

Local optimization of thruster configuration based on a synthesized positioning capability criterion

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ABSTRACT: DPCap analysis can assist in determining the maximum environmental forces the DP system can counteract for a given heading. DPCap analysis results are highly affected by the thrust forces provided by the thrust system which consists of several kinds of thrusters. The thrust forces and moment are determined by the maximum thrust of the thrusters as well as the thruster configuration. In this paper, a novel local optimization of thruster configuration based on a synthesized positioning capability criterion is proposed. The combination of the discrete locations of the thrusters forms the thruster configuration and is the input, and the synthesized positioning capability is the output. The quantified synthesized positioning capability of the corresponding thruster configuration can be generated as the output. The optimal thruster configuration is the one which makes the vessel has the best positioning capability. A software program was developed based on the present study. A local optimization of thruster configuration for a supply vessel was performed to demonstrate the effectiveness and efficiency of the program. Even though the program cannot find the global optimal thruster configuration, its high efficiency makes it essentially practical in an engineering point. It may be used as a marine research tool and give guidance to the designer of the thrust system.

KEY WORDS: DPCap; Synthesized positioning capability; Local optimization of thruster configuration.

INTRODUCTION

A Dynamically Positioned (DP) vessel is by the International Maritime Organization (IMO) and the certifying class societies (DNV, ABS, LR, etc.) defined as a vessel that automatically maintains its position and heading (fixed position or pre-determined track) exclusively by means of active thrusters. Dynamic Positioning System (DPS) has been widely used in offshore engineering over the last five decades. Description of DPSs, including their early history can be found in [Fay \(1990\)](#) and [Morgan \(1978\)](#).

Operation safety is always the first consideration in the design and operation of a new DPS. To be able to plan a safe and efficient operation, it is important to know the window of operation, and the maximum environmental conditions the particular DP vessel can withstand. During critical operations such as drilling, oil production and offloading, the positioning precision requirements are high, regardless of the environmental conditions. It is thus important to know the positioning capability of the vessel in order to plan and execute operations in a safe manner, according to [Pivano et al. \(2012\)](#). It is necessary to perform a

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Dynamic Positioning Capability (DPCap) analysis when designing a new DP vessel.

DPCap analysis can assist in determining the maximum environmental forces the DP system can counteract for given headings, see [IMCA \(2000\)](#). Mostly DPCap analysis investigates the dynamic positioning capability of the vessel from 0° to 360° headings. The environmental forces and moment are statically balanced by thrust forces and moment provided by the thrust system which consists of several kinds of thrusters. The positioning capability is determined by the maximum thrust of the thrusters as well as the thruster configuration.

In the design of a thrust system, there are many factors are subject to changing (i.e. the number of the thrusters, the thruster types, the maximum thrust of the thruster and the thruster configuration, etc.). Many efforts can be found in literature focus on the selection of the thrusters and their configuration. [Mahfouz and El-Tahan \(2006\)](#) has proposed a developed software program as a marine tool in the selection of thrusters, in their configuration, and during preliminary investigation of the positioning ability of a newly designed vessel dynamic positioning system. However, the comparison of a vessel's positioning capability is based on the rough observation of the polar plots, which may cause confusion when these polar plots overlap with each other. [Xu et al. \(2015a\)](#) has proposed a synthesized positioning capability criterion which can quantify the synthesized positioning capability to avoid confusion. The synthesized criterion is adopted to compare the polar plots.

In this paper, the optimization of thruster configuration based on the synthesized positioning capability criterion is focused. The optimization of thruster configuration has been studied in the aircraft area ([Hwang et al., 2003](#); [Servidia and Sanchez Pena, 2002](#) etc.) and in the underwater vehicle area, see [Pierrot et al. \(1998\)](#). However, little effort can be found in the optimization of the thruster configuration for marine surface vessels. Since the thruster configuration is essentially important to the thrust system, an efficient optimization tool is essential to be developed. Based on the local optimization method, one can improve the synthesized positioning capability of the vessel.

The thruster's location region is formed by the feasible locations of the thruster. The thruster's location region is split up into some discrete locations. It is satisfied that the distance of any neighboring locations is less than or equal to a given interval tolerance. The discrete locations of all thrusters are combined to form the thruster configuration, which can be regarded as input of trials. When the number of the thrusters is large, the number of combinations of the thruster locations is significantly large. Since the DPCap analysis and synthesized positioning capability computation should be performed for every thruster configuration, it's significantly time-consuming to conduct the global optimization.

The local optimization of thruster configuration attempts to change only one thruster's location from its discrete locations' set at a time, then conduct the DPCap analysis and compute the synthesized positioning capability. The best synthesized capability corresponding location of the thruster is recorded. A software program was developed based on the present study. The effectiveness and efficiency of the program was demonstrated by a local optimization of thruster configuration for a supply vessel.

DPCAP ANALYSIS

DPCap analysis can assist in determining the maximum environmental forces the DP system can counteract for given headings. The accuracy of DPCap analysis is determined by the precise estimation of the environmental forces as well as the effectiveness of the thrust allocation logic. Estimation of the environmental forces can be based on model tests, hydrodynamic computation and empirical formulas, as addressed in [Sørensen \(2001\)](#). Thrust allocation logic can be formulated as an optimization problem, where the objective typically is to minimize the use of control effort (or power) subject to actuator rate and position constraints, power constraints as well as other operational constraints, see [Johansen et al. \(2004\)](#) and Fossen and [Johansen \(2006\)](#). Many methods for optimization are available in literature and quadratic programming method has been demonstrated to be relatively effective and robust, see [De Wit \(2009\)](#).

Wind, wave and current are assumed coincident in direction when one conduct a DPCap analysis. The forces and moment due to each component are evaluated individually and summed to evaluate the total steady-state environmental forces and moment, as described in [API \(1987\)](#). CFD method can be implemented to evaluate the wind loads, see [Gosman \(1999\)](#) and [Zhang et al. \(2010\)](#). The second order mean wave loads can be obtained based on quadratic transfer functions, as addressed in [Newman \(1977\)](#) and [Faltinsen \(1990\)](#). Estimation of the current loads can be found in literature: e.g. [Kim et al. \(2009\)](#), [Vaz et al. \(2009\)](#) and [Leite et al. \(1998\)](#).

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