

Instantaneous Bispectral Analysis of Non-linear and Non-stationary Ship Motion Data

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ABSTRACT

The instantaneous bispectral analysis was proposed to investigate non-linear and non-stationary ship responses. The method is based on Time-varying coefficient autoregressive (TVAR) modeling and an extension of the instantaneous power spectral analysis. The proposed method was applied to the time history which indicates the fluctuating skewness, and the peak and its phase angle of bispectra were followed in the time domain to explain the fluctuating skewness. The effectiveness of the instantaneous bispectra was shown for analyzing the transition of skewness of non-linear ship responses.

KEY WORDS: Instantaneous bispectrum; TVAR modeling; Non-linear ship motion; skewness.

INTRODUCTION

The non-linear ship responses, such as parametric rolling and pure loss of stability in following seas, have become the key issues in the research field of ship stability. After an accident of a post-Panamax container ship happened in 1998, the experimental and theoretical studies in the time domain are carried out vigorously and revision of the Intact Stability Code of IMO is now under way. On the other hand, it is well known that the ordinary power spectral analysis, which is based on the linear theory, induces a kind of energy leak in the frequency domain and is not effective to investigate these non-linear phenomena. The higher order spectral analysis (Brillinger and Rosenblatt, 1967) should be introduced and the non-linearity must be treated properly. There are, however, few applications of the higher order analysis to ship motion data and the knowledge has not been stored sufficiently yet (Hasselman, 1963; Yamanouchi and Ohtsu, 1972; Dalzell, 1974).

In this paper, the instantaneous bispectral analysis, which is an application of the TVAR modeling (Kitagawa and Gersch, 1985) to the higher order spectral analysis, is proposed to investigate the non-linear and non-stationary ship responses with focusing on the skewness of the data. First of all, the non-linear pitching motion and the fluctuating skewness, which were reported in the previous paper (Iseki, 2007), are investigated and simulated by using simplified equations of motion for a single-degree-of-freedom. Secondly, the instantaneous bispectrum is

defined as an extension of the instantaneous power spectrum that is based on the TVAR model. The time history data that were obtained during on-board tests are investigated by the instantaneous bispectral analysis, and the phase angle of a peak is followed in the time domain to explain the fluctuating skewness. The effectiveness of the instantaneous bispectra is shown for analyzing the transition of skewness of non-linear ship responses.

RIGHTING LEVER OF PITCHING MOTION IN WAVES

Non-linear pitching motion and its fluctuating skewness were reported based on the time histories that were obtained by on-board measurements (Iseki, 2007). The data was measured during the T.S. Shioji-maru was overtaking the waves with 9.5 knots speed. Her length is 46m and the wave length was about 18 m. In this section, variations of the righting lever of pitching motion in waves are investigated and the non-linearity of a single-degree-of-freedom system is discussed.

Variation of restoring moment

Figure 1 shows the hull shape of T.S. Shioji-maru and the waves. The restoring moment was estimated with considering the actual wetted surface in every moment and the hydrostatic pressure and Froude-Krylov forces are taken into account.

Figure 2 denotes variation of the righting lever of pitching motion under the wave condition illustrated by Fig.1. This figure can be recognized as the GZ curves for pitching restoring moment in waves. The head-up direction is the positive angle inclination. The hull shapes of fore and after parts around the water line are not symmetric because of the bow flare and stern form. Therefore, the righting lever is strongly affected by the local changes of displacement based on the trim and wave pattern. The figure shows the righting lever with dividing the encounter period into quarters in order to investigate the changes. It can be seen that the intercept, inclination and curvature of the righting lever are changing periodically.

Assuming that the righting lever of pitching motion can be approximated by a quadratic function within a small pitching angle, time variations of the coefficients are shown in Fig. 3. It is confirmed that the coefficients of the approximated quadratic functions can be represented by sinusoidal functions.