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Journal of Ocean Engineering and Science 000 (2017) 1–7

www.elsevier.com/locate/joes

Original Article

Fuel efficiency optimization of tanker with focus on hull parameters

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Received 25 April 2016; received in revised form 23 February 2017; accepted 6 March 2017
Available online xxx

Abstract

Fuel efficiency optimization is of crucial importance in industries. Marine transportation industry is no exception. Multi-disciplinary optimization is a branch of engineering which uses optimization methods for solving problems in which the objective function is simultaneously affected by several different factors. As one of the tools for this type of optimization, genetic algorithm has a high quality and validity. The objective of the present study is to optimize fuel efficiency in tankers. All presented equations and conditions are valid for tankers. Fuel consumption efficiency of tankers is a function of various influential factors. Given the lack of equations for describing and modeling these factors and unavailability of valid performance database for inferring the equations as well as the lack of literature in this field, the preset study includes five optimizing factors affecting the fuel consumption efficiency of a tanker in genetic algorithm by using the genetic algorithm toolbox of MATLAB software package.

Keywords: Fuel consumption efficiency; Tanker; Multi-disciplinary optimization; Genetic algorithm; Hull parameters.

1. Introduction

With increasing fuel oil prices, fuel performance has become vital for financial reasons. It had led fuel to be one of most important factors in the shipping industries so the attention of designers has been recently attracted to optimize fuel performance in any possible ways. The objective of the fuel performance optimization is to increase the ability of fuel and to establish conditions to produce more output power out of a ship's propulsion system. The fuel performance of a ship is related to many factors. In this study, these factors are considered as physical and chemical properties of fuel, design and features of propeller in an engine, hydrodynamic, dimensional design of ship and the average speed of ship. The quality of fuel is a function of physical and chemical properties such as calorific value, viscosity, ash content, water content, sulfur content, flash point, specific gravity, etc. [1,2]. These properties are usually specified with very high precision by international organizations so the optimization of fuel properties for increasing fuel performance is not practical especially from marine engineer point of view. For this reason, in this study the effects of the properties of fuel on its performance are neglected. Also given the inaccessibility and lack of some performance databases for different statuses of engine and propeller and their attachments, they are neglected in the process of optimization, too. So, the goal of this study will be the multi-disciplinary optimization of the fuel performance of a tanker with genetic algorithm under the disciplines related to hydrodynamic, dimensional design and average speed of the tanker.

The genetic algorithm is an artificial intelligence methodology that is inspired by the evolution theory of Darwin. This was first mathematically formulated by Holland in his paper, "Adaptation in Natural and Artificial Systems". Many researchers and scientists have worked on the genetic algorithm after Holland until now. Mitchel published a great book, *An Introduction to Genetic Algorithm* [3]. It is one of most popular references to genetic algorithm learning. Homaifar et al. presented an application of genetic algorithms to the system optimization of turbofan engines that was similar to the way have been chosen in the present project [4]. Chipperfield et al. provided a user's guide for genetic algorithm toolbox

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http://dx.doi.org/10.1016/j.joes.2017.03.002
2468-0133/

Nomenclature

B	ship width, *m*
T	ship draught, *m*
D	ship height, *m*
C_B	hull bulk coefficient
C_∇	volume–length coefficient
C_p	prism coefficient
A_M	intermediate intersection area, m^2
C_f	friction resistance coefficient
C_{pv}	viscous–pressure resistance efficient
t	trust reducing factor
S	wetted area
L	ship length, *m*
V	ship speed, *knot*
W_{st}	mass of steel used in ship hull, *tone*
R_n	Reynolds number
F_n	Froude number
w	Wake coefficient
∇	ship volume, m^3
Δ	ship mass, *tone*
η_H	hull efficiency
η_o	propeller efficiency in free waters
η_R	propeller relative rotating efficiency

for use with MATLAB in Sheffeild University [5]. Seif and Tavakoli presented new technologies for reducing fuel consumption in marine vehicles. This paper reviewed different methods used for reducing the fuel consumption of marine vehicles in recent years. Methods for optimizing hull forms, use of micro bubbles and new coating, weight saving and improvement of propulsion system efficiency are discussed. Moreover, different components of resistance and methods of drag reduction are investigated and new hull forms are presented [6]. Weck and Willcox presented multidisciplinary system design optimization as a training course in 23 lectures in Massachusetts Institute of Technology [7]. The role and significance of MDO in engineering, various methods, techniques of MDO, etc. have been explained in this course. They also stated that the genetic algorithm is a reliable and efficient method for MDO. Shuaian Wang et al. stated three Bunker consumption optimization methods in shipping [8]. Nelson et al. stated simultaneous optimization of propeller–hull systems to minimize lifetime fuel consumption. This work presented a method (not Multi-disciplinary by genetic algorithm) to optimize the propeller–hull system simultaneously in order to design a vessel to have minimal fuel consumption. The optimization uses a probabilistic mission profile, propeller–hull interaction, and engine information to determine the coupled system with minimum fuel cost over its operational life [9].

2. Multi-disciplinary optimization and genetic algorithm

Multi-disciplinary optimization is a branch of engineering in which optimization methods are used for solving problems in which the optimizing parameter is simultaneously influenced by several disciplines. In this method, the optimization is so carried out that each factor plays a role in proportion with its impact on optimization result.

Four main foundations of multi-disciplinary optimization include (i) design variables, (ii) parameters, (iii) objective function, and (iv) conditions. In multi-disciplinary optimization, design variables can vary in their definition domain to reach to the optimum answer of the problem. But parameters are components that are considered as to be constant in problem space. The design variables in the present study are C_B, T, B, L, D, and V. As these variables change, each discipline of the optimization is so changed that results in the optimization of objective function depending on their impact on fuel consumption efficiency (FCE). Since the density and viscosity of the sea water through which tankers sail cannot be designed or changed, these two properties are considered as design parameters. In the present study, the density and viscosity of seawater was assumed as to be $1025\,\text{kg/m}^3$ and 1.8×10^{-3} Pa.s, respectively.

Objective function is the function whose optimization (maximization or minimization) is the intention of an optimization function. For the FCE of a tanker, there is no precise, thorough mathematical equation that is not impacted by designable variables. Furthermore, a precise or empirical equation can be hardly developed on the basis of valid statistical data for each factor that influences FCE of a tanker. Few numbers of successful researches in this sense proves this claim. Therefore, it is necessary to develop a function for this specific case, i.e., FCE optimization, that although its value does not equal the FCE of a tanker, its behavior shows the enhancement of the FCE. For instance, lower resistance of the ship hull would certainly result in higher FCE. So, the developed objective function should be so that its optimum value corresponding the minimum possible case for the resistance of a ship hull.

Given the fact that the variation domain of the design variables as well as the disciplines of the problem should be in the acceptable domain, then some constraints (conditions) are required for the validity of the problem. These constraints are usually of the type of mathematical equations or non-equations and/or of numerical interval. For example, in the present case, if the variation domain of block coefficient of the hull is as $0.48 \le C_B \le 0.85$ in accordance with standards, then after optimizing it is impossible to have a tanker whose $C_B = 0.9$; therefore, a constraint (condition) should be defined for each component of the problem during its optimization, if required.

2.1. Genetic algorithm

Genetic algorithm is a biological evolution-based calculation method of optimality. It generates a method for effective search in huge and extensive spaces which finally leads towards finding the optimum answer. Genetic algorithm is a heuristic optimization algorithm which takes natural evolution and selection as its paradigm. Although genetic algorithm