Research on ice-breaking induced vibration characteristic of a Ship

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ABSTRACT

Based on numerical simulation, this paper studies ice-breaking induced vibration characteristics of a ship under typical working conditions. Based on acoustic-structure coupling method, an ice-breaking FE model of a ship is established. Vibration of the ship under typical ice-breaking working conditions is discussed by performing the ice-breaking force in time history to the iteration area of the model. Result shows that ice-breaking force will not only yield significant global vibration, but also local vibration in the area where ice and ship hulls collapse and supper structures.

Key words: ice-breaking induced vibration; numerical simulation; acoustic-structure coupling method; global vibration; local vibration.
I-INCE Classification of Subjects Number(s): 54.3

1. INTRODUCTION

In ice, the hull structure of polar ship will be impacted by the sea ice during the normal operation, huge impact force will lead to the overall vibration , local vibration of the hull structure , etc; abnormal vibration of the hull structure will lead to the crew's physical discomfort, the instrument can not guarantee the accuracy of use. Even may lead to damage to the hull structure, causing huge losses of life and property in extreme cases.

A large number of domestic and foreign scholars have been studied in order to reduce the vibration response of the ice breaking ships in the polar regions: Hansen and Loset used a two-dimensional discrete element method to study the force of sea ice in broken ice(1). Kamlin and other used two dimensional circular plate element to simulate the interaction between the different flow velocities and the broken ice, and the test was carried out by laboratory model test(2). Wang Yu han studied ice force of ice breaking ship in the mode of continuous icebreaker, simplified continuous ice breaking mode on the basis of a series of idealized assumptions about sea ice, and the ice force time curve was obtained by software programming in the end(3). Su studied the ice load of ice breaking ship in the mode of ice breaking, and simulated the whole ice breaking process(4). Li Zi lin used discrete element method to establish the contact model of sea ice and ship hull structure, the calculated results are in good agreement with the laboratory model(5).The above research is mainly about the ice load of ice breaking mode, but the research on the vibration response of the polar ships under the ice load is less.

To this end, this paper intends to take a polar ship as an example, based on the numerical analysis method, to carry out the analysis of the vibration characteristics of the polar ice breaking, and to provide reference for the ice breaking vibration control.

2. THE VIBRATION MODEL RESEARCH OF POLAR ICE-BREAKING SHIPS

2.1 Model Building

The basic principle of the finite element method to calculate the vibration response of the ship is as follows: Firstly, the hull structure is discretized, and the mass matrix and stiffness matrix of the hull

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structure are established by using the displacement continuity and force balance condition of the joints. Then, the structural response of the node is solved, and the structural response of the nodes is solved by the predefined shape function.

In this paper, the main hull of a polar ice breaker is made up of five layers, which is mainly composed of an outer bottom plate, an inner bottom deck, a deck, a deck of two and a deck, The diagram shown in Figure 1.

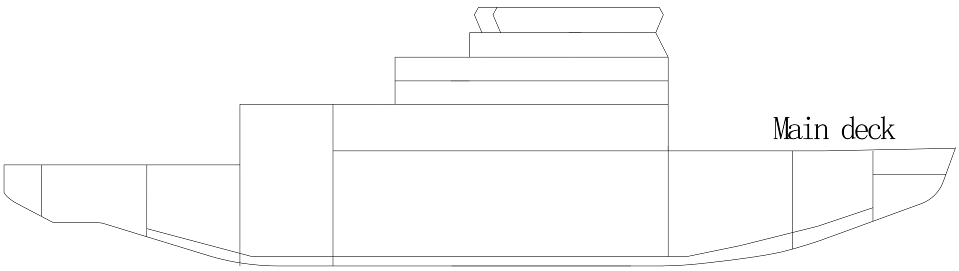


Figure 1 - Schematic diagram of the polar ship

The main parameters of the polar ship of Figure 1 is showed in Table 1:

Table 1 - main parameters of the polar ship

Parameter type	Parameter size
Waterline length Lwl	117.45m
Breadth B	22.30m
Maximum draft Tmax	8.30m
Deep D	11.80m
Main Power P	15000kW
Displacement of water Δ	16000t

According to the typical transverse section, the vertical section, the general layout of the ship, etc,the finite element model of ship hull is established with the aid of ANSYS software in this paper. The material properties of the polar vessel shell is as follows: Elastic modulus E=206GPa; Poisson ratio μ=0.3; Density ρ=7800kg/m3. After completion of the polar ship geometry model, based on the basic theory of the finite element method, at least 4 nodes must be included in a wavelength range of the structure. Based on this premise, the structural mesh size required for a given computation frequency limit can be determined according to the following formula:

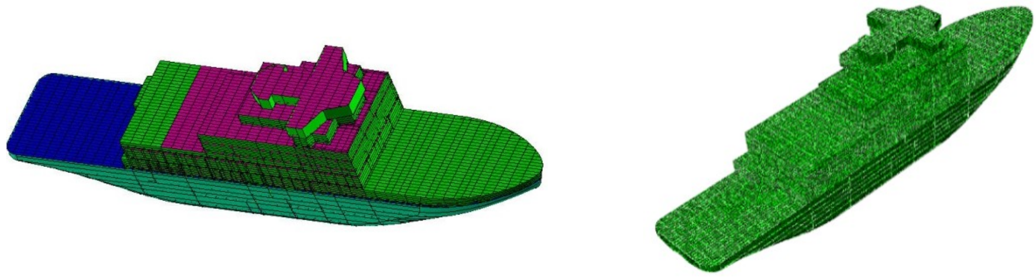
$$x \le 0.4\pi \left(D / \rho h \right)^{1/4} \omega^{-1/2} \tag{1}$$

Formula (1): X represents the grid size; D represents the flexural rigidity of the material;

H represents Plate thickness; ω represents upper frequency limit.

Under the premise of ensuring a certain margin, the frequency range of the low frequency vibration is first determined 20~250Hz in the finite element method. According to the formula (1), the required grid size of the hull structure can be calculated ,which is x≤0.4.Considering the accuracy of the calculation and the requirements of the computer hardware, this paper defines the dimensions of the polar ship grid as 0.2m.

In order to ensure the accuracy of the calculation, after the completion of the grid division, it is necessary to load the ship equipment and instruments in the form of quality points to the corresponding position of the polar ship. After loading is completed, polar ship vibration analysis model can be shown in Figure 2.



(a) Geometric model (b) Finite element model

Figure 2 - Vibration analysis model of the polar ship

2.2 Condition Setting

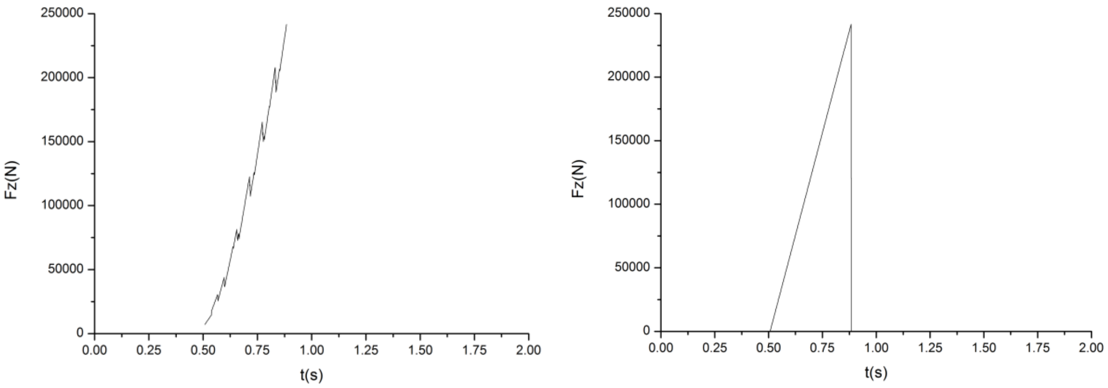
During the ice breaking operation, the ship will generate vibration due to the effect of sea ice on the hull. In order to check the vibration response and evaluate the influence of vibration on the normal operation of the ship hull. In a continuous ice breaking mode, the simulation of the vibration response of the ship is carried out by the ice breaking load of the ship, the ice breaking load of the ship is similar to that of the similar ship's ice breaking load.

The ice thickness of the polar ship collision is 1m, and the stable speed is 1.852m/s, ice breaking load is assumed to be as follows:

(1) The infinite ice is seen as fixed. The ship sail to the polar ice and contact at the waterline of the icebreaker. Once the ice breaking vessel is exposed to the sea ice, the contact process begins. A block or a plurality of ice are broken from the ice, ice number is equal to the number of contact points.

(2) Based on the contact time, the ice is formed at the same time or order. When a piece of ice is undergoing compression or bending stage, another contact process may be happening.

This paper only considers the bow at the ice load, and the bow of position and amplitude of the ice loads is fluctuating. In order to achieve the purpose of verification, intercepting the smaller time period of the force on the total simulation time. The overall simulation time length is 10s, the load period is 2S, the time step is 0.001s. To bow end load in the case, when the maximum load in the simulation of long range 241KN, time from 0.507s to 0.883s. The load is simplified, and the load is modeled as a zigzag period, its maximum load unchanged. After the end of the simplified ship history curve as shown in Figure 3:



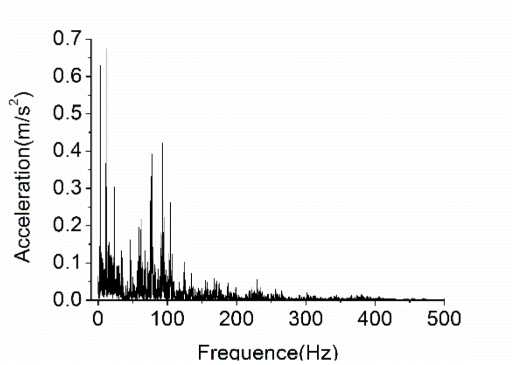
(a) Original load (b) Simplified load

Figure 3 - bow end load time history curve

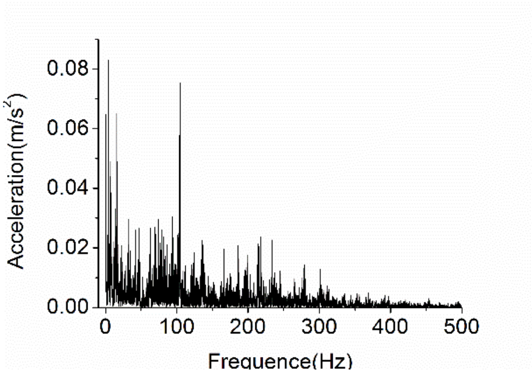
3. RESULIT ANALYSIS AND EVALUATION

3.1 vibration characteristics analysis

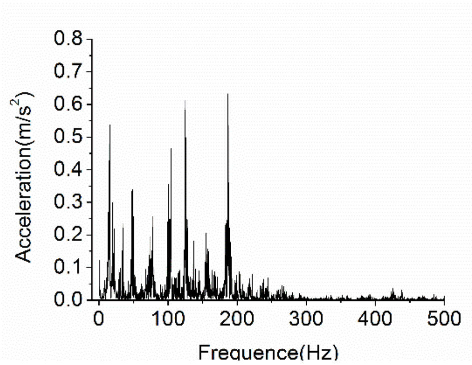
In order to analyze the vibration characteristics of the ice breaking operation, the time domain results are calculated by Fourier transform, and the frequency response curves of the typical locations during ice breaking operation are obtained. In the horizontal direction, the vibration response from the bow deck to the aft deck is as shown in Figure 4:



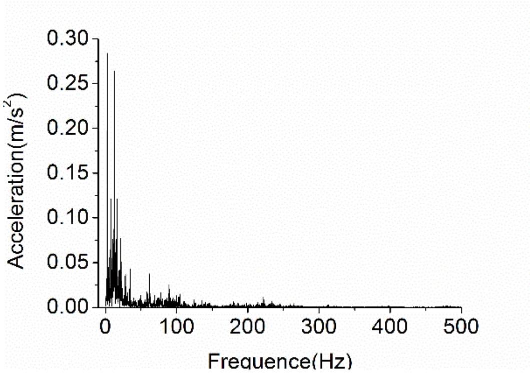
(a) The bow deck



(b) Host base



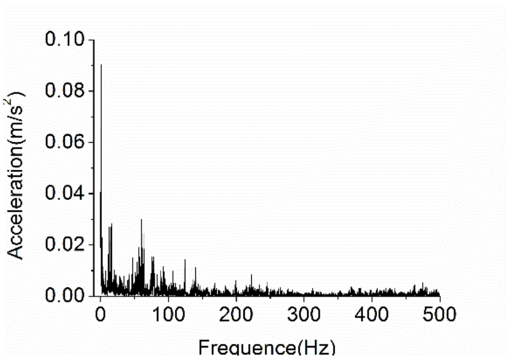
(c) Mid-ship port



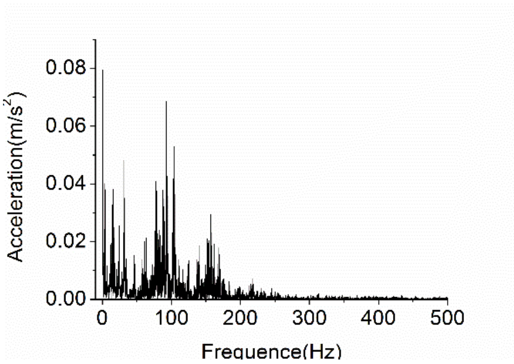
(d) Aft deck

Figure 4 - Amplitude frequency response curves of typical parts in horizontal direction

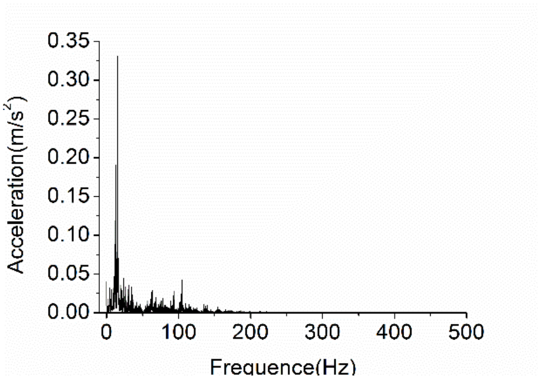
As is shown in Figure 4, from the ship deck, via the host base transfer to the aft deck, showing the trend of the vibration response, which is the mid-ship is smaller than the bow and stern. The reason is that the bow is located in direct acting area of ice breaking, resulting in large amplitude vibration response; When the impact is transmitted to the mid-ship, the internal structure of the hull has a certain obstacle to its vibration transmission. In the process of vibration propagation, the energy is dissipated and the vibration response is reduced; For the aft deck that away from the bow shock region, by contrast the bow deck and aft deck, shipboard vibration response, the reasons that vibration response is larger can be found, this is because the violent vibration of the aft deck is caused by vibration of bow. The vibration response from the bottom to the ship built on the compass deck in the vertical direction is as shown in Figure 5:



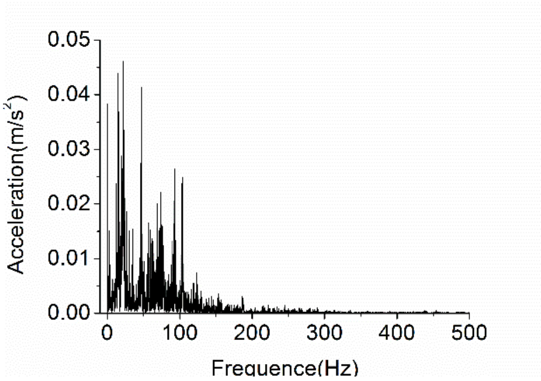
(a) Crew living room



(b) Master living room



(c) The hangar deck



(d) Compass deck

Figure 5 - vibration amplitude frequency response curves of typical parts in vertical direction

Can be seen from the figure, By Hull host at the bottom of the base, through the crew living room. The hangar deck. Captain living room to compass deck. The vibration response shows a general trend of decreasing with the increase of vertical height. The reason is that the ice breaking vibration response generated by the bow breaking impact zone, whose energy dissipation gradually accumulated with the increase of the transmission distance. Under the general trend, the vibration response of hangar deck is larger, the reason is that the ship hangar deck is lack of vertical structure support and the strengthening of local structure, which leads to the weak structure strength. The vibration of the main base is strong, The reason is that the host base located in the hull mid-ship area, with the perfect local structure strengthening measures.

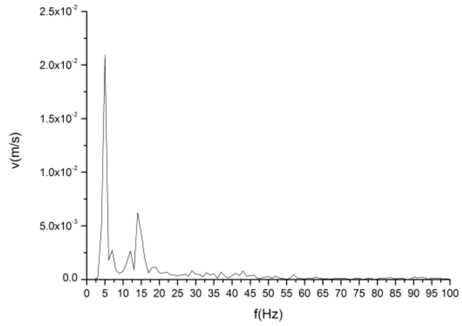
3.2 vibration evaluation

In order to further assess the vibration response of the ice breaking operation of the polar vessel, vibration response evaluation is carried out by using 6954-2000 (E) "mechanical vibration and shock - a comprehensive evaluation standard of ship vibration" established by international standard organization ISO. ISO is used for merchant ship, which total length is more than 100m, the ship is in line with the scale. The standard divides the ship into three types of areas: A for the passenger accommodation, B for the crew accommodation, C for the working area.

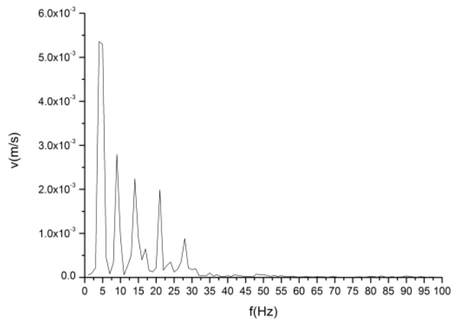
Table.2- ISO 6954 for habitability of different areas on a ship

The effective value of the response based on the frequency weighted summary	Region division					
	A（Passenger accommodation）		B(Crew accommodation)		C(Working area)	
	Acceleration mm/s2	Speed mm/s	Acceleration mm/s2	Speed mm/s	Acceleration mm/s2	Speed mm/s
Upper limit value	143	4	214	6	286	8
Lower limit value	71.5	2	107	3	143	4

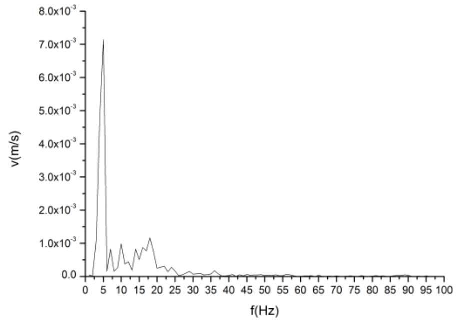
As is shown in figure 4~ figure 5, acceleration response peak value is more in the range of 1~100.In order to improve the work efficiency, the vibration velocity is chosen as the main measure; According to the results of numerical simulation, the vibration evaluation of the measurement points in the assessment area is selected. The frequency domain characteristics of the 1~100 in the examination area are plotted as follows:



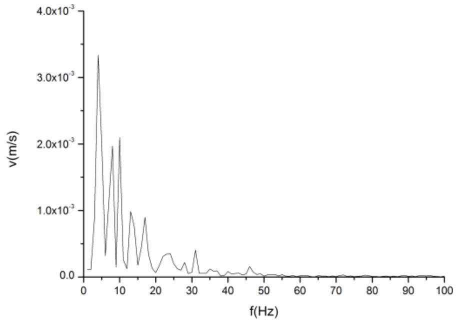
(a)The bow deck



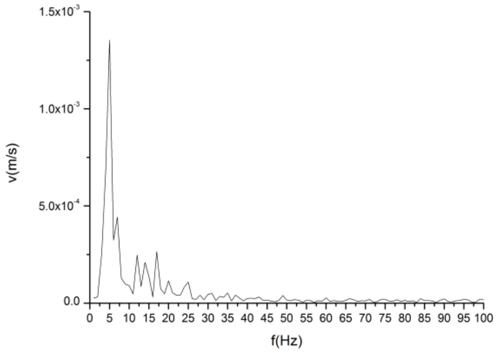
(b) Stern main deck



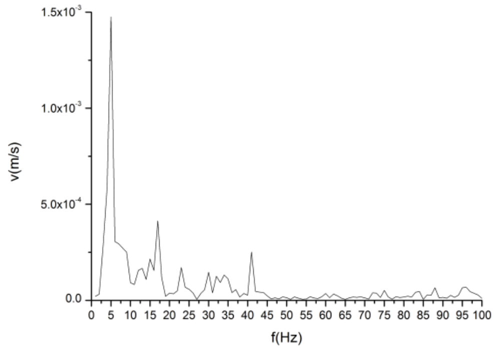
(c) Stern deck two



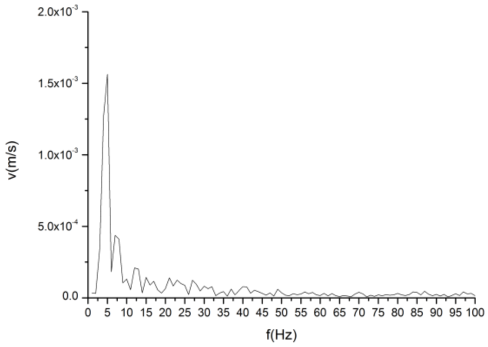
(d) The hangar deck



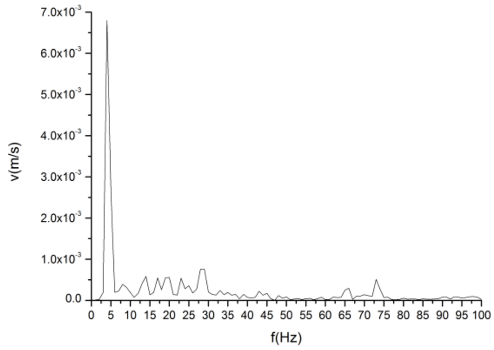
(e) Compass deck



(f)Master living room



(g)Crew living room



(h) The base of the host

Figure 6 - frequency domain curve of typical check position

From Figure 6, we can see that the vibration velocity response and vibration acceleration response are the same during the ice breaking operation of the polar ship. According to the table 1 provides a living standard, the vibration response assessment results of the typical position of the ship are shown in Table 2:

Table3 - the vibration response of different assessment locations

Examination area	Regional level	Response value mm/s	Standard mm/s	Evaluate
The bow deck	C	24.6	≤8	Harmful vibration
Aft deck	C	8.3	≤8	Harmful vibration
The aft deck two	C	6.475	≤8	Harmless vibration
Compass deck	C	1.59	≤8	Harmless vibration
Crew living room	B	1.68	≤6	Harmless vibration

Captain living room	A	1.59	≤4	Harmless vibration
Hangar deck	C	7.68	≤8	Harmless vibration
The host machine	C	7.39	≤8	Harmless vibration

From table3, During the ice breaking operation of the polar vessel, the vibration response of the living room, the cab and the middle deck of the crew is low, which is in accordance with the vibration standard. But the vibration response of the aft and bow deck area is large, does not meet the standard of vibration. Therefore, we should be appropriate to strengthen the bow and stern regional structure strength in order to ensure the safety of the ice breaking operation before the ship was to break the ice.

4. CONCLUSIONS

Based on the finite element method, an icebreaker in continuous ice simulated vibration response of the model is analyzed. And through the analysis of vibration response the characteristics and the vibration evaluation was carried out, Conclusion as follows:

（1）When ships operating in ice，from bow to stern，the bow and the stern vibration response is very larger, and the stern vibration main passing through the side structure.

（2）When ships operating in ice，from Hull to superstructure, due to energy dissipation the vibration response reduced as the height increases.

（3）By ISO 6954-2000 (e) assessment of hull vibration, we find that the area of bow vibration exceeds the requirements of the international standard, so in order to control the vibration the bow construction should be strengthened.

（4）In order to ensure the safety of the ship and persons on board, we should do something to protect the bow、the stern and the side area of the icebreaker.

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