CONCLUSION

The analysis of the mathematical model of a generalized electric machine has shown that this model is suitable for describing a stepping motor because the equations obtained describe a synchronous two-phase electric motor.

In addition, a comparison with existing models of electric motors has shown that the constructed mathematical model corresponds to the standard *RL*-electric motor model, but one also takes into account the equations that describe the relation between the electric parameters (the frequency of the current in the stator windings ω) with mechanical parameters (rotor speed ω_r).

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SIMULATION OF INTERACTION OF ACOUSTIC OSCILLATIONS WITH FOREST

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Abstract—In this paper the problem of interaction of acoustic waves falling at a given angle on the ground with a forest and seismic waves arising in the ground is considered for a three-layer "air-forest-ground" model. A mathematical simulation of the infrasound oscillations propagation in the atmosphere considering friction force are implemented. The influence of the friction coefficient to the attenuation speed of acoustic oscillations are estimated. The algorithm and program of calculation of the acoustic pressure levels in the different media using wave equation for the atmosphere, system of gas dynamics equations for the forest and elastic equation for the ground, are developed and realized.

Keywords—Multifactorial problem, geoecological risks, predication, infrasound, informative factors, gas dynamics equations, vegetable layer.

INTRODUCTION

Among modern geoecological problems an important problem is that estimation the geoecological risks for the environment from the impact of powerful acoustic waves generated by technogenic and natural explosions of increased danger including powerful quarry and polygonal explosions, technogenic roads noises, earthquakes, volcanic eruptions etc. Of greatest interest is to study of seismic and acoustic effects from mass explosions, since they determine the integrity of industrial and residential objects. [1]. Along with the meteofactors increasing the environmental risks from explosions there are factors that lead to weakening of acoustic vibrations from explosions. These include the presence of a snow cover, forest massifs, and rugged terrain along the propagation path of acoustic waves. Particular statements of the problems of acoustic oscillations propagation associated with the estimation of the influence of individual factors on the characteristics of propagation were considered earlier [2-3]. The problem of acoustic oscillations propagation under such conditions is a multi-factor one, and its solution in full statement is rather complicated.

In the present paper, the weakening characteristics taking into account influence of the forest to the surface propagation of acoustic waves are estimated. In an "air - vegetable layer (forest) - elastic half-space (ground)" model the problem of interaction of acoustic waves falling at a given angle on a ground covered forest with seismic waves arising in the elastic half-space modeling the ground is studied. The question of the influence of the vegetable layer on the amplitude of acoustic and seismic waves excited in the elastic half-space is investigated. A system of differential equations of the gas dynamics, wave and elastic equations with boundary conditions is constructed. It describes the propagation of incident and reflected acoustic waves in the air, and refracted and reflected seismic waves in the forest and elastic media for a three-layer “air-forest-ground” model. The amplitudes and pressures of reflection and refraction of acoustic and seismic waves are calculated and analyzed depending on the vegetable layer height. Theoretical and experimental investigations of acoustic wave’s propagation in the forest as ecological security from adverse technogenic acoustic oscillations are actual but poorly studied.

Currently there are only individual models of interaction of the acoustic oscillations with forests [4]. Present theoretical models investigate sufficient particular cases. To solve many practical problems, it is necessary to investigate the process of interaction of wave acoustic shock fronts with various types of obstacles (rigid, impedance and penetrable) [4]. Environmental problems such as the problem of protection from technogenic noise through the planting of tree belts along major highways and railways are becoming increasingly important [5]. Until recently, the wave equations were the main tool in solving many problems of acoustics [6]. However, recently methods of gas dynamics have been actively used to solve problems of acoustics. Using this approach allows to explore more detailed models taking into account the climatic conditions and terrain, as well as to study the propagation of high intensity disturbances [7]. For the completeness of models have to pay more computational complexity.

PROBLEM STATEMENT

Consider the problem of an acoustic wave falling at a given angle on a ground with vegetable layer on the surface for farther propagation of acoustic waves from the infralowfrequency source. For solution of the problem we consider a three-layer model consisting of an acoustic medium (air), a vegetable layer (forest), and an elastic half-space (ground). Assume that a harmonic acoustic wave with falls from the air onto the forest at angle θ ($0 \le \theta \le 90^o$) to the vertical. In this model the air occupies the upper half-space with sound velocity c and density ρ. The forest is characterized by a friction coefficient α associated with absorption effect created by a penetrable obstacle (forest). The friction coefficient depends on the aerodynamic resistance coefficient c_d and specific density of forest surface (leaves and branches) S. The ground occupying the lower half-space is characterized by density ρ_g and velocities of longitudinal and transverse waves V_p и V_s.

Question how forest absorbs the acoustic waves and how amplitude of the acoustic wave decreases depending on forest characteristics, is investigated. It is assumed for simplicity that at large distances from the source the spherical wave field is locally flat and admits 2-dimensional modeling.

Consider the following wave equations for the air with constant density and sound speed.

$$\frac{1}{c^2}\frac{\partial^2 p}{\partial t^2} - \Delta p = 0; \quad \rho\frac{\partial \vec{u}}{\partial t} + \nabla p = 0, \tag{1}$$

where p, $\vec{u}=(u_x, u_z)$, and c are the pressure, the displacement vector, and the sound speed in the air. The solution of equation (1) can be represented in the form of harmonic waves. The resulting air pressure will be written as the sum of the pressures of the falling and reflected waves:

$$P = P_0 e^{i\omega t - ik_x x - ik_z z} + P_1 e^{i\omega t - ik_x x - ik_z z} \tag{2}$$

where P_0, P_1 are the amplitudes of the falling and reflected waves, $\omega=2\pi f$ is the angle frequency, and $k=\omega/c$ is the wave vector directed toward the wave propagation, k_x, k_z are wave vectors projections along x and z axes.

Consider 2-dimensional problem statement of interaction of the acoustic waves with the forest. This problem is based on the Euler equation system and can be represented in coordinate form:

$$\begin{cases} \frac{\partial \rho}{\partial t} + \rho c^2\left(\frac{\partial u_x}{\partial x} + \frac{\partial u_z}{\partial z}\right) = 0 \\ \frac{\partial u_x}{\partial t} = -\frac{1}{\rho}\frac{\partial p}{\partial x} - \frac{\alpha}{\rho}u_x \\ \frac{\partial u_z}{\partial t} = -\frac{1}{\rho}\frac{\partial p}{\partial z} - \frac{\alpha}{\rho}u_z, \end{cases} \tag{3}$$

where u_x, u_z are components of the displacement velocity vector of the air particles, ρ is the air density, c is sound speed, α is friction coefficient in the forest. As a result, we obtain the expression that depends on only the pressure p:

$$\frac{\partial^2 p}{\partial t^2} - c^2\left(\frac{\partial^2 p}{\partial x^2} + \frac{\partial^2 p}{\partial z^2}\right) + \frac{\alpha}{\rho}\frac{\partial p}{\partial t} = 0. \tag{4}$$

The solution of the equation (4) can be represented as the sum of the pressures of the reflected and refracted waves

$$P = P_2 e^{i\omega t - ik_x x - ik_z z} + P_3 e^{i\omega t - ik_x x - ik_z z} \tag{5}$$

where P_2, P_3 are the amplitudes of the reflected and refracted waves in the forest from the “forest-ground” boundary. The friction coefficient α depends on the aerodynamic resistance coefficient c_d and specific density of forest surface (leaves and branches) S. The characteristics of the forest are given in Table 1. For real massifs the uneven distribution of the forest surface density S is characteristically.

Table 1.

Forest type	Height H, m	S	c_d
Small-leaved forest	10-50	1.2	0.02
Pine	10-50	1.2	0.03
Bush	1-5	7	0.05

The boundary conditions at the "air-forest layer" boundary is the equality of pressures and velocities for the component z in both media.

$$u_{z1}\big|_{z=0} = u_{z2}\big|_{z=0},\ P_1\big|_{z=0} = P_2\big|_{z=0};$$

The acoustic refracted wave falling on the “forest – ground” is taken into account in the boundary condition as follow: the pressure of the acoustic wave is equal to the normal stress of the ground. It is necessary that the medium is inseparable at the boundary.

$$\begin{gathered} \sigma_{xz}^{gr}\big|_{z=h} = 0,\ \sigma_{zz}^{gr}\big|_{z=h} = p\,e^{i(\omega t - kx)} \\ u_z^{air}\big|_{z=h} = u_z^{gr}\big|_{z=h} \end{gathered} \tag{6}$$

For the elastic ground the dynamic Lame elasticity equations with constant elastic characteristics λ_{gr}, μ_{gr}, and ρ_{gr} are solved.

$$(\lambda_{gr}+\mu_{gr})\text{grad}\cdot\text{div}u_{gr}+\mu_{gr}\Delta u_{gr}-\rho_{gr}\cdot\frac{\partial^2 u_{gr}}{\partial t^2}=0. \quad (7)$$

The solution of the equation (7) can be represented in the form of potentials.

$$\varphi = P_4 \exp i(\omega t - kx - k_{\phi z} z), \psi = P_5 \exp i(\omega t - kx - k_{\psi z} z)$$

The potentials $\varphi(x,z,t)$ and $\psi(x,z,t)$ are associated with the displacement field:

$$u_x=\frac{\partial\varphi}{\partial x}-\frac{\partial\psi}{\partial z},\quad u_z=\frac{\partial\varphi}{\partial z}+\frac{\partial\psi}{\partial x}, \quad (8)$$

Substituting the potentials φ and ψ from (8) into the boundary conditions (6), we obtain the equations system for coefficients P_4 and P_5:

$$\sigma_{xz}\big|_{z=0}=\mu\left[2\frac{\partial^2\phi}{\partial x\partial z}+\frac{\partial^2\psi}{\partial x^2}-\frac{\partial^2\psi}{\partial z^2}\right]_{z=0}=0,$$
$$\sigma_{zz}\big|_{z=0}=\left[\lambda\frac{\partial^2\phi}{\partial x^2}+(\lambda+2\mu)\frac{\partial^2\phi}{\partial z^2}+2\mu\frac{\partial^2\psi}{\partial x\partial z}\right]_{z=0}=\rho\exp^{i(\omega t-kx)}; \quad (9)$$

Let P_0=1 be the falling wave amplitude. P_1 is the amplitude of the wave reflected from the forest; P_2, P_3 are amplitudes of the refracted and reflected waves in the forest from the “forest-ground” boundary; P_4, P_5 are the refraction amplitudes of the longitudinal and transverse waves in the ground. It is necessary: to calculate the reflection and refraction amplitudes P_1, P_2, P_3, P_4, P_5 to estimate the influence of forest layer on the pressure of waves passing into the ground.

RESULTS OF THE NUMERICAL SIMULATION

A simulation program was developed and implemented to calculate the acoustic pressure levels of wave oscillations using a mathematical model based on the equations (2)-(9) for three-layer “air-forest-ground” model.The acoustic pressure values for the refracted and reflected waves in the case the passing of a harmonic acoustic wave through forest to the ground taking into account the friction coefficient. It is noted that absorption effect of the acoustic wave energy is observed.

As example figure 1 represents graphs of the acoustic pressure for refracted and reflected waves respectively depending on the falling angle θ in the case the passing of an acoustic wave across forest at different heights H=0, 5, 10, 50 meters and frequency f =10 Hz. Figure 1 shows the absorption effect mentioned above. At the height H=50 m and the angle θ=90 the amplitude of an acoustic pressure can decrease more than order. As other example in figure 2 graphs of the acoustic pressure for refracted and reflected waves depending on the angle θ at different frequencies f=8, 15, 80 Hz are shown. As follows from figure 2 if frequency increase by an order the attenuation velocity of the acoustic pressure increase almost 10 times. Also a presence of wind influences to the dissipation velocity. Figure 3 shows graphs of the attenuation of the acoustic pressure in the forest at the frequency f=8 Hz. As follows from the figure the acoustic pressure is more at a wind blowing in the direction from source to the forest and it is less at a wind blowing in the opposite direction.

CONCLUSION

A mathematical simulation of the processes of infrasound oscillations in the lower atmosphere taking into account vegetation layer and friction force were implemented. It was assumed for simplicity that at large distances from the source the spherical wave field is locally flat and admits 2-dimensional modeling. The problem of interaction of acoustic waves falling at a given angle on the ground with vegetation layer and seismic waves arising in the ground for a three-layer “air-vegetation layer-ground” model was considered and solved. The conditions and results of the solving problem of the acoustic oscillations propagation through the penetrable obstacles as forest were analyzed. The influence of the friction coefficient to the attenuation speed of acoustic oscillations in the forest was estimated. The algorithm and program of the calculation the levels of the acoustic pressure in the different media using wave equation for the atmosphere, a system of gas dynamics equations for the vegetation layer and elastic equation for the ground, were developed and realized. For the created mathematical model, initial parameters and boundary conditions for calculating pressures levels was chose and test calculations using the developed programs were performed.

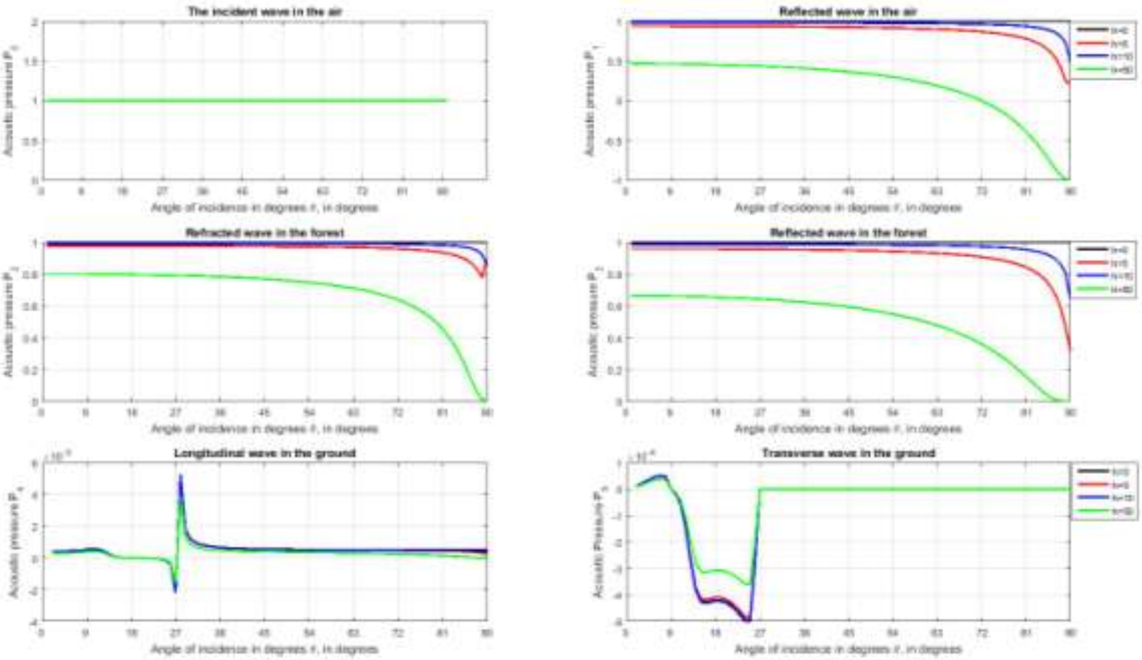

Fig.1. Graphs of the acoustic pressure dependence for refracted and reflected waves on the angle of incidence θ in the case of acoustic wave propagation through the forest at different heights
H = 0, 5, 10, 50 meters, frequency f = 10 Hz.

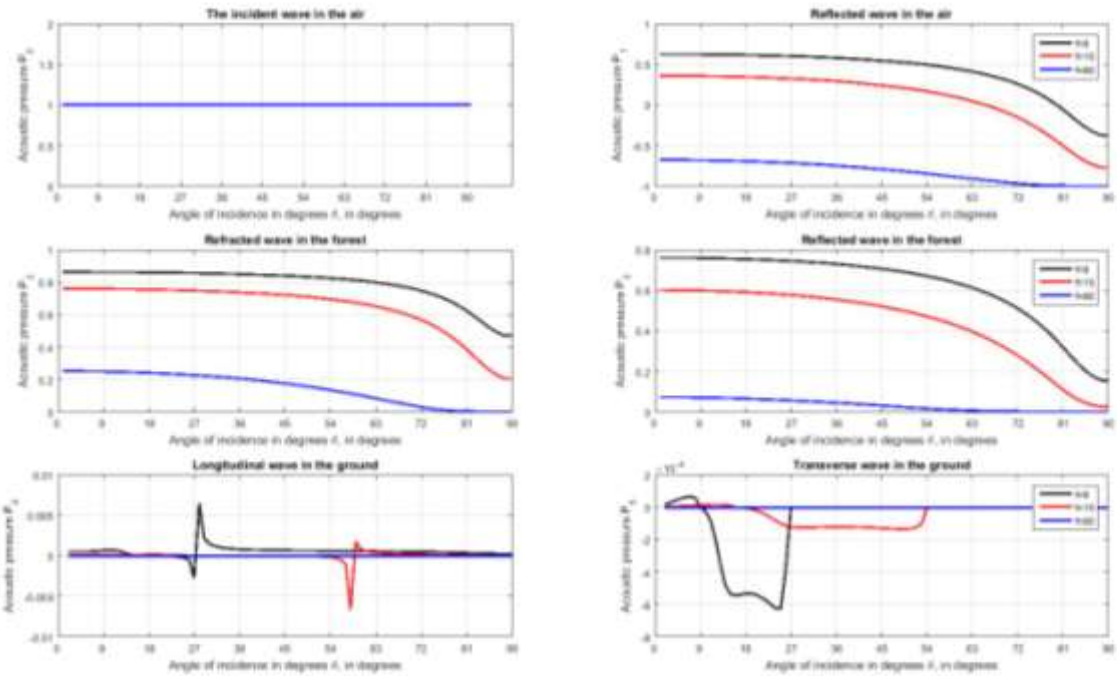

Fig.2. Graphs of the acoustic pressure dependence for refracted and reflected waves on the angle of incidence θ at different frequencies f=8, 15, 80.

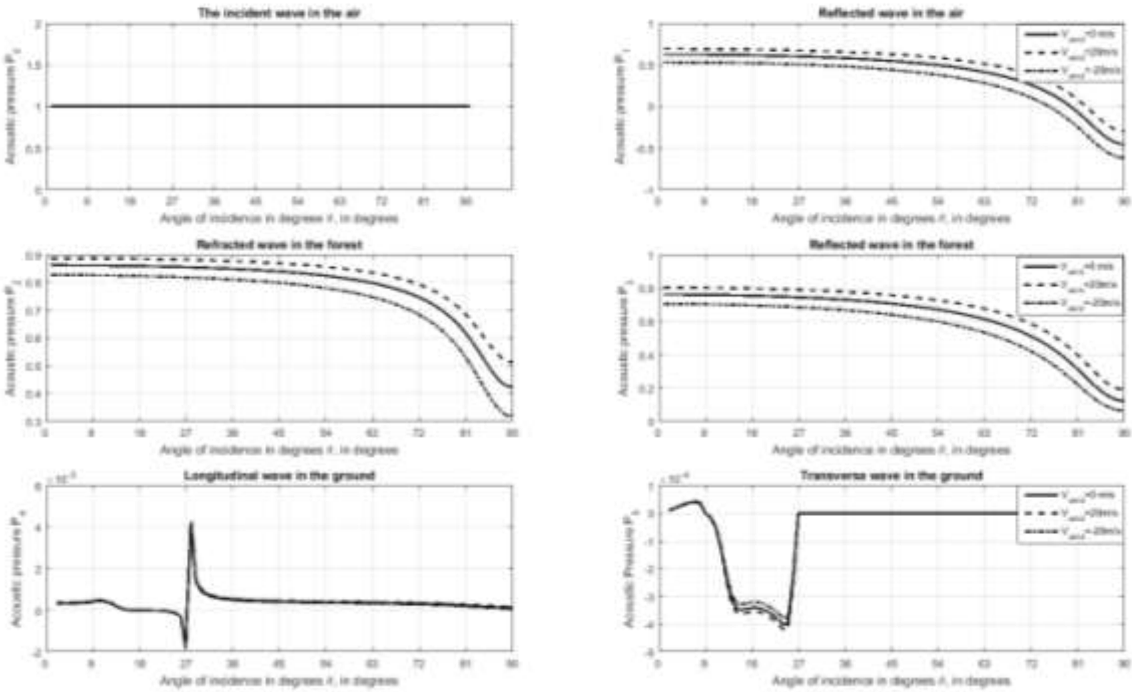

Fig.3. Graphs of the acoustic pressure attenuation in the forest in the presence of wind, frequency
f = 10 Hz. The solid line is the absence of wind; dashed-wind from the source to the forest (20 m/s); dot-dash-in the opposite direction (-20 m/s).

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