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I.M. Gvozdeva

COMPUTER SIMULATION OF THE ACOUSTIC COHERENT IMAGES FORMING AND PROCESSING

Abstract. The approach to increasing the acoustic coherent images space contrast on the base of the using of the proposed methods of multiplicative weighted processing of their space spectra in the receiving plane and effectiveness confirmation of the developed methods by computer simulation of all stages of considered images formation and processing.

Keywords. Methods of image processing, computer simulation.

Introduction. The main purpose of non-destructive testing of power equipment is the detection of latent defects in metal constructions and their space localization and classification with probing of different nature fields. Acoustic waves have a high penetrating power, which enables to study not only the constructions surfaces, but their internal structure. Field, reflected from the investigated object, forms on the receiving aperture its acoustic image. The main feature of these images is their coherent nature, which displays itself in the so-called “speckle pattern”, that impede of their visualization and interpretation. Known mathematical models of objects acoustic fields at the receiving point, that are described in the literature [1,2], are mainly qualitative nature and do not take into account the features of all stages of acoustic coherent images (ACI) formation, namely the creation of a given probe field, its propagation in an inhomogeneous medium, dispersion on a complex surface of the probing object, conditions of backpropagation, processing in receiving equipment [3]. In order to ensure the required ACI space contrast it is necessary to create the receiving apparatus, having a high space resolution in both the longitudinal and broadside directions. The main part of modern receivers are the phased arrays (PA), signal processing in which can be carried out by different methods. Application of classical methods of image processing is based on the theory of linear space-time filtering [2], but they does not give the desired results. It is necessary to use such methods of ACI processing in received arrays, which the most would fit with the characteristics of imades space and time structures. In [4] was proposed the method of weighted multiplicative processing of signals (WMPS), allowing to increase the PA resolution in the breadside direction relative to the resolution of the additive

PA, having the same aperture dimensions, that improves the obtained ACI contrast.

In view of the fundamental differences ACI from their optical analogs there is the need for more in-depth researching and development of methods of improving of these images space contrast on the basis of mathematical models taking into account all stages of their formation and processing.

The purpose of the paper is to justify the possibility of increasing the acoustic coherent images space contrast on the base of the using of the proposed methods of multiplicative weighted processing of space spectra and confirmation of their effectiveness by computer simulation of all stages of considered images formation and processing.

Main part. Creation of adequate ACI mathematical models of the investigated objects in the receiving plane is not possible without simulation of all stages of their formation [3]. Mechanisms of acoustic and optical fields dispersion on the objects surfaces have fundamental differences. Optical fields are inherently incoherent and this leads to the destruction of the phase relations between the signals, reflected from the object surface roughness and to the appearance of the visible image contours.

In the most acoustics applications the space coherence range of the field is comparable or greater than the object dimensions, so the reflected acoustic waves are mostly coherent and the phase information is stored in the received space-time signal. Its preservation is a fundamental difference of optical and acoustic images, that lie to presence in ACI the interference phenomena such as the image spotting. Image spotting is caused by intensity changing of signals, reflected from the character parts of the object surface. This is due to the phase amplification or phase attenuation of the coherent space components of wave fields, receiving on the image plane. In the acoustic image there are interference fringes, arising due to acoustic waves reflection from the sharp corners, cracks on the object surface. Coherent space wave components, taking part in image formation, interfere with each other, that appears in the speckle pattern of images. Acoustic images spotting carries useful information about the object, but the nature of this information is unfamiliar to the observer, so it is difficult to interpret of the object acoustic images.

In view of the difference of space-time scales of the formed secondary acoustic and optical wave fields of investigated objects the interaction of the probe acoustic field with the object surface describes in the literature by the dispersion models, that are significantly different from the incoherent optical dispersion models [5].

For the most problems of secondary field formation of objects complex surfaces by means of ultrasonic probing the description of the wave fields dispersion is based on the Kirchhoff approximation [2,5,6]. Under the conditions, when the Kirchhoff approximation is fulfilment, the object ACI is formed by finite set of local areas of reflection – the first Fresnel zone surrounding area points of stationary phase [5,7], in which the normal to the surface is directed to the receiving point.

Kirchhoff approximation allows sufficiently accurate description of the secondary acoustic fields of objects with complex surfaces, for such its areas, for which the wavelength of the emitted signals are significantly smaller, than the character irregularities of the investigated surfaces. In this case, the complex amplitude of the wave field is described by the equation:

$$w(x,y,z_0)=\frac{e^{jkz_0}}{j\lambda z_0}\cdot\exp\left(jk\frac{x^2+y^2}{2z_0}\right)\cdot(2\pi)^2\cdot F(k_x,k_y), \qquad (1)$$

where x,y – the Cartesian coordinates in the aperture plane, z_0 – the distance between the investigated object and the plane of the receiving aperture, □ – wavelength, k – wave number, $k_x=kx/z_0, k_y=ky/z_0$ – angular frequency, $F(k_x,k_y)$ – angular (space) spectrum of the dispersion function (DF) of the surface relatively to the object plane, defined as follows:

$$F(k_x,k_y)=\frac{1}{(2\pi)^2}\cdot\int_{-\infty}^{\infty}\int_{-\infty}^{\infty}\dot{u}(\xi,\zeta)\exp[-j(k_x\xi+k_y\zeta)]d\xi d\zeta, \qquad (2)$$

where ξ,ζ – the current coordinates, $\dot{u}(\xi,\zeta)$ – the function of the acoustic field distribution on the object surface. As in (1), (2) the scattering surface form is not taking into account, the mathematical description of the indicated distribution is necessary to extend, for example, on the base of the approach, which developed in [8]. Equation for the angular spectrum object DF will look like:

$$F(k_x,k_y)=\frac{1}{(2\pi)^2}\cdot\int_{-\infty}^{\infty}\int_{-\infty}^{\infty}\dot{u}(\xi,\zeta)\exp[-j(k_x\xi+k_y\zeta+k_z\gamma(\xi,\zeta)]d\xi d\zeta, \qquad (3)$$

where $\gamma(\xi,\zeta)$ – equation of the dispersion surface relatively to z_0, $k_z=2k\cos\theta$,

θ – the incidence angle of the primary wave (the angle between the normal to the surface and the normal to the wavefront of the probe field). In contrast to [8] the angular spectrum (3) contains under the integral sign the function of the field distribution on the surface $\dot{u}(\xi,\zeta)$, which depends, in particular, on the type of probing field, so the equation (3) generalize the results and the models, proposed in [6, 8]. On the basis of the Kirchhoff approximation angular spectrum (3) can be represented as:

$$F(k_x,k_y)=\frac{1}{(2\pi)^2}\cdot\int_{-\infty}^{\infty}\int_{-\infty}^{\infty}U(\xi,\zeta)\cdot V(\xi,\zeta)d\xi d\zeta, \qquad (4)$$

and $V(\xi,\zeta)=\exp\left[-jk_z\gamma(\xi,\zeta)\right]$ – is a rapidly oscillating function .

In accordance with the concept of ACI formation as a multistep process, that takes into account the specificity of the interaction of coherent acoustic field with the investigated reflected surfaces, the appropriate models and software package blocks for their implementation, describing all stages of ACI formation and processing, were working out [9]. Developed software using Symbolic Math Toolbox MATLAB permits the machine-assisted realization of the mathematical models for a given configurations of the reflection surfaces and also for the acoustic field distribution on these surfaces. The numerical implementation consist of substituting in the obtained numerical equation the concrete numerical values of the input variables and in the subsequent formation of numerical data arrays of the space distribution of the acoustic field for further operations of its transformation. ACI visualization also carried out with the using of the Symbolic Math Toolbox MATLAB application. This allows on the each step of simulation verify the correctness of the proposed approach for objects with surfaces of a simple configurations (limited plate, disk). Complex surfaces can be approximated by a combinations of simple constructions with phase relationships.

Numerical implementation of ACI space models is fulfilled for the combinations of standard models of reflection surface and verified by experimental data. The illustrations show the angular spectra of the most important types of objects for the solved problem, for example, figure 1 shows the angular spectrum of the superposition of three interfering objects.

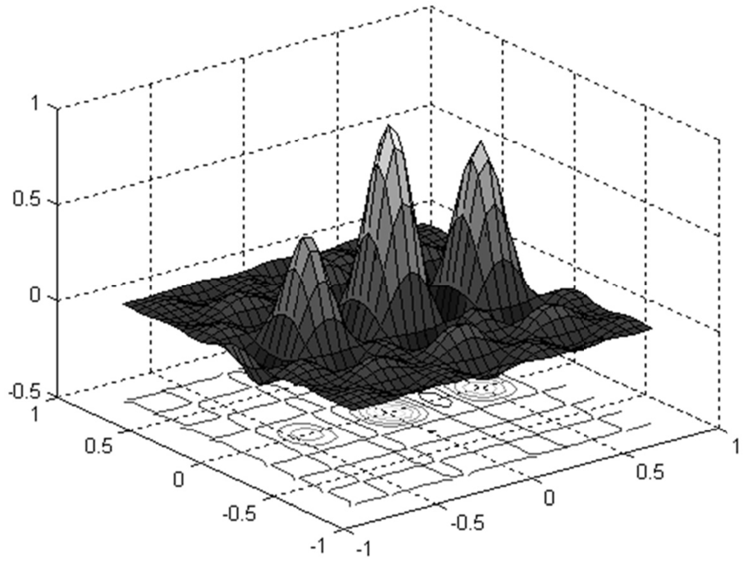


Fig. 1. Angular spectrum of three interfering objects superposition

Carried out the numerical implementation of ACI space models can demonstrate the most important features of the investigated images, namely: the interference of highlight field in the aperture plane at the presence of several local sources in the object plane; the speckle structure of secondary field in the aperture plane at the presence of the noise field in the object plane. As mentioned above, the quality of the received ACI depends on the methods of space-time processing in the received PA therefore for proving of their application effectiveness with the purpose of ACI space contrast improvement the numerical implementation of models of space data processing and visualization was carried out. Its include the following stages:

– Transformation of the object field in the received aperture plane with taking into account the phase relations between space spectra;

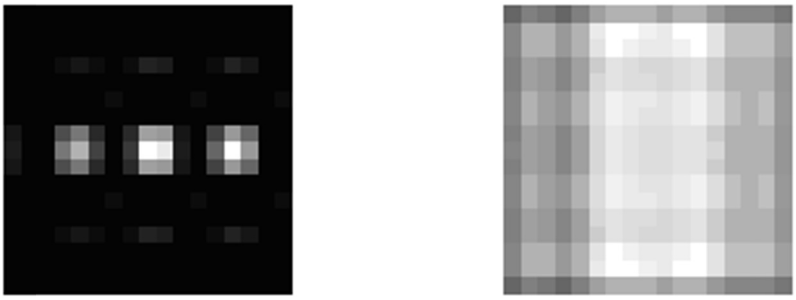
– Additive processing of the received field in the aperture plane;

– Weighted multiplicative processing of the object field in the aperture plane according to the theoretically justified algorithms and algorithms for the direct implementation of the multiplicative convolution;

– Beam forming processing of the object field;

– Visualization and comparing of the processing results.

In figure 2 there are the application results of the proposed weighted multiplicative processing and additive processing of the object field in the PA plane of the stated aperture. As we can see from figure 2, weighted multiplicative processing permits to improvement the ACI space contrast relative to using of the additive processing.



a) b)

Fig. 1. Results of the space processing of interfering sources group:
a) result of WMPS; b) result of additive processing.

Conclusion. It is established, that the high coherentness of the secondary acoustic field permits using of the effective methods of space contrast improving, in particular, the using of the methods of weighted multiplicative processing.

The proposed generalized mathematical models of the acoustic coherent images formation and processing taking into account the equation of the reflection surface permit the simulation of the secondary acoustic field distribution on the objects surfaces in the receiving aperture plane in order to illustration of the effectiveness of well-known and developed algorithms for recognizing the nature of investigated surfaces, that is the subject for further researches.

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