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EVALUATION FOR THE PUMP TOWER VIBRATION OF LNG CARRIER DUE TO PROPELLER EXCITATIONS

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Abstract

The anti-vibration design of pump tower in LNG carrier is very important because it is the main equipment for discharge and loading of LNG. Its structure is very slender and flexible, so the natural frequencies are relatively low, which may cause resonance problem with the propeller excitations around normal operation range. Therefore a thorough investigation on the vibration characteristics of pump tower is necessary at the initial design stage. However an accuracy of the predicted natural frequencies greatly depends on boundary conditions at the upper and lower parts of pump tower, which are very difficult to reflect exactly in analysis model because of their structural complexity such as guiding system, thermal insulation material and so on. These boundary conditions can be simplified into a translational and rotational springs with an equivalent stiffness in finite element modelling. So a dynamic tuning was performed to obtain a reasonable boundary stiffness from the vibration measurement results of actual ships. In this study, a vibration analysis for pump tower of both type LNG carriers, namely Moss and membrane, was carried out and reviewed their own vibration characteristics. Also the vibration measurements at sea trial were followed to confirm the analysis results.

INTRODUCTION

As the consumption of clean energy increases, a large LNG (Liquefied Natural Gas) carrier has been constructed actively. There are two types of LNG carriers, namely Moss type and membrane type, the former has an independent spherical tank system and the latter has a cargo containment system directly installed in the ship hull structure. Although their structures are different from each other, they have pumps in common for discharge and loading of LNG. This pump is installed at the bottom of cargo tank in order to facilitate the discharge of LNG. Because the length of piping system is very long and several pipes with its own function are combined, so we call it pump tower. The structure of pump tower is very slender, flexible and also is in contact with LNG, so its fundamental natural frequency is relatively low. Consequently there is a possibility of resonance with the propeller induced forces. If these items are not thoroughly investigated at the initial design stage, it might cause a fatigue failure due to vibration to the pump tower structure. The manufacturer used to carry out the vibration analysis on pump tower structure, but the results are inaccurate because they did not consider the boundary condition of pump tower in the ships.

In this study, we reviewed the structural features of pump tower and predicted the vibration characteristics based on finite element analysis. Also analysis results were validated through the vibration measurement of pump tower at sea trial.

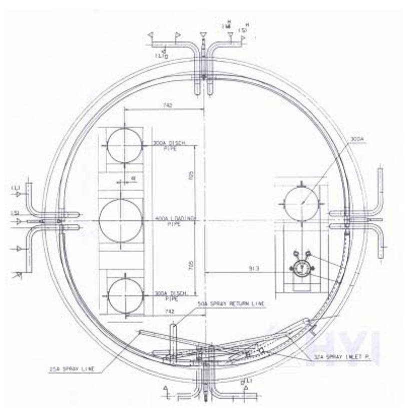
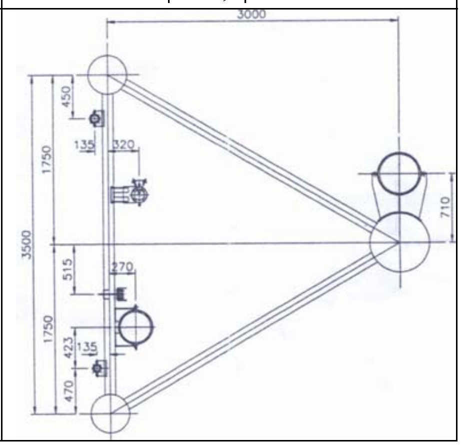
STRUCTURAL CHARACTERISTICS OF PUMP TOWER

Pump tower installed in LNG carrier is different from each other in Moss and membrane type. For Moss type, there is a pipe with large diameter and several functional pipes are set up into the large pipe, in other words a large bore pipe protects the functional pipes. The upper and lower parts of large pipe are connected by welding to the spherical tank. Pump tower in the membrane type consists of main pipes connected with trusses. Also the guiding system is installed to restrict the excessive translational movement at the lower part. As shown in Figure 1, there is no protection pipe with large diameter in the membrane type. Major specification of these two pump tower is summarized in Table 1.

(a) Moss type *(b) Membrane type*

Figure 1 Pump tower of LNG carrier

Table 1 Specification of pump tower

	Moss type	Membrane type
Tank capacity	137,000 m^3	149,000 m^3
Height [m]	45.08	30.75
Diameter [mm]	φ3,000	φ400, φ600
Section		

VIBRATION ANALYSIS OF PUMP TOWER

Free vibration analysis of pump tower structure should be performed to check the resonance possibility with the propeller excitation. Judging from the external shapes of pump tower, we can roughly know that a major parameter dominating the overall vibration feature of pump tower is the large pipe for Moss type and the discharging and filling pipe, emergency pumping pipe and trusses for membrane type.

Actually the cargo tank of LNG carrier is nearly empty or fully loading, sometimes it is partially loaded. The natural frequencies of pump tower vary according to loading condition due to the added mass effect of LNG. In this study, the vibration analysis of pump tower for Moss and membrane LNG carrier was carried out and evaluated for cargo empty and full loading condition.

Moss type [1]

Pump tower for Moss type LNG carrier has connected by welding to the cargo tank structure at top and bottom of pump tower. In finite element analysis, the full model including the cargo tank is considered and there is no special boundary condition. The finite element model is shown in Figure 2. Added mass effect due to loading is considered by the virtual mass method of MSC/NASTRAN fluid capability which implements boundary integral equation method.

The lower modes of pump tower are as shown in Figure 3, which are bending modes and there are no directional features because of symmetry structure with respect to longitudinal and transverse axis. Natural frequencies of pump tower in Moss type are summarized in Table 2.

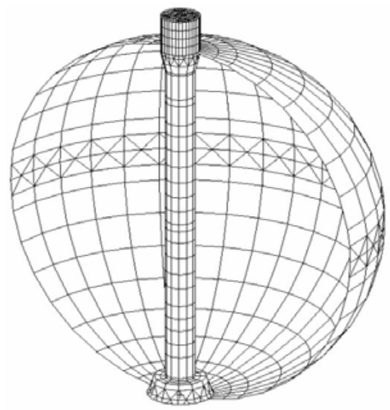
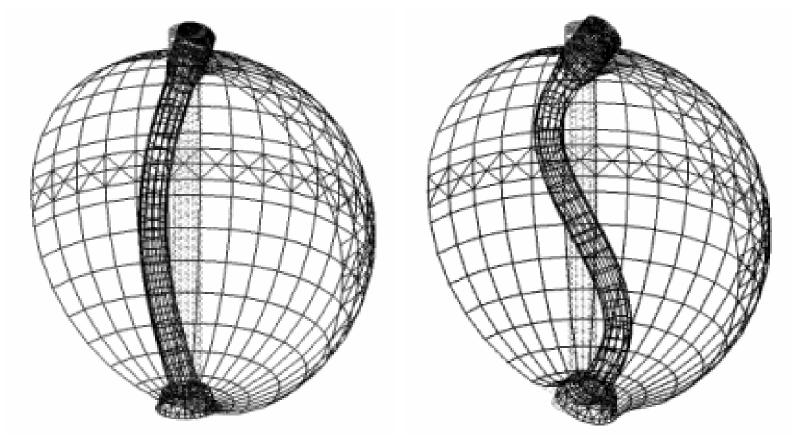


Figure 2 Finite element model of pump tower in Moss type



(a) 1st bending mode *(2) 2nd bending mode*

Figure 3 Mode shapes of pump tower in Moss type

Table 2 Natural frequencies of pump tower in Moss type [unit : Hz]

Mode \ Loading	Empty	Full loading
1st bending	4.79	2.20
2nd bending	16.36	7.76

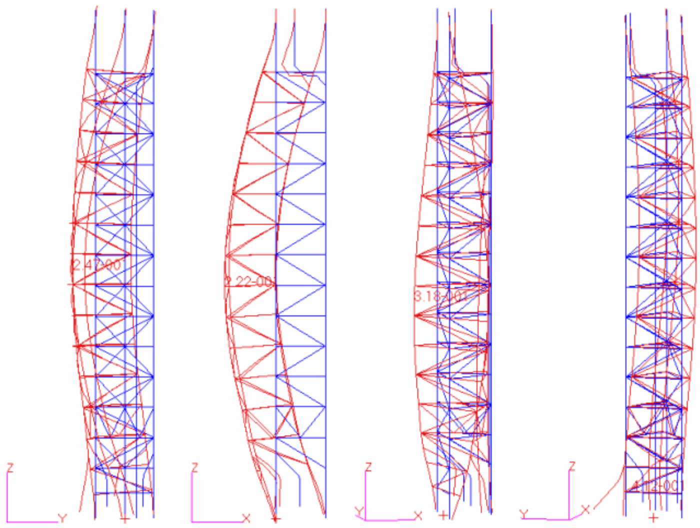
Membrane type

The pump tower for membrane type LNG carrier is different from the pump tower of Moss type carrier. Major pipes are connected by trusses without protection pipe, so beam element is used in the analysis model of pump tower structure. The connection part between the dome cover and the top of pump tower is surrounded by the insulation structure consisting of stainless steel, glass wool and plywood. And there is a guiding system to constrain the movement at the lower part of pump tower, which has sliding pad of high density polyethylene. Because of these structural complexities, it is very difficult to reflect accurately the boundary condition in analysis. Therefore the boundary conditions can be simplified into a translational and rotational springs with an equivalent stiffness. However it is almost impossible without the accumulated data of actual ships.

From the measurement for actual ship, the natural frequencies of pump tower are 5.0 Hz and 5.5 Hz in the empty condition for transverse and longitudinal direction respectively. Based on the measurement results, we have dynamically tuned the stiffness of spring. And the free vibration analysis for full load condition was followed considering the added mass effect, which is $\rho\pi D^2/4$ for a circular cylinder. Natural frequencies of the pump tower in membrane type are summarized in Table 3, and the corresponding mode shapes are as shown in Figure 4.

Table 3 Natural frequencies of pump tower in membrane type [unit : Hz]

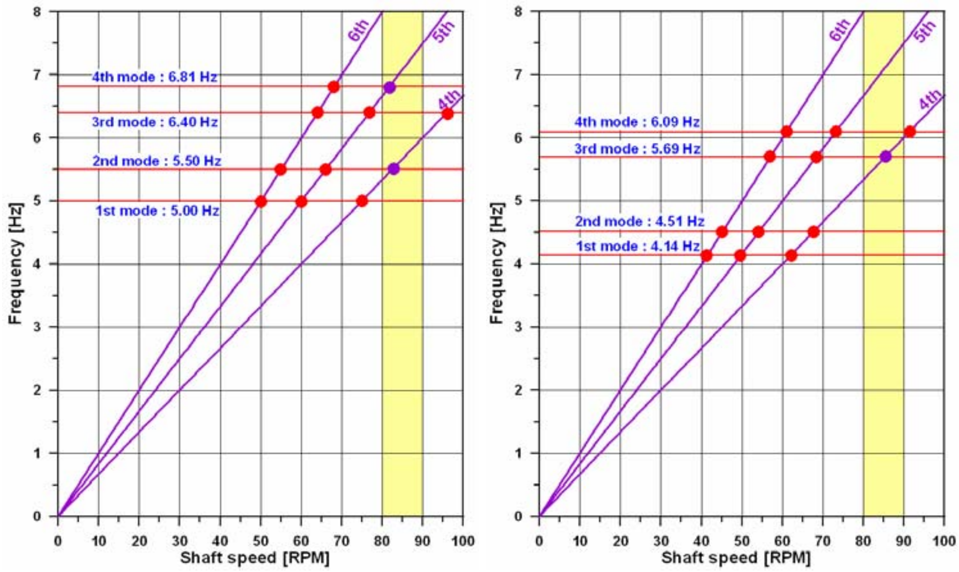
Mode \ Loading	Empty	Full	Description
1st	5.00	4.14	Transverse bending
2nd	5.50	4.51	Longitudinal bending
3rd	6.40	5.69	Twist + Bending
4th	6.81	6.09	Twist + Bending



1st mode *2nd mode* *3rd mode* *4th mode*

Figure 4 Mode shapes of pump tower in membrane type

The transverse natural frequency of pump tower is 5.0 Hz, but there are many successive natural frequencies because of continuous system. If resonance with propeller excitations occurs, it might cause a high vibration. Thus it is necessary to



(a) empty condition *(b) full load condition*

Figure 5 Campbell diagram of pump tower

check the resonance possibility with propeller excitations in advance. Campbell diagram shown in Figure 5 is a helpful tool to identify the potential vibration risks.

Propeller blade number in LNG carrier is generally selected among 4 to 6 blades in view of ship propulsion performance. Propeller shaft speed is running mainly at the normal operation range, 80 ~ 90 rpm, for the objective LNG carriers. Surface force and bearing force induced by propeller are major excitation sources for longitudinal and transverse vibration, and their frequency components are propeller blade order component and higher harmonics. As shown in Figure 5, the resonance of longitudinal vibration will be predicted at 82.5 rpm when 4-blade propeller is adopted. Therefore an actual forced vibration response should be checked to ensure the structural safety.

VIBRATION MEASUREMENT OF PUMP TOWER

Vibration measurement for pump tower was carried out to increase the reliability of analysis results and to deduce a proper boundary assumption. Through the propeller rpm sweep test at sea trial, the vibration characteristics and vibration levels are obtained.

Moss type

Spectral map for the longitudinal direction at middle position is shown in Figure 6. The measured fundamental natural frequency is 4.75 Hz, which coincides with the analysis result of 4.79 Hz. And the maximum vibration level is 3.6 mm/s due to the 5^{th} order excitation at 57 rpm. We think that such a low vibration level is because the corresponding rpm is far away from normal operation range and the stiffness of main pipe structure is basically very high.

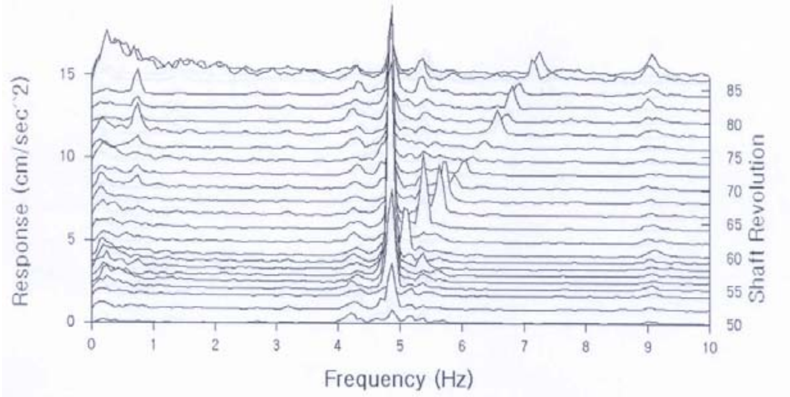


Figure 6 Spectral map of pump tower in Moss type

Membrane type

Figure 7 shows the longitudinal and transverse vibration responses at the middle position. For transverse vibration, there is a resonance with propeller blade order at 60 rpm. If this resonance occurred at normal operation range, it is expected to cause a severe damage.

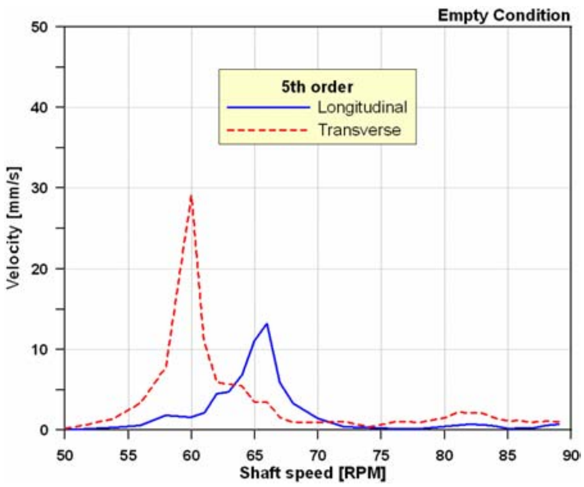
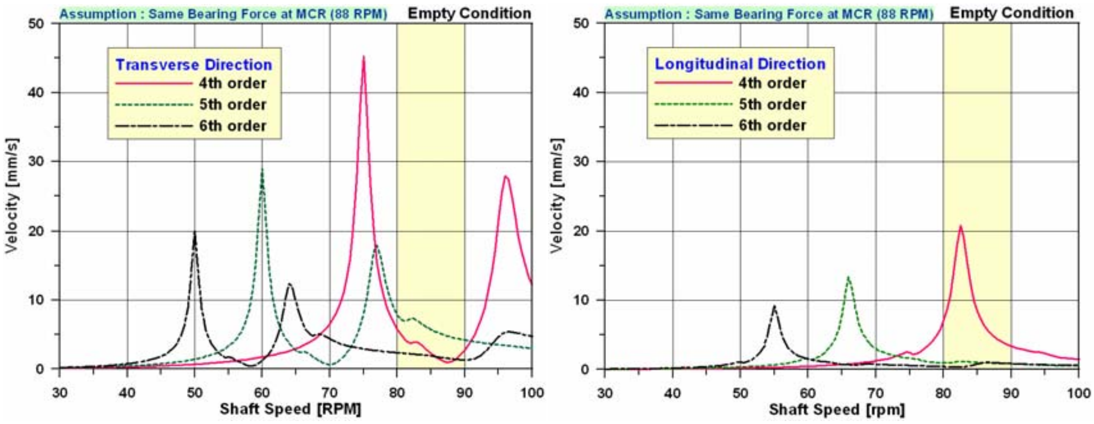


Figure 7 Actual response of pump tower in membrane type

VIBRATION INVESTIGATION ACCORDING TO PROPELLER BLADE NUMBER

For membrane type pump tower, the vibration responses according to the change of propeller blade number are investigated analytically. We assumed that the propeller bearing force for different blade number is the same at maximum continuous rating, and force magnitude is proportional to the square of revolution speed. The relative vibration responses according to the change of blade number were compared and shown in Figure 8. Analysis results show that the vibration response of pump tower is dominated by the lower two mode, bending modes, and the other mode such as twist has little effect on vibration behaviour.



(a) transverse *(b) longitudinal*

Figure 8 Vibration level according to propeller blade number

CONCLUSIONS

We have investigated the vibration characteristics of pump tower, one of the important equipment in LNG carrier, by analysis and measurement. It is confirmed that pump tower has low natural frequencies due to its flexible structure, and there is a possibility of resonance with propeller excitations at normal operation range. And furthermore, a fatigue failure may be occurred because of high vibration due to resonance. Therefore propeller design should be surely considered in determination of blade number and minimization of propeller induced force in initial design for the vibration-free pump tower.

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