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PROPELLER INDUCED HULL VIBRATIONS - THE DETERMINATION OF EXCITING FORCES

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Ship vibrations are often dominated by components at propeller blade frequency and the first few harmonics thereof. This is particularly so for the afterbody of the ship. The main source of excitation is the pressure pulses generated in the water by the action of the propeller. As these pulses propagate over the hull, they will give rise to oscillatory forces with the blade passage frequency (Ω) as the fundamental. For the determination of propeller induced hull vibrations it is thus an important intermediate step to obtain an accurate description of these exciting forces, to be used as an input for response calculations. This paper presents a method to do this, when pressure pulse amplitudes and phase are known at a small number of discrete points on the hull.

Although there are methods for determining pressure pulse generation and propagation from cavitating propellers by purely theoretical means, see e.g. [1] and [2], it is our experience that the reliability and accuracy of such methods are still clearly inferior to model experiments in a cavitation tunnel. The SSPA large cavitation tunnel, which has been in operation since 1970, makes it possible to run propellers in the true wake field behind the stern of the ship. The model used for towing tank tests can be positioned in the cavitation tunnel through a close-fitting recess in the hardboard plate simulating the free water surface. The waterline of the model is adjusted flush to this board and the test section completely filled with water. As well as for measurement of thrust, torque and cavitation pattern, the tunnel also facilitates the measurement of propeller pressure pulses along the surface of the hull by use of flush-mounted pressure transducers. Amplitude and phase (relative shaft position) at $N \times \Omega$ are then determined. The considerable experience of comparisons between cavitation tunnel and corresponding full scale measurements gained at SSPA over the years confirms the reliability of the method. The main data of the tunnel are given below, while a detailed description of the tunnel together with experience of various applications is given in [3].

Table 1. Main data for cavitation tunnel No 2

	High speed section	Low speed section Normal	With insert
Length (m)	2.5	9.6	9.6
Area (m^2)	diam. = 1	2.6 × 1.5	2.6 × 1.5
Max. speed (m/s)	23	6.9	8.8
Min. cav. number	0.06	1.45	0.50

THE DETERMINATION OF EXCITING FORCE AND ITS DISTRIBUTION

In order to calculate exciting force and its distribution a computer programme was written that utilizes measured (or calculated) pressures in a few (3-10) discrete points. The programme was written with commercial ship projects in mind and thus gives a quick throughput with hull shape inputs generated directly from blue-prints using digitizer table and output presented as plots (and print-outs) of:

- Pressure pulse isobars on hull
- Distribution along the length of the ship of force (ampl., phase) in the vertical, horizontal and axial directions
- Distribution of torsional moment
- Total resultant forces and moment with due account taken of phase distribution

The first step in this calculation is the determination of pressure, p(r,t), as a continuous function of r, the distance from the propeller. The pressure pulse registered some distance from the propeller is the sum of three components, which are due to propeller blade thickness, thrust and unsteady cavitation. The latter source, which normally dominates, is due to the pulsating cavitation pattern, which will arise when the propeller is rotating in a non-uniform wake field. Looking at these three causes of pressure pulse generation as sound sources, they could be classified in broad terms as:

- Cavitation - monopole (pulsating sphere)
- Thrust - dipole (oscillating sphere)
- Blade thickness - monopole

From a physical point of view it is thus reasonable to represent the pressure function as consisting of a sum of the terms representing monopole and dipole respectively. Considering pressure pulse propagation some distance from the propeller, the amplitude of monopole and dipole sources are known to undergo an attenuation, which is inversely proportional to r and r^2 respectively. The two components will generally have a different initial phase value and a successive increase of phase lag with r depending on the velocity of sound. The components to be considered are illustrated in vector form in Fig. 1, where besides the monopole term (B^*/r) and the dipole term (C^*/r^2)

also a constant term (A*) is added. The latter should be considered as a noise term - the fact that the analysis is based om measurements means that a fraction of the measured value will be due to external excitation rather than to propeller action and that the subsequent curve-fitting will improve if this fact is acknowledged. The pressure function then takes the form:

$$p(r,t) = [A^* + PL^*(B^*/r + C^*/r^2)]e^{jN\Omega t} \qquad (1)$$

where the asterisk denotes complex numbers. The terms of eq. (1) are:

$A^* = Ae^{j\varphi_1} = x_1 + jy_1$

$B^* = Be^{j\varphi_2} = x_2 + jy_2$

$C^* = Ce^{j\varphi_3} = x_3 + jy_3$

$PL^* = e^{-j2\pi N\Omega r/c} = a(r) + jb(r)$

$N = 1, 2, 3 \ldots$

c = velocity of sound

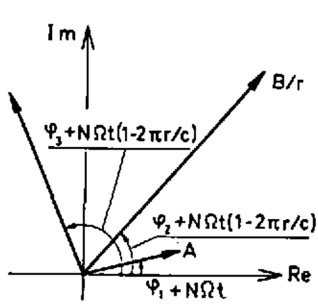

Fig. 1

Eq. (1) contains six unknowns ($x_1;y_1;x_2;y_2;x_3;y_3$) and thus a minimum of three measured values (amplitude and phase) are required. Preferably, however, one would use a somewhat larger number of measurements, say 4-8, and determine the constants by curve-fitting for minimum RMS error. The linear system of equations defining this problem is in matrix form:

$$\begin{bmatrix} 1 & 0 & a(r_1)/r_1 & -b(r_1)/r_1 & a(r_1)/r_1^2 & -b(r_1)/r_1^2 \\ 0 & 1 & b(r_1)/r_1 & a(r_1)/r_1 & b(r_1)/r_1^2 & a(r_1)/r_1^2 \\ 1 & 0 & a(r_2)/r_2 & \cdots & & \\ \cdot & \cdot & \cdot & & & \\ \cdot & \cdot & \cdot & & & \\ \cdot & \cdot & \cdot & & & \end{bmatrix} \begin{bmatrix} x_1 \\ y_1 \\ x_2 \\ y_2 \\ x_3 \\ y_3 \end{bmatrix} = \begin{bmatrix} Re(P_1) \\ Im(P_1) \\ Re(P_2) \\ \cdot \\ \cdot \\ \cdot \end{bmatrix} \qquad (2)$$

Insertion of the thus determined constants (A^*, B^*, C^*) in (1) gives the desired pressure function. Fig. 2 shows an example of pressure function fitting to full scale measurements for blade passage and double blade passage frequency. Pressure pulse magnitude and propagation will normally be different on SB and P side and hence, separate pressure functions have to be determined for each side. This difference is the cause of excitation in the horizontal and torsional directions. By

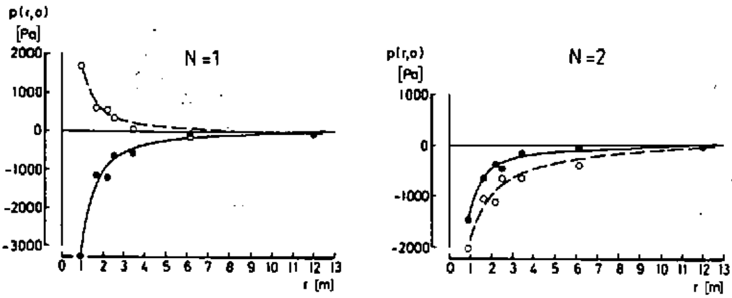

Fig. 2 Measured pressure values (sea trials) and fitted pressure function. Real part (—●—), imaginary part (--o--)

use of the principle of superpositioning the same basic method has been used to determine a pressure pulse function for two-propeller ships. The variable r in (1) is then replaced by the equivalent r-value,

$$r_e = 2r_1r_2/(r_1 + r_2) \quad (3)$$

where r_1 and r_2 are the distances from the two propeller hubs respectively.

Having determined an analytical expression for the amplitude and phase of the pressure function, the next step is then to integrate the pressure over the surface of the hull to obtain the exciting torsional moment and exciting forces in vertical, horizontal and axial directions. Using the p(r,t) function the pressure is calculated at the centre of each of the elements of Fig. 3, whereupon the summation is carried out, first for elements on the same frames, thus giving force per unit length, f(r,0), then over all elements giving the total force, see Figs. 4 and 5.

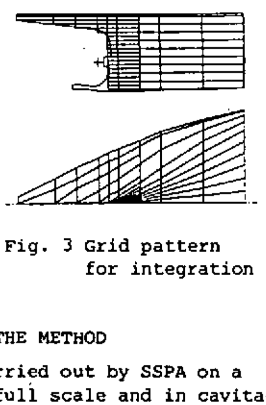

Fig. 3 Grid pattern for integration

EXAMPLES OF APPLICATION OF THE METHOD

Pressure pulse measurements were recently carried out by SSPA on a heck trawler of 1360 tonnes displacement in full scale and in cavitation tunnel. Seven measurement points were used for the full scale measurements and eleven in the cavitation tunnel. The values $P_1^* - P_{11}^*$, measured in the cavitation tunnel, have been used to determine a pressure function, subsequently used for force calculations. The result at blade passage frequency and the first two harmonics is given in Fig. 4.

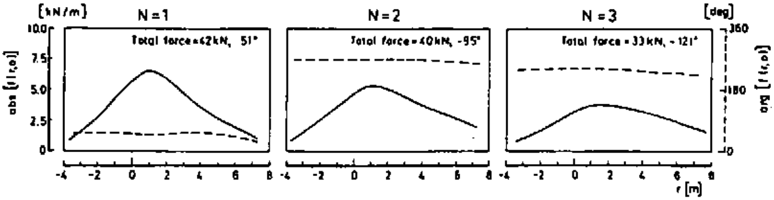

Fig. 4 Vertical force distribution. Propeller positioned at zero, positive r in forward direction

A comparison between results based on full scale measurements and cavitation tunnel results was carried out for three load cases and is presented in Fig. 5. At least for the two higher speeds the agreement seems very satisfactory in this case.

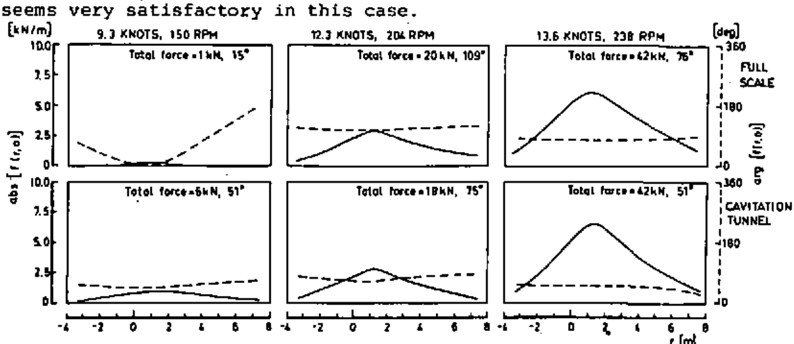

Fig. 5 Vertical force distribution at three load cases for N = 1

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