

On the second order effect of the springing response of large blunt ship

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ABSTRACT: The springing response of a large blunt ship was considered to be influenced by a second order interaction between the incoming irregular wave and the blunt geometry of the forebody of the ship. Little efforts have been made to simulate this complicated fluid-structure interaction phenomenon under irregular waves considering the second order effect; hence, the above mentioned premise still remains unproven. In this paper, efforts were made to quantify the second order effect between the wave and vibrating flexible ship structure by analyzing the experimental data obtained through the model basin test of the scaled-segmented model of a large blunt ship. To achieve this goal, the measured vertical bending moment and the wave elevation time history were analyzed using a higher order spectral analysis technique, where the quadratic interaction between the excitation and response was captured by the cross bispectrum of two randomly oscillating variables. The nonlinear response of the vibrating hull was expressed in terms of a quadratic Volterra series assuming that the wave excitation is Gaussian. The Volterra series was then orthogonalized using Barrett's procedure to remove the interference between the kernels of different orders. Both the linear and quadratic transfer functions of the given system were then derived based on a Fourier transform of the orthogonalized Volterra series. Finally, the response was decomposed into a linear and quadratic part to determine the contribution of the second order effect using the obtained linear and quadratic transfer functions of the system, combined with the given wave spectrum used in the experiment. The contribution of the second order effect on the springing response of the analyzed ship was almost comparable to the linear one in terms of its peak power near the resonance frequency.

KEY WORDS: Springing; Higher order spectral analysis; Cross bispectrum; Quadratic transfer function; Volterra series.

INTRODUCTION

Hydroelasticity is recognized as one of the main challenges in the design of modern merchant ships, such as ultra large container carriers and very large ore carriers. Hydroelasticity refers to either the resonant vibratory response of the flexible ship structure under a random ocean wave load, or transient vibratory response induced by the impulsive slamming load, which takes place when the ship plunges into the free surface with a wave. The former and latter are called springing and whipping, respectively. Traditionally, the hydroelasticity effect was not considered to be a main design issue until problems were unveiled mostly in the bulk carriers of Greak Lake in 1960s, which ignited some early research efforts on the physics. The importance of hydro-

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elasticity has become important since the advent of the larger and faster ships, which has dramatically increased the likelihood of resonance between the ship structure and incoming wave as well as transient vibrations due to the flexibility of the ship.

Considerable research efforts are currently being devoted to the study of hydroelasticity problems to establish a robust design methodology, ultimately targeting the safe operation of unprecedentedly large ships. On the other hand, more research is needed due to the inherent nonlinear nature of the physics behind the hydroelasticity. Some numerical methodologies have been developed under the linear or weakly nonlinear assumption in both the time and frequency domain, the majority of which is based on a combination of potential theory and finite element method (Price and Temarel, 1982; Jensen and Dogliani, 1996; Wu and Moan, 1996; Malenica et al., 2003; Hirdaris et al., 2003; Iijima et al., 2008; Kim et al., 2009; Kim et al., 2013). Efforts have also been made to solve the problem considering the second order interaction between the wave and structure under the potential flow assumption, but the forward speed effect has impeded fruitful research outputs. Computational fluid dynamics coupled with finite element methods is a potentially powerful numerical methodology to solve the problem considering any type of nonlinearities (Oberhagemann et al., 2010; Oberhagemann and Moctar, 2011; Takagi and Ogawa, 2012; Hu et al., 2013). Despite this, the computational demands for obtaining statistically meaningful results under irregular wave using CFD are large, particularly when the focus is on fatigue analysis in which case, all sea states that the ship is exposed to need to be covered.

The model basin test with either a segmented hull model or flexible model is another powerful way to study the hydroelasticity problem. Many model basin tests have been recently carried out (Remy et al., 2006; Iijima et al., 2009; Miyake et al., 2009; Oka et al., 2009; Hong et al., 2011), the majority of which were based on the segmented hull model focusing on measurements of the vibratory behavior of the hull under wave loads. The main focus of the experimental study is normally to obtain the response of a flexible ship under either regular or irregular waves, which are used to validate the numerical analysis results. In some cases, when a more practical output is aimed at, the fatigue damage induced by the hydroelasticity effect was estimated directly under carefully designed test conditions. Storhaug (2007) carried out a systematic experimental test on the segmented scaled model of a large bulk carrier, and claimed that the second order effect related to the diffracted wave near the bow area played an important role in the springing excitation of the flexible ship model. In the experiment, a trial was made to validate the second order effect due to the diffracted wave near the bow by applying different bow segments with different geometries. He also tried to derive the second order transfer function of the system out of the regular wave test, but it was limited to the diagonal component of the transfer function because of the large number of test cases that need to be covered. Unlike the case of a large container carrier, which has a relatively sharp bow shape, this second order effect on springing excitation is more pronounced, particularly when the ship has a blunt bow shape, like ore and bulk carriers. Although the second order effect is influential for the springing excitation of large blunt ship, no study has reported its contribution quantitatively. This study evaluated the relative contribution of both the linear and second order effects in a quantitative manner through a system identification approach. An effort was made to quantify the second order effect through the system identification method, which is based on higher order spectral analysis of the measured test data of the segmented hull model towed in the model basin.

The nonlinear system identification method is generally based on the Volterra series approach. The Volterra series is conceptually similar to the Taylor series in that the system is expressed by the terms of a different order, but distinguishes itself from the Taylor series by the memory effect, which is represented by the convolution integral of the excitation and generalized impulse response functions of each order. The transfer function of each order can be obtained simply by transforming the Volterra kernel to the frequency domain using standard Fourier transform.

The nonlinear system identification on ships and offshore structures under irregular waves has been studied (Hasselmann, 1966; Dalzell, 1975; Pinkster, 1980; Jensen and Pedersen, 1981). Hasselmann (1966) examined the motion response of a ship exposed to the random waves by identifying the Quadratic Transfer Function (QTF), which was obtained by the input-output model. Dalzell (1972) analyzed the added resistance of a ship voyaging through the long-crested random seas by modifying the cross-bispectral analysis proposed by Tick (1961). Dalzell and Kim (1979) examined the second order added resistance problem of a voyaging ship by cross bispectral analysis, under the assumption of a Gaussian input. They reported that the estimated results based on the second order model were in reasonably good agreement with the experimental results. Dalzell (1982; 1984) also proposed the third order model of nonlinear ship responses in irregular seaways. The higher order frequency response function of the considered system was assumed to have a certain form and the probability density function, statistical moments and distribution of extrema were derived.

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