Orientation dependence of the dislocation segment vibration spectrum

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Abstract. Dependences of the dislocation segment vibration eigenfrequencies and the damping coefficients on the angle between the dislocation line and its Burgers vector are found. For the ratio of the transverse sound waves velocity to the longitudinal sound waves velocity, the value 1/2 was used, the different lengths of the dislocation segment were considered. When calculating and plotting the dependency curves, the normalized values of the eigenfrequencies, damping coefficients, and lengths of the dislocation segment were used. The normalized values of the eigenfrequencies and damping coefficients for different frequency numbers by equating the inverse matrix of dislocation oscillators generalized susceptibilities to zero were found. At large values of the dislocation segment normalized lengths, sharp changes in the frequencies values with numbers 5 and more were observed on the orientation dependence graphs. To explain this, the surface level of the real and the imaginary part of the inverse generalized susceptibility built.

1. Introduction
To describe the oscillations of the dislocation segment, Koehler proposed a string model [1]. This model was further developed by Granato and Lucke [2, 3]. Specific mechanisms of energy dissipation by a moving dislocation in reviews [4, 5] were considered. Various problems of oscillations of dislocation segments in later works [6-11] have been investigated. The nonlocality of the dislocation characteristics in the string model was analyzed in [12, 13], and also in [14] on the basis of [15]. In [16, 17], the authors found the generalized susceptibility of a dislocation segment. In this paper, based on the results of [16, 17], the orientational dependence of the dislocation segment vibrational spectrum is investigated.

2. Dependences of the dislocation segment vibration eigenfrequencies and the damping coefficients on the angle between the dislocation line and its Burgers vector
In this section the dependence of the eigenfrequencies of the oscillations of the dislocation segment and the damping coefficients on \( \cos^2 \beta \), where \( \beta \) is the angle between the dislocation line and its Burgers vector, for \( c_t^2/c_l^2 = 1/4 \), where \( c_t \) and \( c_l \) are the velocities of the transverse and longitudinal sound waves, and different lengths of the dislocation segment are constructed. The first six normalized eigenfrequencies of the vibrational spectrum \( \bar{\omega}_n = \text{Re}(\omega_n - i\gamma_n) L/c_t = \omega_n L/c_t \) and \( \bar{\gamma}_n = -\text{Im}(\omega_n - i\gamma_n) L/c_t = \gamma_n L/c_t \) (\( L \) is the length of the dislocation segment) were investigated. The values of \( \bar{\omega} \) and \( \bar{\gamma} \) for different frequency numbers were found from the solution of the equation...
\[ B(\bar{\omega} - i\bar{\gamma}) = 0, \] where \( B \) is the inverse matrix of the dislocation oscillators generalized susceptibilities [16, 17]. In the calculations, the normalized value of the length of the dislocation segment \( \bar{L} = \ln\left(Le^C/\lambda^2\right) \) was used, where \( \lambda \) is the half-width of the dislocation and \( C = 0.577 \) is the Euler constant. The results of the calculations are shown in figures 1-3.

\[ a, b \]

**Figure 1.** Dependences of the natural frequencies (a) and damping coefficients (b) of the dislocation segment oscillations on \( \cos^2 \beta \) for \( \bar{\omega} \approx 10.4 \).

It is noted that for the values of \( \bar{L} \approx 15 \), sharp changes in the frequencies with the numbers 5 and 6 are observed. This is due to the transformation of the dislocation oscillators generalized susceptibility poles. The poles corresponding to certain frequencies (modes) of oscillations go away, and other poles begin to correspond to these modes of oscillation. Thus, there is a shift of the vibration modes relative to the poles. From figure 2b, it can be seen that during the transformation of the poles, there is a sharp increase in the corresponding damping coefficients of the dislocation oscillators.

For values of \( \bar{L} \approx 19.6 \), the first 9 normalized frequencies of the vibrational spectrum were studied for a more detailed study of the dependence. As can be seen from figure 3, there is also a transformation of the poles and a transition of vibration modes, accompanied by a sharp increase in the corresponding damping coefficients.
Figure 2. Dependences of the natural frequencies (a) and damping coefficients (b) of the dislocation segment oscillations on $\cos^2 \beta$ for $L \approx 15$.

Figure 3. Dependences of the natural frequencies (a) and damping coefficients (b) of the dislocation segment oscillations on $\cos^2 \beta$ for $L \approx 19.6$. 
3. Surface level of the real and the imaginary part of the inverse generalized susceptibility $B$

We illustrate the evolution of the poles and the transition of the vibration modes of the dislocation segment in figures 4-6. As an example, consider odd frequencies, $\tilde{L} \approx 15$. In figures 4-6 numbers of poles are marked with figures, typed in bold. The poles of the generalized susceptibility were determined by the intersection of the zero lines on the surfaces of the level of the real and imaginary parts. It can be seen from the figures that the pole corresponding to the fifth frequency goes up to the region of high damping ($5 \rightarrow 5'$), the seventh pole ($7 \rightarrow 5$) starts responding at the fifth frequency, the ninth pole starts responding for the seventh frequency, etc.

![Figure 4. Re B (a) and Im B (b), $\cos^2 \beta = 0.625$.](image-url)
4. Conclusion

In this paper, we find an orientation dependence of the dislocation segment vibration spectrum for different dislocation segment lengths. Sharp changes in the curves of the dependences and the corresponding transformation of the generalized susceptibility poles are observed. The authors assume that the transformation of the poles at certain values of the angle between the dislocation line and the Burgers vector is caused by the presence of a quasilocal vibrations branch [18]. The obtained results can be used for further development of the dislocation amplitude-independent internal friction theory.
References

[1] Koehler J S 1952 *Imperfections in Nearly Perfect Crystals*, ed W Schockley et al (New York: Wiley) p 197

[2] Granato A V and Lucke K 1956 *J. Appl. Phys.* 27 583

[3] Granato A V and Lucke K 1956 *J. Appl. Phys.* 27 789

[4] Kaganov M I, Kravchenko V Ya and Natsik V D 1974 *Sov. Phys. Usp.* 16 878

[5] Alshits V I and Indenbom V L 1986 *Dislocations in Solids* vol 7, ed F R N Nabarro (Amsterdam: Elsevier Science Publishers) p 43

[6] Nikolaev V V and Taluts G G 1968 *Fizika Metallov i Metallovedenie* 26 193

[7] Charkina O V and Chishko K A 2001 *Phys. Solid State* 43 1898

[8] Kamaevo O V and Chernov V M 2002 *Phys. Solid State* 44 1676

[9] Krasilnikov V V, Savotchenko S E and Udovenko I V 2005 *Izvestiya Tul'skogo gosudarstvennogo universiteta. Seriya: Fizika* No 5 71

[10] Maurel A, Pagneux V, Barra F and Lund F 2005 *Phys. Rev. B* 72 174110

[11] Rodriguez N, Maurel A, Pagneux V, Barra F and Lund F 2009 *J. Appl. Phys.* 106 054910

[12] Bross H and Stenzel G 1967 *Phys. Lett.* 25 236

[13] Ninomiya T 1970 *Fundamental Aspects of Dislocations Theory*, ed J A Simmons, R de Wit and R Bullough (Nat. Bur. Stand. (U.S.) Spec. Publ. 317) p 315

[14] Bataronov I L and Dezhin V V 2006 *Vestnik Voronezhskogo gosudarstvennogo universiteta* No 8 15

[15] Bataronov I L, Dezhin V V and Roshchupkin A M 1993 *Bulletin Russian Academy Sciences - Physics* 57 1947

[16] Bataronov I L and Dezhin V V 2016 *J. Phys.: Conf. Ser.* 738 012108

[17] Bataronov I L and Dezhin V V 2017 *J. Phys.: Conf. Ser.* 936 012036

[18] Bataronov I L and Dezhin V V 2017 *J. Phys.: Conf. Ser.* 936 012035