Dissertations

High intensity elastic waves in water

OCEANOLOGIA, 44 (3), 2002.
pp. 389–391.

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Habilitation thesis in underwater acoustics

The thesis is a monograph published as volume 146A/2001 of the Polish Naval Academy series Zeszyty Naukowe Akademii Marynarki Wojennej, Gdynia. It comprises an introduction and 6 chapters, a list of 212 references and a 3-page summary in English, a total of 203 pages.

In her introduction the author stresses the importance of the investigations undertaken in nonlinear hydroacoustics: this applies not only to the medium (water) but also to systems generating high-intensity sound and ultrasound waves, as well as the measuring systems in that medium. The relations between the sound source, the radiated high-intensity wave field and wave distortion caused by nonlinear interactions during propagation in water is of theoretical interest and of practical importance. These interactions are considered under real conditions of acoustic fields generated in water by high-power sources of given geometry and construction: this is the main topic and purpose of the investigations reported in the thesis. Mainly experimental, they are supported by the numerical solution of the KZK (Khokhlova – Zabolotskaya – Kuznetsov) equation for the experimental conditions. In particular, these concern the influence of the finite surfaces of the sources, their directional and focusing properties, as well as the nonlinear and dissipative features of water, including sea water. The nonlinear properties of the sea water column in vertical distributions specific to the southern Baltic have also been examined and the results presented in the thesis.

In chapter 1 the author has comprehensively reviewed the literature on nonlinear acoustics, chiefly in liquids: in doing so, she has taken into account sources of high intensity and systems focusing acoustic energy.

Chapter 2 is a review of fundamental nonlinear acoustics equations for real dissipative media. It describes nonlinearity as a physical phenomenon in high-intensity waves and the properties of the medium alone. Both general theoretical and approximated approaches are presented and fundamental nonlinear characteristics, quantities and coefficients defined.

Chapter 3 considers the relationships between the nonlinear coefficient and the acoustic Reynolds number in the propagation of finite amplitude waves and their distortions. Two cases of strong (large Reynolds number) and weak (small Reynolds number) distortions are differentiated. Applying a simplification of the Burger equation appropriate to these cases, the author calculated (for Baltic Sea water properties) such characteristics as the distance of continuity loss and intensity limits as a function of frequency for two acoustic pressures. She also calculated the ratio of nonlinear to absorptive attenuation against the distance normalized with respect to the characteristic distance of continuity loss, and compared the results for sea and distilled water. The dependences of the amplitudes of the first three harmonics on the distance from the source are presented (exemplified for two acoustic particle velocities – different Reynolds numbers at the same frequency), as examples of high harmonics generation in the light of nonlinear wave distortion in sea water. Like the others given in this chapter, these results represent typical dependences characteristic of liquids; nevertheless, they are original for sea water.

Chapter 4 presents interesting results of the experimental investigation of nonlinear wave distortion in the acoustic field of a plane transducer of finite surfaces. The following sources were selected and studied: plane circular transducers of diameter 2a = 38 mm and resonance frequency 2.25 MHz (Ka = 81), and two complex plane sources (transmitting arrays) of 16 elements (circular transducers each of 12.5 mm radius and resonance frequency 600 kHz in the first array, and of 5 mm radius and 1.5 MHz in the second array). A detailed description of the experimental setup, its accuracy, and the reproducibility of results is given. The author measured the shape and the spectrum of waves at different distances from the sources along their radiating axes, determined the amplitudes of several harmonics, and compared these with calculated data. The results confirmed that while propagating, waves undergo dynamic changes: in particular, these changes reflect the individual behaviour of the harmonics near the axis, and within the range before the distance of the last minimum of the distribution of the first harmonic.

Next, the differences in hydroacoustic near-field characteristics between a single circular source and a multielement source with the same radiating surface are discussed. The experimental and numerical results have been used to show that acoustic pressure distributions are formed as a complex interaction of nonlinear distortions and interference effects of components originating from several elements of the array.

The results obtained for the biharmonic array are of practical interest and importance. Although the literature contains much information about single element biharmonic sources, multielement arrays have rarely been studied: the author's results are thus promising for hydroacoustic measurement practice.

Chapter 5 reports on the nonlinear effects of the focusing of the acoustic wave source. It presents measurements and calculations for acoustic pressure distributions of the first, second, third and fourth harmonics for a plane transducer of 1.5 MHz and an acoustic lens at a few cross-sections before the focal point in front of the lens, at the focal point and behind the lens. The case for a wide frequency band focusing source has also been examined.

The final chapter 6 is most closely related to the sea. Measurements of high-intensity acoustic wave propagation in sea water in the southern Baltic Sea were used to determine *in situ* vertical distributions of the nonlinear B/A parameter. Examples for several measuring stations in the southern Baltic averaged over the period 1979–99, as well as their comparison with seasonal variations, are illustrated and discussed with respect to temperature and salinity dependences. Comparison of B/A and vertical distributions of sound velocity with temperature and salinity distributions shows a characteristic correlation. Although the results of this chapter are sparse and fragmentary with respect to the Baltic, they are a clear demonstration of important trends in the spatial and seasonal variations influencing the propagation of high-intensity acoustic waves in this sea. They are a good illustration of the author's broader discussion based on her other published papers. So far, there are no other results of nonlinear effect measurements in the Baltic Sea apart from those carried out by the author.

The experimental and numerical results presented in this thesis are extensively discussed against the background of existing knowledge and reveal new aspects of nonlinear effects in the acoustic field generated in water by acoustic arrays of great power and different aperture and directivity characteristics. The specific aspects of sea water taken into account in this study provide valuable data for practical use. The results obtained for the case of acoustic focusing systems are significant not only for hydroacoustics but also for the application of high-power ultrasonics in medicine (e.g. lithotripsy) and other fields.

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