Monitor Technology Research on Hull Structure Condition

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ABSTRACT

On the basis of analyzing the necessity and significance of the condition monitoring of hull structure, aiming at the two key technical problems of selecting monitoring points and ship sensing and communication technology, the effective solutions are proposed. For the first problem, the response functions of structure stress under external loads were obtained through the method of the whole ship structural finite element analysis, the monitoring points were selected in two methods which are finding the monitoring points on the area of high-stress and considering the information of sea states. As for the second problem, supplies a complete framework for hull monitoring and assessment system based on fiber Bragg grating technology, analyzes the system’s composition and the function of each part briefly.

INTRODUCTION

Hull strength is the science of studying the safety of hull structure. In the course of sailing, the ship has been subjected to the action of wind and waves, current, collision, and so on, which will produce the shear deformation, buckling failure, fatigue fracture damage, etc. [1], so as to make the hull structure with potential danger. Therefore, it is important to construct the state monitoring system of ship structure to provide real-time monitoring data, to improve the safety of the ship and to ensure the service life of the ship. The main goal of building the safety monitoring system of hull structure is to collect all kinds of data and signal of the ship hull in the operation state. Only accurate data can be used to reflect the parameters of the hull, to monitor its working and health status, to identify the damage extent and location of the structure. Therefore, the selection of the monitoring points and the layout of
DETERMINATION OF MONITORING POINTS

At present, there are two main approaches to select the monitoring points of the hull structure. The first is based on the simplification and assumption of hull structure, and then select the monitoring points according to the size of the structural stress. This method depends on people's experience and the subjective factors, so the selection results are not unique. The second method is based on the signal coverage; the sensor is arranged without considering the stress characteristics of the hull structure [3]. On the basis of these studies, this paper considering the ship sailing area and its state, obtaining the structure stress response function by the finite element analysis of the whole ship, and then studying the selection of monitoring points, finally, the selection method of the monitoring points is given.

Solving Method for Stress Response Function

The stress response function of this paper is obtained by the finite element analysis of the hull structure by MSC/NASTRAN. The finite element model of the whole ship is built according to the shell, the beam, the rod and the quality unit [4]. Finally, the hydrostatic pressure, wave load, cargo pressure, inertia force of goods, gravity acceleration and the whole ship inertial force caused by wave load are applied to the whole ship structure model. The application of various modes of loads is shown in Table I.

Hydrostatic pressure was calculated by Equation (1):

\[ P_{sw} = \rho_w g (T - z) \]  

(1)

Where \( \rho_w \) is the sea water density, \( g \) is the gravity acceleration, \( T \) is the draft, \( z \) is the distance to the baseline.

Cargo pressure was calculated by Equation (2):

\[ P_s = \rho_c g (h - z) \]  

(2)

Where \( \rho_c \) is the density of the goods, \( h \) is the top height of the goods.
TABLE I. LOADING MODE.

<table>
<thead>
<tr>
<th>Load Form</th>
<th>Loading Mode</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hydrostatic pressure</td>
<td>Pressure</td>
</tr>
<tr>
<td>Wave load</td>
<td></td>
</tr>
<tr>
<td>Cargo pressure</td>
<td></td>
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<tr>
<td>Inertia force of goods</td>
<td></td>
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<tr>
<td>Gravity acceleration</td>
<td>Inertial load</td>
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<tr>
<td>Full inertia force</td>
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</tbody>
</table>

Inertia force of goods was calculated by Equation (3):

\[
P_d = \rho_c [a_x (x_0 - x) + a_y (y_0 - y) + a_z (z_0 - z)]
\]  

(3)

Where \(a_x, a_y, a_z\) are the acceleration components of the goods along the three axis, \(x_0, y_0, z_0\) are the center points of the goods; \(x, y, z\) are the inertia force of the goods. The acceleration of gravity is \(9.81 \text{ m/s}^2\), and the direction is negative.

In order to simulate the state of the ship on the wave, the hull is considered as a completely free beam. In the finite element solution, the hull structure is not imposed any constraints, but by the method of inertia release.

The stress response function of the hull structure which is shown in Equation (4), can be obtained by the above method.

\[
H = H(k, w_e, \beta)
\]  

(4)

Where \(k\) is the loading condition, \(w_e\) is the calculating frequency, \(\beta\) is the sea direction.

**Method for Selecting Monitoring Points**

**SELECT MONITORING POINTS BASED ON HIGH-STRESS POSITION**

According to its characteristics the hull structure is divided into seven categories: deck and platform, hull plate, bulkhead, the bottom stringers and ribs, longitudinal stiffeners, flank ribs, pillar. In each category of structure, the stress response points are sorted from big to small.

Because the finite element model number of the whole ship is large, it is difficult and not necessary to list all the elements in each category. To solve this problem, we introduce the parameter \(N\), which indicates that the stress response of all the elements in each category of structure is sorted from the big to the small. The stress response of the next step is needed to analyze the maximum number of \(N\) units.
When the mesh size is close to the length of a rib, it is appropriate to take 20 of the N [5].

In finite element analysis, the stress of the high-stress area and the stress concentration area are higher than those in other parts. Therefore, the selected N units stresses are not necessarily representative of the high stress or stress concentration, in most cases, these units are distributed in a number of high stress areas or near the stress concentration area. In order to facilitate the computer programming to find these high stresses and stresses concentration positions, we set a reference distance \( D \). In the selected N units, the distance of any two units is less than \( D \); a unit with a larger absolute value of the stress is maintained. The stress and the coordinates of the N units are assumed to be as Equation (5) [6]:

\[
\{[S_1, C_1(x_1, y_1, z_1)], [S_2, C_2(x_2, y_2, z_2)], \ldots, [S_n, C_n(x_n, y_n, z_n)]\} \quad (n = 1, 2, \ldots, N) \tag{5}
\]

where \( S_n \) is the stress of the unit \( n \), \( C_n(x_n, y_n, z_n) \) is the center coordinates of the stress of the unit \( n \). The distance between any two units is as Equation (6):

\[
d_{ij} = \sqrt{(x_i - x_j)^2 + (y_i - y_j)^2 + (z_i - z_j)^2} \tag{6}
\]

where \( i \) represents the unit \( i \), \( j \) represents the unit \( j \).

Calculation steps are as follows:

The first step, calculate \( d_{12} \), if \( d_{12} < D \), then remove the unit 2, otherwise calculate \( d_{13} \);

The second step, calculate \( d_{13} \), if \( d_{13} < D \), then remove the unit 3, otherwise determine whether unit 2 is removed, if unit 2 exists, then calculate \( d_{23} \), otherwise calculate \( d_{14} \);

The third step, and so on, until N units are all calculated.

According to the above method, the N high stress units are first calculated, which are selected for the various operating conditions. After obtaining the high stress area in each operating condition, the second time of these parts are calculated, and then eliminate the repeated parts of the operating conditions, finally, get the final full ship high stress area.

SELECT MONITORING POINTS UNDER THE CONSIDERATION OF SEA STATE

Can be seen from the above process, the selected positions are the maximum stress of the hull, which are the results of the co-action of sea direction and frequency combination. That means if a particular sea state encounter, the selected
will be the most easily damaged position. But the condition of the ship on the voyage suffered a certain sea direction and frequency combination is relatively low, the vast majority of cases are ships will encounter a variety of different sea conditions, so if the sea state information is complete, the position selected by the above method is not comprehensive enough. In this paper, response functions under various operating conditions are weighted; the structural stress monitoring points are selected according to the weighted average value. It should be pointed out that this method is based on the assumption of the following two assumptions: the first is that the encounter sea direction is uniformly distributed; the second is that the speed has little effect on the linear wave loads [7].

As the encountering sea direction is considered to obey the uniform distribution, so the weight function is only related to the loading condition and the encountering frequency. The time distribution coefficient of the loading condition can be determined by the actual conditions of the ship, or identified in accordance with the relevant norms. According to the ocean wave spectral of the voyage regional, we can obtain the probability of each encountering frequency, and then multiply the probability and the time distribution coefficient as the weight of solving the weighted average stress response function.

The relationship between the encountering frequency and the actual wave frequency is shown in Equation (7):

$$\omega_e = \omega (1 + \frac{2\omega U}{g} \cos \theta)$$  \hspace{1cm} (7)

Where $\omega_e$ is encountering frequency; $\omega$ is the actual wave frequency; $\theta$ is course angle; $U$ is navigational speed. Since the speed has little effect on the linear wave load, the navigational speed can be determined as a constant value, that is the probability of the occurrence of the speed is 1; the occurrence probability of the course angle is subject to the uniform distribution between 0 and 360 degrees. Therefore, in the calculation of weight functions, we can use the probability of the actual wave frequency instead of the probability of encountering frequency.

Assuming that the time distribution coefficient of the ship loading condition is $\alpha$, the probability of wave frequency is $P$, then the weight function is shown as Equation (8) and the weighted average stress response function is shown as Equation (9):

$$\lambda_{ij} = \alpha_i \cdot p_j$$  \hspace{1cm} (8)

$$\bar{H} = \frac{1}{A} \sum_i \sum_j \sum_k \lambda_{ij} \cdot H(k_i, \omega_j, \beta_k)$$  \hspace{1cm} (9)
Put the weighted average stress response function as a sort of priority, and then according to the method of calculating the monitoring points of high-stress position, we can get monitoring points under the consideration of sea state.

3 DESIGN OF MONITORING SYSTEM

In recent years, with the continuous improvement of the production process of the fiber Bragg grating, the research on the application of fiber Bragg grating has been widely carried out. Because of its ability to resist electromagnetic interference, high temperature resistance and corrosion resisting, fiber Bragg grating sensor has been widely used in the field of structural health monitoring, such as aerospace, civil engineering and bridge monitoring [8]. Therefore, it is of great significance and wide application prospect to apply the fiber Bragg grating to monitor the state of the hull structure.

Because of the great advantages of grating, the ship structure health monitoring system can form a larger scale, so it can be more comprehensive to monitor the state of the key positions of the ship. The fiber Bragg grating hull structure monitoring system is mainly composed of two parts, these are software and hardware. Hardware including sensor, demodulation equipment, communication equipment, etc.; the software includes the drive, the control unit, the signal processing, the database, the evaluation system and so on. The system is divided into four modules according to different functions, the fiber Bragg grating sensor detection system, the wave length demodulation and data acquisition system, data storage and database management system, signal analysis and response system. The frame structure is shown in Figure 1:
Figure 1. Structure of optical fiber grating ship structure health monitoring software.

**Fiber Bragg Grating Sensor Detection System**

The main function of the Fiber Bragg grating sensor detection system is through the fiber Bragg grating strain sensor and temperature sensor to turn the tested physical into wavelength variation of fiber Bragg gratings, which is the basic part of the hull structure monitoring system. The main monitoring physical quantities are the critical load, bending moment, vibration, torsion deformation and temperature of the key area of the hull. The other function of the system is to monitor the ship navigation status and the sea state, and the parameters include the position of ship, scale of state of sea, direction of wind, ship speed, ship attitude, etc.

**Wavelength Demodulation and Data Acquisition System**

This part is the main part of the hull structure monitoring system; the main function is to collect the output signal of the fiber Bragg grating sensor. The wavelength signal can be identified by the demodulation system, and then transfer it to the central control display platform for preservation and subsequent processing. Sometimes it includes using wireless network to transmit the monitor information to different monitoring sites to facilitate the analysis of the hull structure.
Data Storage and Database Management System

The function of this part is storing and managing the collected data, and establishing the hull health status database; so as to we can inquire the parameters, modify the model, and improve the reliability of the hull health monitoring system.

Signal Analysis and Response System

This part is the key unit of the hull structure monitoring system. By using the corresponding software and hardware, the load signals are analyzed and processed, all kinds of loads are determined, the hull structure and the possible damage are determined. At the same time, the captain can guide the crew to adjust the direction and speed of the ship with the current situation of the hull, and realize the safe operation of the ship.

CONCLUSION AND PROSPECT

In general, the evaluation of a typical hull structure health monitoring system is mainly determined by the following three factors: First is the sensitivity and accuracy of the sensor, as well as the performance of data transmission and acquisition equipment; the second is the spatial distribution of monitoring points, that is the optimal allocation of sensor; the last is the ability to test data analysis and processing [9].

At present, the condition monitoring of hull structure is still in the initial stage. Because of the complex structure of the hull and the ever-changing working environment, the requirements for hull structure monitoring system is higher than other monitoring systems. The use of fiber Bragg grating technology on the hull structure monitoring, compared to the ordinary electric sensor, the sensitivity is higher, the anti-jamming and the corrosion resistance is stronger; it’s of great significance for the modeling and early warning [10]. The hull monitoring system which constructed based on fiber Bragg grating technology has wide application prospect.

REFERENCES


