Prediction of low-order blade frequency noise of submarine propeller based on surface panel method

LIU Zhonghua

Training department, Naval Univ. of Engineering, Wuhan 430033, China

Keywords: Submarine propeller, unformed flow, surface panel method, noise, time domain

Abstract. The unsteady loading(dipole source) on the blade surface was calculated by a potential-based surface panel method. Then the time-dependent pressure data were used as the input for Ffowcs Williams–Hawkins formulation to predict the acoustics pressure. The blade frequency noise of submarine propeller can be calculated quickly by the method, which can provide a technology support for the noise evaluation and optimization of submarine propeller.

Introduction

Radiation noise produced by the rotation of the propeller is one of main noise source in submarine. In the radiation noise of propeller, low-order frequency noise account for most of it and has a long propagation distance. Therefore, low-order frequency noise of propeller is related to the sound stealth performance of the submarine. Measuring low-order frequency noise of propeller through domestic tunnel model test is not valid at present, so computing low-order frequency noise of submarine propeller by numerical prediction has important value of engineering application.

Lighthill^[1] proposed Lighthill equation which describes the sound source distribution of sound field in 1952; Ffowcs-William and Hawkins^[2] deduced the acoustic formula for the fluid voices while any movement of solid boundary exists from generalized function according to the Lighthill equation in 1969. This is so-called FW-H equation which becomes an important milestone in the development of theory of propeller noise.

In early 1970s, most of people used frequency domain method to forecast the noise of propeller^[3-4]; In 1980s, Farass subtly transformed for FW-H equation and got integral representation in time domain^[5-7] and provided the corresponding solution. The paper uses CFD method to calculate the wake field behind stern of all-appendage suboff, then predict the unsteady pressure distribution of propeller surface using method of laminae based on velocity potential. On this basis, this paper integrates distribution of the noise source on the blade surface directly in order to forecast the low-order frequency noise of the propeller.

Solution

The solution of unsteady pressure

The method of laminae of control equation based on velocity potential is that:

$$2pf(P) = \iint_S \left[f \frac{\partial}{\partial n} \left(\frac{1}{r} \right) + \frac{1}{r} \frac{\partial f}{\partial n} \right] dS + \iint_{S_w} \Delta f \frac{\partial}{\partial n} \left(\frac{1}{r} \right) dS \quad (1)$$

S is the propeller surface, S_w is trailing vortex sheet^[8-12].

Solution of noise

Farassat proposed the time domain method based on arbitrary boundary sound source, and its solution form of pressure field is that:

$$P'(\vec{x}, t) = P_T'(\vec{x}, t) + P_L'(\vec{x}, t) \quad (2)$$

P_T' is the sound pressure caused by the thickness; P_L' is the sound pressure caused by the loading which is corresponding to the dipole.

Farassat proposed two kinds of tegral formula about the noise sound pressure:

$$4pP_T'(\mathbf{x},t) = \int_{f=0} \frac{r_0 \mathbf{g}_n}{r(1-M_r)} dS + \int_{f=0} \left[\frac{r_0 v_n (r M_r^2 + c_0 M_r - c_0 M^2)}{r^2 (1-M_r)^3} \right]_{ret} dS \quad (3.a)$$

$$4pP_L'(\mathbf{x},t) = \frac{1}{c_0} \int_{f=0} \frac{r_0 \mathbf{g}_n}{r(1-M_r)} dS + \int_{f=0} \left[\frac{l_r - l_i M_i}{r^2 (1-M_r)^3} \right]_{ret} dS + \int_{f=0} \left[\frac{l_r (r M_r^2 + c_0 M_r - c_0 M^2)}{r^2 (1-M_r)^3} \right]_{ret} dS \quad (3.b)$$

M is mach number; M_r is radial mach number; l_i is local force per unit area of i direction.

The calculation results and analysis

CFD calculation of submarine wake field

This paper performs a numerical simulation of viscous flow about the SUBOFF AFF-8 model which is proposed by the defense advanced research projects agency (DARPA). A numerical simulation about the wake field of all-appendage Suboff is performer by the STAR-CCM+ software, and this simulation chooses SST k- ω turbulence model. The axial wake distribution about radius of 0.25L at propeller disk is compared with experimental value, and the result is shown as Fig.1. The phase of computed value matches with experimental value from 0o to 180°. The computed value has a certain angle deviation with experimental value from 180° to 360°. Since the symmetry of numerical simulation is fairly good and the wake fraction of the peak in X axis is corresponding to the location of the rudder after the boat, we can think that both the deviation is caused by the experimental error. As can be seen from the comparison result, the computed result about the rear flow field of ship has a good precision in this paper.

The Suboff model which Scaled up four times is calculated at J=2.768m/s by the above method, and the computed result of axial velocity at propeller disk every radius is shown as figure 9(R=0.829m).

Fig.1 Axial flow comparison between calculation and test result

Fig.2 Calculation result of axial flow at different radius on propeller disk

Calculation low-order blade frequency noise of submarine propeller

The object of calculation is DTRC4383 propeller which works after the suboff which Scaled up four times. The speed of advance in ship is 2.768m/s ; the diameter of propeller is 0.82m;the revolving speed of propeller; the depth of propeller is 10m.

Under this condition , the sound pressure curve which is 4 m and 10 m above the propeller is shown as figure 10 , and its low-order blade frequency noise sound pressure level is shown as figure 11.

The directionality of radiation noise is researched , and the sound pressure level of different angle at $d=10\text{m}$ about propeller meridian plane (the position of 0 degree is the downstream of propeller shaft , the position of 90 degree is above the propeller) and the sound pressure level of different angle at $d=10\text{m}$ about propeller disk (the position of 0 degree is above the propeller , the position of 90 degree is the port of boat) are shown as figure 12 . It is observed that the sound pressure level change of different angle at meridian plane and propeller disk is not great ; the sound pressure of and at meridian plane is the maximum; The radiation noise sound pressure level of and at propeller disk is the maximum.

Fig.3 Acoustic pressure time histories of propeller DTRC4383 at 4m and 10m above

Fig.4 Sound pressure level of DTRC4383 at 4m and 10m above

Fig.5 Sound pressure level of propeller DTRC4383 in different angle at $d=10\text{ m}$

In order to study the rule about the noise attenuation with distance, the noise sound pressure of propeller under the working condition of the upper part 1 m, 2 m, 4 m, 16 m, 32 m, 64 m, 128 m are calculated . The sound pressure level at different distance of the relationship with the distance function is shown as table1. With the increase of distance , sound pressure level of observation points decreases . Observation distance doubles while the distance increases , the noise reduces by 6dB . But observation distance doubles while the distance decreases, the noise reduces by more than 6dB. This shows that the law of sound pressure level attenuation between near-field and near-field has a little difference .

Tab.1 Sound pressure level with $\lg(d/R)$

d(m)	$\log_2 d$	SPL (dB)	$\Delta\text{SPL}/\Delta\log_2 d$
1	0	121.57	
2	1	109.96	11.61
4	2	98.18	11.79
8	3	86.82	11.35
16	4	76.78	10.04
32	5	68.69	8.10
64	6	61.95	6.74
128	7	55.73	6.22

conclusion

This paper calculated the low-order blade frequency noise of submarine propeller in time domain. The tail wake field of boat was calculated by CFD method, and the unsteady pressure distribution of propeller was computed by panel method based on velocity potential. Both computed result of submarine wake field and computed result of unsteady of propeller compared with the test result, and they matched well. Pressure distribution was substituted into noise integral equation of Ffowkes Williams and got the sound pressure of observation point so that a set of methods which predict the low-order blade frequency noise of propeller take shape. The noise source was distributed on real propeller surface not the curved arch of the propeller. This method don't make any approximation about noise source and observation point's distance and can consider the noise sound pressure influence from the hub. Therefore, this method can make rapid calculation of low-order blade frequency noise of propeller.

This paper make a research about the directionality of the radiation noise of propeller by this method. The first-order noise sound pressure level of different angle about propeller is different. At the same time, the rule about the noise attenuation with distance was studied. The result shows that with the increase of distance, sound pressure level of observation points decreases. The law of sound pressure level attenuation between near-field and far-field has a little difference. Observation distance doubles while the distance increases, the noise reduces by 6dB. But observation distance doubles while the distance decreases, the noise reduces by more than 6dB.

Acknowledgements

This work was financially supported by the National Natural Science Foundation (51579243).

References

- [1] Lighthill M. J. On sound Generated aerodynamically, I: general theory [C]. Proceedings of the Royal Society, 1952, A221:564–587.
- [2] Ffowkes Williams J. E., Hawkings D. L. Sound generated by turbulence and surfaces in arbitrary motion [J]. Philosophical Transactions of the Royal Society, 1969, A264(1151):321–342.
- [3] Hanson D. B., Fink M. R. The importance of quadrupole sources in prediction of high speed propeller noise [J]. Journal of Sound and Vibration, 1979, 62(1):19-38.
- [4] Hanson D. B. Influence of propeller design parameters on far-field harmonic noise in forward flight [J]. AIAA, 1980, 18(11):1313-1319.

- [5] Farassat F., Brown T. J. A new capability for predicting helicopter rotor and propeller noise including the effect of forward motion [R]. New York: NASA, 1977.
- [6] Farassat F., Succi G. P. The prediction of helicopter discrete frequency noise [J]. *Vertica*, 1983, 7(4):309–320.
- [7] Farassat F., Brentner K. S. The uses and abuses of the acoustic analogy in helicopter rotor noise prediction [J]. *Journal of the American Helicopter Society*, 1988, 33(1):29–36.
- [8] Kinnas S, Fine N. A nonlinear boundary element method for the analysis of unsteady propeller sheet cavitation [C]. 19th Symposium on Naval Hydrodynamics, Seoul, Korea, 1992:102-112.
- [9] XIONG Ying, YE Jin-ming, WANG De-xun. Prediction of unsteady cavitation of propeller using surface panel method [J]. *Journal of Hydrodynamics, Ser. B*, 2005, 17(1):43-49.
- [10] YE Jin-ming, XIONG Ying. Prediction of Podded Propeller Cavitation Using Unsteady Surface-panel Method Based on Velocity Potential [J]. *Journal of Hydrodynamics, Ser. B*, 2008, 20(6):790-796.
- [11] YE Jin-ming, XIONG Ying. Prediction of 3-D Hydrofoil and Propeller Cavitation Using BEM Method by Pressure Kutta Condition [J]. *Journal of Ship Mechanics*, 2008, 12(3):335-343.
- [12] YE Jin-ming, XIONG Ying. Several problems in numerical prediction of propeller unsteady cavitation [J]. *Journal of Wuhan University of Technology*, 2006, 30(6):961-964. (in Chinese)