Dry-Wet Modal Analysis of Balance Frame for Mounting Hydrophone

Zhen WANG, Yi ZHENG, Qun YANG, Yu-feng MAO, Wei SU, Teng LI and Cheng-fie GAO

Shandong Provincial Key Laboratory of Ocean Environment Monitoring Technology, Shandong Academy of Sciences Institute of Oceanographic Instrumentation, Qingdao 266061, China

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Abstract. To analyze the vibration characteristics of the balance frame for mounting hydrophone in water, the resonance frequency and modal shape of the balance frame are calculated with ANSYS Workbench software. The model results are compared between the analysis environment being in the water and in the air. Two modules in ANSYS which are Model and Acoustic Extension are adapted to carry out the dry-wet modal analysis, and the first six modes are obtained. It’s indicated from the results that the wet modal frequency is at most 40% lower than the dry mode, and the influence of the interior frame is obvious.

Introduction

Balance frame is adapted to maintain the attitude of hydrophone in the underwater monitoring, which the structure is variable and complicated according to the monitoring objects, positions and buoy body patterns. This paper designs the gymbal balance frame to offset the deviation interference caused by current. Hence, the vibration characteristic of the balance frame is necessary to obtained and especially the modal parameters in the water are needed to compared with the results in the air to acquire the modal characteristics in different medium. The analysis results can be adopted to prevent the resonance interaction and fatigue damage [1].

Modal analysis is to calculate the eigenvalue and eigenvector in essence, which the eigenvalue is the modal frequency and the eigenvector is the modal shape. The normal modal analysis is carried out in the air medium. Since the density of the air is less than the water, the coupling effects between the structure and the fluid have an influence on the analysis results [2]. The wet modal analysis which includes the fluid-structure interaction should be used to analyze the vibration characteristics of balance frame. Reference [3] analyzes the ship structure with FEA and BEA based on fluid-structure interaction to improve the precision of modal calculation. Reference [4] concluded that the internal water will make a great effect on the first order of natural frequency of hull vibration. Reference [5] calculated the coupling model with discontinuous boundary integral method. This paper calculates the dry-wet mode of balance frame based on fluid-structure interaction theory to analyze the coupling mode between different part of the whole frame.

Modal Analysis Theory

As to the Eigen value calculation of non-damping modal analysis in the air, the characteristic equation for the dynamic problem is

\[ [M] \ddot{x} + [K]x = 0 \]

which \([M]\) is mass matrix, \([K]\) is stiffness matrix, \(\ddot{x}\) is acceleration vector, \(x\) is displacement.

The coupling effects between different parts of structure are also analyzed and the characteristic equation is

\[ [M] + [M_w] \ddot{x} + [K] + [K_w]x = 0 \]

which \([M_w]\) is the added mass matrix of fluid, \([K_w]\) is the added stiffness matrix of fluid.
Finite Element Modeling and Analysis

Establishment of Geometric Model

The assembly parts of balance frame are simplified to import into ANSYS Workbench to analyze. The material is set as constructional steel, and enwrapped in the seawater which is modeled with “Enclosure” mode and the dimensions are 500mm × 500mm × 500mm. In order to make the nodes of different interface being in good agreement, the structure model and the seawater model are merged into a new model, then the mesh superposition can be avoided. The model of the balance frame is shown in Figure 1.

Figure 1. Geometric Model.

Model Meshing

The structure grid is set as Mechanical, and Solid 186 is chosen as the structural element. The smoothing mode is set as low, and the transition mode is fast. The span angle center is coarse.

The fluid grid is set as CFD, and Fluid 220 is chosen as the fluid element. The smoothing mode is set as medium, and the transition mode is slow. The span angle center is coarse.

Numerical Modeling

The material of balance frame is structural steel, and the density is 7850kg/m$^3$, the elastic modulus is 2.0e$^{11}$Pa, and the Poisson's ratio is 0.3. The seawater is modeled in Enclosure mode which is defined as Acoustic Body. The density of seawater is 1025kg/m$^3$, the elastic modulus is 0Pa, and the Poisson's ratio is 0. The sound velocity is 1500m/s. The algorithm is set as coupled with symmetry. The gravitational acceleration is 9.8m/s$^2$. The surface of balance frame is set as the coupling surface between fluid and structure.

The dry-wet modal analysis is carried out and the first three modal frequencies are compared in Table 1, the modal shapes are described in Table 2.

Table 1. Comparison of dry and wet modal frequency.

<table>
<thead>
<tr>
<th>No</th>
<th>Wet modal frequency(Hz)</th>
<th>Dry modal frequency(Hz)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>223.83</td>
<td>226.18</td>
</tr>
<tr>
<td>2</td>
<td>549.39</td>
<td>851.2</td>
</tr>
<tr>
<td>3</td>
<td>603.5</td>
<td>1111.9</td>
</tr>
</tbody>
</table>

Table 2. Comparison of dry and wet modal shape.

<table>
<thead>
<tr>
<th>No</th>
<th>Wet modal shape</th>
<th>Dry modal shape</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Inner frame swings around axis X</td>
<td>Inner frame swings around axis X</td>
</tr>
<tr>
<td>2</td>
<td>Inner frame swings around axis X; Brace swings in plane XOZ</td>
<td>Inner frame swings around axis Y</td>
</tr>
<tr>
<td>3</td>
<td>Inner frame swings around axis Y; Brace swings in plane YOZ</td>
<td>Inner and outer frames wring in plane XOY</td>
</tr>
</tbody>
</table>
The modal shape results are shown in Figure 2 to Figure 7.

Figure 2. 1st-order wet modal shape.

Figure 3. 1st-order dry modal shape.

Figure 4. 2nd-order wet modal shape.

Figure 5. 2nd-order dry modal shape.

Figure 6. 3rd-order wet modal shape.

Figure 7. 3rd-order dry modal shape.

It’s indicated from table 1 that the value of each wet modal frequency is lower than the dry mode, and the maximum decreasing amplitude is more than 40%. Table 2 illustrates that there isn’t obvious difference between the dry mode and the wet mode in the first order, while the second and the third modes vary greatly, especially for the inner frame. Hence, the inner frame has a great effect on the modal characteristics of the entire structure.
Summary

1. The balance frame structure is analyzed by FEM method based on fluid-structure interaction theory, and the dry-wet modal parameters are calculated out that the second and third modes have a larger difference;
2. The wet modal frequency is obviously lower than the dry mode in the first three order modes;
3. Inner frame has a great effect on the modal characteristics of entire structure.

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References