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Development of a Control-Oriented Model of the Vertical Motions of a Fast Ferry

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As a main part of a research study on the control of active flaps and a T-foil of a high-speed ferry, a control-oriented model of vertical motions of the ship has been developed. The objective of the control is to improve comfort, decreasing the impact of heave and pitch motions. We have experimental data from a towing tank institution and simulations with PRECAL. The model is based on a decomposition of the physic phenomena into two main aspects: the coupling of the ship with distance between waves and the dynamics of a semisubmerged mass. The model can be handled with MATLAB-SIMULINK, which is useful for studying control strategies. The model shows good agreement (model validation) with the experimental and simulated data for regular and irregular waves. The article shows a methodology, based on MATLAB tools, for obtaining control-oriented models from computer-aided design (CAD)–based programs. That means that the control-oriented model can be derived from the ship design, even before the ship is built.

Introduction

IN FAST-FERRY–BASED passenger transportation, speed is most important. To achieve speed, many solutions are under way, such as the use of aluminum hulls. But there are vertical accelerations that cause seasickness and create structural risks, so speed must be reduced, unless the ship has the means to alleviate these accelerations. In the case we are dealing with, active control surfaces—transom flaps and a T-foil—are used to counteract the vertical motions due to sea waves. The problem to be solved is to move the control surfaces in the most effective way. That means an analysis in the context of automatic control.

In general, the automatic control study of a problem requires having a mathematical model of the plant to be controlled. With this model, nonrisk tests of control strategies can be tried, and specifications of control parameters (for instance, proportional integral differential [PID] controller tuning) can be easily refined.

For a given plant (in this case, a ship), several kinds of models can be elaborated, according to the objectives of study. For example, a small-scale replica for a towing tank, a computer-assisted design/manufacturing (CAD/CAM) model for hydrodynamic studies on computer, or mathematical models of diverse nature as static or dynamic aspects are mainly considered. For the automatic control perspective, interest is centered on the dynamic responses of the plant to stimuli: for instance, the response of the ship to sea waves. Because models focus on certain aspects, they usually apply simplifications and admit limits on the valid conclusions that can be reached.

A main objective of our research has been to find a mathematical model of the ship's vertical motions, pitching and heaving, with head seas. The model must be control oriented. The best way to get a reliable model, for different work conditions, is to consider the physics of the problem. Taking this approach, a satisfactory control-oriented model has been obtained, being also useful for a better understanding of the ship behavior.

The scientific literature offers several works of interest for this research. The fundamental knowledge is in the books of Lloyd (1989), Lewis (1989), and Fossen (1994). Key aspects of the ship motions are considered in Korvin-Kroukovski (1955) and Korvin-Kroukovski and Jacobs (1957) for regular waves, and completed in Salvesen et al (1970). The article of Ewing and Goodrich (1967), on the influence of wave spectra and ship length, presents interesting clues for our modeling purposes. In Van Sluijs and Gie (1972) we find a set of curves describing the vertical motions of frigates, which are relevant (as fast ships) for comparison. Concerning the problems related to speed, the article of Lewis (1959) makes a good account, considering also actuators to alleviate vertical motions. The article of Ferdinande and De Lembre (1970) describes the behavior of a ferry similar to the ship pertaining to our research, only that our ship is aluminum, and the ferry studied by Ferdinande

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