Underwater Noise Radiation Source Model Simplification of a Catamaran

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ABSTRACT

This paper studies model simplification of underwater radiated noise of a catamaran. Based on theoretical analysis, a mathematical model of underwater noise radiation of a catamaran is established. Sound pressure level expressions of near and far field are thus obtained. Discussion shows that the standing wave effect occurs within the region of two hull bodies of the catamaran, while sound pressure level vanishing with distance in the far filed regions. With the help of acoustic-structural coupling analysis, numerical model of underwater noise radiation of a twin hull ship is established. And result shows that the mathematical model fit well with simulations.

Key words: Catamaran; Radiated noise; model simplification; mathematical model; acoustic-structural coupling analysis. I-INCE Classification of Subjects Number(s): 12.1

1. INTRODUCTION

With twin-hull technology matures Catamaran quickly becomes quite popular for its excellent performances of large deck area, low resistance and reliable stability. However, its underwater noise characteristic has not been explored deeply yet. Underwater noise can be extremely harmful, for civilian ships it often adversely affects marine environment, marine fish's migration, reproduction and other life activities; for military vessels such as destroyers, aircraft carriers and stealth warships it often leads to great risk to their stealth and vitality. Obviously, research on catamaran underwater noise radiation is of great significance.

Currently, on the research of underwater noise radiation characteristic, scholars have made considerable achievements with the following methods in the field of mono hull craft, including statistical energy analysis (1,2), finite element method (3,4,5), boundary element method (6,7), acoustic-structure coupling method (8,9,10,11),while in the field of catamaran still rarely reported.

In fact, as for catamaran structure, the two bodies each as a sound source will lead to coupling effect, which contributes to the complication of the underwater radiated noise problem of a catamaran. Therefore, based on linear acoustic basic assumptions, combined with radiated ball source theory, this paper establishs a mathematical model of the noise sources of a catamaran, aiming to analyse the characteristics of underwater radiated noise of a catamaran from a mathematical perspective.

2. THE MATHEMATICAL MODEL

In order to simplify the problem, consider the simplest case, two pieces of body was simplified to two ball of radiation sources with the same phase, and on this basis to study the near-field acoustic radiation characteristics. The reference[12] makes discussions with the two ball of radiation sources with the same phase in the far field, while not in the near field. In this paper, the expression of the pressure of the two ball of radiation sources will be deduced so that we can unlock the characteristics of underwater radiated noise of a catamaran.

Assuming that located in infinite space, there are two pulsating balls and with a distance of between each other. The vibration frequency, amplitude and initial phase are all the same, one of which the radiated sound pressure is[12]:

$$p = \frac{A}{r_0} e^{j(\omega t - kr)} \quad (1)$$

Where p = the sound pressure in the watchpoint p ; r_0 = the distance between the watchpoint p and pulsating balls; ω = the circular frequency of pulsating balls; A/r_0 = the amplitude of sound pressure(generally, A may be a complex number, here we make it a real nunber to simplify the problem.); k = wave number and the relation between k , ω and c_0 can be demonstrated as:

$$k = \frac{\omega}{c_0} \tag{2}$$

Where c_0 = the sound velocity in the medium.

As for micro-amplitude sound waves, the sound pressure of synthetic sound field equals to the sum of each column, which satisfys the principle of linear superposition of sound waves [12]. Therefore, we can get the expression of synthetic sound field sound pressure as:

$$p = \frac{A}{r_1} e^{j(\omega t - kr_1)} + \frac{A}{r_2} e^{j(\omega t - kr_2)} \tag{4}$$

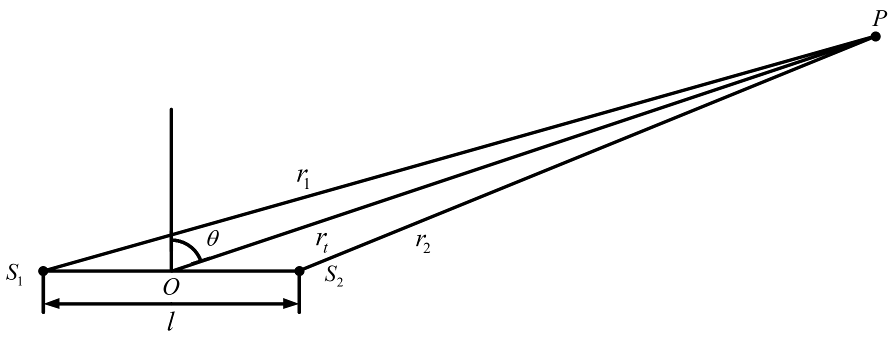

Figure1. The far field of the double pulsating balls

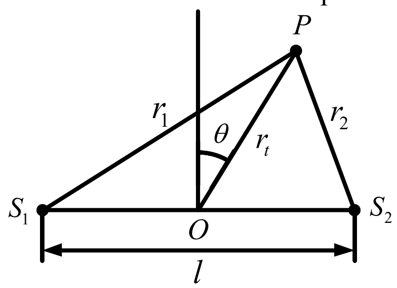

Figure2. The near field of the double pulsating balls

Where p = the synthetic sound pressure in the watchpoint; r_1 = the distance between the watchpoint P and pulsating ball S_1 , r_2 = the distance between the watchpoint P and pulsating ball S_2 ; A/r_1 = the amplitude of sound pressure in the watchpoint P from pulsating ball S_1 , A/r_2 the amplitude of sound pressure in the watchpoint P from pulsating ball S_2 ; O = the center point between the two pulsating balls; r_t = the distance between the watchpoint P and O ; k = wave number and satisfy the equation（2）.

Here we define r as the "characteristic radius" of the wavefront of the double pulsating balls source synthetic sound field, Δ as the half of the acoustic path difference of watchpoint P between S_1 and S_2 , and there are:

$$r + \Delta = r_1 \tag{5}$$

$$r - \Delta = r_2 \tag{6}$$

From（5）and（6）we can obtain:

$$r_1 - r_2 = 2\Delta \tag{7}$$

$$\frac{r_1 + r_2}{2} = r \tag{8}$$

Put （5）and （6）into （4）we can obtain:

$$p = \frac{A}{r+\Delta} e^{j[wt-k(r+\Delta)]} + \frac{A}{r-\Delta} e^{j[wt-k(r-\Delta)]} \tag{9}$$

Here we define $\left|\Delta\right| \neq r$, which means that S_1 and S_2 are two singularities of the synthetic sound field and not satisfy the equation （9）. Therefore, we can draw the equation from （9）:

$$\begin{aligned} & p(r+\Delta)(r-\Delta) \\ & = A(r-\Delta)e^{j[wt-k(r+\Delta)]} + A(r+\Delta)e^{j[wt-k(r-\Delta)]} \end{aligned} \tag{10}$$

namely:

$$p = \frac{2Ae^{j(\omega t - kr)}}{(r+\Delta)(r-\Delta)} \bullet (r\cos k\Delta + j\Delta \sin k\Delta) \tag{11}$$

The equation （11）is the expression in the near field of the synthetic sound sources of the double pulsating balls, due to that any acoustic variables were simplified or ignored from（4）to（11）, so equation（11）is suitable in the far field obviously.

Now we discuss the relation between equation （11）.From figure 2 we can see that after we dropping the two singularities, no matter where watchpoint P are, there are always:

$$\left| r_1 - r_2 \right| < l \tag{12}$$

From equation （7）we can obtain:

$$\left| 2\Delta \right| \leq l \tag{13}$$

there

$$r \ \square \tag{14}$$

And

$$r \ \square \tag{15}$$

there

$$\left| \sin k\Delta \right| \leq 1 \tag{16}$$

So that based on equation （14）and equation （16）, Δ can be seen as the first trace, thus the difference of the amplitudes of sound waves from two pulsating balls to the watchpoint P can be ignored, while the difference of phases remains. Here there the the following approximate relationship found:

$$r + \Delta \approx r \tag{17}$$

$$r-\Delta \approx r \tag{18}$$

$$\frac{j\Delta \sin k\Delta}{(r+\Delta)(r-\Delta)} \approx \frac{j\Delta \sin k\Delta}{r^2} \approx 0 \tag{19}$$

Put equation （17）~ equation（19）into equation（11）, and equation （11）will be

$$p=\frac{2Ae^{j(\omega t-kr)}}{r} \bullet \cos k\Delta \tag{20}$$

Obviously, equation (20) is the expression of sound pressure in the far field of the double pulsating balls, which indicates that equation (20) is the special form of equation (11) to meet the far-field , and proved equation (11) the validity and universality.

3. CONCLUSIONS

Based on linear acoustic basic assumptions, combined with radiated ball source theory, this paper establishs a mathematical model of the noise sources of a catamaran, aiming to analyse the characteristics of underwater radiated noise of a catamaran from a mathematical perspective. Such conclusions can be drew:

1. The two pieces of catamaran body can be simplified to two balls of radiation sources with the same phase.
2. The equation (20) is the expression of sound pressure in the far field of the double pulsating balls, which indicates that equation (20) is the special form of equation (11) to meet the far-field, so that we can use the equation(20) to describe the characteristics of underwater radiated noise of a catamaran.

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