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Frenkel–Kontorova solitons in the registration of small physical fields

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The results of an experiment on excitation of solitons of a coherent acoustic field in a liquid resonator and registration of the response of this field to the vector action of the Coriolis forces are presented. The result of the experiment is to determine the direction to the geographic pole of the Earth. In the process of research, a number of regularities in the dynamics of the acoustic field of solitons corresponding to the Frenkel–Kontorova model were revealed.

Keywords: Coriolis acceleration, Frenkel–Kontorova solitons, geocompass, acoustics.

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The present study is a continuation of research first presented in [1,2], where the construction of a geocompass determining the position of an object in a rotating reference frame was discussed. The interaction of an acoustic soliton field in a condensed medium of a resonator and a vector acoustic field induced by the Coriolis acceleration of the rotating Earth is used to enhance the accuracy of measurements. The study of the proposed method for measurement of weak acoustic fields in condensed media appears to be relevant.

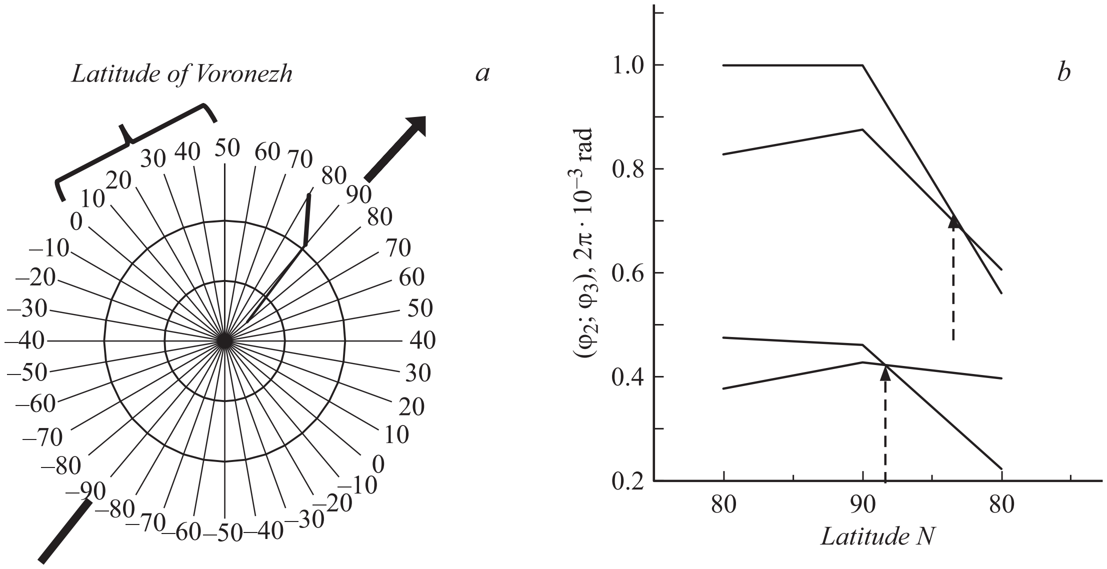
The resonator in a device of a well-known design [2] detecting the interference of coherent acoustic fields has the form of a fused quartz plate. It turned out that internal stresses vary in the process of spatial scanning as the plate position with respect to the gravity vector changes. Deformations distort the acoustic field of the resonator, affecting the results of measurements. Longitudinal and transverse waves induced simultaneously in a solid make the field structure more complex, thus also making it more difficult to interpret the obtained data. The use of a liquid as a condensed medium in a resonator provides an opportunity to exclude transverse waves and bending stresses.

A resonator for experiments was constructed on the basis of a 23-Q-10 cuvette (Starna Cells, Inc.) filled with mercury. This resonator features piezoelectric element C_1 of the exciting electrode, which is connected to the frequency generator of an SR-7265 lock-in amplifier, and two side electrodes C_2 and C_3 that are used to measure phase differences φ_2 and φ_3 of voltages $C_1{-}C_2$ and $C_1{-}C_3$, respectively, with an HDO4054 oscilloscope. The cuvette is kept in a thermostatically controlled container ($T = 25^\circ\mathrm{C}$, $\Delta T \sim 0.1^\circ\mathrm{C}$) mounted on a dual-axis scanner. Linear dimensions of the resonator interior are $10 \times 10 \times 40$ mm. The calculated fundamental frequency for the speed of sound in mercury (1453 m/s) is $\sim 72\,650$ Hz.

Measurement revealed resonances both at the calculated frequency and at a frequency of 9080 Hz in the resonator spectrum. The eight-fold difference between these frequencies and the extended lifetime of excited states ($\sim 10^5$ s) recorded in experiments indicate that quasiparticles were observed in mercury [3]. In all series of experiments, the dynamics of interaction of the Coriolis acceleration field with the motion of quasiparticles of the field of acoustic coherent oscillations had a number of features consistent with the description of the Frenkel–Kontorova soliton model [3].

According to the one-dimensional model, the dispersion law in the atom chain–substrate system is nonlinear. The emerging mutual compensation of effects induced by the nonlinearity of oscillations at large displacements of atoms in a chain and by the dispersion enables the presence of solitons in this chain. The mentioned nonlinearity is attributable to the medium that forces the chain of atoms to remain in a state of compression with the stored energy being maximized in the center. Atoms in the center of a soliton are in a state of unsteady equilibrium. Even a weak external influence may destabilize a soliton, inducing a rearrangement of its structure and macroscopic parameters. The possibility of measurement of variations of these parameters is the basis for the present study. The mode of excitation of solitons is defined in the Frenkel–Kontorova model. A single excitation should be sufficiently strong so as to avoid the excitation of common acoustic waves, which correspond to acoustic phonons propagating with the speed of sound, in the lattice. The engineering solution proposed in [4] is implemented in the present study. The Frenkel–Kontorova acoustic soliton field model is also applicable in interpretation of the experimental data from [4]. The deviation from the model is in the fact that an acoustic soliton field was excited by pumping the medium with a coherent signal from a low-power source.

The model from [3] provides for excitation of pair solitons: compression and depression stress chains (solitons and antisolitons), which exist in motion. Solitons of different signs attract each other. Their attraction may lead either to annihilation or to the formation of a bound state (bisoliton),



General diagram of scanning of the 80–90–80° latitude interval, which corresponds to inversion of the Coriolis force sign, by vector $\mathbf{V}^*$ (*a*) and plot of two successive corrections of referencing of the scanner scale to the results of passive localization of position of the Earth's rotation axis (*b*). The site latitude is the complement of the measured angle of axis inclination relative to the vertical.

which has an infinite lifetime. In the present study, a lifetime of $\sim 48\,\mathrm{h}$ after deactivation of the excitation generator was observed. It is difficult to perform a new cycle of measurements within this time interval. Newly excited solitons get scattered off bisolitons. The energy exchange leads to loss of information. In order to wipe the memory of the medium, one needs to excite the resonator for a short period at the fundamental frequency for the speed of sound in the linear mode (in the present case, 72 650 Hz).

Coriolis acceleration $\mathbf{a}_C$ corresponds to the following vector product [5]:

$$\mathbf{a}_C = 2\boldsymbol{\Omega} \times \mathbf{V}^*, \tag{1}$$

where $\boldsymbol{\Omega}$ is the axial pseudovector of angular velocity of the Earth's rotation and $\mathbf{V}^*$ is the velocity vector of excited solitons in the resonator medium. In the case of $\mathbf{V}^*$ lying in the meridional plane, the stationary vector field of Coriolis accelerations (1) is tangential to circles of rotation about the Earth's axis. In the resonator medium, effective mass m^* of a moving soliton is affected by force $\mathbf{F}_C$ in accordance with acceleration (1). The parameters of the resulting vector for side detectors are specified by the „Zhukovsky rule“ [5] that characterizes vector transformation

$$\begin{aligned} |\mathbf{F}_C|_2 &= 2m^*|\boldsymbol{\Omega}||\mathbf{V}^*|\sin\alpha\sin(\omega^* t + \varphi_2), \\ |\mathbf{F}_C|_3 &= 2m^*|\boldsymbol{\Omega}||\mathbf{V}^*|\sin\alpha\sin(\omega^* t + \varphi_3), \end{aligned} \tag{2}$$

where $|\mathbf{V}^*|\sin\alpha$ is the projection of $\mathbf{V}^*$ onto the orthogonal to the Earth's rotation axis and ω^* is the soliton excitation frequency.

The magnitude of vector $\mathbf{F}_C$ is altered by angular scanning of vector $\mathbf{V}^*$ (2). In accordance with vector product (1), $\mathbf{F}_C = 0$ for parallel vectors $\boldsymbol{\Omega}$ and $\mathbf{V}^*$. In the process of scanning in the meridional plane, force $\mathbf{F}_C$ goes through a minimum in the neighborhood of $\alpha = 0$ and changes its direction by 180°. This transition is the basis for determination of the direction of pseudovector $\boldsymbol{\Omega}$ and calculation of the measurement site latitude in the present study. The figure presents the overall trend of the phase difference of sensors C_2–C_3 and (in an enlarged normalized scale) the position of the point of inversion of the phase difference corresponding to the true direction of the Earth's axis relative to the scanner scale.

The acoustic field of solitons corresponding to the Frenkel–Kontorova model was used for the first time to detect an ultralow energy of the vector field of Coriolis accelerations with a resonator filled with 4 ml of mercury. The principle of self-organization of solitons, which react to small variations of an external acoustic field by a change in macroscopic measurable parameters, provided an opportunity to determine the direction of the vector of Earth's Coriolis accelerations in the process of angular scanning of space. An algorithm for passive determination of direction of the Earth's rotation axis as a stationary linear object in an absolute frame was proposed. At the present stage, the error of measurements of the angular position of the Earth's axis relative to the measurement site is no greater than 5° and is limited by the accuracy of the scanning system.

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Conflict of interest

The author declares that he has no conflict of interest.

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