A. N. Vasil'ev and Yu. P. Gaĭdukov. *Contactless excitation of sound in metals (experiment).* The studies on electromagnetic excitation of sound are using both the traditional acoustic methods, and the approaches developed for the study of high-frequency properties of solids.

The pulsed method which is most commonly used now is based on the principles of radar techniques. A high-power probing RF pulse is applied to an inductive coil located near the surface of a metal (the amplitude of the variable magnetic field H is 10^{-3}–10^{-1} Tesla). In the regime of the normal skin-effect the linear generation of sound can be observed only in the presence of a constant magnetic field H_0 (this quantity lies usually in the range 10^{-1}–10 Tesla). Conversion of waves in this case is caused by the inductive interaction of the variable current in the skin-layer with the field H_0. Depending on the orientation of $\mathbf{H}_0$ relative to $\mathbf{H}$ and the metal surface, the inductive mechanism excites the longitudinal ($\mathbf{H}_0\|\mathbf{H}\perp\mathbf{n}\mathbf{n}$ is the normal to the metal boundary) or transverse ($\mathbf{H}_0\|\mathbf{n}\perp\mathbf{H}$) sound polarized along $\mathbf{H}$.

In pure metals at low temperatures there exists also, in addition to the inductive mechanism, the deformation mechanism[1] of sound excitation. Its principle is based on the fact that under the conditions of anomalous skin-effect, the direct effect of the variable electric field $\mathbf{E}$ on the ions of the lattice is not compensated by the interaction of ions with electrons. The largest portion of electrons carries the acquired additional momentum outside the skin-layer. The deformation mechanism excites the transverse sound polarized along $\mathbf{E}$.

The contactless methods are used not only for generation of the volume sound, but also for the excitation of surface waves. The coils used for this purpose have as a rule the meander or grid shape. Inductive transducers are placed usually at the smallest possible distance from the metal surface. Some types of coils and the fields of elastic displacements caused by them are shown in Fig. 1.

The registration of excited sound is accomplished by inverse conversion of an elastic wave into an electromagnetic wave, and peformed either by the second coil in the "transmittance" experiments, or by the same coil in the pulsed-echo experiments.

The efficiency of described generation mechanisms de-

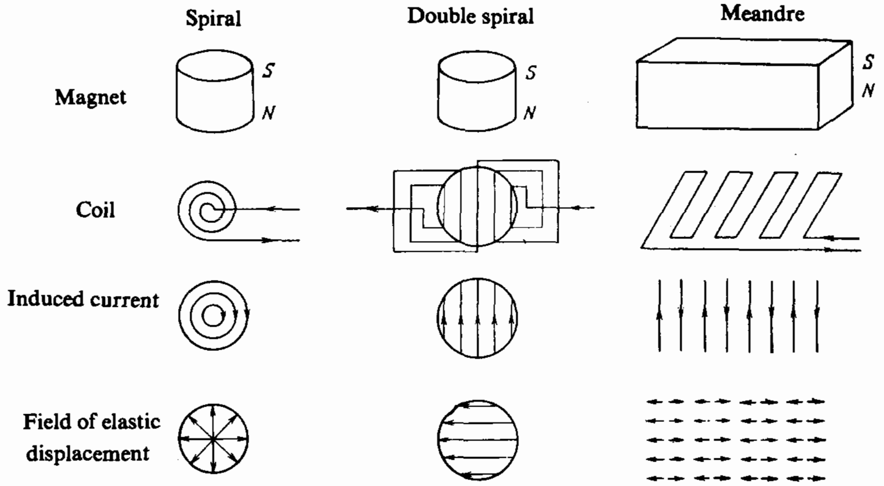

FIG. 1.

creases with an increase of frequency. The dominant mechanism in the microwave frequency range becomes the "surface" mechanism[3], caused by the diffuse scattering of electrons by the boundary of a metal. The change of dominating conversion mechanisms is accompanied by a change in experimental techniques. Inductive transducers work efficiently only up to 10^8–10^9 Hz, at higher frequencies microwave resonators have to be used.[4] The studied metal is sputtered onto one of the edges of an acoustical delay line, which is pressed down on to an opening in the bottom of a microwave resonator. After an excitation pulse one can observe several echo-pulses with the delay times corresponding to the passage of the transverse sound to the second edge of the delay line and back.

Experimental studies of high-frequency properties of metals (the surface impedance, weakly attenuating waves, etc.) are often performed on thin flat-parallel high frequency plates. This form of crystals ideally suits both the study of the conversion phenomenon itself (the plate in this case is treated as an acoustic resonator of the Fabry–Perot type), and the application of contactless excitation for the study of elastic properties of materials. In semiconductors and insulators sound can be excited by sputtering on their surfaces a thin metallic film, which serves as the converter.[5]

The schematic diagram of the experiment which is performed in the regime of continuous vibrations is shown in Fig. 2. The output signal from the high-frequency generator 1 is applied to a fixed coil surrounding the sample 2. A signal from the receiving coil is applied to the wide-band amplifier 3 and after that to the phase detector 4. The use of phase detection is justified by the high noise immunity of this circuit. The recording device 5 registers in this experiment the special resonant features of the surface impedance, originating during the formation of standing sound waves in the bulk of the plate. The frequencies and amplitudes of acoustic resonances carry the information about the effectiveness of contactless excitation of sound, as well as about the attenuation rate of sound in the metal.

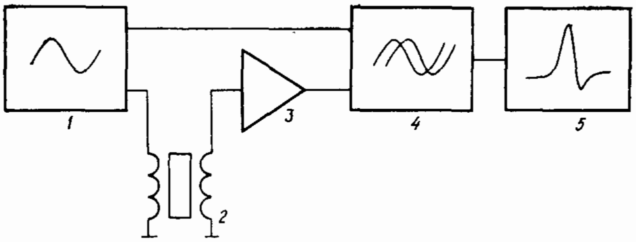

FIG. 2

Since the transmitting characteristics of a plate together with the surrounding coils in the field $\mathbf{H}_0$ have a sharply expressed resonant character, this makes it possible[6] to realize the "acoustic autogenerator, working at resonant frequencies. In the absence of $\mathbf{H}_0$, a coupling coefficient between the coils is selected to be below the selfexcitation threshold of the generator. When a constant field is applied, the coupling between the coils caused by conversion of electromagnetic and acoustic waves in a metal increases, and this leads to generation at the frequency of an acoustic resonance in the plate. The autogeneration scheme is particularly convenient for registration of small variations of the velocity and attenuation of sound during, for example, recording of quantum oscillations of these quantities.[7,8]

One of the advantages of electromagnetic excitation of sound is, first of all, the absence of a contact with the studied material. Besides, this method allows one to excite new types of acoustical vibrations[9] and, in some cases, to carry out measurements that cannot be made by other methods.[10] A disadvantage of the contactless excitation method is its low efficiency. It is possible, however, to overcome this difficulty with modern instrumentation, and this is confirmed by the constantly increasing use of this effect in research laboratories and practical applications.[11]

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[1] V. M. Kontorovich, Zh. Eksp. Teor. Fiz. **45**, 1638 (1963) [Sov. Phys. JETP **18**, 1125 (1964)].

[2] C. M. Fortunko and P. B. Thompson, Ultrasonic Symposium Proc. IEEE, 1976, p. 12.

[3] M. I. Kaganov and V. B. Fiks, Fiz. Met. Metalloved. **19**, 489 (1965) [Phys. Met. Metallogr. (USSR) **19**, 81 (1965)].

[4] B. Abeles, Phys. Rev. Lett. **19**, 1181 (1967).

[5] A. N. Vasil'ev, Yu. P. Gaidukov, and V. N. Nikiforov, Pis'ma Zh. Eksp. Teor. Fiz. **41**, 466 (1985) [JETP Lett. **41**, 568 (1985)].

[6] A. N. Vasil'ev, Yu. P. Gaĭdukov, and A. P. Perov, Prib. Tekh. Eksp. **6**, 176 (1980) [Instrum. Exp. Tech. (USSR) **23**, 1511 (1980)].

[7] A. N. Vasil'ev and A. A. Nurmagabetov, Fiz. Nisk. Temp. **9**, 714 (1983) [Sov. J. Low Temp. Phys. **9**, 362 (1983)].

[8] A. N. Vasil'ev and Yu. P. Gaĭkukov, Zh. Eksp. Teor. Fiz. **81**, 2234 (1981) [Sov. Phys. JETP **54**, 1186 (1981)].

[9] R. B. Thompson and C. F. Vasile, Appl. Phys. Lett. **34**, 128 (1979).

[10] A. N. Vasil'ev, Yu. P. Gaĭdukov, E. A. Popova, and V. Yu. Fedotov, Pis'ma Zh. Eksp. Teor. Fiz. **42**, 197 (1985) [JETP Lett. **42**, 245 (1985)].

[11] a. R. B. King and C. M. Fortunko, Ultrasonics Symposium Proc. IEEE, 1982, p. 885; b. D. Husson, S. D. Bennett, and G. S. Kino, *ibid*. p. 889; c. S. K. Datta, A. H. Shah, and C. N. Fortunko, J. Appl. Phys. **53**, 2895 (1982); d. C. M. Fortunko, R. B. King, and M. Tan, *ibid*., p. 3450.