Broadband Acoustic Radiation by Ducted Marine Propeller

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The present work aims to study numerically broadband acoustic radiation from ducted marine propellers. The latter have found wide use as propulsion devices for fishing vessels and ships designed for exploration and processing of ocean resources. The vessels of this type are characterized by employment of various hydroacoustic apparatus for the purposes of echo sounding, navigation, communication as well as for remotely controlled oceanographic instruments. The need for provision of reliable operation of these systems brings into existence a number of external, i.e., operational noise requirements that must be imposed upon the shipborne equipment. The topicality of the stated problem stems from the fact that of amongst all the sources of acoustic radiation, the propulsion device spends the greatest amount of power.

The detailed analysis of the propulsion systems of the ducted propeller type was carried out by the Research and Production Enterprise Marine Equipment in collaboration with the research Institute Giprorybflot under the programme of design of fishing vessels with enhanced cargo space. The need for meeting the latter objective substantially affected the geometric parameters of the duct and the propeller [1]. The untraditional character of the adopted design solution [2,3] and virtually total absence of publications on acoustics of ship propulsion systems [4] as compared to the amount of studies on the noise of aircraft engines [5-8] has motivated extension of the above mentioned hydrodynamic research into the field of sound radiation.

The difficulties associated with computation of the broadband component of the noise spectrum are due to the complications in the derivation of the strengths of sources of the turbulent noise. In the case of the ducted propeller the problem becomes more involved owing to the necessity to calculate the scattering and reflection of acoustic waves by the duct and the centrebody placed inside it. Since direct numerical turbulent flow simulation requires costly expenditures of supercomputer time [8], in order to estimate the strengths of sources of the turbulent noise, we make use of the semi-empirical theories of broadband noise generation developed in [9]. As is shown in the fundamental studies on hydrodynamic noise generation, the radiation features quadrupole character. However, for the flow Mach numbers which are of interest for underwater acoustics this mechanism of direct flow radiation has extremely low acoustic efficiency. Hence, the quadrupole theory is incapable of accounting for the high levels of the efficiency observed in practice. Several mechanisms of acoustic radiation were proposed in the literature [6]. According to them, the intensive reactive energy of turbulent eddies is transformed into active energy of dipoles distributed over the body surface placed into the turbulent flow. Hence, within the framework of the present model of propeller acoustic radiation the sources of the broadband noise are as follows:

1) pressure fluctuations generated by the turbulent boundary-layer flow at the trailing edge of the blade,

2) lift fluctuations due to the interaction of the initial turbulence in the oncoming flow with the blade,

3) vortex breakdown at the blade's tip and its interaction with the duct's inner surface.

Since the flow Mach number which is of interest for hydroacoustics is sufficiently small, the analyses of wave scattering and wave propagation inside the duct and in the surrounding near-field is carried out on the basis of the Helmholtz equation. In order to numerically solve the boundary-value problem with radiation conditions at the outer boundary of the calculation domain for different frequency bands, the second-order finite difference method is invoked. The computational grid is non-orthogonal and generated by means of solution of an elliptic system of partial differential equations for the physical co-ordinates. It has about 150x80 nodes and is refined near the duct edges. The obtained algebraic system is solved by means of a factorization procedure.

The calculations of acoustic pressure inside the duct and in the near-field at the distances up to 10 duct radii for various radiation frequencies are presented. Total and spectral intensities of the far-field radiation are analyzed. The study of radiation directivity redistribution due to the scattering at various radiation frequencies is performed.

Resonant frequencies corresponding to different longitudinal and transverse oscillation modes are found. The influence of geometric properties of the duct and the centrebody as well as that of initial oncoming flow turbulence, propeller geometry, blade number, and its angular velocity are examined. Also studied is the effect of different noise generating mechanisms on total radiated acoustic power and on radiation in discrete spectral ranges with allowance made for accommodation of sound absorbing materials at the surface of the duct.

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