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Laws of formation of grating lobes in the acoustic field of electromagnetic–acoustic transducers as a linear array of unidirectional conductors

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ABSTRACT

Investigation of acoustic fields of transducers is the important stage of development of techniques and means of ultrasonic testing. Appearance of grating lobes in the acoustic field of phased array is possible, thus leading to misinterpretation of testing results. The paper proposes the model of an electromagnetic acoustic (EMA) transducer represented as a linear array of unidirectional conductors with current. The influence of the design features and excitation parameters of this transducer on formation of grating lobes is investigated. It is shown that the amplitude of grating lobes is mainly determined by the gap between the inductor and the testing object, the operating frequency of the transducer, pulse character of excitation and the aperture, number and parameters of unit elements of the inductor. The necessity of searching for a compromise between achieving the required sensitivity and the absence of grating lobes is stated. The obtained results can be applied when developing the design of EMA transducers with optimization of the gap, aperture, number and parameters of the inductor elements to achieve the required directional pattern.

1. Introduction

A strong interest of the scientific and industrial society to application of phased antenna arrays at the advanced stage of development of ultrasonic diagnostics and non-destructive testing is provided by doubtless advantages of multiple element transducers, in particular, possibilities of focusing, angular scanning and investigations of hardly accessible areas of the testing object [1–3]. Piezoelectric transducers [3,4] got a wide application as phased arrays in ultrasonic diagnostics and non-destructive testing. There is information on application of contactless electromagnetic acoustic transducers (EMATs) as phased arrays within the waveguide pipe testing [5–7]. The EMAT is represented as the linear array of unidirectional conductors or meander conductors with current can also be related to phased (in-phase or anti-phase) arrays [8–13].

The development of nondestructive testing methods by using noncontact electromagnetic–acoustic transducers is determined by a number of substantial performance advantages, in particular [13–16]:

- the possibility of testing through the air gap without coupling fluids, including high temperatures conditions;
- the absence of wear for EMA transducers;
- the independence of testing results on deviations of transducers relative to the surface of the object and the presence of corrosion, oxide scale, paint, and contaminations on the surface of the object;
- the possibility of excitation and receiving any type of waves, including transverse ones with horizontal polarization which can not be excited and received by means of the contact process.

The main limitation of this equipment is the relatively small value for coefficients of energy transformation for electric oscillations into the acoustic energy and for coefficients of inverse transformation.

The main parameters of testing (sensitivity, depth gauge error, transverse resolution, scanning step and others) depend on the acoustic field of transducers [1,5,17]. Moreover, the correct formation of the acoustic field can reimburse the low coefficient of EMA transformation in some way.

It is commonly believed that the directional pattern for acoustic transducers is interfered by side lobes adjacent to the main lobe, giving rise to artifacts of ultrasonic signals and images [1,5,8,9]. The specific feature for phased arrays of transducers is the possibility of grating lobes appearance in their acoustic fields, the lobes being conditioned by the interference of ultrasonic waves due to discrete elements of the phased

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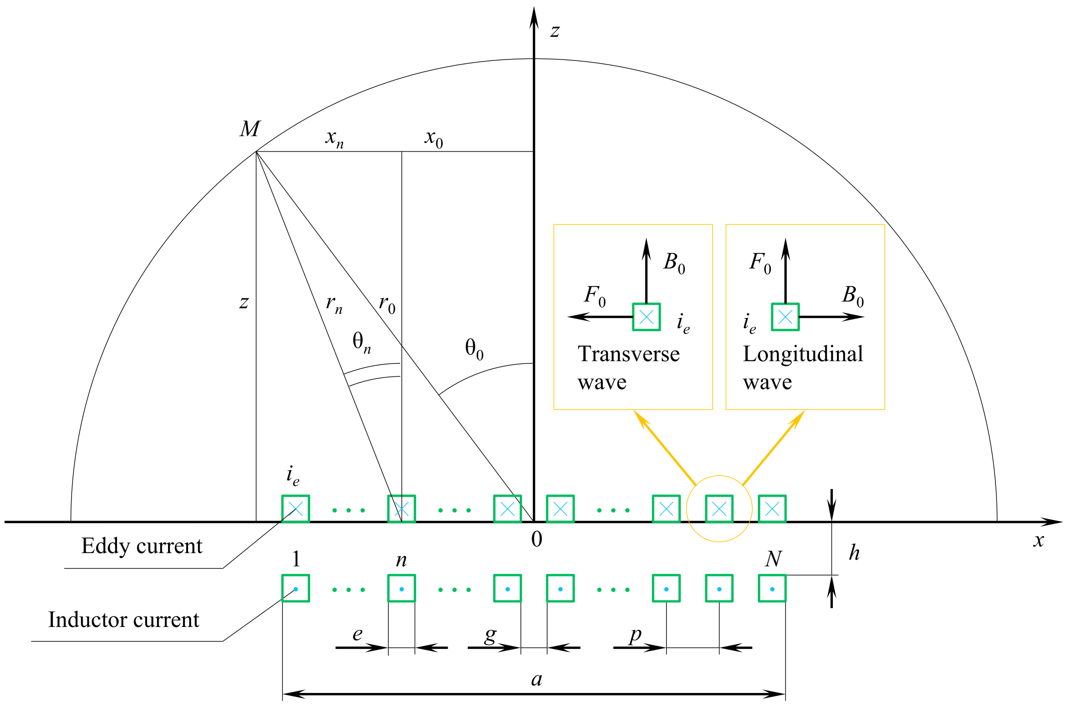

Fig. 1. Statement of the problem for analysis of the acoustic field of the EMAT at the specified observation point *M*, *a* – active aperture, *g* – gap size between two neighboring elements, *e* – width of the unit element, *N* – number of elements, *n* – *n*-th element of the array, *p* – period of the array, *h* – gap between the inductor and the testing object.

array [1,5,8,9,11,12,18–20]. The amplitude of grating lobes can be commensurable with the amplitude of main lobes, which can lead to misinterpretation of the testing results in the presence of a well reflective surface in the direction of the grating lobe and of a low reflective surface in direction of the main lobe. The theory of phased arrays describes the main design requirements for phased transducers [1,2,4,17,20,21] in order to achieve the required directional pattern.

Application of the theory of phased arrays [1,17,20,21] to analyze the acoustic fields of the EMA transducer is complicated by the fact that along with the generally accepted parameters (spacing of elements, frequency, number of elements, pass bandwidth) of the transducer, its directional is determined by the mechanism of elastic wave excitation, orientation of a magnetic bias field, and the gap between the inductor and the tested object [10,13,14,18,22].

A number of requirements is known for design engineering of the EMAT, which can be of diverse influence on its acoustic field. In particular, it is recommended [10,13,14,18,22]:

- to minimize the gap between the inductor and the tested object to improve the efficiency of EMA transformation;
- to minimize the number of elements in the inductor in the radiation mode to provide the maximum current in the probing pulse;
- to increase the number of elements in the inductor in the receive mode to increase the electromotive force.

The number of elements in the inductor determines the inductance of the EMAT, influences the operating frequency, conformance with the generator and amplifier of the flaw detector. The aperture of the EMAT determines the opening character of the directional pattern, wave attenuation with the distance due to discrepancies and it influences the amplitude of the valid signal.

There is a number of specifications in the EMAT design, which can influence (sometimes oppositely) its acoustic field. In particular, the number of turns in the inductor is aimed to be minimized in the radiation mode in order to provide maximum currents in the probing pulse; and otherwise, to increase the number of ampere turns to the maximum in the receiving mode. In case of applying the EMAT in the combined mode (radiation – receipt), a certain intermediate number of elements in the inductor is chosen. The distance between elements of the inductor should provide eliminating the breakdown when affected by a powerful probing pulse. The operating frequency of the EMAT is determined by its inductivity and also by circuitry layouts of the generator of probing pulses. Resistance of the EMAT in radiating and receiving modes directly affects the agreed operation of the generator and amplifier of the control equipment. Moreover, the aperture of the EMAT determines disclosing of the directional pattern and, correspondingly, it affects the attenuation of the wave with the distance due to geometrical divergence; and also it influences the amplitude of the desired signal. Minimization of the clearance between the inductor and the object of control is also one of the main conditions of improving the efficiency of the EMA transformation.

The majority of investigations on directional patterns of the EMAT is based on representation of the transducer in the form of a turn, a plane circular coil, a strip with current, or a couple of opposing strips with current [6,13,22,23], not allowing for evaluation of the influence of structural parameters of the EMAT on formation of acoustic fields, in particular, appearance of grating lobes.

The aim of the present work is to investigate the influence of structural features and excitation parameters of the EMAT, represented in the form of a linear array of unidirectional conductors with current, on formation of grating lobes, and to develop the scientifically based requirements to the engineering design of the EMAT in view of optimizing the aperture, spacing of elements, number and parameters of inductor elements, frequency and parameters of the excitation pulses to eliminate the grating lobes.

The EMAT as a linear array of unidirectional conductors is intended for emitting process, that is, receiving linearly polarized longitudinal and transverse waves. It is applied for a number of acoustic structure detecting tasks, in particular, to estimate the residual stresses of railroad rails, wheels, and to estimate the tension of locomotive tires [24–26].

2. Applied approaches

The performed investigations involved application of a model (proposed in Refs. [8,9,17,27]) for formation of acoustic fields of a self-