Peculiarities of Design of Angled Electromagnetic-Acoustic Transducers (EMAT)

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Abstract. Main difficulties are described that occur in designing electromagnetic-acoustic transducers, and the methods of improving their sensitivity and noise immunity.

The need in developing reliable electromagnetic-acoustic transducers (EMAT) is first of all cause by that traditional USC based on piezo-converters does not allow inspecting products free of contact, under high and low temperature conditions, it is difficult to do flaw inspection of moving products and so on. All this limits the field of cost-efficient and technically reliable inspection with the help of ultra-sound; impedes its application in flow production, prevents inspection automation. EMAT largely enable resolving the above problems but their sensitivity, noise immunity, signals selectivity, particularly, in case of inclined inspection, leaves much to be desired for the majority of existent designs.

This is first of all explained by insufficient elaboration of their theory. Indeed, there turns out to be so many parameters determining EMA transducers' performance and their mutual correlation is so great that only experimental optimization of transducers' design becomes a complex and expensive undertaking. Some knowledge cannot be obtained through experiment at all, hence, all EMAT showing good performance owe their design to the talent and mastership their developers rather than attributable to reliable theory or analytical analysis of their performance.

Theoretical studies of EMAT were carried out by numerous authors, first of all, by G.A. Budenkov, V.T. Bobrov, Yu. V. Volegov, I.V. Iljin, V.A. Komarov, A.V. Malinka, Yu. M. Shkarlet, S.N. Shuvaev, and many other researchers [1] - [6]. At the same time, some very important peculiarities of their performance remain unclear up till now. For example, the impact on the characteristics of excited sound of screens (magnetic conducts) is not established, or their parameters, the influence of various structural clearances unavoidable in manufacture of transducers. The influence of the shape of pulse signals on the characteristics of generated acoustic waves is not defined sufficiently well, and so on. And though designing direct EMAT usually does not encounter many difficulties, development of reliable high-sensitive and noise-immune EMAT for operation at inclination is currently a complex problem.

The authors have developed a physics & mathematics apparatus, which application allows largely reducing the process of designing required EMAT to numerical simulation of their design. Its features are described in [7] - [8]. Basic provisions of the theory underwent numerous checks not only numerically but experimentally as well, thus, confirming the adequacy of conclusions derived with their help. All this permitted identifying some principles of designing reliable direct and inclined EMAT, reveal basic requirements to their magnetic and electron tracts.

This paper gives some of them. In particular, it has been established that:

1. It is comparatively easy to design direct EMAT with coil consisting of direct cophasal loaded conductions. Nevertheless, there are difficulties here as well. In particular, those consist in the requirement of optimizing the magnetic system so that magnetostaticfield induction depended to a lesser degree on the clearance between the magnetic conduct and surface of the inspected item (this difficulty is typical for inclined EMAT); in selection of the working frequency at which the necessary inspection sensitivity is achieved and at the same time acceptable signal to noise ratios are maintained. This is a rather acute problem since the amplitudes of emitted and received EMAT signals turn out to be greater than the working frequency. On the other side, the reflection power of defects grows as frequency increases.

In EMAT design, an important role belongs to choosing the correct correlation of the coil length and transversal dimensions of magnetic conduct setting forth the directional diagram width. Besides, the amplitudes of signals are also significantly affected by the material of magnetic conduct (screen). In this instance, it turns out that the lower is their electric conductivity the higher are the amplitudes of emitted and received signals, all other conditions being equal. The amplitude and width of the «silent zero» is hugely influenced by the shape and duration of pulse signals but their specific values can be established only through computational or practical experiment.

2. EMAT designed for operation at inclination are capable of steady performance only if the maximums of their emission correspond to angles $30^0 \div 40^0$ and $55^0 \div 60^0$. At that, the steadiness of the first maximum is ensured by the influence of the 3rd critical angle of emission (at which $\theta = \arcsin(c_t/c)$, where c_t and c are, correspondingly, the propagation speed of transverse and longitudinal wave in the inspected material). Steadiness of the second maximum is conditioned, on one side, on that through variation of the doublets base and wavelengths one can achieve signal maximum at the required working angle. On the other side there is a clearly expressed limitation as regards emission of transverse waves by lumped sources, which cannot be passed by (see monograph [9]). At all other angles, the emission maximums are unsteady and can move in space depending on variation of frequency, signal duration, dimensions of various clearances and so on.

3. EMA transducers running at inclined angles, concurrently with signals emitted and received at above working angles, are also capable of generating and registering signals with significant amplitudes at lower angles. This is due to the fact that not only pulses emitted by neighboring conductions can mutually interfere but further ones as well. This leads to wider directional diagrams and lower sensitivity, noise immunity of EMAT. This problem is resolved by selecting the screen material, nature of coil winding, also by selecting the correct shape of pulse signal. This can be done with the help of computational experiment using the EMAT theory developed by the authors, of course, followed by experimental verification of the recommendations obtained.

The figures below demonstrate these circumstances.

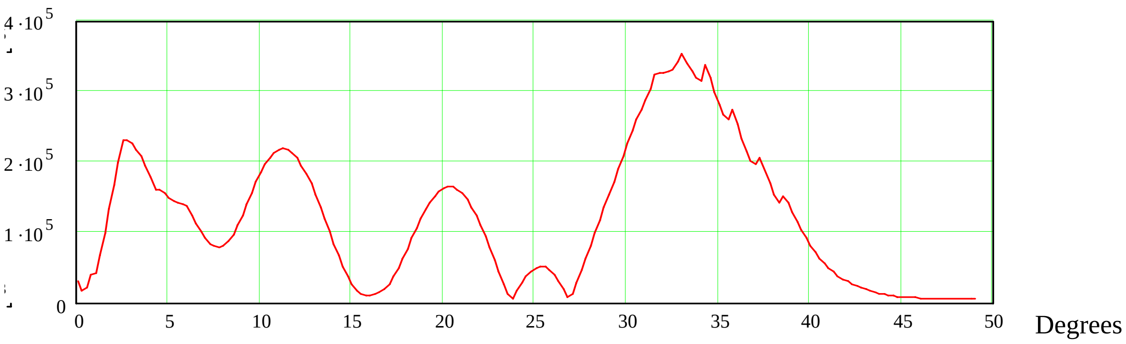

Fig. 1. Estimated directional characteristic of a typical EMAT (Pa) designed without compensation of spurious emission angles, at working frequency of 0.9 MHz, in the presence of a clearance between the transducer and the product surface equal to 0.5mm.

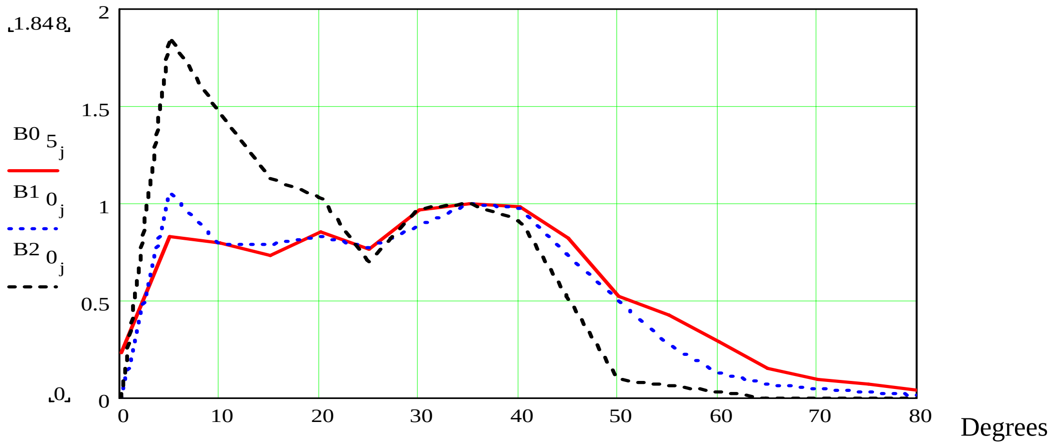

Fig. 2. Comparative normalized experimentally measured directional diagrams of the same transducer (Volts at the amplifier output), in case of different clearances. Curve $B0_5$ refers to the clearance equal to 0.5mm, $B1_0$ - 1mm, and $B2_0$ - 2mm.

Below the optimized characteristics of EMAT operating at the same frequency are given.

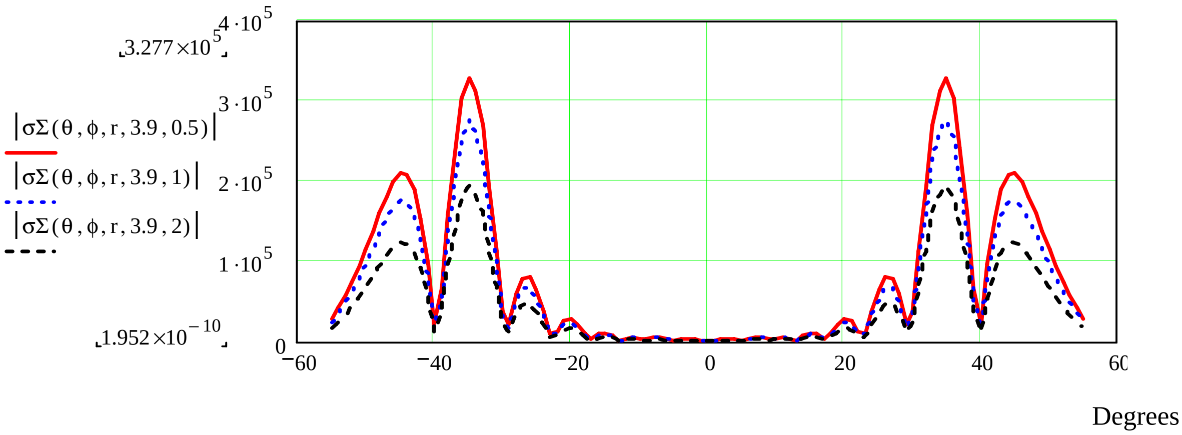

Fig. 3. Estimated directional diagrams of emission of optimized EMA transducer designed for operation at an angle of 35^0 in case of different clearances (the last figure in the design functions, i.e. 0.5, 1, and 2mm).

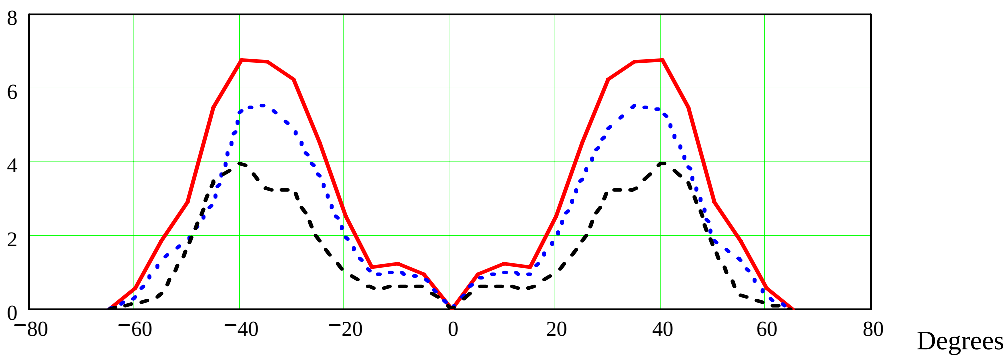

Fig. 4. Experimentally measured and statistically treated characteristics of emission direction of the same EMAT in case of the same clearances (Volts at the amplifier output). Clearances here correspond to those shown above.

It is typical that the same transducer, excited at a different frequency, is already capable of reliable performance at another angle as well. Its estimated and experimental characteristics are shown below:

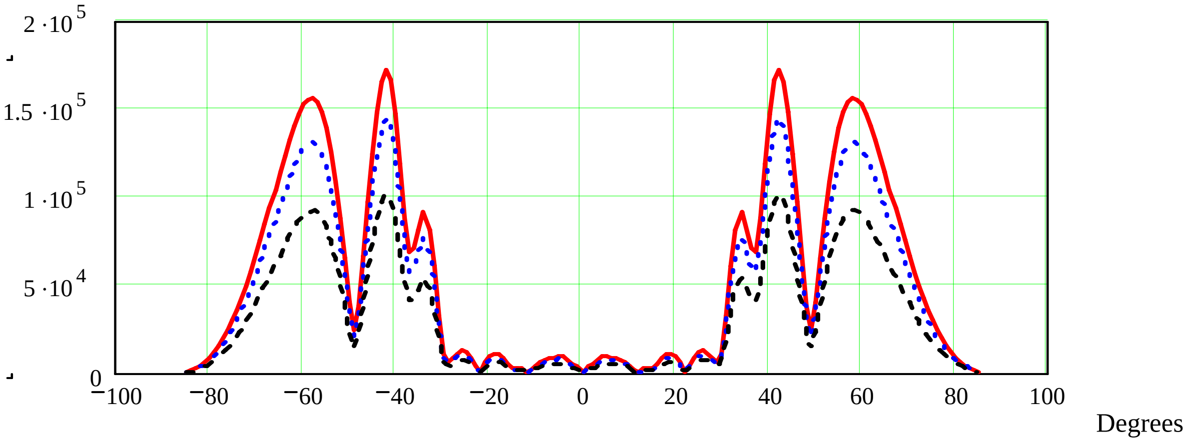

Fig. 5. Estimated characteristic of the same EMAT during its operation at a different frequency (the clearances are the same).

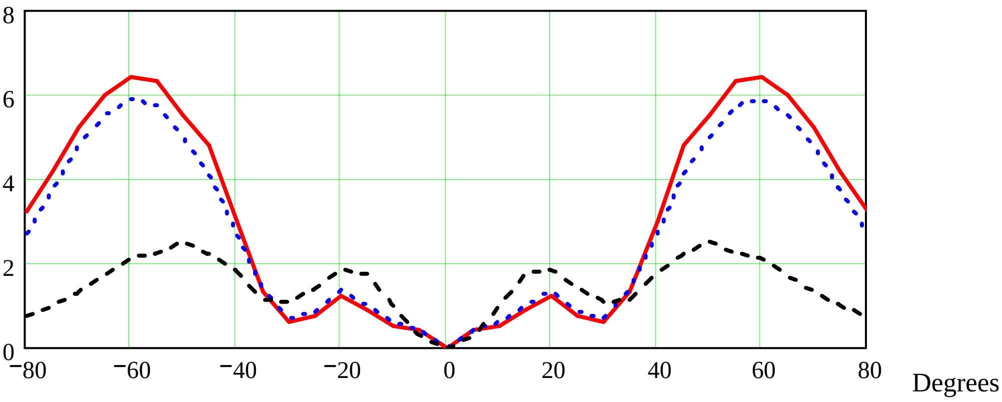

Fig. 6. Experimental characteristic of the same EMA transducer during its operation at a different frequency

It is easy to see that here the computational and experimental results qualitatively match too, while gaps observed in the course of computations are usually poorly observed during the experiment. It is worth noting that while amplitudes of spurious signals emitted by a common EMAT (see Fig. 2) grow disproportionately as clearances increase, this does not happen in those optimized up to the 2mm clearance.

4. Inclined EMAT simultaneously emit (and receive) signals symmetrically to the perpendicular to the inspected surface. Significant disruption of this symmetry is possible only when several generators are used feeding different conductions with different current phases. At the same time, it is possible to achieve this also by regulating the pulse signal shape, selecting the material and choosing the width of the screen, the nature of coil winding, non-uniformity of the doublets base used therein etc. In particular, such transducer was simulated numerically, and its characteristic is shown on the following figure:

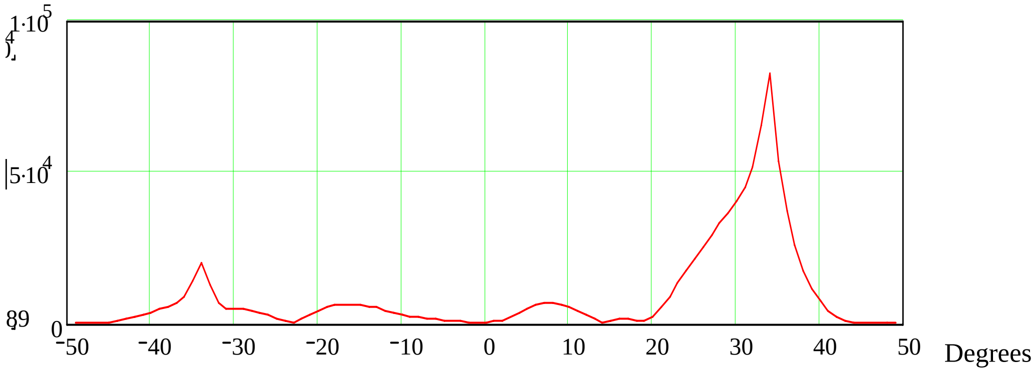

Fig. 7. Acoustic field of EMAT with single-direction emission

Still, all this is achieved rather expensively.

5. In designing inclined EMAT, the principle of simulation does not work. Hence, for each case, for any working frequency or required direction, one has to select own parameters of transducer.

The figures below show the outward appearance of some of developed EMATs.

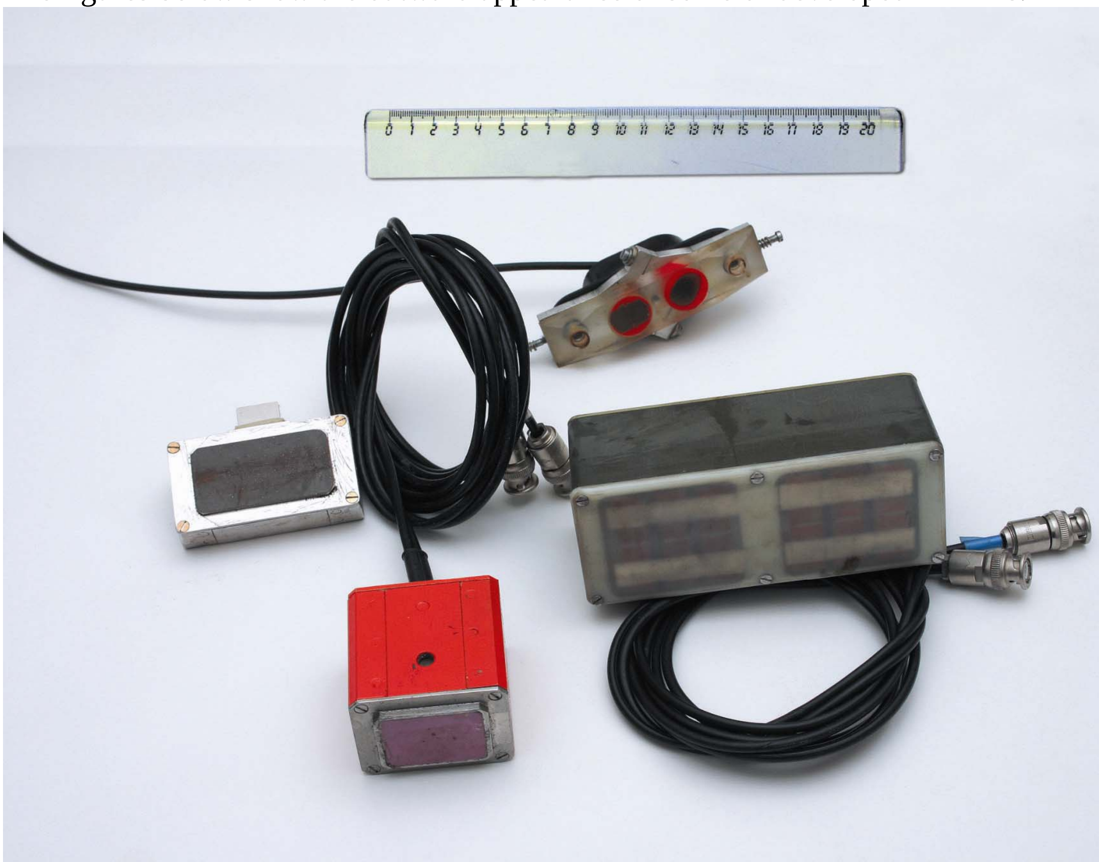

Fig. 8. Some EMAT types designed in NPP «VIGOR» that are functioning in nondestructive check setups created by this institution