'hree-pulse acoustic echo in piezodielectric owders

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For the case of a powder that falls freely in an electric capacitor, a theory is constructed for the three-pulse electroacoustic echo connected with rotation of the powder granule by an external electric field.

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The recently observed phenomenon of three-pulse electroacoustic echo in ezodielectric powders[1–4] has not yet been explained. It is, however, quite ›vious that we are dealing with excitation of a system of independent oscillars. We therefore consider below a simple case of freely falling powder, when ere is no interaction between the individual granules. Experimental realizaon of this scheme in the observation of two-pulse ferromagnetic echo was re›rted in[5].

Let the powder granules fall freely between the plates of a capacitor. For mplicity we consider only spherical particles made of piezoactive crystals of bic symmetry (in which case they are isotropic in their electric properties). ıe particles have approximately equal dimensions, and it possible to excite them elastic oscillations at one of the normal modes, with a frequency close ω. If an alternating electric field of frequency ω is produced in the capacitor the instants of time $t=0$, τ, and T, then a spontaneous electric signal (echo) ll be observed at $t=T+\tau$. We shall now trace its appearance. (We confine rselves to time intervals approximately up to 10^{-2} sec, which are too short r the granules located between the capacitor plates to be replaced by new es.)

At the instant $t=0$, the electric field produces electric oscillations in the wder. Connected with these oscillations is the dipole electric moment of the h particle

$$P_{ni}(t) = Q_{ni}(t)\sin[\omega t - \beta_{ni}(t)],$$

ıere $i=x, y, z$ and $Q_{ni}(t)$ and $\beta_{ni}(t)$ vary slowly with time, owing to the small difference between the resonant frequency and ω and owing to the damping of the sound. We assume that, on the average over the particle ensemble, $\beta_{ni}(t)$ changes by $\pi/2$ after a certain time τ_0 (we assume $\tau_0 < \tau$).

We follow henceforth a well-known study[6] when taking account of such a nonstationarity factor. The sound does not manage to attenuate within not too long a time τ. Then, when an electric pulse $\mathbf{E} = \mathbf{E}_0 \sin\omega t$ is applied for a time $\tau \le t \le \tau + \Delta t$ (for simplicity, $\Delta t \lesssim \tau_0$), the dipole is acted upon by an orienting torque $\mathbf{P}_n \times \mathbf{E}$. Since $\mathbf{P}_n$ and $\mathbf{E}$ vary practically with the same frequency during the time interval Δt, it is clear that a constant torque is produced. It rotates the particle with angular velocity $\dot{\theta}_n$. If we choose the direction of $\mathbf{E}_0$ to be the Z axis, then at $t > \tau + \Delta t$ we obtain

$$\dot{\theta}_{nx} = \frac{Q_{ny} E_0 \cos \beta_{ny}(\tau)\, \Delta t}{2I_n}; \qquad \dot{\theta}_{ny} = -\frac{Q_{nx} E_0 \cos \beta_{nx}(\tau)\, \Delta t}{2I_n}, \qquad ($$

where I_n is the moment of inertia of the particle. In order of magnitude we have $P_n \sim eAV$, where e is the characteristic value of the piezoelectric modulu A is the average amplitude of the relative deformation, and V is the average volume of the particle. At a particle radius 5×10^{-3} cm, a density 5 g/cm^3, $e \sim 10^6$ cgs esu, $A \sim 10^{-4}$, $E_0 \sim 10^4$ V/cm, and $\Delta t \sim 10^{-6}$ sec we have $\dot{\theta}_n \sim 30$ rad/sec. In order for a random rotation of the particles not to smear out the resultant orientation, we assume that the initial rotation speeds are much lower than this rather large quantity (the viscosity of air plays no role at $t \lesssim 10^{-2}$ sec and at these values of the parameters).

We call attention to the following extremely important detail. All the rotations are effected in such a way that the vectors $\mathbf{P}_n$ and $\mathbf{E}$ (the frequencies of which are practically the same within the time Δt) tend to become parallel. This dipole orientation, of course, leads to an electric-induction signal. However, after a time on the order of τ_0 the dipole phases β_{ni} become random, an the induction signal vanishes. (Of course, the phases β_{nx} and β_{ny} for a single particle are not random.)

Assume that after a sufficiently long time T all the acoustic oscillations ar damped. Turning on the electric field at the instant of time $t = T$ (we assume for simplicity that it is identical with the first pulse) we again excite in the crystal the same normal-mode oscillations (the slight change in their amplitude, due to the rotation of the particles, is neglected as a second-order effect). These oscillations are produced in granules that have already been rotated in a special manner. At the instant of time $t = T + \tau$, when the phases $\beta_{ni}(t - T)$ of the new oscillations coincide with the phases $\beta_{ni}(\tau)$ of the initial temporal oscillations of the orienting interaction, an oscillating polarization the medium should again be observed (and the rotation after $t = \tau + \Delta t$ should continue in the same direction, thereby increasing the echo signal). This response is in fact the three-pulse echo.

A rigorous calculation yields the following expression for the total dipole moment of the powder at the instant of time $t = T + \tau$

$$P_z = \frac{1}{6} E_0 \Delta t\, TN \left\langle \frac{Q_n^2}{I_n} \right\rangle \sin[\omega(t - T)],$$

here N is the number of particles in the capacitor, and $\langle\cdots\rangle$ denotes averaging ver all the particles. The initial orientation of the granules is assumed ran- om. At $T \sim 10^{-2}$ sec and at a particle density 10^{-4} cm^{-3} in the capacitor volume he remaining parameters are indicated above) one should expect an electric cho signal of about 10^2 V/cm.

We note that in the particular scheme considered by us, with free fall of the articles, the two-pulse echo signal (it is produced by acoustic oscillations due the second electric pulse) will be much less than the three-pulse echo. We not consider two-pulse echo signals.

For the geometry assumed in[1-4], the theoretical analysis becomes extreme- complicated. If the rotation of the particles is limited by "dry" friction, and e expression assumed for the torque is the same as for the free particle, then e torque will greatly exceed the friction force at rather modest fields (of ourse, such an approximation is too crude, so that we do not present the cor- esponding formulas). Since the particle density is very large here, one should xpect a noticeable three-pulse echo signal of the type described above at this xperimental geometry, too.

In conclusion, we wish to call attention once more to the desirability of ealizing in experiment the described simple and theoretically easy to treat cheme with freely falling powder.

S.N. Popov, N.N. Kraĭnik, and G.A. Smolenskiĭ, Pis'ma Zh. Eksp. Teor. Fiz. **21**, 543 (1975) [JETP Lett. **21**, 253 (1975)].
S.N. Popov, N.N. Kraĭnik, and G.A. Smolenskiĭ, Zh. Eksp. Teor. Fiz. **69**, 974 (1975) [Sov. Phys.-JETP **42**, 494 (1975)].
Ya. Ya. Asadullin, V.M. Berezov, V.D. Korepanov, and V.S. Romanov, Pis'ma Zh. Eksp. Teor. Fiz. **22**, 285 (1975) [JETP Lett. **22**, 132 (1975)].
V.M. Berezov, Ya.Ya. Asadullin, V.D. Korepanov, and V.S. Romanov, Zh. Eksp. Teor. Fiz. **69**, 1674 (1975) [Sov. Phys.-JETP **42**, 851 (1976)].
S. Kupca and C.W. Searle, J. Appl. Phys. **46**, 4612 (1975).
G.F. Herrmann, D.E. Kaplan, and R.M. Hill, Phys. Rev. **181**, 829 (1969).