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# The distribution of the electric field around the vibrating edge dislocation in the ferroelectric crystal

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# The distribution of the electric field around the vibrating edge dislocation in the ferroelectric crystal

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**Abstract.** The amplitude of the electric fields around the vibrating edge dislocation on the distance from the dislocation line in long-wave and short-wave cases is found. The laws of decrease modulus of the amplitude of the electric fields at the distance from the dislocation line are determined.

## 1. Introduction

The problem of the distribution of electric fields around the dislocations in the static case was solved in paper [1]. In papers [2-7] were further investigated electroelastic fields created by dislocations. In [8] the general expressions for the electroelastic fields of moving dislocations and disclinations in piezoelectric crystals are obtained. In this paper, based on the results of [9], [10] are expressions for the distribution of the electric field around oscillating edge dislocation in a ferroelectric is found. The case of small oscillations of the dislocation is considered. It was assumed that the active ferroelectric axis coincides with the coordinate axis $Oz$: $\boldsymbol{P}=(0,0,P)$ along the same axis located equilibrium position of the edge dislocation line: $\boldsymbol{\tau}_0=(0,0,-1)$, Burgers vector is directed along the axis $Ox$: $\boldsymbol{b}=(b,0,0)$. In this case, the electric fields associated with the dislocation are of a purely dynamic nature.

## 2. The distribution of electric fields in the long-wave case

Earlier [10], under the assumption that the dislocation makes bending vibrations according to the $u=u_0\exp(\mathrm{i}kz-\mathrm{i}\Omega t)$, for the components of the electric field intensity authors obtained expression

$$E_z(\boldsymbol{r},t)=4\mu bP_0u_0\chi_0k^2\left(\frac{1+\nu}{1-\nu}g_1\frac{\partial^2 J_l}{\partial x\partial y}+g_2\frac{\partial^2 J_t}{\partial x\partial y}\right)\exp(\mathrm{i}kz-\mathrm{i}\Omega t)\,, \tag{1}$$

where

$$J_{l,t}=\frac{\eta}{\omega_0^2}K_0\left(\frac{r\omega_0}{\sqrt{\eta}}\right)-\frac{\pi}{2}\frac{1}{dk^2/\omega_0^2+\Omega^2/c_{l,t}^2}Y_0\left(r\sqrt{\Omega^2/c_{l,t}^2-k^2}\right)$$
$$-\frac{1}{dk^2/\omega_0^2+\Omega^2/c_{l,t}^2}K_0\left(rk\sqrt{1+d/\omega_0^2}\right). \tag{2}$$

After calculating derivatives [11], the expression for the electric field intensity components (1) takes the form:

$$E_z(\boldsymbol{r},t) = 4\mu b P_0 u_0 \chi_0 k^2 \left( \frac{1+\nu}{1-\nu} g_1 M_l + g_2 M_t \right) \exp(\mathrm{i}kz - \mathrm{i}\Omega t), \tag{3}$$

where

$$M_{l,t} = \frac{\sqrt{\eta}}{\omega_0} \frac{xy}{r^2} \left[ \frac{2}{r} K_1\left(\frac{r\omega_0}{\sqrt{\eta}}\right) - \frac{\omega_0}{\sqrt{\eta}} K_0\left(\frac{r\omega_0}{\sqrt{\eta}}\right) \right] - \frac{\pi}{2} \frac{\sqrt{\Omega^2/c_{l,t}^2 - k^2}}{dk^2/\omega_0^2 + \Omega^2/c_{l,t}^2} \frac{xy}{r^2} \left[ \frac{2}{r} Y_1\left( r\sqrt{\Omega^2/c_{l,t}^2 - k^2} \right) \right.$$
$$\left. - \sqrt{\Omega^2/c_{l,t}^2 - k^2}\, Y_0\left( r\sqrt{\Omega^2/c_{l,t}^2 - k^2} \right) \right] - \frac{k\sqrt{1+d/\omega_0^2}}{dk^2/\omega_0^2 + \Omega^2/c_{l,t}^2} \frac{xy}{r^2}$$
$$\times \left[ \frac{2}{r} K_1\left( rk\sqrt{1+d/\omega_0^2} \right) - k\sqrt{1+d/\omega_0^2}\, K_0\left( rk\sqrt{1+d/\omega_0^2} \right) \right]. \tag{4}$$

Here $Y_0(w)$, $Y_1(w)$ are Neumann functions of zero and first order, $K_0(w)$, $K_1(w)$ are MacDonald functions of zero and first order, $r = \sqrt{x^2 + y^2}$, $c_t$ и $c_l$ are the transverse and longitudinal sound velocities, $\mu$ is shear modulus of the crystal, $\nu$ is Poisson's ratio, $g_1$ and $g_2$ are striction coefficients, $P_0$ is polarization equilibrium value in a homogeneous crystal, $\omega_0^2 = \sqrt{2\alpha/m}$, $\eta = \delta/m$, $d = 4\pi/m$, $h$ и $m$ are damping coefficient and mass coefficient for polarization vibrations, respectively, $\delta$ is correlation constant, $\alpha$ и $\beta$ are coefficients in Landau expansion for free energy, $\chi_0 = 1/(m\omega_0^2)$. In the formulas (1)-(4) satisfaction of the condition $k^2 < \Omega^2/c_{l,t}^2$ was assumed.

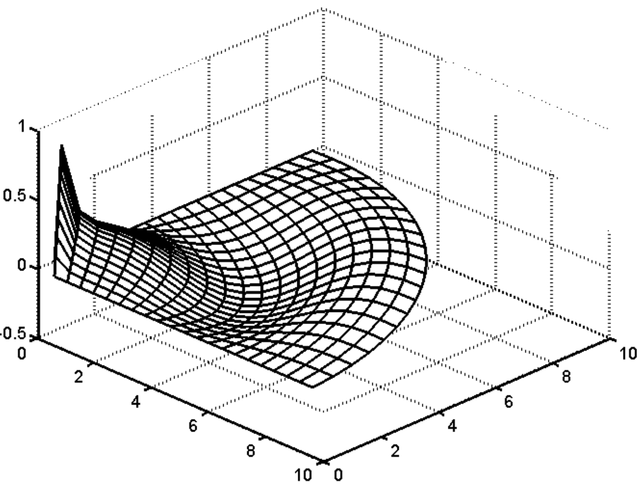
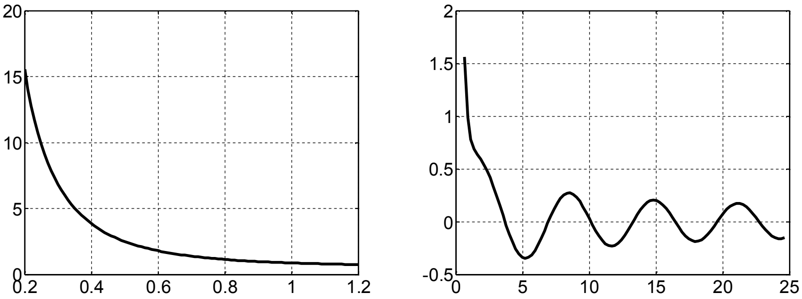



**Figure 1.** Dependence of the electric field intensity component of the distance to the dislocation line and the polar angle in the long-wave case.

Figure 1 in cylindrical coordinates shows the dependence of the amplitude of the electric field intensity component $E_z(\boldsymbol{r},t)$ of the distance from the dislocation line and the polar angle, based on the formulas (3) and (4) in normalized units in the long-wave case $k^2 < \Omega^2/c_{l,t}^2$. From formulas (3)-(4) it follows that for small values of the distance to the dislocation line $r < \left(\Omega^2/c_{l,t}^2 - k^2\right)^{-1/2}$ electric field amplitude decreases proportionally $r^{-2}$, and for large values $r > \left(\Omega^2/c_{l,t}^2 - k^2\right)^{-1/2}$ the modulus of the electric field amplitude decreases proportionally $r^{-1/2}$ (figure 2).




*a*) *b*)

**Figure 2.** Dependence of the electric field intensity amplitude of the distance from the dislocation line at small (a) and large (b) of values $r$ in the long-wave case.

## 3. The distribution of electric fields in the short-wave case

In section 2 has been considered a long-wave case $k^2 < \Omega^2 / c_{l,t}^2$ . If $k^2 > \Omega^2 / c_{l,t}^2$ , in the expression (2) for $J_{l,t}$ the replacement $Y_0\left(r\sqrt{\Omega^2/c_{l,t}^2 - k^2}\right) \to -\frac{2}{\pi} K_0\left(r\sqrt{k^2 - \Omega^2/c_{l,t}^2}\right)$ needs to be done. Then for the components of the electric field we obtain

$$E_z(\boldsymbol{r},t) = 4\mu b P_0 u_0 \chi_0 k^2 \left(\frac{1+\nu}{1-\nu} g_1 T_l + g_2 T_t\right) \exp(\mathrm{i}kz - \mathrm{i}\Omega t), \tag{5}$$

where

$$\begin{aligned} T_{l,t} = {} & \frac{\sqrt{\eta}}{\omega_0} \frac{xy}{r^2} \left[\frac{2}{r} K_1\left(\frac{r\omega_0}{\sqrt{\eta}}\right) - \frac{\omega_0}{\sqrt{\eta}} K_0\left(\frac{r\omega_0}{\sqrt{\eta}}\right)\right] + \frac{\sqrt{k^2 - \Omega^2/c_{l,t}^2}}{dk^2/\omega_0^2 + \Omega^2/c_{l,t}^2} \frac{xy}{r^2} \left[\frac{2}{r} K_1\left(r\sqrt{k^2 - \Omega^2/c_{l,t}^2}\right)\right. \\ & \left. - \sqrt{k^2 - \Omega^2/c_{l,t}^2}\, Y_0\left(r\sqrt{k^2 - \Omega^2/c_{l,t}^2}\right)\right] - \frac{k\sqrt{1 + d/\omega_0^2}}{dk^2/\omega_0^2 + \Omega^2/c_{l,t}^2} \frac{xy}{r^2} \\ & \times \left[\frac{2}{r} K_1\left(rk\sqrt{1 + d/\omega_0^2}\right) - k\sqrt{1 + d/\omega_0^2}\, K_0\left(rk\sqrt{1 + d/\omega_0^2}\right)\right]. \end{aligned} \tag{6}$$

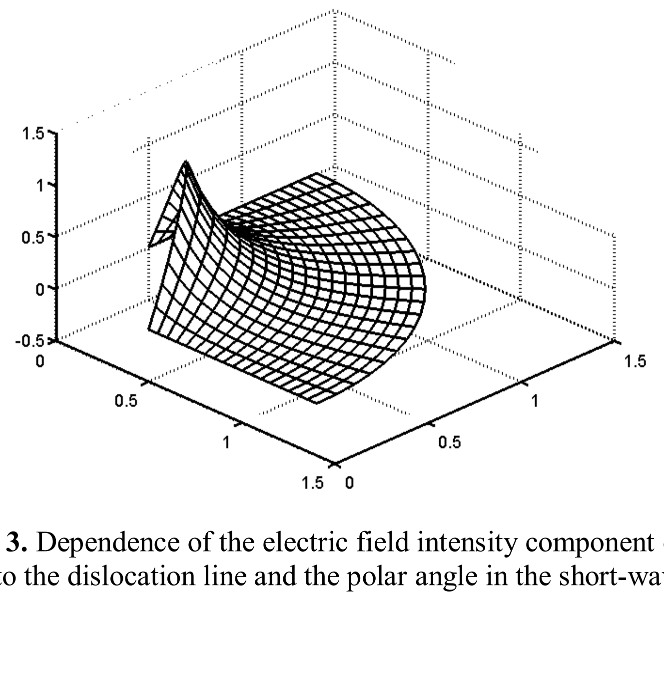
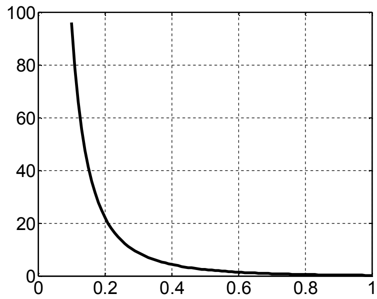
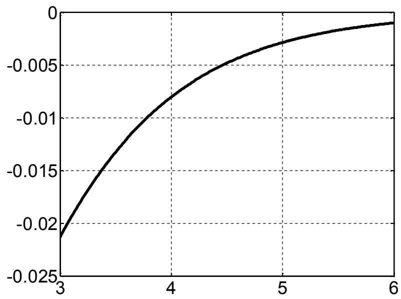



**Figure 3.** Dependence of the electric field intensity component of the distance to the dislocation line and the polar angle in the short-wave case.

Figure 3 in cylindrical coordinates shows the dependence of the amplitude of the electric field intensity component $E_z(\boldsymbol{r},t)$ of the distance from the dislocation line and the polar angle, based on the formulas (5) and (6) in normalized units in the long-wave case. From formulas (5), (6) it follows that for small values of the distance to the dislocation line $r < \left(k^2 - \Omega^2 / c_{l,t}^2\right)^{-1/2}$ electric field amplitude decreases proportionally $r^{-2}$, and for large values $r > \left(k^2 - \Omega^2 / c_{l,t}^2\right)^{-1/2}$ the modulus of the amplitude of the electric field decreases proportionally $r^{-1/2}\mathrm{e}^{-r}$ (figure 4).




*a*)




*b*)

**Figure 4.** Dependence of the electric field intensity amplitude of the distance from the dislocation line at small (a) and large (b) of values $r$ in the short-wave case.

## 4. Conclusion

In this paper a quality form of the dependences of the electric field intensity amplitude component of the angle and the distance to the dislocation line is obtained. For the exact form the specific values of the constants of the crystal must be used. The results can be used to study the attenuation and scattering of ultrasound and electromagnetic waves in a ferroelectric with dislocations.

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