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Calculation of Propeller Excitation Force for a Law-enforcement Ship

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Abstract: The vibration and noise of the marine propulsion shafting is a fairly common problem. The low frequency vibration caused by propeller excitation is one of the main sources of underwater radiation noise. This paper takes a law-enforcement ship as the research object, analyzes the influence of wake and cavitation on propeller excitation, and calculates the propeller excitation force and frequency of a law-enforcement ship. The results show that the propeller excitation force is 6 times higher when cavitation is severe than when it is not cavitation. Therefore, to reduce the harmful vibration of ship, propeller cavitation should be avoided in ship operation.

Keywords: Propeller, Excitation force, law-enforcement ship, numerical calculation.

1. INTRODUCTION

The high speed of ships is accompanied by many harmful vibration problems, such as local vibration, vibration of superstructure, structural damage and noise. In the course of operation, the ship will produce overall or local vibration due to the action of different types of incentive force. The propeller shaft system in operation is the main excitation source of low-frequency vibration of ship hull. When the propeller works under different loads, it generates periodic excitation, which causes forced vibration of the hull, which is usually stable. The propeller excitation force will pass through the shaft system to each bearing base, and the vibration acoustic radiation of the hull structure will be induced. To grasp the characteristics of propeller excitation and change rule, this paper takes a law-enforcement ship as the research object, analyzing wake and cavitation effect on propeller excitation, when no cavitation and cavitation are calculated separately, and serious when propeller exciting force. Therefore, the influence of propeller cavitation on ship vibration is obtained, which provides reference for ship dynamic system design and ship vibration noise control.

2. THEORETICAL ANALYSIS

2.1 Classification of propeller excitation

The propeller excitation force can be divided into axial and high-frequency excitation forces according to the excitation frequency. High frequency excitation can be divided into blade frequency excitation and double blade frequency excitation. The axial frequency excitation force is caused by the manufacturing error of the propeller. Propeller of high-order vibration force by its work in non-uniform flow field, vibration frequency is equal to the propeller speed multiplied by the number of blades or multiples of blade number, often referred to as the propeller pressure impulses of exciting force or pressure impulses exciting force.

According to the formation, transmission and action mode of propeller excited vibration force, it can be divided into surface force and bearing force. The pressure fluctuations on the surface of the ship near the propeller are called pressure fluctuations. The total force of the propeller on the hull is obtained by integrating the pulsating pressure along the hull surface, which is called the surface force. The second type is the excitation force caused by the variable flow force on the propeller blade, which is transmitted to the hull through the ship's propulsion shafting and bearing, called bearing force.

2.2 Influence of wake and cavitation on propeller excitation

When a ship moves forward, it will generate a kind of water that follows the ship's motion around the hull, called wake flow. The wake consists of three parts: friction wake, potential wake and wave wake. Friction wake is caused by the stickiness of water, and the wake velocity increases as it approaches the hull surface. Potential wake is when the ship in the water, its first water lined in both sides, and the tail will take some water, thus forming a kind of potential difference makes peripheral flow from both sides of the bow and flow to the stern of the ship. The wake formed during the movement of a ship is a three-dimensional wake. When the flow field is not uniform, the thrust of each blade will be different, so the blade frequency and double blade frequency excitation will be formed.

Propeller running in uniform flow field, due to the limited number of blades, can also cause pressure fluctuation at various points in the flow field, so sometimes may also occur in the uniform field cavitation phenomenon, but the cavitation is generally stable, called unsteady cavitation. For constant cavitation, the blade thickness can be changed according to the fluctuating cavitation layer, that is, the effect of blade thickness on the surface force can be treated as the effect of blade thickness.

When the wake field is extremely uneven, the leaf enters into the high wake zone to produce spatiotemporal bubbles, which disappear when it leaves. This kind of alternate cavitation is called unsteady cavitation. As unsteady cavitation propeller in the tail of the non-uniform flow field operation, the blade into high and low wake periodically, cavitation alternately, and collapse, and the time of the crash is short, make the fluctuating pressure amplitude changes greatly in a short time, but is no cavitation growth of multiplying or dozens of times. The high pressure wave caused by the unsteady cavitation burst propagates around the water at the sound speed, impinging on the hull surface and causing a sharp increase in the value of the ship's shock surface force.

2.3 Calculation method of propeller excitation force

The calculation of propeller excitation force mainly includes surface force and bearing force. According to the related research, bearing force is not the main factor of the vibration of the ship's tail, and the vibration of the tail is mainly caused by the surface force of the propeller. Therefore, this section mainly calculates the surface force of the propeller.

1. Calculation of fluctuating pressure

At present, there are many empirical formulas for estimating the pulsating pressure of the propeller. These methods are useful tools for predicting the pulsating pressure induced by the propeller at the initial stage of ship design. In this paper, the Holden method is used to calculate the pulsating pressure of the propeller. It is concluded by regression analysis that the Norwegian classification society has carried out a large number of experiments on 72 ships in recent years. The following method is used to estimate the pulsating pressure on the hull surface induced by propeller in the absence of cavitation and cavitation:

(1) When the propeller cavitation is serious, the blade pulsating pressure P_c is:

$$P_c = \frac{(ND)^2}{160} \frac{V_s(\omega_{T\max} - \omega_e)}{\sqrt{h_a + 10.4}} \left(\frac{1}{d/R}\right)^{K_C} \qquad (N/m^2)$$

Where, N represents the propeller speed, and the unit is r/min. D is the diameter of the propeller, m; R is the radius of the propeller, m; V_s is ship speed, m/s; h_a is the underwater depth of the axial midline, m; *d* is the distance from the top of the paddle to the hull of the boat in the water when the blade is at the peak position, m; $\omega_{T\max}$ is maximum wake peak; ω_e is effective wake coefficient.

(2) When the propeller is free of cavitation, the blade pulsating pressure P_0 is:

$$P_0 = \frac{(ND)^2}{70} \frac{1}{Z^{1.5}} \left(\frac{1}{d/R}\right)^{K_O} \qquad (N/m^2)$$

Where, N represents the propeller speed, and the unit is r/min. D is the diameter of the propeller, m; R is the radius of the propeller, m; Z is the number of propeller blades.

(3) The total pulsating pressure of the propeller P is:

$$P = \sqrt{P_0{}^2 + P_C{}^2} \qquad (N/m^2)$$

The pulsating pressure of propeller mainly depends on wake field and propeller parameters at stern. The pulsation pressure is about twice as large as that of a lean single-propeller ship in a large twin propeller ship. Blade size, speed, blade, the distance to the plate and the tail shape factors will affect the size of the exciting force, one of the biggest impact were the number of blades and the distance of propeller to the outside of the hull plate.

2. Surface force calculation

In the design stage of a ship, for a ship with a flat top above the propeller, the single amplitude of vertical surface force without cavitation can be calculated by the following formula:

$$F = 4.77 K K_{P_O} \frac{SHP}{ND} \frac{B}{2} \quad \text{(kN)}$$

Where, *SHP* represents the shaft power of propeller, and the unit is kW. D is the diameter of the propeller, m; N is the propeller speed, r/min; Z is the number of propeller blades; $K = 0.73\frac{C}{D} + 0.08$ (Z=3), $K = 0.48\frac{C}{D} + 0.032$ (Z=4), $K = 0.25\frac{C}{D} - 0.003$ (Z=5).

When the cavitation is very serious and there is no wake flow distribution data, the approximate estimation of the single amplitude value of the surface force can be calculated according to the following formula:

$$F = 4.77 K K_{P_O} \frac{SHP}{ND} K_A K_{PH} \quad \text{(kN)}$$

Where, K_A represents the Amplitude correction factor; K_{PH} is phase difference correction factor.

3. CALCULATION OF PROPELLER EXCITATION FORCE

The propeller parameters of the law-enforcement ship are shown in the following table:

Table 1 Propeller parameters of the target ship

name of parameter	numerical value	Unit
propeller speed	603.5	r/min
Number of propellers	2	-
number of blades	5	-
Diameter	1.36	m
Single propeller power	1398	kW

(1) The propeller excitation frequency calculation

The excitation frequency of propeller can be divided into shaft frequency, pressure impulses and times pressure impulses. Since the axial frequency excitation force is mainly caused by the calculation error of the propeller, no calculation is made here. This paper mainly considers the propeller blade frequency and double blade frequency excitation frequency. By calculation, the propeller blade frequency is 50.29Hz, and the double blade frequency is 100.58Hz.

(2) Calculation of surface force

The law enforcement ship adopts two main engines and two propellers to push forward, and the calculation of single blade surface force amplitude under the condition of full load port is shown in the following table:

Table 2 Calculation process of propeller surface force

name of parameter	non-cavitation	Severe cavitation
C/D	0.208	0.208
N(rpm)	603.5	603.5
D(m)	1.36	1.36
SHP(kW)	1398	1398
K	0.049	0.049

K_{P_0}	1.000	1.000
B	2	—
K_A	—	3
K_{PH}	—	2
surface force F(kN)	0.398	2.39
blade frequency f(Hz)	50.29	50.29

It can be seen that when there is no cavitation, the single amplitude of the surface force of the propeller is only 0.398kN.When the cavitation is very serious, the single amplitude of surface force is 2.39kN.When the propeller cavitation is serious, the surface force is 6 times that of the non-cavitation, which indicates that the cavitation has a great influence on the pulsation pressure of the propeller.

4. SUMMARY

This paper takes a law-enforcement ship as the research object, analyzes the influence of wake and cavitation on propeller excitation, and calculates the propeller excitation force and frequency of a law-enforcement ship. The main conclusions drawn from the results of this study are listed as follows:

(1) The propeller blade frequency is 50.29Hz, and the double blade frequency is 100.58Hz.

(2) The single amplitude of the surface force of the propeller is only 0.398kN.When the cavitation is very serious, the single amplitude of surface force is 2.39kN.When the propeller cavitation is serious, the surface force is 6 times that of the non-cavitation.

(3) The cavitation has a great influence on the pulsation pressure of the propeller.

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