Inverse determination of ship propeller source strength

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Introduction

Ship trials aimed at the determination of propeller-induced hull excitation forces are often performed with a limited number of hull-mounted pressure transducers from which no accurate resultant force can be integrated. Instead, the result is usually given in terms of maximum pressure amplitude on the afterbody at several blade passage frequencies. These amplitudes are then compared with contract requirements stated in the same terms. This procedure may easily lead to a wrong qualification of the propeller cavitation as a source of inboard noise and vibration. It is proposed to solve this problem by qualifying the propeller on the basis of its source strength. A boundary element method is applied for the inverse determination of the propeller source strength given a set of hull-pressure measurements (thus solving an inverse scattering problem). The method is tried out on data of a cavitating and non-cavitating propeller measured in a depressurized towing tank. The same method is used in combination with another boundary element method for propeller analysis to determine the hull-pressure field (thus solving a scattering problem). The pressure distributions on the hull thus found are compared with those computed from the inversely determined propeller source description.

Background

In Refs. [1,2] it was argued that the maximum pressure amplitude on the hull above the propeller tip at a certain blade rate frequency may not be an objective measuring-staff for the judgment of the hull vibratory excitation forces. This follows from the simple reasoning that the hull-pressures induced by the propeller consist of contributions due to propeller cavitation dynamics, propeller loading and blade thickness. Where propeller cavitation causes a hull-pressure field approximately in phase across the afterbody, the pressure field due to loading and thickness shows strongly varying phases, especially in the transverse direction. When the interference by the latter contribution is significant the maximum pressure cannot be used as a measure of the integral excitation force.

For this reason in Refs. [1,2] it was advocated to make a distinction between cavitating and other components in the hull-pressure field and express the propeller cavitation dynamics in terms of just a single number, its source strength. The source strength could be derived by applying an inverse scattering analysis on the hull-pressure data after the non-cavitating contribution to the pressure field had been separately measured and subtracted from the total. Figure 1 shows a case in which this procedure produced results with relative percentage errors of 10-15% for the first two harmonics, the error norm being defined as the total length of all complex amplitude errors divided by the total length of all measured complex amplitudes.

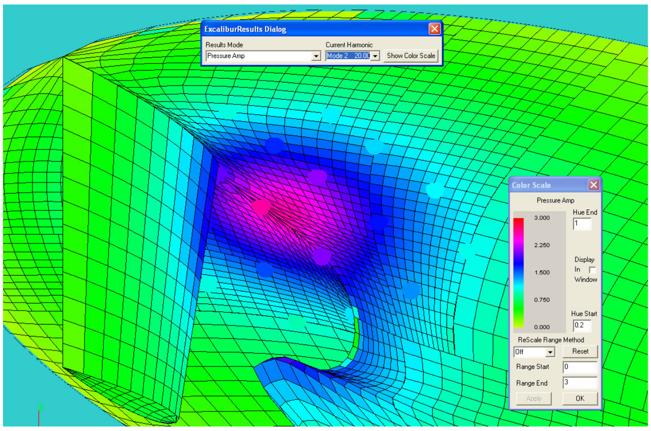

Figure 1: Simple example of source identification. Viewer looks from underneath to boundary element description of single screw hull. Dots indicate locations on the hull where pressure measurements have been made. The continuous color distribution on the hull indicates pressure amplitude in kPa due to the best fitting monopole source at the second harmonic of blade passing frequency (From Ref. [2]).

However, non-cavitating information is not always measured in cavitation tunnels or towing tanks, and when hull-pressures are obtained from ship trials this will definitely not be the case. Then, an additional model for thickness and loading would be needed. Obviously, one could try and compute the hull-pressure fluctuations of the non-cavitating propeller directly. For this purpose, we have combined two boundary element methods, one for the velocity potential disturbance on the propeller, the other for the acoustic scattering of those disturbances on the hull. The method is tried on a single screw vessel with a two-bladed propeller for which towing tank measurements of non-cavitating hull-pressures were made. The measurements were made at ship speed zero and the (constant) pitch of the relatively thick propeller was set to zero as well. Thus, a good impression of the thickness contribution could be obtained, the latter being much greater than the loading contribution right above the propeller.

If no propeller geometry information is available, a simple inverse model can be tried instead. In this paper an attempt is made at modeling the thickness by means of ring sources of constant amplitude and varying phase along the ring, which is centered at the propeller center and of a typical radius. The rings may be of a monopole or dipole nature and only have their complex strength amplitude as unknown. Thus, the non-cavitating hull-pressure field would be modeled by a set of sources with only a few unknowns that need to be determined by an inverse scattering procedure.

Modeling of (forward) scattering

For the determination of the velocity potential disturbance on marine propeller blades (and their wake) we use the

Laplace-based boundary element method that is described in Ref. [3], where quadrilateral flat elements of constant strength are used in the time domain. Blade loading is determined by application of a Kutta condition at the trailing edges of the blades and an estimate of the effective wake field at the propeller disc is used as input. At all time steps during a propeller revolution the method outputs the strength of the monopole (outward normal velocity) and dipole (velocity potential) source strengths.

With these data as input another boundary element method is used to determine the hull-pressure complex amplitudes in the frequency domain. This method, which is described in Refs. [1,2], is a Helmholtz-based boundary element method, where also quadrilateral flat elements of constant strength are applied. The pressure release condition at the free surface is modeled through a mirror imaging procedure of the source system and diffracting hull.

Transformation of the propeller source system from the time to the frequency domain is performed by replacing the rotating sources by stationary ones distributed along their paths and developing the strengths of the stationary sources into a Fourier series of blade passing frequencies (Ref. [4]).

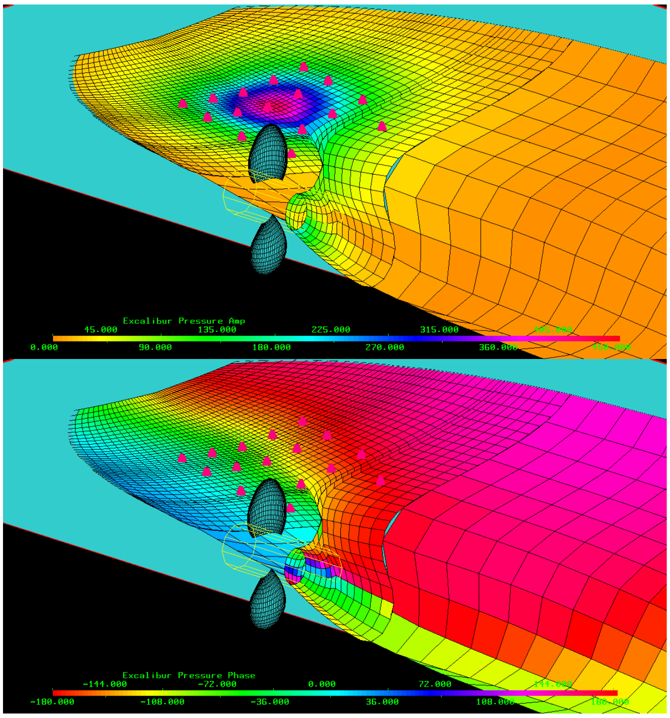

Figure 2: Hull-pressure amplitudes (top, in Pa) and phases (bottom, in deg.) at 20 Hz for the 2 blade propeller. Dots indicate locations on the hull where pressure measurements were made. The blue plane indicates the free surface.

The two boundary element methods and the procedure through which they are coupled have been tested on the single screw vessel depicted in Figure 1. The ship's 6-bladed propeller was replaced by a special 2-bladed propeller design already mentioned. An example result is shown in Figure 2. Note that the propeller hub was not taken into account in the diffraction computation.

Figure 3 shows a comparison with scale model test results from a towing tank. The tests were made with propeller at pitch zero and zero forward speed. Thus, the hull-pressures are almost exclusively caused by blade thickness effects and the pressure release surface is still flat. These simplifications were made to ensure the exact draught in the computations and to test our ability to compute thickness effects in isolation, because in the area above propeller disc thickness effects are far greater than those due to blade loading. In Figure 3, the maximum pressures are found around station (X,Y) = (200, 0) mm (i.e. right above the top dead center of the propeller), where the amplitude and phase errors are of the order of a few percent and 10 degrees, respectively.

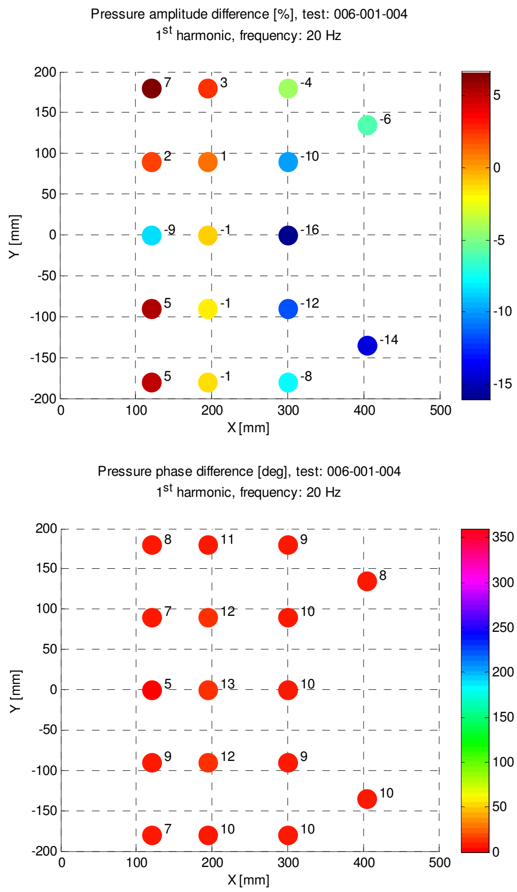

Figure 3: Errors in hull-pressure amplitudes (top, %) and phases (bottom, in deg.) at the location of the dots in Figure 2. X denotes the longitudinal direction (positive to bow), Y the transverse direction (positive to port). Scale model ship coordinates are indicated. The propeller plane is at X=200.

It seems that the boundary element codes are reasonably well capable of computing the hull-pressures, but for a definitive judgment more propellers should be tested at various loading conditions. Results of such investigations will be presented in Ref. [4].

Modeling of inverse scattering

In Refs. [1,2] the problem of finding the source distribution in strength and position was approached in a pragmatic way by assuming the source field to consist of a simple monopole with unknown position and strength. For the effect of the passing blades the situation is more complex in that the source system is rotating. A pragmatic approach this time would be to assume the source strength to be constant around a revolution and use a set of sources distributed in the propeller disc and centered at the propeller center. Thus, a rotating source of constant strength could be replaced in the frequency domain by a ring of sources of constant strength but varying phase depending on the number of blades and harmonic order involved. The ring source as a whole would be of unknown complex amplitude and the inverse scattering problem would be one of finding these unknown ring amplitudes together with the axial position of their centre points, given a set of hull pressure data.

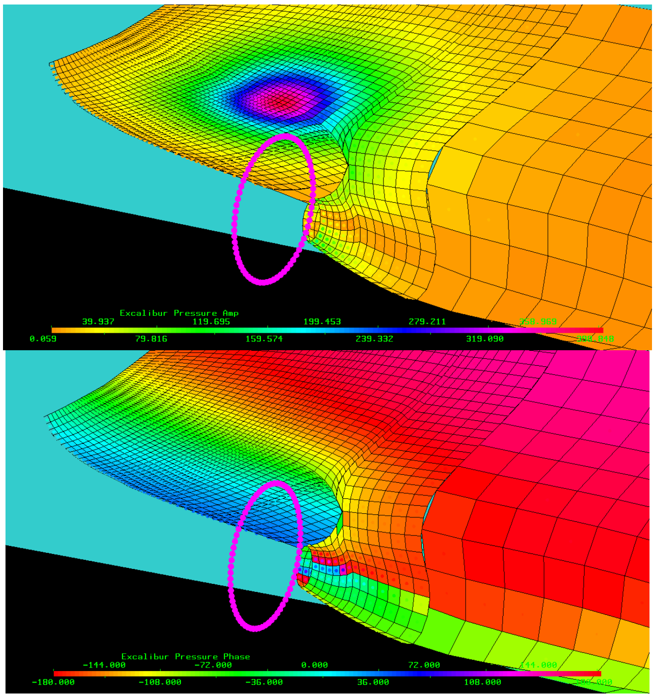

Figure 4: Hull-pressure amplitudes (top, in Pa) and phases (bottom, in deg.) at 20 Hz for the 2-bladed propeller. The single ring indicates the monopole source system.

As an example, the monopole pressure field caused by the displacement effect of the propeller blades in Figure 2 is modeled by one ring of monopoles in the propeller disc and of a radius of 82% of the propeller radius (although the results vary little for other radii), see Figure 4. The relative percentage error on the complex amplitude was 6%. This measure of error is based on all panel data. When the computation is performed with only the measurement locations as input, a 5% error is found.

The dipole field caused by the pressure distribution on the blades is modeled by two monopole rings of the same radius as before and at very close proximity to each other. The result is shown in Figure 5. The relative percentage error on the complex amplitude was 8% this time. This error drops to 6% when the computation is based on just the pressure at the measurement locations. The difference is primarily caused by deviations in the predicted hull-pressures at the vicinity of the bossing, which is of no concern in this context. The amplitudes of the two rings only differed by 2% and their phases were 179 degrees apart, thus effectively modeling a ring of axially directed dipoles.

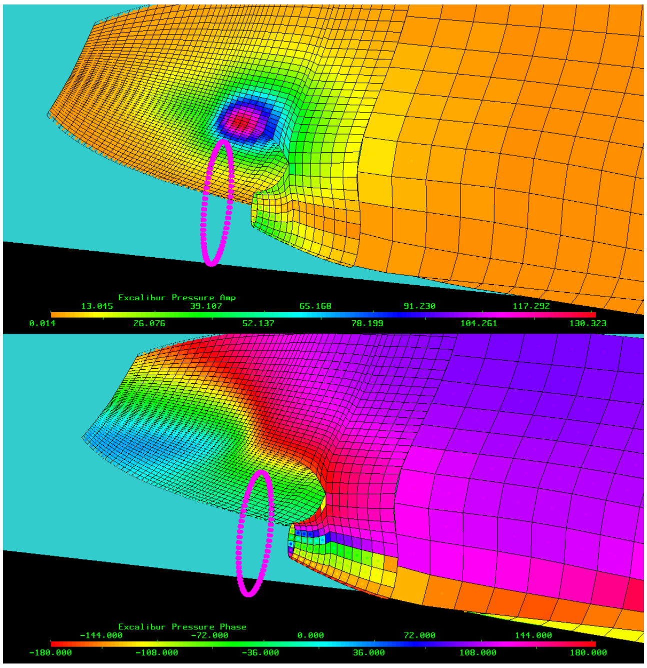

Figure 5: Hull-pressure amplitudes (top, in Pa) and phases (bottom, in deg.) at 20 Hz for the 2-bladed propeller. The double ring indicates the source system.

Concluding remarks

In this paper it is shown how the effect of a cavitating propeller w.r.t. afterbody hull-pressure fluctuations may be modeled in a simple way by a monopole source, and the effect of the thickness by two rings of monopoles, or alternatively, one ring of monopoles and one of dipoles. For the simple case of a two-bladed propeller these models showed very reasonable results, which enables the inverse derivation of the propeller source strength based on measured hull-pressure data. More validation work is necessary before these results can be generalized to heavily loaded propellers. Such work is presently being undertaken.

References

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