran di perairan terbuka. Untuk mengatasi masalah ini, ramai penyelidik telah memperkenalkan kapal tangki tindakan ganda (DAT) yang dapat berlayar secara mengundur di laut liputan ais dan belayar ke hadapan di perairan terbuka. Masalah utamanya ialah hubungan antara badan kapal, air, dan kipas pendorong sewaktu kapal berlayar secara mengundur adalah sangat kompleks dan ketiadaan perisian simulasi. Tambahan pula, ujian model di tangki tunda masih memerlukan data lengkap bagi menentukan rintangan ais. Objektif kajian ini adalah untuk mencadangkan kaedah empirikal untuk meramal rintangan DAT berdasarkan kaedah Koto. Komponen rintangan adalah terdiri daripada rintangan air, rintangan geseran, rintangan momentum, rintangan tenggelam dan rintangan pemutus ais. Pemalar tanpa dimensi untuk setiap komponen rintangan ditentukan melalui pemboleh ubah regresi. Rintangan model DAT yang berlayar ke hadapan telah disimulasikan pada 0.4 m/s, 0.5 m/s dan 0.6 m/s pada perairan liputan ais. Tambahan pula, kaedah empirikal yang dicadang ini juga meramalkan daya sedutan daripada kesan putaran kipas pendorong apabila DAT berlayar pada kelajuan 1.8 m/s, 2.4 m/s dan 2.7 m/s dalam perairan berais. Rintangan DAT telah diramalkan dengan Kaedah Unsur Terhingga (FEM) bergabung dengan teori pasangan Eulerian-Lagrangian (CEL) untuk mengenalpasti hubungan antara kapal dan kepingan ais. Keputusan menunjukkan bahawa kepingan ais akan memanas apabila DAT berlayar ke hadapan dan kepingan ais membengkok apabila DAT berlayar secara mengundur. Daya yang diperlukan untuk memecahkan kepingan ais semasa DAT berlayar secara mengundur adalah kurang berbanding dengan daya DAT berlayar ke hadapan kerana panjang bengkok kritikal adalah lebih pendek berbanding dengan panjang bengkok yang normal. Keputusan simulasi menggunakan kaedah empirikal menunjukkan penjajaran yang baik dengan data eksperimen. Sejumlah 60% daya seretan dapat dlikurangkan apabila DAT berlayar secara mengundur. Kepentingan hasil penyelidikan ini adalah kerumitan kapal DAT sewaktu berlayar secara mengundur dapat dikenalpastikan dengan jelasnya dan jumlah rintangan DAT dapat diramalkan dengan menggunakan kaedah empirikal yang dicadangkan ini.

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LIST OF ABBREVIATIONS

AAT	-	Aker Artic Technology
AZIPOD	-	Azimuthing Electric Propulsion Drive
CAD	-	Computer Aided Design
CEL	-	Coupled Eulerian-Lagrangian
DAS	-	Double Acting Ship
DAT	-	Double Acting Tanker
EoS	-	Equation of State
EVF	-	Euler Volume Fraction
FEA	-	Finite Element Analysis
FEM	-	Finite Element Method
FPSO	-	Floating Production Storage Offloading
FS	-	Full Scale
FSI	-	Fluid Structure Interaction
FSICR	-	Finish Swedish Ice Class Rule
FSR	-	Full Scale Regression
ITTC	-	International Towing Tank Conference
MARC	-	Masa–yards Arctic Research Centre
MaxPS	-	Maximum Principal Stress
MS	-	Model Scale
NURBS	-	Non Uniform B-Spline
NSR	-	Northern Sea Route
QCM	-	Quasi Continues Method
RANS	-	Reynold Average Navier Stokes
RHP	-	Right Hand Propeller
USCG	-	United Stated Cost Guard

LIST OF SYMBOLS

$\left(\frac{A_D}{A_O}\right)$	-	Blade area ratio
$\left(\frac{P}{D}\right)$	-	Pitch ratio
B	-	Breadth of ship
B_{PS}	-	Breadth of pre-sawn
C_S	-	Coefficient suction propeller at astern in level ice
C_1 , C_2	-	Experimental constant
C_S, C_B, C_V	-	Empirical determine value
C_T	-	Coefficient of thrust
C_f	-	Coefficient friction in water
$C_{breaking}$	-	Coefficient resistance breaking at level ice
C_{moment}	-	Coefficient resistance momentum at level ice
C_o, C_1, C_2	-	Coefficients determined by experimental
C_{sub}	-	Coefficient resistance submersible at level ice
C_w	-	Water plane area coefficient of entrance part
μ	-	Coefficient friction between model and ice
E	-	Flexural strength of ice
E_1	-	Energy when ship moves through the ice-filled channel
E_2	-	Energy impact local crushing at bow and ice
E_3	-	Energy needed for ship climbs onto the ice
E_4	-	Energy to make fracture of ice
E_5	-	Energy to forcing the ice downward
E_T	-	Total energy needed for ship moving on ice
$F_{suction}$	-	Resistance of suction propeller
F_{frict}	-	Resistance of friction floating ice-hull
$F_{breaking}$	-	Resistance ice breaking at level ice
F_{moment}	-	Resistance momentum at level ice
$F_{suction}$	-	Resistance suction propeller at astern in level ice
$F_{ship-ALiC}$	-	Resistance total in astern level ice

$F_{ship-HLI}$	-	Resistance total in head level ice
F_{sub}	-	Resistance submersible at level ice
$F_{(water)}$	-	Resistance of water
F_x	-	Force in the *x* direction
h_i	-	Ice thickness measurement
J	-	Advance coefficient
K_{T_n}	-	Coefficient regression of thrust
L	-	Length of ship
L_{WL}	-	Length of water line
N_{Δ}	-	Volume metric number
N_I	-	Inertial number
Q	-	Torque of propeller effect at level ice
$R^{\prime}$	-	Non-dimensional mean ice resistance
$R_{I,corr}$	-	Ice resistance after correction
$R_{I,meas}$	-	Resistance ice measurement
$R_{I,p}$	-	Resistance ice in prototype
$R_{IT.presawnice}$	-	Resistance total in pre-sawn ice condition
Rn	-	Reynold's Numbers
$R_{V,meas}$	-	Resistance measurement in certain velocity
R_{wave}	-	Resistance wave in water
R_{im}	-	Mean resistance excluding water
S	-	Wetted surface area
V	-	Velocity of ship
Z	-	Number of blade
a	-	Stem angle at waterline
aj_n	-	Exponents of advance coefficient
a_n	-	Exponents of blade area ratio
b	-	Stern angle at waterline
b_h	-	Coefficient ice breaking force
c_h	-	Coefficient ice crushing force
d	-	Draft of ship
g	-	Acceleration of gravity

f_{ID}	-	Dynamic model of ice friction coefficient
k_1	-	Coefficients experimental
r_n	-	Exponents of pitch ratio
t_1	-	Time starting integration
t_2	-	End time of integration
x_1	-	Start point of integration
x_2	-	End point of integration
z_n	-	Exponents of number of blade
$\emptyset$	-	Stem angle
n	-	constants
α	-	Waterline entrance angle
β	-	Arc tan of coefficient friction
λ	-	Scale factor in model scale
ρ_{Δ}	-	Difference density between on the water and the ice
ρ_w	-	Density of water
ρ_i	-	Density of ice
μ_o	-	Shimansky's ice cutting parameters
ψ	-	Angle between the normal of the hull surface and the vertical vector

LIST OF APPENDICES

CHAPTER 1

INTRODUCTION

This chapter discusses the background of study, problem statements, objectives, and scopes of the research. It also introduces description content briefly each of chapter of the thesis.

1.1 Background of Study

Northern Europe areas such as the Baltic Sea, the Gulf of Finland, the Gulf of Bothnia, the North Sea and areas around the Arctic Sea such as the Norwegian Sea, the Barents Sea and the Kara Sea are almost covered with ice throughout all the seasons. Even in summer season from June to September, the thickness of the ice will still be ranging from 80 to 250 cm and temperature of -7°C to 10°C as reported by Riska (2011). In order to travel through Northern Europe areas, an ice breaker is usually needed as an escort ship. Historically, in 1890 there was a Swedish ship, Murtaja, which was able to sail in extreme environments as reported by Jones (2008). This ship was the first to be known as an ice breaker with an unusual arc shape than an ordinary ship.

With the application of advanced offshore oil and gas exploration technology, the Artic area is identified have many oil and gas reserves. Norway's Statoil has made a second big oil discovery in the Barents Sea in less than a year and predicted more discoveries to come in the region, Statoil (2012). With the discovery of new oil fields, this could lead to an increase in sea traffic in the Artic area.

Jones (2004) recorded since 1962 there was a large increase in shipping activities especially in the Artic Sea. Increasing in the freight forwarding activities through the Northern Sea Route (NSR) and growth of oil and gas exploration activities in the Arctic region that is needed a specialized ship designed to sail in it. It should be noted that ice conditions is vary depending on the location. The special ship should have ability considering the different area in the operation.

Wilkman and Nini (2011) reported that since the end of 1970, there has been increasing traffic at Arctic, not only cargo and merchant ships but also passenger ships. Besides shipping activities, exploration also begun developing at the North Sea, such as Varandey drilling at the Pechora Sea began operating since 2000. Juva and Riska (2002) reported that to cross the northern route required high shipping costs. This pathway is not like a usual shipping route. It requires an ice breaker ship to make a channel, so that other ships will be following behind it. The Operational Costs will increase when the ship sailing is large and sometimes it takes two ice breakers ship to make a channel. Besides that, queuing and travelling like this makes the shipping time to be longer, especially while sailing there is a damaged ship.

An ice breaker ship was originally built based on conventional form designs. The conventional form design of the ice breaker ship is used within a long time and does not develop significantly due to the higher investment needed to make a model and testing it in an ice towing tank as reported by Wilkman (2015). This also limited available ice towing tank facilities to conduct the experiment of a ship in model scale. Therefore, the development of designs such as stem and stern hull forms, powering systems and ship dimensions do not have much progress. In 1959, Arctic Research Centre has initiated development of an innovative hull form of ice breaker. They have conducted experiments in ice towing tank at Wartsila, Finland by Wilkman et al. (2006). The ice breakers have been followed by many researchers. Now there are 11 ice towing tanks has been built in the world such as National Maritime Research Institute in Japan, Russia, Canada, USA, Finland, Germany and Korea.

The performance of an ice breaker ship can be identified by experiments on a scale model in the ice towing tank using several measuring instruments such as the strain gauge and load cell placed on the model. The results of these experiments can be used to calculate the thrust needed by the ice breaker ship. One of the common problems found during experiment is difficult to get the same ice thickness and long waiting time for freezing ice for every repeating experiment.

In order to reduce time consuming and cost of model scale experiments, many researchers have proposed basic empirical method to calculate ice breaker ship resistance. The scientific approach used in their study is to collect scale model data of ice breakers sailing in fresh water and from the sea. There is also a comparison between model scale and full scale in lakes and oceans. Lewis et al. (1970) argues that semi-empirical equations where the ability of resistance is measured by the contribution of total ice damage, friction, ice buoyancy, and momentum. Other researchers also use ice breakers to formalize resistance formulas such as Crago et al. (1971), Enkvist (1972) studied three ice breakers: Moskva class, Finncarrier, and Jelppari, other researchers Milano (1973), Vance (1975), Lindqvist (1989), Keinonen et al. (1996), Daley et al. (1997 and 1998). As a more specific example, Koto (2002) estimates certain resistance to the level of ice in which ships have never sailed before.

The basic empirical methods have been used to develop the design of ice breaker ships. Koto (2002) developed a numerical model applied to conventional ice breakers. The basic empirical method also has been improved to be advanced numerical methods. Tan et al. (2013) developed a numerical model using a method published by Lindqvist (1989) to calculate the magnitude of resistance that occurs when several working vessels work on ice level conditions. However, the study still has not gotten the magnitude of the propeller effect because the numerical model only covers the number of obstacles due to friction from soaking fragments of ice to the stomach. In another paper, Tan et al. (2014) also suggested in mathematical models to consider ice breaking patterns, the effect of ship speed, the width of the channel formed, and consider the contact angle formed at the interaction between ship and ice.

Another numerical approach was also developed by Lubbad and Løset (2011) to simulate ship-ice interaction in real-time. Ice is divided into 2 groups, breakable and unbreakable. The breakable part is a function of compressive strength of ice, contact area, and contact coefficient while the unbreakable part is related to gravity, buoyancy, damping and contact force. But in the simulation, modelling is done only for bending failure while other fracture conditions that also occur in ice such as stem crushing, shearing, and buckling are neglected. Another thing that is also neglected is added mass due to water, and inertia of ice. Meanwhile, to calculate the deflection and stress on the ice sheet, the COMSOL Multiyphysics software is used. Indeed, the final results were compared with the full-scale test on the KV Svalbard ice breaker but limited to Ahead conditions.

The numerical simulation was also developed by Su et al. (2012) for predicting ship performance in level ice based on empirical estimation of ice crushing pressure at the shoulder caused by interaction between ship and ice, ice bending failure at the amidships of ship and ice resistance when submerged ice was sliding at the bottom hull. The simulation results were not accurate because of the simplifications and assumptions applied in the simulation without considering resistance in the direction of heave, roll and pitch. The simulation also did not include the influence of open space between ships and ice and did not take into account the regularity and irregularity of the ice breaker continuously. Net thrust involved in propeller is calculated by Su et al. (2011) based on open water conditions, where there is a reduction in propeller capability due to deduction factor. So the final form of resistance is to summarise of ice resistance, net propulsion and resistance of current. For numerical model validation, the data is taken from the journey of ice breaker Tor Viking II.

In this study a new empirical approach will be proposed to investigate the ice-resistant strength of Double Acting Tanker (DAT). The main advantage of this ship is that it can sail alone in the ice sea without requiring escort by an ice breaker, Juurmaa et al. (2002). While other researchers Su et al. (2010) has involved propellers in numerical analysis, but the calculations only for deduction of thrust at open water conditions. Tan et al. (2014) has not done yet but has suggested calculating the effect of propeller. Almost all researchers only using ice breaker to verify numerical method predictions offered. On the other hand, other researchers such as Wilkman and Juurmaa (2003) published the results of an experimental full-scale test of Double Acting Tankers (DAT). But it has not been accompanied by any numerical approach or mathematical model to calculate resistance force.

1.2 Problem Statement

An innovative ice breaker ship has been developed for oil and gas transportation on the ice cover water such as Northern Europe namely Double Acting Tanker (DAT). The DAT has ability to sail solo astern through sea covered by ice as well as sailing ahead in open water. The first DAT namely Mastera and Tempera tankers were built by Sumitomo Heavy Industries, Japan. These ships use bulbous bow on the stem part while the stern part is shaped like an ice bow. Juurmaa et al. (2002), Sasaki et al. (2004) and Koto (2005) suggested that the estimated resistance of DAT must involve the interaction between propeller and ice when the DAT sails astern. They also stated that the interaction between hull-ice and propeller is theoretically difficult to be approached due to very complex. Tan et al. (2013 and 2014) studied numerical hull-ice interaction on multiple-ability vessels running ahead based on thrust deduction factor taken from model scale tests. Hu et al. (2015 and 2016) has conducted model scale experiment in ahead and astern conditions. The experimental result showing the vessel could be travelling astern faster than ahead in level ice situation. Hu et al was also developed numerical method based on the formula of Lindqvist (1989), Keinonen (1996) and Riska (2011) to predict ice resistance of Double Acting Ship (DAS). They prediction results were not agree compared to experiment. Jeong (2017) stated that momentum energy loss while difference when ship crushing the ice depend on speed of ship and ice thickness to make a channel. This momentum energy could be using just early study and only applied in the certain icebreaker and he did not consider the effect of propeller.

In briefly, it meaning there no method could sufficient explain why the DAT sailing astern at level ice except the reason due to could move faster. Meanwhile, in the open water, the DAT will be sailing ahead to minimize the friction resistance. This thesis will examine that problem by proposing a method. This method was developed based on the existing Koto's method but this is only covering for icebreaker.

Meanwhile, as a comparing to verify the interaction between DAT with sea water and ice, a commercial software Abaqus will be selected. This software based on the Finite Element Method (FEM) has one of its advantages that is the Coupled-Eulerian-Langrangian (CEL) facility. This facility will interpret solid objects as Langrangian while the fluid objects as Euler. So if there is contact between solid and fluid, Abaqus will simultaneously examine the response of each component even though every component had been separated after the collision occurs.

1.3 Research Question

To achieve the objectives of the research, the questions on the solution and factors required to be considered are stated as follows:

i. How to develop the empirical proposed method based on existing empirical methods: Lindqvist (1989), Keinonen (1996), Riska (2011), Koto (2005) and Jeong et al. (2017) to predict ice resistance of Double Acting Tanker when is sailing ahead at the open water and astern at the level ice ?

ii. How to validate the perform of empirical proposed method on Double Acting Tanker ?

iii. How is Finite Element Method based on Coupled-Eulerian-Langrangian (CEL) able to investigate interaction fluid-hull-ice of Double Acting Tanker sailing ahead and sailing astern ?

1.4 Objectives

In order to find solution to the problems mentioned in the Section 1.2 above, there are two objectives of this research are listed below:

i. To propose a new empirical method in calculation of resistance force affected by propeller suction of Double Acting Tanker (DAT) sailing astern at level ice condition

ii. To conduct Fluid Structure Interaction (FSI) simulation based on Coupled-Eulerian-Lagrangian (CEL) as verification of the proposed method then validated with experimental data.

1.5 Scopes of Research

i. Ice resistance of DAT is investigated when DAT sails ahead and astern on level ice.

ii. Ice resistance of DAT are assumed consisting of ice breaking, submersion, water friction, ice friction and momentum.

iii. The proposed empirical method was selected from the following existing empirical methods: Lindqvist (1989), Keinonen (1996), Riska (2011), Koto (2005) and and Jeong et al. (2017). The proposed empirical method was developed by adding propeller effect.

iv. Interaction between water, ice sheet and hull was investigated by using Coupled Eulerian-Langrangian (CEL) in the Abaqus FEA software.

1.6 Significance of Study

A new empirical method including suction force induced by the propellers is developed based on the existing publishing methods. The proposed empirical method has capability to estimate ice resistance of DAT when the ship sails astern at level ice conditions. Besides that, this research also shows hull-fluid-ice sheet interaction simulation based on Coupled-Eulerian-Lagrangian (CEL) when DAT sails ahead and astern.

1.7 Organization of Thesis

This thesis consists of seven chapters. Chapter 1 is an introduction, containing background of this research. This chapter discusses the objectives and contribution of research in finding a solution to the problem. Scope of research and field of research explains in this chapter showing the solution ideas at the discussion area of this thesis.

Chapter 2 discuss about some of previous studies that have done by other researchers. This is discussed in literature review including reason why this thesis focused on DAT, accompanied by discussion of mechanism of failure of ice. Some previously researchers have taken a numerical approach and the validation steps which they have taken are also described in this chapter.

Chapter 3 provides an explanation of stages working on the thesis. This is described in path hint of thesis in form of flowchart diagram, so it can see the step of job to validation of idea.

Chapter 4 clarify the concept of Double Acting Tanker (DAT), the interaction occurs between ship and ice when the ship sailing head and astern and calculation all force involved when ship is breaking ice to create a line channel. In Chapter 4 there is also an explanation how the proposed method determines the effect of propeller suction when a ship is sailing astern.

Chapter 5 shows the results of resistance force which is calculated using existing methods described in chapter 2 and proposed method in Chapter 4. By using Finite Element method in software Abaqus which is explained in Chapter 5, the resistance force is obtained after extracting from time series results. Besides comparing with Finite Element Method in Abaqus simulation results, the results of proposed method and published experimental data are also carried out.

Chapter 6 is conclusion, summarizes various things that have been achieved in this study. The advantages of proposed method are emphasized again in this chapter compared to the numerical methods which are carried out by other previous researchers and finally some suggestions are discussed for further development of proposed method.

1.8 Summary

This chapter introduces the overall purpose of the research. The background of this research and the objectives aimed to be achieved in this research are presented in this chapter. Besides, the tasks conducted in this research are also briefly discussed in this chapter. The detail discussions on the tasks conducted in this research are presented in the remaining chapters of this thesis.

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APPENDIX D

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Efi Afrizal, Jaswar Koto, Adhy Prayitno, Warman Fatra. (2018). Analysis Resistance Force on Interaction of Double Acting Tanker (DAT) –Ice using Couple Eulerian Langrangian (CEL) in Abaqus Simulation. *Proceeding of Ocean, Mechanical and Aerospace -Science and Engineering-, Vol.1.*

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