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Vibration analysis of a DWT 1,000-ton ocean-research vessel with electric propulsion

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In vibration analysis of ships, the principle aim is to determine the natural frequencies and excitation frequencies, and use this information to avoid resonances and vibration damage. The simplest method is to prevent resonance conditions, which is effective as long as the natural frequencies and excitation frequencies can be regarded as independent from environmental conditions. For ships that use electric propulsion systems, the sources of vibration are reduced compared with those caused by a diesel engine or other combustion-based propulsion systems. However, the frequency spectrum of these vibrations may be different; therefore, to understand the characteristics of the electric propulsion, we also should investigate how the ship responds to these vibrations. We focused on a 1,000-ton deadweight (DWT) ocean-research vessel using an electric propulsion system and analyzed the response to vibration.

Keywords : Hull vibration characteristics, Vibration assessment, Electric propulsion, FEM

INTRODUCTION

Current trends indicate that both the size and sailing velocity of ships are increasing, which has led to a greater focus on the importance of vibration and noise. Periodic unbalanced forces in the propulsion system inevitably give rise to vibration, and when the excitation frequency is close to a resonance frequency of a vibrational mode of the ship, significant motion of the structure may occur (Nippon Kaiji Kyokai, 1984). Close to resonance, the displacement and acceleration of the hull plate may be large, which may lead to serious structural effects for the vessel, as well as comfort issues for the crew and passengers. To avoid this, the structure and propulsion system should be designed to avoid exciting the vibrational modes of the vessel (Okumoto et al., 2009).

With the development of power electronics, electric propulsion systems have become increasingly important, especially for niche applications and military vessels. Electric propulsion systems have significant benefits in terms of mobility, reliability, and efficiency, as well as in terms of environmental sustainability. For these reasons, electric propulsion has the potential to become the dominant method of propulsion for ships in the future (ABS, 2006).

To avoid damage to the vessel and discomfort to the crew and passengers, it is important for engineers to analyze the response to vibration prior to production. The finite element method (FEM) is an effective method for such an analysis, and is a convenient and efficient means of modeling the response to vibration (Bathe et al., 1996).

The objective of this paper was to study the vibrations of the hull of a special-purpose vessel with electric propulsion. We used a three-dimensional (3D) FE model to ana-

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*Corresponding author: dmbae@pknu.ac.kr, Tel: 82-51-629-6613, Fax: 82-51-629-6608 lyze the response to vibration of a 1,000-ton deadweight (DWT) ocean-research vessel. We examined the response to vibration generated by a diesel generator and by the propeller.

CHARACTERISTICS OF THE OCEAN-RESEARCH VESSEL

Description

Figure 1 shows an overview of the structure of the vessel. The principal dimensions of the vessel are listed in Table 1, and the major characteristics of the generator are listed in Table 2.

Loading conditions

Two loading conditions were investigated with ballast and full load. The details of these loading conditions are shown in Figs. 2 and 3, and data describing these loadings are listed in Table 3.

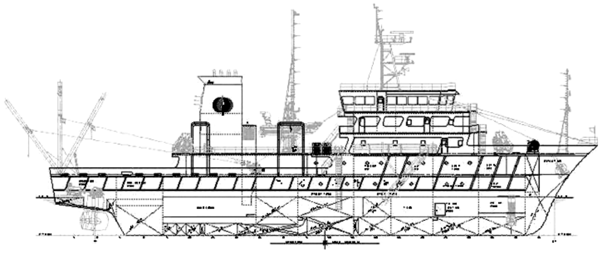

Fig. 1. Overview of the vessel.

Table 1. Dimensions of the vessel

Item	Dimension
LOA	70.70 (m)
LBP	59.30 (m)
Depth (Mld)	7.40 (m)
Draft (Lwl)	4.70 (m)
Breadth (Mld)	13.50 (m)
Service speed	12.5 (knot)

Table 2. Main generator data

Output	805 KW at 900 rpm
Main exciting frequency	30 Hz
Establishing position	A/B, Fr.19~Fr.28

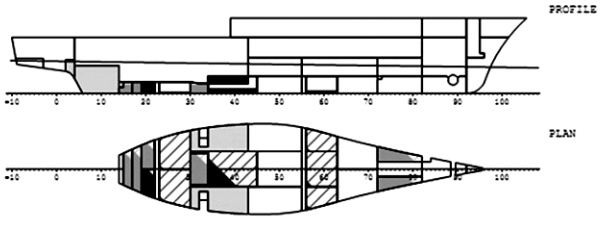

Fig. 2. Ballast condition.

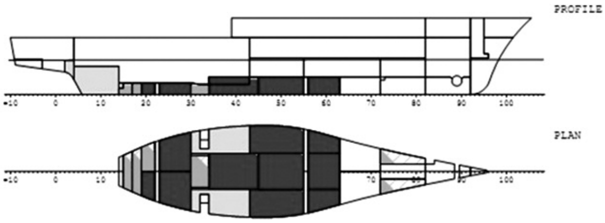

Fig. 3. Full load condition.

Table 3. Loading conditions

	Ballast Cond. (Arrival)	Full Load Cond. (Departure)
Light ship weight (tons)	1500.00	1500.00
Dead weight (tons)	354.755	761.176
Displacement (tons)	1854.755	2261.176
Draft forward (m)	3.543	4.641
Draft MID (m)	3.946	4.604
Draft aft (m)	4.348	4.567

CALCULATION AND ANALYSIS

FE model

Due to the asymmetry of the cargo hold, 3D structural FE models of the entire ship were constructed, as shown in Figs. 4 and 5. The plates of the ship's deck, side-shell, bulkhead, and web were modeled as plate/shell elements, and the stiffener and girder were modeled as beam elements. QUAD4 and TRIA3 elements found in MSC/NASTRAN were used for the plate/shell elements, and BAR elements were used for the beam elements. The total number of nodes and elements in the model were as follows:

- Number of node : 18,575
- Number of plate/shell element : 25,125
- Number of beam element : 22,977

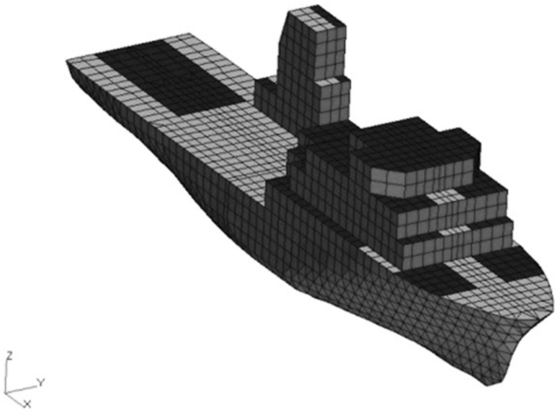

Fig. 4. Overview of the FE model of the vessel.

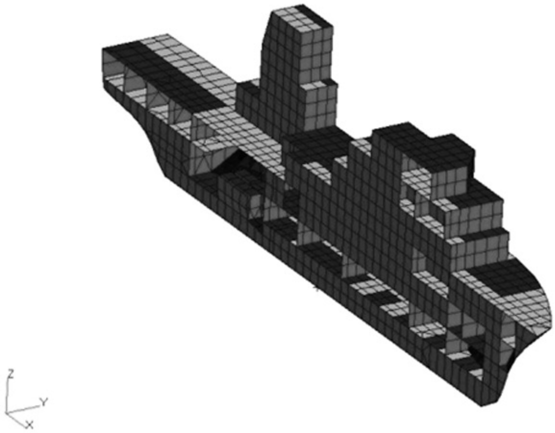

Fig. 5. FEM model showing the internal structure.

The masses of the structural members were applied by considering the density of the hull, and the masses of the major items of machinery were replaced with point masses located at nodes corresponding to their centers of gravity. The distribution of other masses was considered in a similar manner.

The fluid boundary element method was used to estimate the virtual added mass in the MSC/NASTRAN simulation. The fluid- structure interaction was analyzed via a combination of the fluid boundary element method and the structural FEM equations considering virtual masses.

Table 4 Natural modes of vibration

No. of Mode	Full (Hz)	Ballast (Hz)	Vibration Mode
1	6.620	7.873	2-node Vertical
2	9.851	10.437	1-node Torsional
3	11.344	12.089	2-node Horizontal
4	13.466	14.651	3-node Vertical
5	16.675	17.575	2-node Torsional
6	19.640	21.114	4-node Vertical
7	19.948	21.564	3-node Horizontal
8	23.912	25.414	5-node Vertical

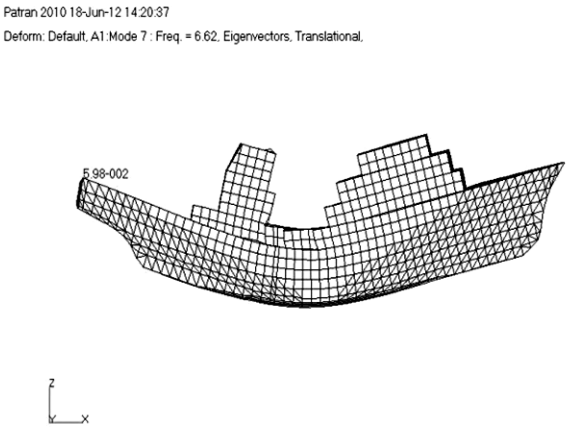

Fig. 6. 2-node vertical vibration mode of hull girder.

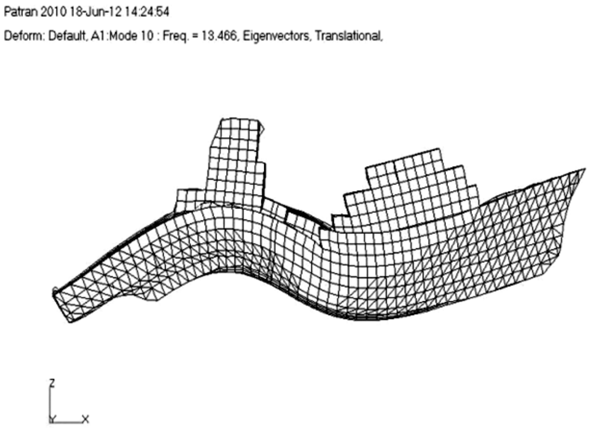

Fig. 7. 3-node vertical vibration mode of hull girder.

Hull structure natural vibrations

To determine the frequencies of the natural vibrations of the ship, we carried out a modal analysis of the structural vibrations at frequencies below 30 Hz. The vibrational modes of the ship for fully loaded and ballast conditions are listed in Table 4. These vibrational modes are illustrated under full load conditions in Figs. 6 – 13. The modes involved three degrees of freedom: vertical, torsional, and horizontal.

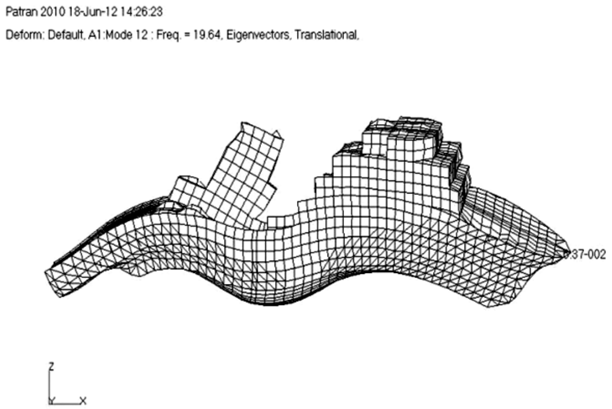

Fig. 8. 4-node vertical vibration mode of hull girder.

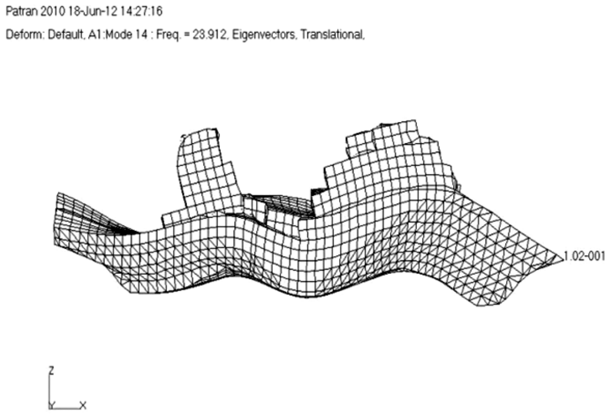

Fig. 9. 5-node vertical vibration mode of hull girder.

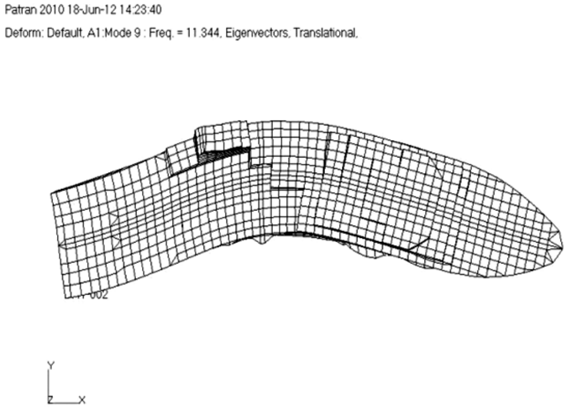

Fig. 10. 2-node horizontal vibration mode of hull.

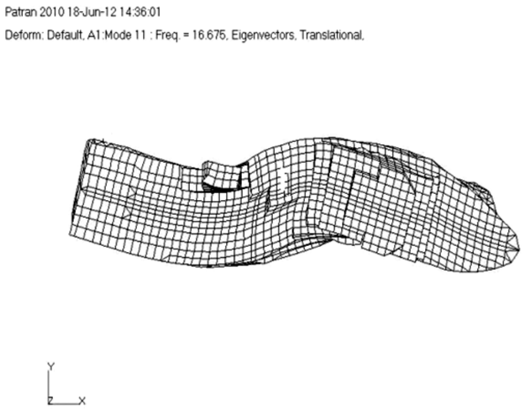

Fig. 11. 3-node horizontal vibration mode of hull girder.

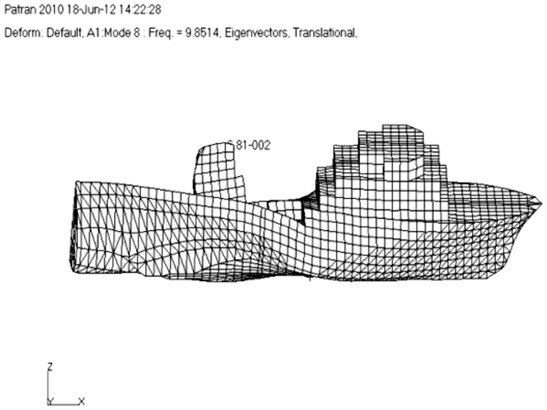

Fig. 12. 1st torsional vibration mode of hull girder.

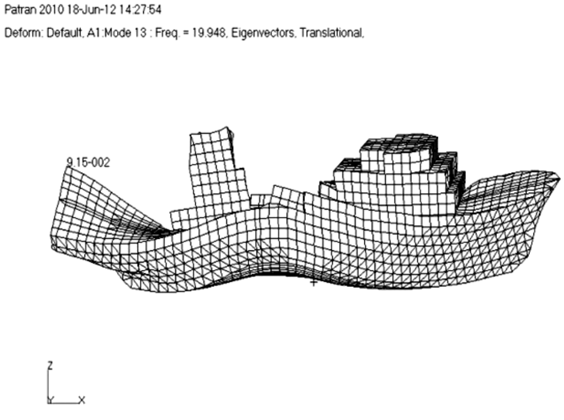

Fig. 13. 2nd torsional vibration mode of hull girder.

Response to excitation

The excitation force is typically induced by the main engine, propeller, and main generator and air compressor. However, in this vessel, the main power is provided by a generator, which serves as a power source for the electric motor and propulsion system. The excitation forces induced by the propeller and the generator are transmitted into the vessel via the shaft line, inner surface of the bottom of the hull, and the stern surface, and form pressure waves acting on the shell of the vessel.

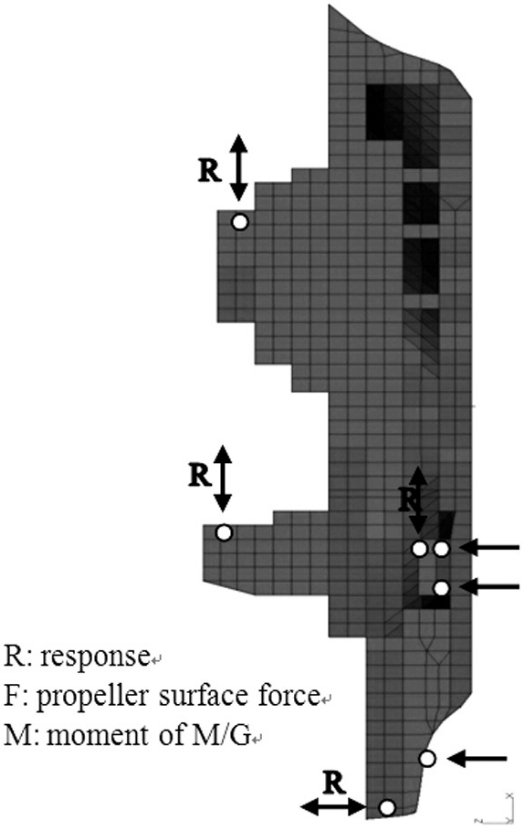

Fig. 14. Location of the excitation force and calculation of the vibration response.

The external unbalanced moment and the guide force generated by main generator were considered by applying an equivalent force with a phase difference of 180… at the fore and aft of the lower part of the generator. To model the shaft bearing forces induced by the propeller, the forces were applied to a node at the location of the thrust block of the generator in the fore of the ship.

The other forces and moments in the five axial directions were applied to the node at the location of the bearing of propeller shaft. The hull surface forces induced by the propeller were already described at the nodes of the hull surface in the stern. The above forces and moments, and also the response nodes to vibration, which were located at the front of the navigation deck, the stern, the top of the funnel, and the top of generator, are shown in Fig. 14.

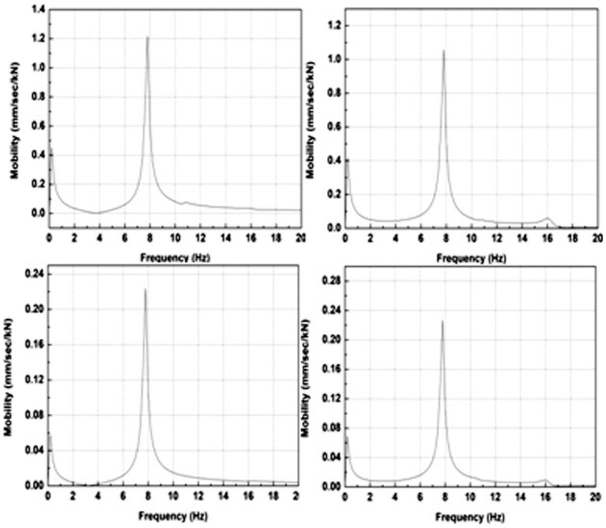

Fig. 15 Frequency response of the 4 nodes due to unit force excitation by the main generator.

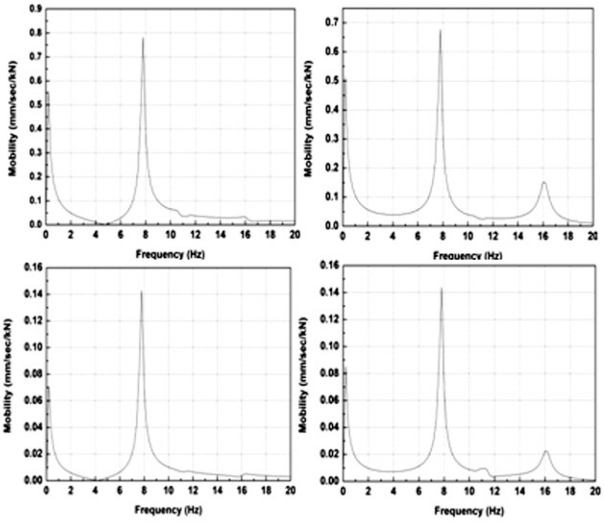

Fig. 16 Frequency response of the 4 nodes due to unit force excitation by the propeller.

The vibration response at each frequency for unit forces due to operation of the main generator and due to the hull surface force induced by the propeller are shown in Figs. 15 and 16.

Local vibrations

We analyzed the vibration of panels in the engine room, stern, and deckhouse, and determined whether resonant peaks occurred at the frequencies of the main generator located in the tweendeck. For safety and comfort, the main vibrational modes of the local structure were analyzed at frequencies up to 22 Hz, as shown in Figs. 14 – 20. We found that there was little possibility of resonance being generated in the accommodation deck due to excitation from the main generator.

CONCLUSIONS

The relationship between the vibration modes of the hull girder and the excitation frequencies of main generator is shown in Fig. 24. From the results of this analysis, there appears to be some possibility of resonances of the hull girder

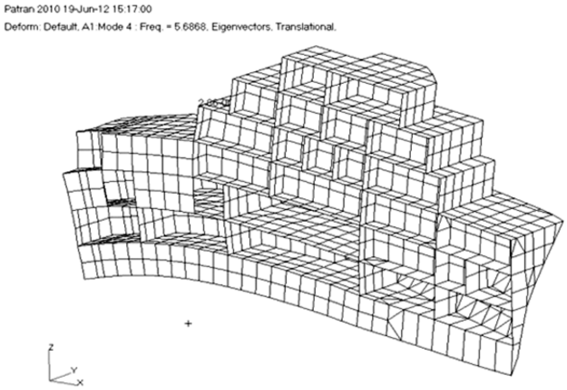

Fig. 17. 1st vibration mode of accommodation deck.

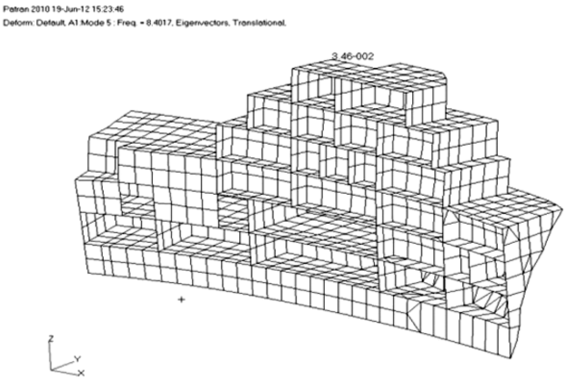

Fig. 18. 2nd vibration mode of accommodation deck.

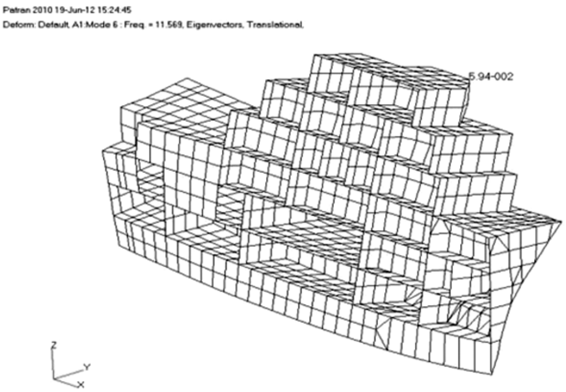

Fig. 19. 3rd vibration mode of accommodation deck.

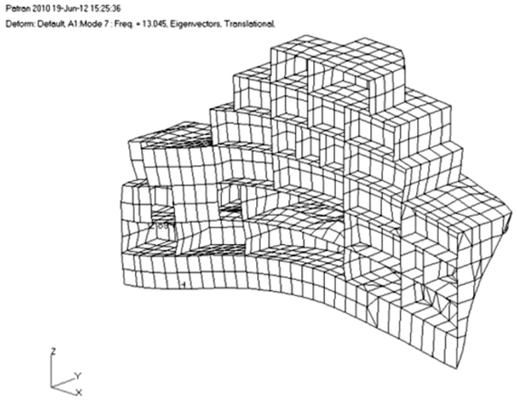

Fig. 20. 4th vibration mode of accommodation deck.

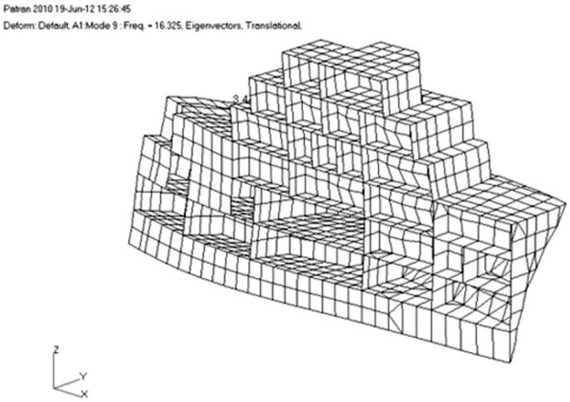

Fig. 21. 5th vibration mode of accommodation deck.

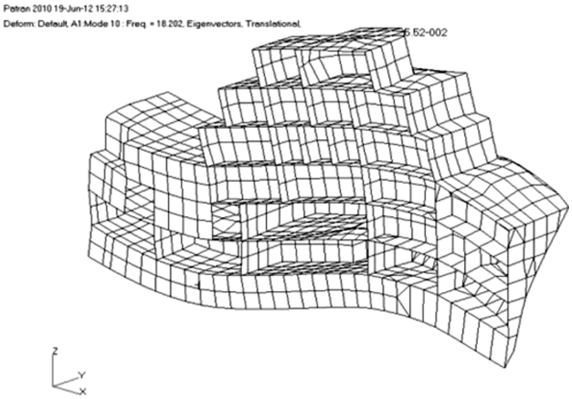

Fig. 22. 6th vibration mode of accommodation deck.

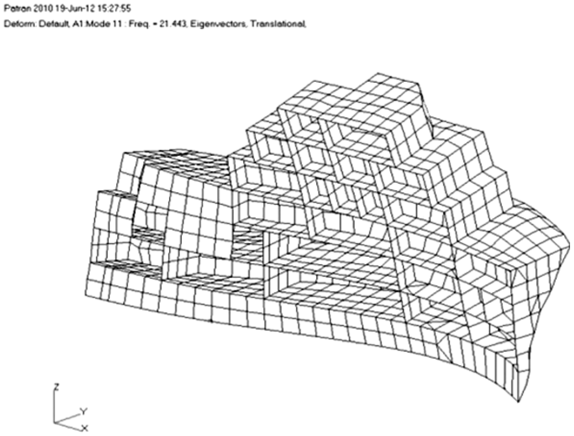

Fig. 23. 7th vibration mode of accommodation deck.

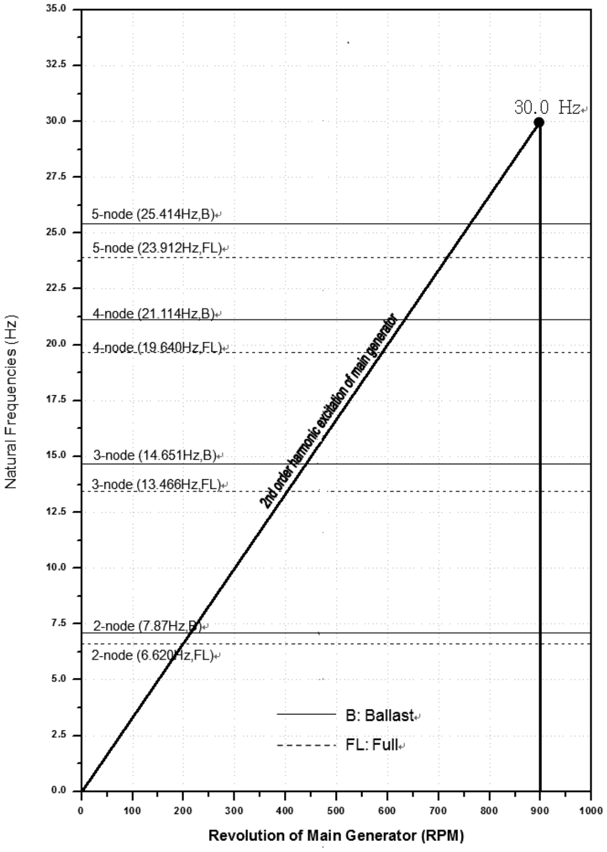

Fig. 24. Excitation frequencies of main generator vs. natural frequencies of hull girder.

at excitation frequencies of the main generator operating at the maximum continuous rating (MCR).

The accommodation area should be limited to within the range of the "stippled zone", as defined by the ISO 6954-2000(E) guidelines for the evaluation of vertical and horizontal vibration for a normal continuous rating of the main engine. Therefore, the ISO 6954 code was applied in the evaluation of the vibration levels of the accommodation deck. The maximum response on the accommodation deck was compared with ISO 6954, as shown in Fig. 25. The requirement of ISO 6954 is that the motion at 5 Hz should not exceed 4 mm/s; this was not exceeded by the second-order component of main generator.

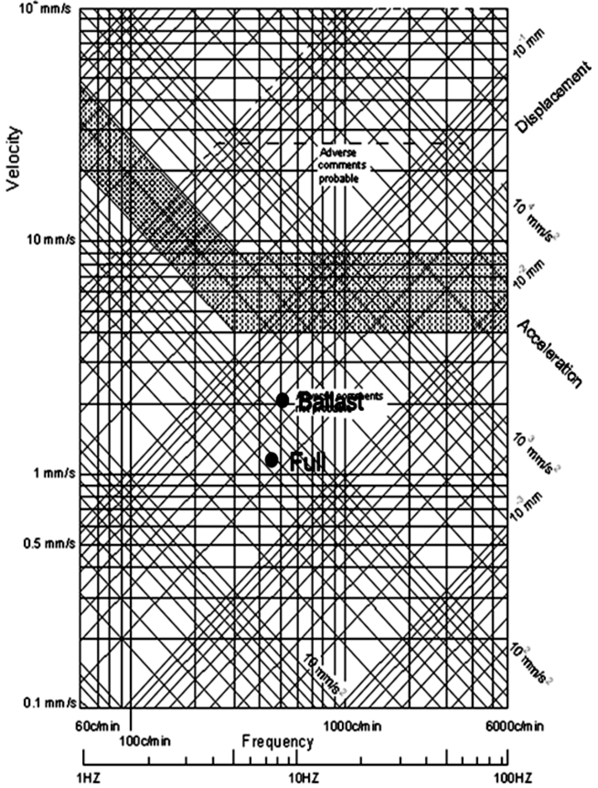

Fig. 25. Maximum vibration responses.

We have modeled the response of a 1000-ton DWT ocean-research vessel to vibrations generated by a diesel generator and by the propeller. Based on this analysis, the basic requirements of the target vessedl in terms of vibration were met. However, there is scope for improvements in the accuracy of the analysis. In particular, for electric propulsion without a diesel engine, the propeller vibration becomes more significant. Further analysis with different methods and experimental data are expected to be useful for future work.

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