Nearfield of multi-element source radiating a finite amplitude wave

PACS REFERENCE: 43.25.LJ

Grelowska Grazyna[1]; Kozaczka Eugeniusz[1,2]
[1]Naval University of Gdynia
Smidowicza 69
81-103 Gdynia
Poland
Tel: (+48 58) 626 28 72; (+48 58) 626 28 68
Fax: (+48 58) 625 48 46)
E-mail: grelowska@amw.gdynia.pl; ekoz@amw.gdynia.pl
[2]Technical University of Koszalin
Raclawicka 13-17
75-620 Koszalin
Poland

ABSTRACT

Sources designed in form of array composed of piezoceramic elements are often used in underwater applications. The paper contains results of experimental investigations of the nonlinear wave generation by means of a multi-element source. Special attention is paid to the area near the radiating surface, where the impact of the discontinuity of the surface on the nonlinear distortion process is visible. Considerations are based on measurements of the field distribution of two sources, each in form of 16-element array. The elements of the first source are pistons of 25-mm-diam and resonant frequency equal to 600 kHz. The second source is using piezoelements of 10-mm-diam and resonant frequency of 1.5 MHz.

INTRODUCTION

Technological limitation in production of the piezoceramic elements that are at present the radiating elements most often used in underwater acoustics are the one of main reason for applying multi-element radiating antennas in underwater acoustics. The limitation concerns chiefly the area of piezoelement and the transmitting power.

Construction of the underwater antenna in the form of a multi-element array allows to increase the abilities of devices. Multi-element transmitting arrays are used for instance in sonars with electronically controlled beam. Application of many radiating elements is in certain cases necessary because of power limitation. For this reason, multi-element arrays are used also for finite amplitude wave creation. The array most often consists of many elements, each of them is characterised by the same geometric and piezoceramic parameters [5 ,6, 8]. It could be used as a source of harmonic wave or a source radiating biharmonic wave of finite amplitude known as parametric source [1, 6]. Parametric sources are used in underwater investigation [4] especially in bottom and sub-bottom profiling [1, 7]. They can also be used as sources of wave of relatively low frequency designed for measurement purpose. In some cases other radiating apertures are applied [2]. Array of multi-elements could be used as a plane source or - together with an additional lens may be applied in a focusing source construction.

There are comparatively little available experimental or theoretical data concerning the radiation of finite amplitude wave by multi-element array and data on nonlinear interaction in the vicinity of the radiating surface are practically inaccessible. In the case when radiating surface consists of a set of separated elements, the boundary condition becomes complicated. Radiating surface is non-continuous without axial symmetry, while most of applying theoretical models are elaborated assuming axial symmetry of the radiating surface.

Experimental set up

Examination of phenomena occurring in the nearfield of multi-element nonlinear source has been performed using arrangement shown in Figure 1. The PVdF needle hydrophone with a nominal diameter of 1 mm was scanned along the beam axis and across the beam at various distances form the radiating surface. The investigation was conducted with the use of high precision device positioning the source and controlling the movement of the receiver. The measurements were performed in a 1.0 m x 1.2 m water tank 1.0 m deep. To simulate CW operation the tone burst with 50 cycles was used. The digital storage oscilloscope was used as a digital converter. The time waveform was downloaded to the controlling computer and analysed off-line.

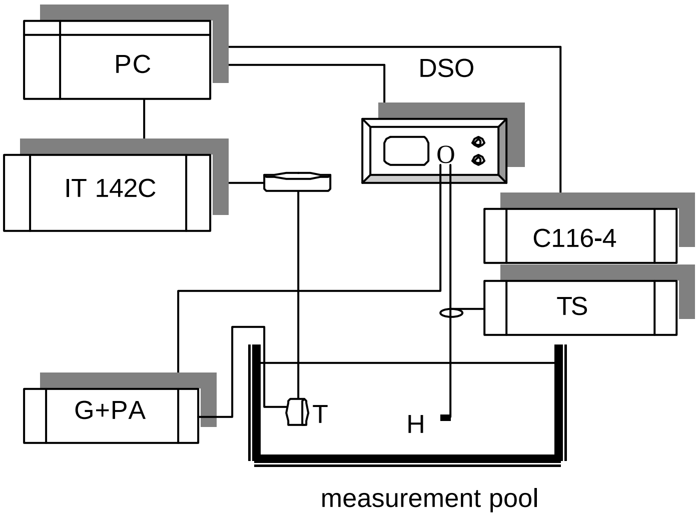

Figure 1. The measurement set up: IT142C – round table controller, C116-4 – stepping motor controller, TS – translation stage, G – generator, PA – power amplifier, DSO – digital storage oscilloscope, T – transmitting antenna, H – hydrophone

Two transmitting arrays composed of circular piezoceramic pistons of the same dimensions and radiating properties were examined. Each of arrays consists of 16 circular piezoceramic elements arranged as shown in Fig. 2. The first array was composed of elements 25-mm-diam of 600 kHz resonant frequency. The applied matching layer allowed to obtain the frequency range of radiation from 540 kHz to 660 kHz. The second array was designed using 10-mm-diam elements of 1.5 MHz resonant frequency. Its frequency band was 1.2 MHz - 1.8 MHz.

Figure 2. Multi-element arrays used in the investigation

The construction of both of the sources was similar. The elements of the array were grouped in four sections; each composed of four piezoelements. Each section could be supplied independently. By means of parallel connection of two various sections it allowed to obtain two arrangements of elements. Each group of transducers shown in the pictures (Fig. 3 and Fig. 4) could be supplied with signal of the same frequency or of different one.

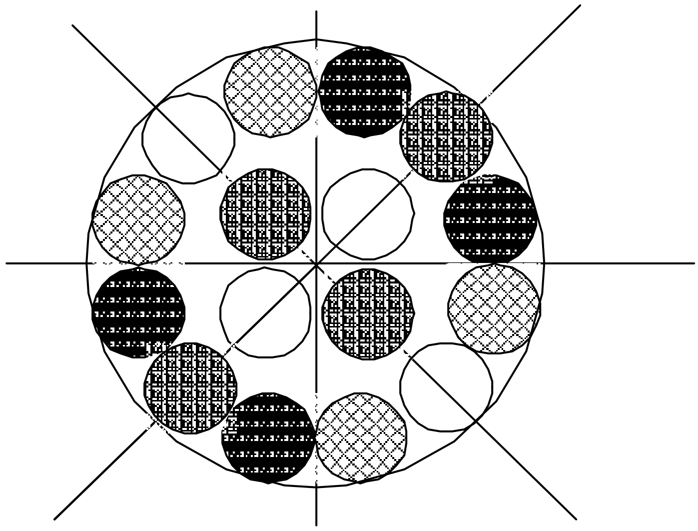

Figure 3. The arrangement of the array – four sections of four transducers

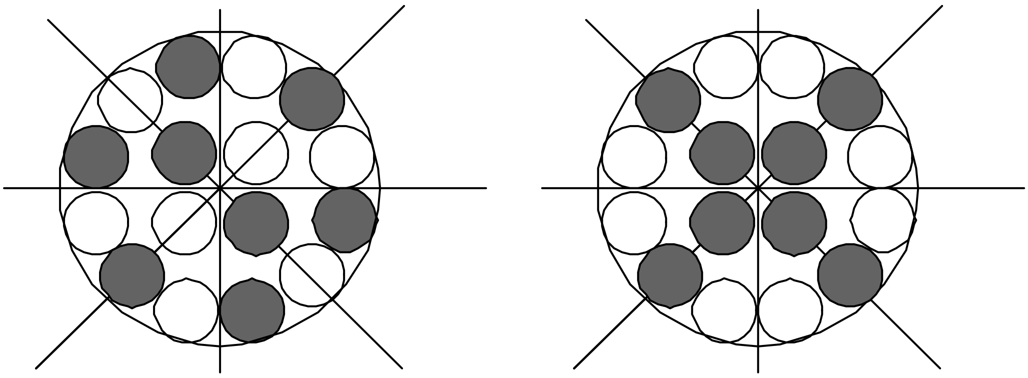

Figure 4. Possible arrangement of array while parallel connection of two various sections

MULTI-ELEMENT SOURCE OF FINITE AMPLITUDE HARMONIC WAVE

The arrangement of radiating aperture is the main factor that has an impact on the pressure field distribution. The example shown in Figure 5 and in Figure 6 allows to assess the difference between the pressure field distribution in the vicinity of the source of a complex aperture and of the simple shape of radiating surface. There are shown characteristics representing the changes in pressure along the beam axis and in transverse cross-section of the beam. The characteristics are determined theoretically for the 16-element array, shown in Fig. 3, and the circular piston of the same radiating area. The results concern the linear propagation case.

The differences in the on axis distribution are noticed distinctly in the vicinity of the source up to the distance equals about 3-4 R_o (R_o – the Rayleigh distance determined for the circular piston source). The shape of transverse pressure distribution obtained for multi-element source has its specific features even at such a distance. The most distinctive one is the higher level of the sidelobes.

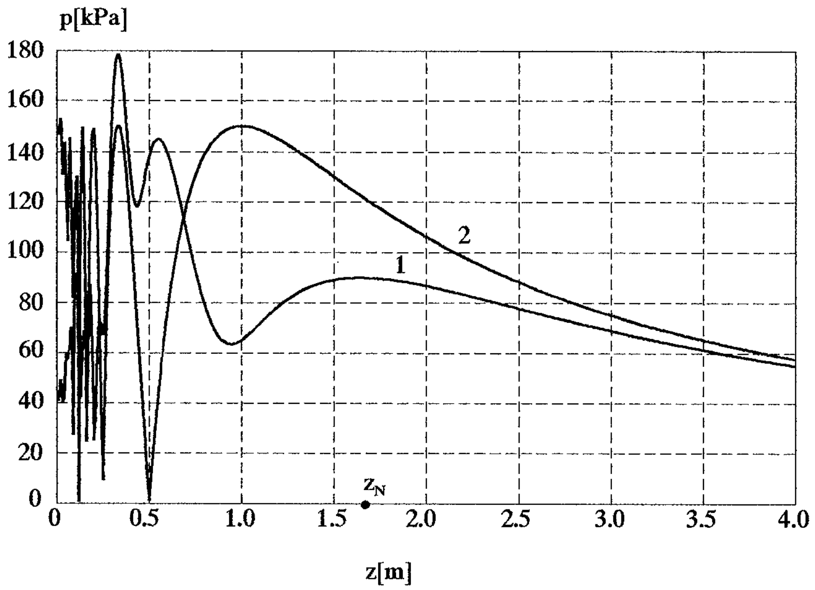

Figure 5. Pressure distribution pressure along the beam axis: 1) 16-elements array, 2) circular piston; f=600 kHz, v_0=0.1 m/s

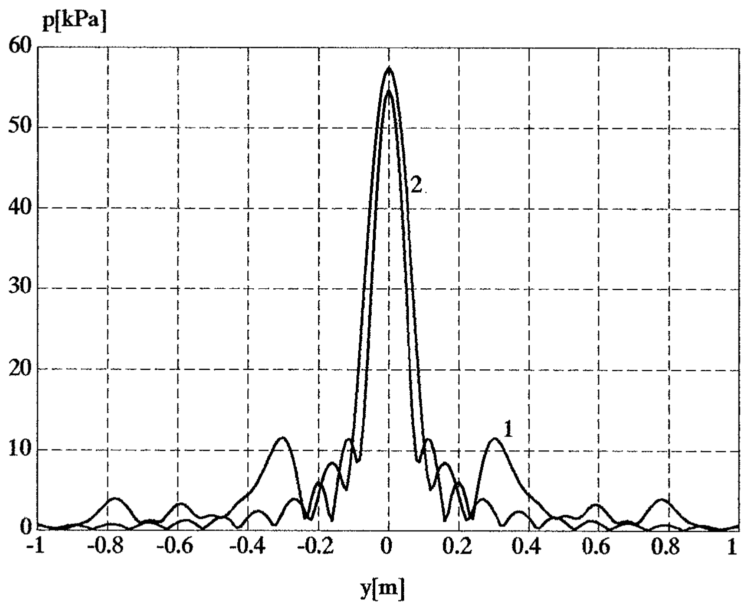

Figure 6. Transverse pressure distribution at the distance of 4 R_0 from radiating surface: 1) 16-elements array, 2) circular piston; f=600 kHz, v_0=0.1 m/s

Forming the nonlinear pressure field in the vicinity of a source with non-continuous radiating surface could be observed basing on result of measurements of multi-element radiating antenna. Characteristic features of the pressure field in the vicinity of the multi-element source applied as a source of finite amplitude wave are visible in following set of illustrations. The figures present transverse distribution of the three first harmonic components of the pressure at planes of various distances from the source. The data concern the source of wave composed of 16 elements radiating at frequency of 1.5 MHz. To make it possible to show all considered harmonic components they were multiplied: the second harmonic component of frequency of 3.0 MHz – by 10, and the third one of frequency of 4.5 MHz – by 20.

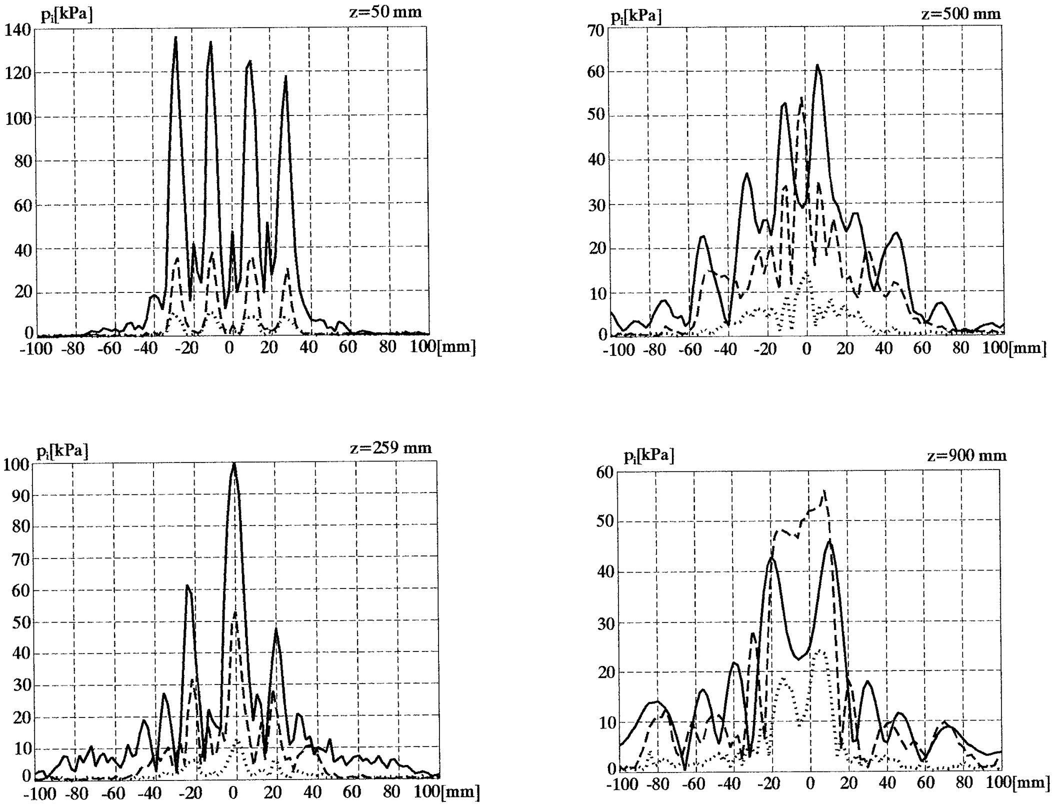

Figure 7. Transverse pressure distribution of the three first harmonic components in the vicinity of the source of finite amplitude wave of frequency 1.5 MHz; (——) p_1, (- - -) 10 p_2, (······) 20 p_3

MULTI-ELEMENT BIHARMONIC SOURCE OF FINITE AMPLITUDE WAVE

The multi-element source could be easy applied as the multi-frequency one. The matter of great importance in investigation of the interaction of two waves of different frequencies radiating by the same array is the information on similarity of spatial distribution of the field of each primary wave. An example of prediction of the pressure distribution of waves emitted by array is illustrated in Figure 8.

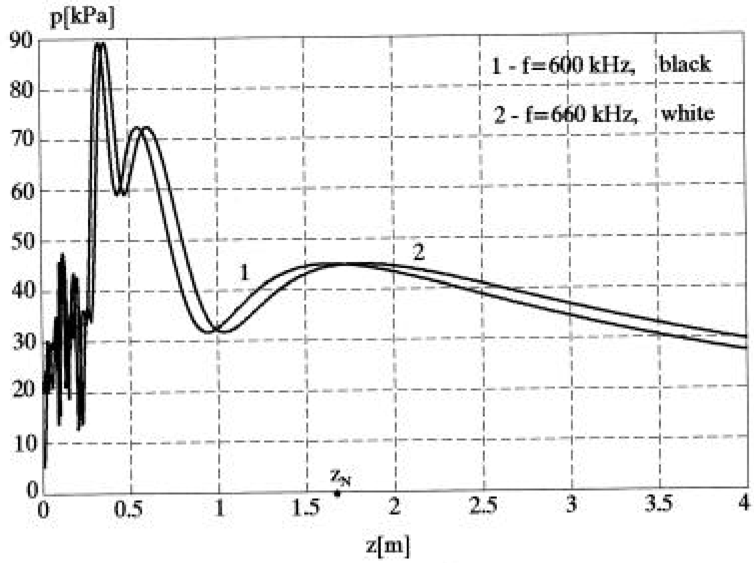

Figure 8. Pressure distribution along the axis of array shown in Fig. 4 (at the left-hand side)

Curves are determined assuming that the arrangement of the array is the same as in Fig. 4 (at the left-hand side) and transducers marked as black radiate the wave of 600 kHz frequency whereas the white marked transducers radiate the wave of 660 kHz frequency.

Radiation of biharmonic wave of finite amplitude into the same area involves considerable broadening of the spectrum of wave. There appear higher harmonic components of primary waves, as well as the waves of frequencies equal to the sum and the difference of the frequencies of primary waves. The waves that appeared as a result of secondary nonlinear interaction could also be observed.

CONCLUSIONS

Experiments concerned multi-element array radiating finite amplitude wave allow to obtain a number of data on properties of finite amplitude underwater sources with non-continuous radiating area:

- the nonlinear distortion process in the vicinity of the multi-element radiating area differs from the one typical for the source with continuous area. That is why the characteristics of the pressure field distribution of such a source could not be interpreted on the analogy of the one-element source pressure distribution,

- in the area close to the multi-element radiating area, the nonlinear interaction occurs independently for each element of the matrix,

- for each multi-element source, a characteristic distance depending on the Rayleigh distance characteristic for each element of the array and the distribution of the radiating elements could be determined. Above that distance, beams produced by particular elements interpenetrate and a common beam is formed,

- up to that distance, the spatial distribution of higher harmonic components is similar to the distribution of the primary wave. Above it, the individual spatial distributions for each harmonics begin to form. In case of the source with continuous radiating area, this process begins from its surface,

- when the source is used as a biharmonic one and waves of various frequencies are radiated by separated groups of elements of the matrix, the nonlinear interaction between those two waves is possible in the area above the certain distance. Only above that distance, waves of frequencies equal to the sum and the difference of frequencies of primary waves could appear.

REFERENCES

[1] J. Dybedal: TOPAS: Parametric end-fire array used in offshore applications, Advances in nonlinear acoustics, World Scientific, Singapore 1993, pp. 264-269.

[2] P. Edson, R. A. Roy, S.G. Kargl: Nonlinear wave propagation from a discrete annular array: experiments, Proceedings of the 16th International Congress on Acoustics, Seattle 1998, pp. 533-534.

[3] G. Grelowska: Pressure field produced by some finite amplitude sources, Proceedings of the 2nd EAA Intern. Symp. on Hydroacoustics, Gdansk - Jurata 1999, pp. 237-246.

[4] A. Kalachev et al.: Long-range sound propagation from parametric array, Advances in nonlinear acoustics, World Scientific, Singapore 1993, pp. 259-263.

[5] B. G. Lucas, T. G. Muir: Field of a finite-amplitude focusing source, J. Acoust. Soc. Am., **74,** (1983), pp. 1522-1528.

[6] B. G. Lucas, J. N. Tjotta, T. G. Muir: Field of a parametric focusing source, J. Acoust. Soc. Am., **73,** (1983), pp. 1966-1971.

[7] T. G. Muir: The penetration of highly directional acoustic beams into sediments, J. Sound Vibr., **64**, (1979), pp. 539-551.

[8] B. K. Novikov at al.: Nonlinear acoustics, Leningrad, Sudostroenie, 1981 (in Russian).