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SOME ASPECTS OF THE PROPELLER BEARING FORCES EXCITING HULL VIBRATION OF A SINGLE SCREW SHIP*

By Toyoji KUMAI**

Abstract A study is made on the propeller bearing forces exciting hull vibration of a single screw ship. As the external vibratory forces, vertical moment and force, horizontal moment and force, thrust and torque are calculated for 3- to 6-bladed propellers with two types of ship wake. The above moments and forces applied at the propeller disk are approximately estmated provide that the harmonic components of the curves of the circumferential distributions of thrust and torque coefficients of given propeller that rotating in optional ship wake are obtained.

Introduction

The external vibratory excitation of the hull of a ship consists of six components, namely, vertical moment and force, horizontal moment and force, twisting moment and longitudinal force. It is to be noted that neither thrust variation nor torque variation contributes to the main vibratory excitation of the flexural hull vibration of a ship. On the other hand, the torsional vibration of the hull of a single screw ship will be excited by the couple due to surface force.

The present paper gives the calculation of the first four components of moment and force produced by the propeller blades mentioned above. These components of mement or force are computed by summing up those of the moment due to thrust or the tangential force with respect to each blade that encounters the flow of unequal wake at the propeller disk.

The components of moment other than that mentioned above are accounted those of the thrust eccentricity due to gravity of the propeller itself and also as the twisting moment of the blade induced by the peak of wake concentration. These two kinds of moments should be added to the moment due to thrust. For the sake of simplicity, however, these moments are ignored in the present study. No surface forces have taken into account in the present paper.

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1. Calculation of Propeller Bearing Forces

When a one-bladed propeller rotates in the flow of uniform wake, neither the thrust variation nor the torque variation is accounted. However, the vertical and horizontal components of the moment due to thrust and of tangential force of the blade are clearly accounted as periodic ones. One can understand that the above mentioned components of the moment due to thrust as well as those of the tangential force are the vibratory ones exciting hull vibration of a single screw ship at the stern tube and bearings through the propeller shaft, as be shown in Fig. 1. If the number of blades of the propeller consists of more than two, the components of vibratory force and moment cancel in the uniform wake. However, since the ship wake at the propeller disk is nonuniform along circumference, the vertical and horizontal components of the moments of thrust and tangential forces of blades which encounter the corresponding wake are accounted. Consequently, the vibratory moments and forces exciting hull vibration are calculated by summing up the vertical or horizontal components of the thrust moments and tangential forces produced by blades at the corresponding wake fractions.

As the thrust or torque coefficient of the propeller at the given advance coefficient is obtained by using the chart of open test results of a given propeller, the relation between the wake fraction and the thrust or torque coefficient is easily shown, for instance, as was presented by Hans Brehme for an example [1]. Accordingly, the distribution of thrust or torque coefficient along circumference of the propeller disk at 0.7R, as an approach, is obtained for a given wake pattern and the propeller.

In the next stage, the fraction of the thrust or torque coefficient varying along the circumference of the propeller disk is represented by Fourier cosine series respectively provide that only the longitudinal wake is adopted, namely

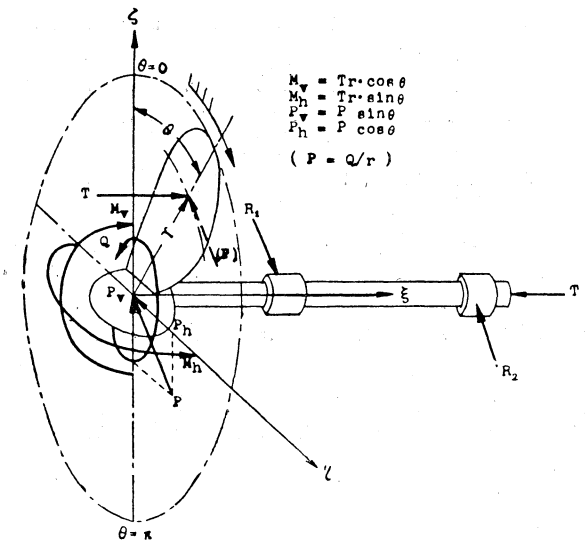

Fig. 1. Components of moment and force due to one-bladed propeller.

$$\frac{T_m}{T_0}=\frac{K_T}{K_{T0}}=a_0+\sum_{n=1}^{\infty}a_n\cos n\theta, \tag{1}$$

$$\frac{Q_m}{Q_0}=\frac{K_Q}{K_{Q0}}=b_0+\sum_{n=1}^{\infty}b_n\cos n\theta, \tag{2}$$

where, $\frac{K_T}{K_{T0}}$, $\frac{K_Q}{K_{Q0}}$ fractions of thrust and torque coefficients respectively

a_0, b_0, a_n, b_n respective Fourier coefficients, $n=1, 2, \cdots$

θ turning angle of datum blade measured clockwise from zero at the upper vertical axis

The vertical and horizontal components of moment due to thrust and tangential force of the blade at the corresponding wake are summed up in each blade respectively as shown by the following forms; (see also Fig. 1)

$$\frac{M_v}{M_0}=\frac{1}{z}\sum_{m=1}^{z}\frac{T_m r}{T_0 r_0}\cos\left\{\frac{2\pi(m-1)}{z}+\theta\right\}, \tag{3}$$

$$\frac{M_h}{M_0}=\frac{1}{z}\sum_{m=1}^{z}\frac{T_m r}{T_0 r_0}\sin\left\{\frac{2\pi(m-1)}{z}+\theta\right\}, \tag{4}$$

$$\frac{P_v}{P_0}=\frac{1}{z}\sum_{m=1}^{z}\frac{Q_m r_0'}{Q_0 r'}\sin\left\{\frac{2\pi(m-1)}{z}+\theta\right\}, \tag{5}$$

$$\frac{P_h}{P_0}=\frac{1}{z}\sum_{m=1}^{z}\frac{Q_m r'_0}{Q_0 r'}\cos\left\{\frac{2\pi(m-1)}{z}+\theta\right\}, \tag{6}$$

where,

$\frac{M_v}{M_0}$, $\frac{M_h}{M_0}$ fraction of the vertical and horizontal components of moment due to thrust respectively

$\frac{P_v}{P_0}$, $\frac{P_h}{P_0}$ fraction of the vertical and horizontal components of tangential force respectively

z number of blades of a prepeller

$m=1, 2, \cdots\cdots z$

$\frac{T_m}{T_0}$, $\frac{Q_m}{Q_0}$ fraction of thrust and torque at the m-th blade respectively

r, r' lever of moment due to thrust and torque respectively at the m-th blade

r_0, r'_0 mean lever length which corresponds to r, r' respectively

In the above expressions of the components, the levers of thrust moment and torque denoted by r, r' are assumed to be equal to r_0, r'_0 respectively as an approach in the present study, so the fractions of the thrust and tangential force presented in the foregoing (1) and (2) at the m-th blade are substituted into (3), (4) and (5), (6) respectively.

Carrying out the above substitutions, the following components of moment and force are delivered;

[1] Brehme, H. "Der Einfluss der Flügelzahl eines Schiffspropellers auf die Erregung von Schiffsvibrationen" Schiff u. Hafen 6, 1954.

$$\frac{M_v}{M_0}=\frac{1}{2}a_1+\frac{1}{2}\sum_{k=1}^{\infty}(a_{kz-1}+a_{kz+1})\cos kz\theta, \tag{7}$$

$$\frac{M_h}{M_0}=\frac{1}{2}\sum_{k=1}^{\infty}(a_{kz-1}-a_{kz+1})\sin kz\theta, \tag{8}$$

$$\frac{P_v}{P_0}=\frac{1}{2}\sum_{k=1}^{\infty}(b_{kz-1}-b_{kz+1})\sin kz\theta, \tag{9}$$

$$\frac{P_h}{P_0}=\frac{1}{2}b_1+\frac{1}{2}\sum_{k=1}^{\infty}(b_{kz-1}+b_{kz+1})\cos kz\theta, \tag{10}$$

where, $k=1, 2, 3,\cdots\cdots\infty$.

On the otherhand, the thrust and torque as the functions of z and θ are easily calculated in the following forms [2].

$$\frac{T}{T_0}=a_0+\sum_{k=1}^{\infty}a_{kz}\cos kz\theta, \tag{11}$$

$$\frac{Q}{Q_0}=b_0+\sum_{k=1}^{\infty}b_{kz}\cos kz\theta. \tag{12}$$

The variations in the above moments, forces, thrust and torque as variables θ with the parameter z up to the second harmonic, for practical use, are easily obtained.

As the rough estimation of the maximum values of components, the double amplitude of the variations of the components for the fundamental and the second harmonic, namely, those in the blade-frequency and twice the blade-frequency respectively are shown by simple forms as follows:

$$\left(\frac{\Delta M_v}{M_0}\right)_{\max 1}=|a_{z-1}+a_{z+1}|,\quad \left(\frac{\Delta M_v}{M_0}\right)_{\max 2}=|a_{2z-1}+a_{2z+1}|, \tag{13}$$

$$\left(\frac{\Delta M_h}{M_0}\right)_{\max 1}=|a_{z-1}-a_{z+1}|,\quad \left(\frac{\Delta M_h}{M_0}\right)_{\max 2}=|a_{2z-1}-a_{2z+1}|, \tag{14}$$

$$\left(\frac{\Delta P_v}{P_0}\right)_{\max 1}=|b_{z-1}-b_{z+1}|,\quad \left(\frac{\Delta P_v}{P_0}\right)_{\max 2}=|b_{2z-1}-b_{2z+1}|, \tag{15}$$

$$\left(\frac{\Delta P_h}{P_0}\right)_{\max 1}=|b_{z-1}+b_{z+1}|,\quad \left(\frac{\Delta P_h}{P_0}\right)_{\max 2}=|b_{2z-1}+b_{2z+1}|, \tag{16}$$

$$\left(\frac{\Delta T}{T_0}\right)_{\max 1}=2|a_z|,\quad \left(\frac{\Delta T}{T_0}\right)_{\max 2}=2|a_{2z}|, \tag{17}$$

$$\left(\frac{\Delta Q}{Q_0}\right)_{\max 1}=2|b_z|,\quad \left(\frac{\Delta Q}{Q_0}\right)_{\max 2}=2|b_{2z}|, \tag{18}$$

where, 1 and 2 in suffix show the double amplitudes of the first and the second harmonics respectively.

As noticeable in the above results, the maximum values of the vibratory exciting moments and forces depend on a_{kz-1}, a_{kz+1} and b_{kz-1}, b_{kz+1} respectively, whereas the thrust and torque variations depended on a_{kz} and b_{kz} respectively, though in the same periodic function of θ with kz in argument in both cases. The Fourier coefficients mentioned above are determined by only the circumferential distribution of the thrust or torque coefficient of given propeller in the present steady state calculation.

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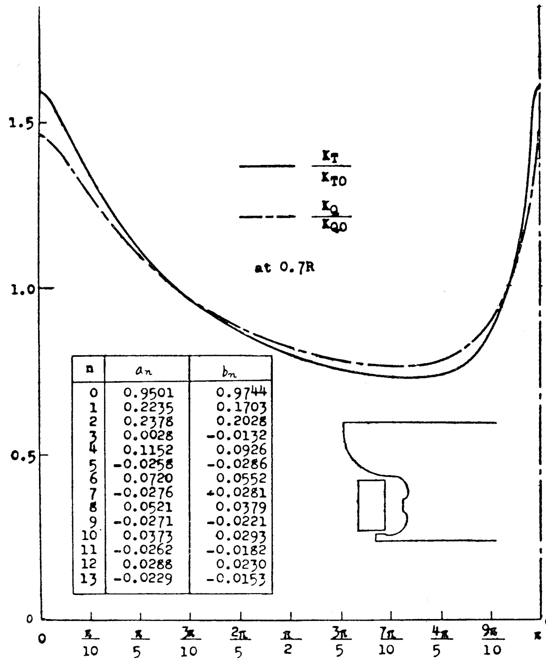
[2] Ritger, P. D. and Breslin, J. P.: "A Theory for the Quasi-Steady and Unsteady Thrust and Torque of a Propeller in a Ship Wake" E. T. T. Rep. No. 686. 1958.

2. Numerical Examples

(a) Bearing Forces in Ordinary Stern

The distribution of the thrust and torque coefficients along circumference at the radius 0.7R of propeller disk in ordinary U-type stern [3] with Troost propeller B4–55, as an example, are shown in Fig. 2 with the numerical table of Fourier coefficients.



n	a_n	b_n
0	0.9501	0.9744
1	0.2235	0.1703
2	0.2378	0.2028
3	0.0028	-0.0132
4	0.1152	0.0926
5	-0.0258	-0.0286
6	0.0720	0.0552
7	-0.0276	+0.0281
8	0.0521	0.0379
9	-0.0271	-0.0221
10	0.0373	0.0293
11	-0.0262	-0.0182
12	0.0288	0.0230
13	-0.0229	-0.0153

Fig. 2. Circumferential ditsributions of thrust and torque and these Fourier coefficients in ordinary stern.

Substituting the respective numerical values into (13) to (18), the variations of the vertical and horizontal components of the exciting moment and force and also of the thrust and torque are obtained in the thee- four- five- and the six-bladed propellers by using K_T, K_Q-charts of given propellers with the same advance coefficient respectively. (Fig. 3)

It is to be noted that the distributions of both the thrust and torque coefficients represented by Fourier series mentioned above in the ordinary stern seem more predominant in the Fourier coefficients of the even numbers than in those of the odd numbers. Accordingly, it is concluded from the results of above calculation that the vertical moment and horizontal force are generally seen to be larger than thrust and torque variations in the five-bladed propeller, whereas the

[3] Neifert. H. R. and Robinson, J. H.: "Further Results from the Society's Investigation of Tailshaft Failures" Trans. S. N. A. M. E. 63, 1955.

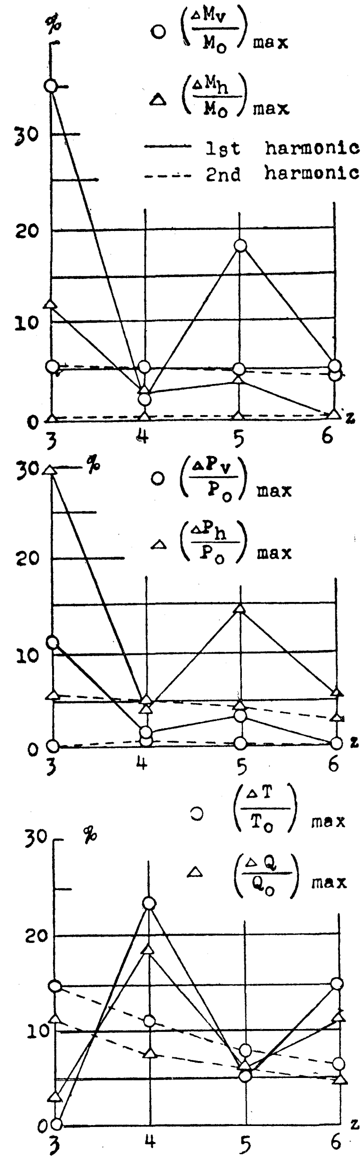
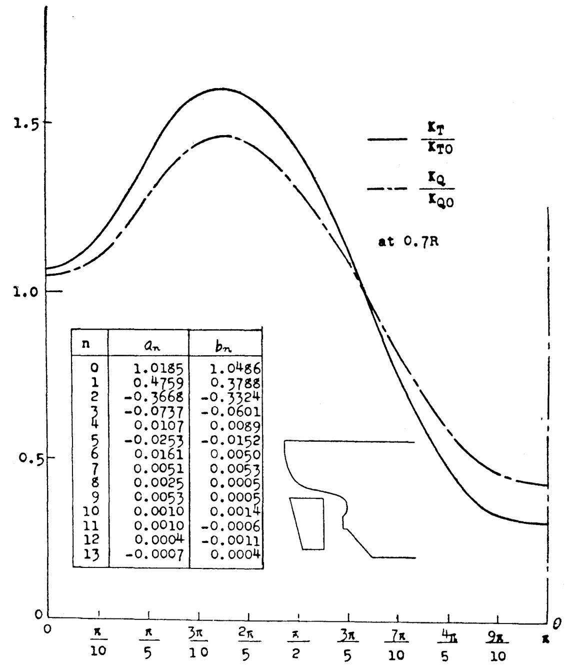


Fig. 3. Double amplitudes of variations of bearing moments, forces, thrust and torque in ordinary stern.

former is smaller than the latter in the four-bladed propeller in the same flow at the propeller disk in the ordinary type of the stern.

(b) Bearing forces in Weser-stern

The same process as was shown in the previous article is applied for the respective wake distribution produced by various types of the stern form. The second example provides the bearing moments and forces in the Weser-stern. The wake survey in the Weser-stern has been carried out by Nitzki and Weser [4].



n	a_n	b_n
0	1.0185	1.0486
1	0.4759	0.3788
2	-0.3668	-0.3324
3	-0.0737	-0.0601
4	0.0107	0.0089
5	-0.0253	-0.0152
6	0.0161	0.0050
7	0.0051	0.0053
8	0.0025	0.0005
9	0.0053	0.0005
10	0.0010	0.0014
11	0.0010	-0.0006
12	0.0004	-0.0011
13	-0.0007	0.0004

Fig. 4. Circumferential distributions of thrust and torque and these Fourier coefficients in Weser-stern.

Using one of the results of Nitzki-Weser's tests of wake distribution, the harmonic components of the curves of K_T/K_{TO} andK_Q/K_{QO} for given propeller that obtained by the same process as described in the previous article are obtained as shown in Fig. 4. The maximum values of the components of the mement and force and thrust and torque variations are computed with respect to the number of blades as shown in Fig. 5.

Conclusion

From the results so far obtained, it will be concluded that the propeller vibratory bearing forces exciting flexural hull vibrations of a single screw ship are less in the propellers with even number blades than that of the odd number ones, whereas the thrust and torque variations in the propeller of the odd number blades are less than that in the even number ones in the ordinary stern. As the second example, the numerical calculation was carried out into vibratory forces in the Weser-stern and the results were compared with that of the ordinary stern.

The brief conclusions mentioned above are qualitatively confirmed by the experimental investigations into the propeller forces recently carried out by van Manen and Wereldsma [5].

As a result, the vertical and horizontal components of the vibratory moment and force as well as thrust and torque variations due to action of the propeller blades are approximately estimated provide that the harmonic components of the curves of the circumferential distributions of the thrust and torque coefficients of given propeller that rotating in optional ship wake are obtained.

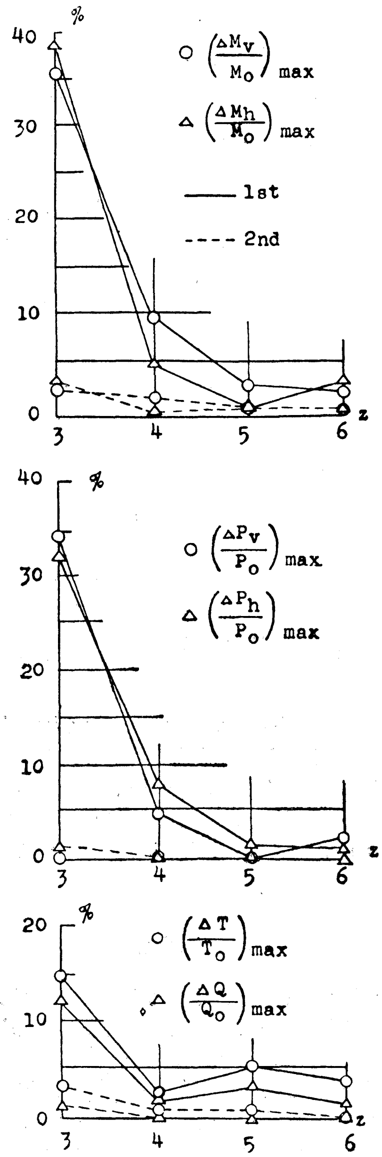


Fig. 5. Double amplitudes of variations of bearing moments, forces, thrust and torque in Weser-stern.

(Received Aug. 30, 1961)

[4] Nitzki, L. and Weser, A. G. "Resistance and Propulsion of High-Powered Single Screw Vessel". European Shipbuiding, No. 3, 1959.

[5] van Manen, J. D. and Wereldsma, R. "Vom Propeller erregte Wechselkräfte in der Welle eines Einschrauben-Tankers." Schiff u. Hafen 1960, H. 9. "Propeller Excited Vibratory Forces in the Shaft of a Single Screw Tanker" I. S. P. No. 73. Vol. 7, 1960.