Possibility of exciting Gulyaev-Bleustein waves by developing defects

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It is shown that defects that develop in piezoelectric crystals should generate Gulyaev-Bleustein surface waves (GBW). The waveform of a GBW pulse is calculated for a screw dislocation emerging to an unstressed grounded surface of a crystal of class 6 mm.

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As they are produced and developed in a crystal, defects can generate not only elastic waves (acoustic emission[1]) but also arbitrary other existing types of waves.

Thus, a defect that develops in a piezoelectric half-space will excite also GBW, in addition to elastic volume and surface (Rayleigh) waves. To illustrate this, we consider a screw dislocation that emerges at constant velocity v on a grounded piezoelectric-crystal surface free of mechanical stresses.

The simplest case is that of a hexagonal crystal, say of class 6 mm, inasmuch as there is no piezoelectric effect for an isotropic medium. Let the dislocation line be parallel to the crystallographic Z axis, let the motion be along the X axis, and let the free surface be the ZY plane. We note that in this case, in the absence of a piezoelectric effect, a screw dislocation does not excite surface waves.[2,3]

The system of equations describing the displacement field $u(x,y)$ and the potential $\phi(x,y)$ of the electric field is of the form[4]

$$c_{44}\nabla^2 u - \rho\ddot{u} = -e_{x5}\nabla^2\phi, \qquad (1)$$

$$\epsilon_{xx}\nabla^2\phi = e_{x5}\nabla^2 u.$$

The boundary conditions for an unstressed grounded surface $x=0$ are

$$\phi = 0, \quad \sigma_n = c_{44}\frac{\partial u}{\partial x} + e_{x5}\frac{\partial\phi}{\partial x} = 0. \qquad (2)$$

Writing out the reciprocity relations for a piezoelectric medium of the symmetry in question, we obtain[1)] an integral representation of the defect field:

$$u(x,y,t) = \int_{-\infty}^{t} dt' \int_l G(x,y,x',y',t-t')\, a(x',y',t')\, dl',$$
$$\phi(x,y,t) = \int_{-\infty}^{t} dt' \int_l F(x,y,x',y',t-t')\, a(x',y',t')\, dl', \qquad (3)$$

where

$$G = c_{44}\frac{\partial \mathscr{G}_{uu}}{\partial x'} + e_{x5}\frac{\partial \mathscr{G}_{\phi u}}{\partial x'}, \quad F = c_{44}\frac{\partial \mathscr{G}_{u\phi}}{\partial x'} + e_{x5}\frac{\partial \mathscr{G}_{\phi\phi}}{\partial x},$$

$\partial \mathscr{G}_{ij}$ are the components of the Green's function of the system (1) with the conditions (2), and $a(x,t)$ is the jump of the displacement on the surface of the defect l.

Carrying out further transformations with respect to the time and the coordinate y, substituting the expressions for the Green's-function components, and calculating the integral with respect to l, we obtain the Fourier components of the displacement and of the potential. These quantities have [at $(v/c \ll 1)$] branch points at $k^2=\omega^2/c_T^2$ and poles at $k^2=\omega^2/c_{GB}^2$, where c_T is the velocity of the transverse waves and c_{GB} is the velocity of the GBW. The inversion of the Fourier integral with respect to k is effected with the aid of contour integration analogous to that in Lamb's problem.[5] The integral along the cut represents cylindrical transverse waves, and the residue at the pole represents GBW.

Inverting the Fourier integral with respect to time, we obtain the waveform of the exciting GBW pulse

$$v^{\circ} \approx \frac{b v^2 e_{x5}^2 (\beta - 1/c_{GB})}{2\pi^2 c_{GB}^2 \epsilon_{xx} H} P \frac{1}{c_{GB} t - |y|}, \tag{4}$$

where $v^0 \equiv \dot{u}(0,y,t)$ is the velocity of the surface points,

$$\beta^2 = c_{GB}^{-2} - c_T^{-2}, \quad H = \frac{e_{x5}}{\epsilon_{xx}} - \frac{\rho c_T^2}{c_{GB}^2 \beta}$$

and the symbol P stands for the principal part.

Registration of GBW can be used as a convenient experimental method of observing developing defects in analogy with the method of acoustic emission. The actual organization of the experiment can consist of observing GBW generated by a defect that develops under the influence a concentrated load applied to the crystal surface, in analogy with the procedure of [6–8].

By covering the crystal surface with GBW sensors[9] it is possible to register pulses generated by dislocations, twins, microcracks, and other defects.

It must be borne in mind, however, that the obtained formula (4) pertains to the case of an infinite linear dislocation and is not suitable, just as the formulas of[2,3], for an exact quantitative analysis of the pulses waveform in real experiments.

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[1)]Detailed calculations will be published elsewhere.

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