HIGH RESOLUTION OBJECTIVES FOR ACOUSTICAL MICROSCOPY

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The reasonable way to enhance the spatial resolution of acoustical microscopy is to increase the working frequency range of the system. Additional improvements can be obtained by the optimisation of sound field distribution to avoid or decrease the side lobe influence in the directivity diagram of electroacoustical transducer.

The acoustical objectives which where calculated and designed at present work for acoustical microscopy are described. Among the peculiarities of new objectives there is improved acoustical beam forming with suppressed first order side lobes of excited sound field. Such sound beam forming leads to improving of the dynamic range and space resolution of acoustical microscopy.

The set of acoustical objectives for different frequency ranges (from 25 MHz to 1 GHz) where developed and designed.

The details of high frequency transducer building for special sound field distribution excitation are considered. The questions of electrical and acoustical matching of electroacoustical transducer are discussed.

1. Introduction

One of serious problems which occurs when creating the objectives for acoustical microscopy concerns to necessity of forming of sound beam with smooth distribution. In the ideal case the sound field distribution must be closed to the Gaussian one. The acoustical beam, formed by disc-shape transducer, has big side-lobes, which lead to parasitic signals excitation, that disturbs the summary response.

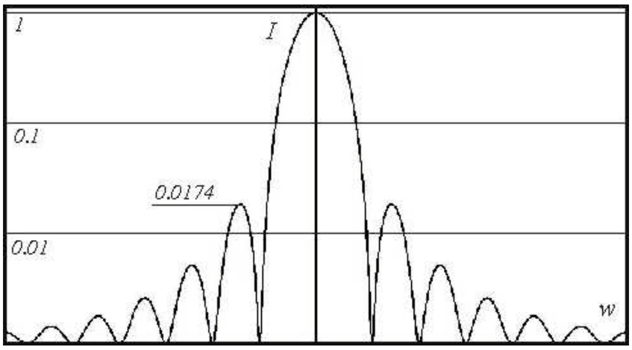

Fig. 1. Disc-shape radiator directivity diagram

At Fig.1 the angular spectrum of round – shape hole source radiation is shown when the relation between the hole radius and the wavelength is equal to 80.48. In this case the first order side lobe's intensity is equal to about 1.74% of maximum in zero order.

At work [1] is shown that by putting the diaphragm to the center of optical hole it is possible to about two times suppress the first order side lobes and to increase the resolution of optical system. In present work for further suppression of side lobes the disc plus two rings-shape appodization shape is used and optimized. It is shown numerically the possibility for about ten times suppression of first order side lobes.

2. Theory

Following to the theory, developed in [1] let us find the amplitude and then the intensity of the field excited by the plane system of transducers which represents the co-axially placed round-shape radiators (see Fig.2).

The amplitude U of the field in the point P of the disc-shape radiator is given by formula:

$$U(P) = CD\left[\frac{2J_1(kaw)}{kaw}\right], \qquad (1)$$

and the intensity:

$$I(P) = |U(P)|^2 = \left[\frac{2J_1(kaw)}{kaw}\right]^2 I_0, \qquad (2)$$

where k – is a wave number; a - radius of a disc radiator; and w – is the sinus of angle between the wave vector k and the normal vector to the radiator's plane; $D = \pi a^2$; $C = (1/\lambda)(E/D)^{1/2}$; E – whole energy that comes from the radiator; λ - wave length.
I_0 – is the field intensity in the narrowest cross section

$$I_0 = C^2D^2 = ED/\lambda^2;$$

and J_1 – is the Bessel function of first kind.

For the ring-shape radiator the amplitude U and the intensity I of field in the point P can be written accordingly:

$$U(P) = C\pi a^2\left[\frac{2J_1(kaw)}{kaw}\right] - C\pi\varepsilon^2 a^2\left[\frac{2J_1(k\varepsilon aw)}{k\varepsilon aw}\right] \tag{3}$$

$$I(P) = \frac{1}{(1-\varepsilon^2)^1}\left[\left(\frac{2J_1(kaw)}{kaw}\right) - \varepsilon^2\left(\frac{2J_1(k\varepsilon aw)}{k\varepsilon aw}\right)\right]^2 \tag{4}$$

where ε - is the relation of internal radius of ring to the external one.

The superposition of amplitudes for n rings gives the formula (5) for the amplitude U of complicated system, which consists on number of rings with common center and different radiuses: a^e – external one, and a^i - internal radius of the ring; n – current number of ring.

$$U(P) = C\pi\sum_n\left\{(a_n^e)^2\left[\frac{2J_1(ka_n^e)}{k\,a_n^e\,w}\right] - (a_n^i)^2\left[\frac{2J_1(ka_n^i w)}{ka_n^i w}\right]\right\} \tag{5}$$

The Intensity then can be found as

$$I(P) = |U(P)|^2 \tag{6}$$

3. Calculation

Numerical modeling gives the optimum in number of rings $n = 3$ and in their radius relationship. The best suppression occurs when the internal radius of the rings is equal to 2/3 of external radius.

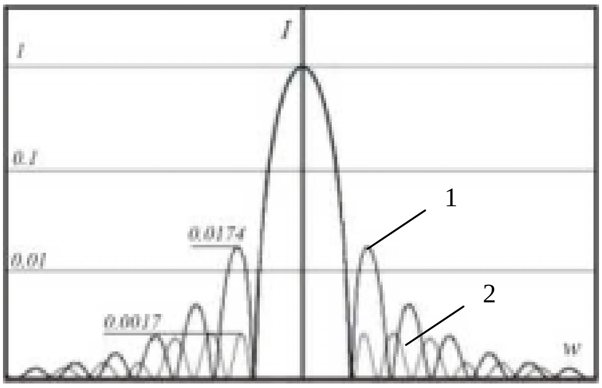

Fig.3. The Angular spectrums of two radiator's system. 1- disc-shape radiator; 2 – disc, plus two rings-shape radiator.

It is seen from the figure 3, that the appodisation of radiator's shape with disc plus two rings and additional optimization of their radiuses relations gives the suppression of first order side lobes at about ten times (from 0.0174, to 0.0017 related to maximum meaning).

At Fig 4. three curves are presented for disc plus two rings shape radiator tuned to three different frequencies: 0.5; 1; and 1.5 GHz.

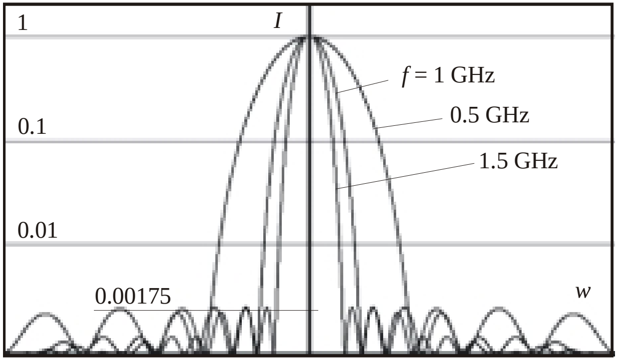

Fig. 4. Angular spectrum for disc plus two rings shape radiator for three frequencies: 0.5; 1; and 1.5 GHz.

One can note that frequency overtuning in wide frequency range not much changes the level of the first order side lobes that remains at the meaning of about 0.00175 from the maximum of zero order. When changing the frequency just the width of the side lobe is changed. The main inference from these results is that suggested radiation system can be successfully used for wideband excitation of sound beam with improved directivity diagram.

4. Acoustical Microscopy Objectives Design

Design of high frequency acoustic Microscope, working in time domain regime assumes the creation of acoustical objective, which allows operating with very short pulses down to subnanosecond duration. In this case the spatial resolution can be enhanced down to submicron domain depending on applied acoustical objective and the signal processing method.

The set of objectives for acoustical microscopy for different frequency regions, from 25 MHz to 1 GHz, was successfully developed and designed at Saratov State University. For frequency region from 25 to 500 MHz the lithium niobate plates for piezo transducers were used. The plates were bonded to the fused quartz sound conductor butt end which the cold compression method. After that the thickness of plates was reduced down to necessary value mechanically and then by ion polishing. For 1 GHz region the thin film ZnO transducers were applied. The thickness of all layers of multilayer transducer were calculated taking into account the acoustical matching of the transducer with sound conductor in wide frequency range. The electrical matching scheme was also design in accordance to preliminary calculation.

The acoustical lenses were manufactured mechanically with specially created tool and then tested first optically and then acoustically.

5. Conclusion

At present work the method of spatial resolution enhancement for acoustical microscopy objectives is discussed. Method is based on the new suggested geometry of sound radiators that allows to suppress in about ten times the level of first order side lobes in the transducer's directivity diagram.

Some peculiarities of objective design for acoustical microscopy are considered.

6. References

[1] M.Born, E.Wolf, Principles of Optics. Pergamon Press, Oxford-London-Edinburg-NewYork-Paris-Frankfurt, 1968.