CHAPTER «ENGINEERING SCIENCES»

MODELING OF DEFINITION OF A DEPTH OF THE CONDENSED SOIL LAYER ULTRASOUND AND FORMATION OF AN ACOUSTIC SIGNAL

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Abstract. The condensed soil layer is a serious problem for development of a root system of agricultural plants, and the harvest depends on it. At the moment there are already various densitometers of the soil, but all of them demand huge labor input and time, the accuracy of indicators of such densitometers not always answers reality because it is impossible to measure a depth of a dense layer of the soil by such device. Presently search of more progressing methods of loosening of the soil is necessary that will allow to define a depth of the compressed soil layer quickly and the operator of the farm vehicle will be able to regulate depth of processing of the soil. Use of devices which are based on interaction of ultrasonic fluctuations with the soil is more optimum at present as attenuation of sound waves in soil scanty in comparison with electromagnetic waves, especially as use of ultrasonic frequencies gives the chance to create sound bunches, which under the influence of external factors poorly disperse, considerably weakening attenuation and dispersion of a sound wave. Ultrasound – a peculiar physical basis for obtaining information in various measurements there-

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fore. Application of ultrasound concerning the soil is a little investigated in acoustics, as the soil is very difficult object for passing of ultrasound. Vegetable cover, roughnesses, existence of air pockets – all these considerably complicates passing of ultrasound in the environment concerning soils. Except already listed factors attenuation, dispersion and a divergence of ultrasound in the parties are influenced by air and wind. Also attenuation of an ultrasonic wave is influenced by mechanical and physical properties of the top layers of the soil, which are over the condensed layer. Problem of this research is to show a possibility of application of ultrasound in the course of loosening of the soil. As is well-known from laws of acoustics that the sound wave passed the elastic medium is necessary, in which there would be deformation processes. In fact such condition can will be executed unless in sandy soils but in any way not in too dense soil where both air and moisture are absent. For our research the fact that ultrasound does not pass through strongly condensed soil layer and it was put in work of the experimental automated system of loosening of the soil. In a word, the sound wave does not dissipate and does not fade, and beats off with a new force. At the same time the period from the moment of radiation and acceptance of a sound impulse is considered by the sensor taking into account power losses when passing through the top soil layers. In article features of mathematical model of passing of ultrasound for definition of a depth of the condensed soil layer are described, the acoustic behavior of the dense soil is analyzed, the comparative analysis of acoustic behavior of absolutely rigid body and the condensed soil layer is carried out.

1. Introduction

Development of modern technologies of agriculture demands the advancing development and improvement of methods and technical means which will allow to take mass measurements of certain parameters of the soil (in particular – density) directly during the movement of the farm vehicle.

Soil density in many respects defines a harvest of agricultural plants. It influences growth of roots of plants. Reasons of density of the soil are different. The soil is especially subject to consolidation at the increased humidity. Heavy machinery should come around only once in the field when the humidity is higher optimum for processing as the blanket of the soil becomes excessively condensed. One more aspect of density is a density of a subarable layer, so-called accumulative or subsoil density. Under the influence of repeated passes of agricultural machinery the consolidation is observed more and more deeply. The layer, subarable condensed badly permeable for water and air, is formed.

Soil density is very difficult to control inside. It is imperceptible on the surface of the soil as the erosion or superficial consolidation are visible, for example. The analysis and the forecast of this phenomenon is closely connected with assessment of physical and mechanical properties of the soil. Thus, density both superficial, and subsoil this very harmful phenomenon which accompanies intensive agricultural production. It is very difficult to return the soil to a former state. The second aspect of a problem is loosening of the soil.

It is possible to solve this problem the soil which is correctly designated by the system of cultivation. In this regard there is also demand for various densitometers of soils. But as it was already mentioned above, those densitometers which are for this time have complex structure and trenut big labor input. Especially as they do not allow to conduct a research of all field in general but only partially. Therefore there is a need of search of new technologies for loosening of the soil.

In this regard there was an idea of application of more progressive methods on measurement of density of soils, namely an ultrasonic method. However it was necessary to consider that in the nature the interaction of ultrasound with the soil becomes complicated a set of factors. It was necessary to determine also the optimum speed of the movement of the tractor and a height of installation of the sensor and, in general, a possibility of application of ultrasound to soils in the field.

Taking into account fundamental laws of acoustics it was necessary to understand carefully acoustic behavior of the condensed soil layer and to simulate ultrasonic fluctuation with it. Then taking into account this model to calculate an acoustic path and to understand as the acoustic signal will be formed. On the basis of these theoretical researches the experimental ultrasonic device on measurement of density of the soil was made.

The device for definition of a depth of strongly dense layer of the soil works at acoustic and ultrasonic frequencies and is the pulse electronic device. Basic principle of operation of the experimental ultrasonic device is as follows: the transmitter (generator of impulses), which is placed in the block of formation, reception and processing of signals, generates an electric impulse, the ultrasonic sensor – emitter turns it into a sound wave and sends it to the soil. The ultrasonic wave is reflected from the strongly dense layer of the soil and returns to the sensor – emitter which turning it into an electric signal. The receiver, which is placed in the block of formation, reception and processing of signals, strengthens the accepted signal and sends it to the microcontroller. The microcontroller processes the signal accepted by the sensor – converter and issues the processed information on the display of the block of indication and management in the form of the image, according to this image the driver reduces or increases depth of cultivation of the soil.

The conducted laboratory researches, and then and field showed that application of an ultrasonic method on measurement of density of the soil are quite possible. Moreover, it is also possible to determine the type of soil by the nature of reflection of sound waves as the previous researches showed. If there are air pockets, then the sound wave will not be reflected at all, and will be disseminated in the soil. Also there can be a double effect of reflection: passing through the top soil layers (with energy losses) and reducing the speed, and then with a new force is reflected from strongly dense layer. These researches are already described in scientific articles therefore [1, 5]. We would like to stop on the description of model of formation of an acoustic path and on features of ultrasonic fluctuations with the condensed soil, as this question was practically not considered in general.

2. Acoustic behavior of the condensed soil layer

In all questions of acoustics it is necessary to consider both elasticity and density and inertial properties of environment or a subject. His acoustic behavior does not depend on all other properties of material or a subject [3, p. 10].

Passing of ultrasound in it depends on certain properties of material (an ultrasonic wave). Whether soils have such properties? Answering this question we will carry out the analysis of influence of mechanical structure of soils on passing of an ultrasonic wave.

To analyze a possibility of use of ultrasound for measurement of density of soils it is necessary to understand processes of distribution of ultrasound and to find out that there is a dense soil as an acoustic object.

Ultrasonic fluctuations with the soil process difficult and can not always be used ultrasonic a method to soils as the soil is very difficult object for passing of ultrasound. And the soil has the strong absorbing properties (these properties are not always stable, they can fluctuate depending on increase or, on the contrary, reduction of an amount of water, air and salts in soils). Secondly, because of roughnesses and a vegetable cover of the soil sound bunches can disperses in the parties and to distort signals, that is there will be a diffraction phenomenon (dispersion of waves). In the third the soil is the parts which are not connected among themselves, it is amorphous structure which is not capable to transfer some frequency range. In the fourth the soil is a dispersive material and can be elastic under certain conditions.

For example, at compression of sand there are elastic waves. But at extension of a part of sand just depart from each other and elastic force does not arise. That in sand the movement of a sound wave is impossible as inertia of parts of sand which would be transferred from one volume to another. It means that in loose objects the sound wave fades. The linear ratio deformation – force arises if sand is already compressed in advance as in the sandy soil deeply, where parts are pressed to each other by the top layer of the soil.

As well as any object the soil have own ability to pass and absorb sound waves. So, for example, in sandy soils the sound fades because of loss of the energy over time, which turns into other types of energy, in particular – in thermal. Such views of soils are practically not created by the wave resistance and a wave cannot be reflected, as on its way there is no barrier which will create resistance. Absolutely other picture with the dense and very condensed soils. In very condensed soil the effect of resistance of firm particles to deformation processes is observed, and than the soil is more dense, that this resistance is stronger, that will quicker displayed a wave.

Conclusions about mechanical, deformation and other physical parameters of soils do from this with what speed there passes the sound wave. Parameter of its speed has huge value for definition of a throughput possibility of an object. If an object very dense that acoustic speed in it is too small acoustic resistance increases with increase in density of an object (acoustic impedance).

Acoustic (wave) resistance it is ability of an object to carry out acoustic energy. Acoustic resistance is defined by ability of an object to absorb, refract and reflect ultrasonic waves.

In literature there are already calculations for the wave resistance of soils (table 1). Values characteristic of the most widespread $\boldsymbol{c}$ (acoustic speeds) and $\boldsymbol{\rho}$ (density of soils) in the environment are highlighted in bold type. From the table it is visible that with any acoustic speed with increase in density of the soil wave resistance increases.

The majority of soils, as we know, have density of 1000 to 1500 k/m³. Speed of distribution of a sound in soils changes from 85 to 180 m/s [6, p. 48-52].

In the table data of soils in the environment. Very dense layer of the soil as result of economic activity of the person has very small porosity. In it water and air practically otsustvut therefore it renders strong wave resistance. Such soil layer is absolutely rigid body (object).

In acoustics rigid call a body which is not deformed under any conditions. The distance between two points (particles) in such body does not change under any conditions. Such body does not change the form and maintains invariable distribution of weight inside. One conclusion that the body which does not give in to compression is more rigid. The ability to contract does not give the exact answer to the main question yet. As an object concerning the falling wave will behave: will pass a wave or will become a rigid barrier. In acoustics, especially when we speak about a sound, it is necessary to compare only acoustic resistance of objects (density attitude towards ability to contract). More rigid will be that object for which this relation is more.

Table 1

Wave impedance of the soil at different values of its density and speed of an elastic wave [6, p. 48–52]

c,m/s	**ρ, k/m³**					
	1000	**1100**	**1200**	**1300**	**1400**	**1500**
85	**85**	93,5	102	110,5	119	127,5
100	**100**	**110**	120	130	140	150
140	140	**154**	**168**	182	196	210
180	180	198	**216**	**234**	252	270
220	220	242	264	**286**	**308**	330
260	260	286	312	338	**364**	**390**
300	300	330	360	390	420	**450**

But it is necessary to find out: application of an ultrasonic method for control of density of soils in the field which is cultivated is effective? For this purpose we will carry out the analysis of akustichesy resistance of very condensed soil.

As we already found out very condensed soil this absolutely rigid body. In acoustics rigid bodies are not considered at all as they are not capable to pass sound energy.

But as for measurement of a depth of very dense layer of the soil, the effect of not passing of ultrasound through the soil layer which is brought down without air phases and liquid also is the basis for this research. Not dispersion and attenuation of a sound wave as, for example, in sand, and fast reflection. We consider a period from the moment of radiation of a sound impulse until its acceptance by the sensor. Also surely we take in attention power losses in a top soil as the condensed soil layer lies at a depth of 25-36 cm.

An assessment of resistance of a sound wave in technology of acoustic measurements is given in two sizes: the first is acoustic rigidity of an object. Which formula such:

$$\varrho_{A.r.} = \rho c \omega = \frac{P}{A}, \tag{1}$$

where ρ – object density, c – acoustic speed, ω – frequency of a sound wave. This formula shows dependence of sound pressure $\boldsymbol{P}$ on amplitude of shift of parts of an object $\boldsymbol{A}$.

The second size it is a wave (or acoustic) resistance $\boldsymbol{R}$ which evidently or generally is shown by resistance to distribution of a sound wave, and its formula such is:

$$R_A = \rho c = \frac{D}{U}, \tag{2}$$

where ρ – object density, c – acoustic speed, D – amplitude of sound pressure, U – maximum amplitude of speed of fluctuation.

Measurement of distance to very dense layer of the soil at a depth is a basis of our research. Acoustic rigidity and wave resistance of very dense layer of the soil, its ability to do not pass ultrasound and quickly to reflect a sound wave, give all grounds for carrying out a research with application of an ultrasonic method.

3. Modelling of ultrasonic fluctuations with the soil

Ultrasound is a process of movement and time of exitements which the sound wave has. Soil layers in which the sound extends enter interaction with energy of a sound wave and absorb a part of this energy. The most part of that energy which was absorbed by the soil will turn into heat. And a smaller part will make structural changes to acoustically carried out soil layers. Absorption of sound energy depends from the frequency of ultrasonic fluctuations and from acoustic conductivity of different soil layers. It is characterized by the acoustic resistance (impedance) of the top $\boldsymbol{Z}_1$ and condensed $\boldsymbol{Z}_2$ soil layers.

$$Z_1 = \rho_1 c_1;\ Z_2 = \rho_2 c_2, \tag{3}$$

where ρ_1 i ρ_2 – the density of layers of the soil, c_1 i c_1 – acoustic speeds in them.

In acoustics it is necessary to compare impedances of objects, namely a ratio of density to ability to contract: from two objects for what this ratio is more will be more rigid. This ratio by determination of rigidity quite answers characteristic of the condensed soil layer because it is always placed on a depth. And his behavior is close to behavior of absolutely rigid body.

In modeling of definition of a depth of the condensed soil layer by an acoustic method it is taken a technique of passing of ultrasound on border of two solid bodies. But this model is developed taking into account specifics of the acoustic behavior the condensed layer and top layers of soil: their acoustic conductivity and speeds of distribution of a sound in them, their wave resistance, their coefficient of attenuation (absorption) of ultrasound different types of soils, corners of falling, of reflections and refractions of an ultrasonic wave.

The volume of absorption of an acoustic wave by soils is characterized by intensity of a sound in them. The intensity of ultrasound is amount of energy which moves for unit of time through unit of area and is perpendicular to distribution of a sound wave. If sound energy $\bar{\boldsymbol{w}}$ extends with acoustic speed c, where $\boldsymbol{P}$ – the sound pressure, υ – the oscillatory speed of parts of an object, $\boldsymbol{K}$ – the module of volume compression:

$$\bar{w} = \rho \ \frac{\upsilon_{max}^2}{2} \times \frac{P_{max}^2}{2\rho c^2} = \frac{P_{max}^2}{2K}\ ; \tag{4}$$

$$\mathrm{I} = \bar{w}\ \mathrm{c} = \frac{\upsilon_{max}^2}{2}\ \rho\ \mathrm{c} = \frac{P_{max}^2}{2}\ \frac{1}{\rho c} = \frac{\upsilon_{max} P_{max}}{2} \tag{5}$$

The intensity of a sound is directly proportional to a square of amplitude of sound vibrations (the maximum shift of an oscillatory point from position of balance):

$$\mathrm{I} = \frac{1}{2}\rho A^2 w^2 \upsilon, \tag{6}$$

where w – the cyclic frequency of a wave; υ – the speed of a sound wave; ρ – the density of the object.

In the course of distribution of flat waves in the soil the intensity of a sound becomes less in process of a distance from a radiation source. This regularity can be written down under the law of falling off of intensity of a sound:

$$I = I_0\ e^{-2\alpha x} = I_0\ e^{-2\alpha' x} \quad (7)$$

$$\text{here } \alpha' = 2\,\alpha \quad (8)$$

where I_0 – the initial intensity; x – the distance from a radiation source; α – the coefficient of absorption of ultrasound by object; α' – the eneogetichesky coefficient of attenuation which shows at what distance from a source energy of a sound wave decreased by $\boldsymbol{e}$ times.

For determination of average density of energy, and also coefficient of absorption of ultrasound and hour coefficient of attenuation of amplitude of a wave or its energy depending on time we find by the technique stated by Shutilov [7, p. 56–60, 144–145].

For the average density of energy it is similarly had:

$$\bar{w} \cong \bar{w}_0 (1 - \alpha' c) = \bar{w}_0 - \bar{w}_0 \alpha' c\,, \quad (9)$$

where $\bar{w}_0$ – the initial density of energy.

Average quantityof energy which in unit of volume absorbed environment for unit of time:

$$\bar{w}_0 - \bar{w} = \overline{\Delta w}_{\text{absorption}}. \quad (10)$$

From formula (9) we have that:

$$\overline{\Delta w}_{\text{absorption}} \cong \bar{w}_0 \alpha' c\,. \quad (11)$$

If according to formula (5) it is intensity of ultrasound, then power coefficient of attenuation such:

$$\alpha' = \frac{\overline{\Delta w}_{\text{absorption}}}{I_0}. \quad (12)$$

For absorption coefficient according to formula (8) respectively we have:

$$\alpha = \frac{\overline{\Delta w}_{\text{погл}}}{2 I_0}. \quad (13)$$

Such determination of coefficients $\boldsymbol{\alpha}$ and $\boldsymbol{\alpha'}$ gives the chance to calculate coefficient of absorption of ultrasound without calculation of complex wave number. Behind the law of falling off of energy of a wave with distance the power coefficient of attenuation is found on a formula:

$$\alpha^{'} = -\frac{1}{\bar{w}_0}\frac{d\bar{w}(x)}{dx} = -\frac{1}{I_0}\frac{dI(x)}{dx}, \tag{14}$$

where d – the thickness of the top layers of the soil (the depth of strongly dense soil).

Similarly we calculate time coefficient of attenuation depending on amplitude of a wave or its energy from time, that is:

$$\delta_0 = -\frac{1}{\upsilon_{max\,0}}\frac{d\upsilon_{\max(t)}}{dt} = -\frac{1}{2I}\frac{dI(x)}{dt}, \tag{15}$$

where the zero index belongs by the time of $t = 0$.

It should be noted that formulas (14) and (15) give a constant of coefficients of attenuation. Generally these coefficients can depend on distance and time.

The soil and the strongly condensed soil is the firm environment. As is well-known from fundamental laws of acoustics: on border of solid bodies the nature of a wave in difference from liquid and gases changes. In gases and liquids there can be only longitudinal waves. Wave which falls on border of two solid bodies only longitudinal or only shift (cross) which create both longitudinal and tangent shifts on border of two solid bodies. It in both solid bodies is resulted by both longitudinal and cross waves which have different speeds of distribution and therefore are reflected and refract under different corners.The difference in distribution of these waves depends on elastic characteristics which define "rigidity" of an object in relation to this type of deformations. The effective rigidity ϱ of an object is connected with the speed of distribution of a certain wave the relation:

$$\varrho = \rho c^2, \tag{16}$$

from here

$$c = \left(\frac{\varrho}{\rho}\right)^{\frac{1}{2}}. \tag{17}$$

$$\frac{c_{\text{cross}}}{c_{\text{longitudinal}}} = \sqrt{\frac{(1-2v_o)}{(1+2v_o)}} = 2^{\frac{1}{2}} = \sqrt{2} \cong 1{,}4, \tag{18}$$

where v_o – Puasson's coefficient.

This formula (18) shows that in any environment the speed of distribution of longitudinal waves exceeds the speed of distribution of cross waves in $\cong 1.4$.

If the flat wave extends on border of two environments then the nature of its shift remains on this border and only the speed of its distribution changes, only the wave number will change. Its formula:

$$k_x = \frac{\omega}{c}, \tag{19}$$

The ability of ultrasound to be reflected in border of two environments is defined by their wave resistance. If that is about strongly condensed soil it is actually necessary to consider passing of ultrasound for the environment consisting of several layers. It is not about one view of the soil, and about at least two. One layer is placed at a certain depth and in it there are no air phases and liquid and the top soil will be acoustically softer always: $\boldsymbol{Z}_1 < \boldsymbol{Z}_2$. Under such condition the wave is reflected completely (fig. 1) and as in this case on border of environments there is a change of a phase of oscillatory speed and pressure does not feel a jump of a phase and a half of a wave is reflected without loss.

We draw a conclusion that on the border from which the wave is reflected the bunch of pressure (folding of a wave) and knot of oscillatory speed (shift) is formed. Physically it corresponds to the fact that the border of the rigid environment remains immovable, and as a result of a part in the environment which adjoins to border cannot feel shifts. It is especially important to emphasize this moment (increase in amplitude of pressure on border with a rigid barrier) for definition of a depth of the condensed soil layer with an ultrasonic method on coefficient of reflection of a wave, as receivers of ultrasound fix acoustic pressure. Such receiver will register almost doubled amplitude (pressure) of an ultrasonic wave which falls on limit of the section with the rigid environment.

Owing to this fact, the reflection coefficient on energy V of any wave at normal falling is found on a formula:

$$V_I = \left[\frac{\rho_2 c_2 - \rho_1 c_1}{\rho_2 c_2 + \rho_1 c_1}\right]^2 = \left[\frac{Z_2 - Z_1}{Z_2 + Z_1}\right]^2, \tag{20}$$

where Z_1 and Z_2 – the wave resistance of the top and lower soil layer.

If there is no strongly dense layer of the soil on the way of distribution of a sound wave, then the power coefficient of transmission W on border of two soil layers will be:

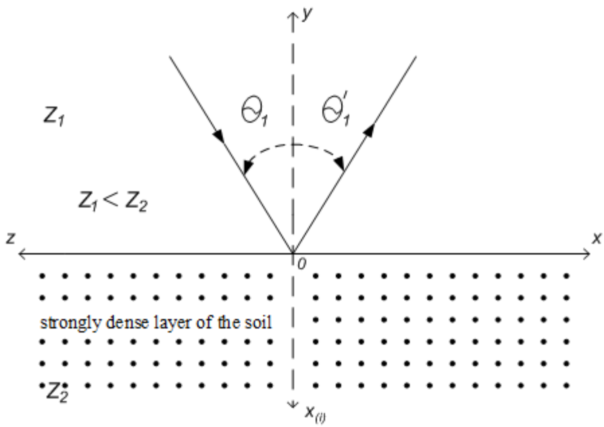

Figure 1. Reflection of an ultrasonic wave from strongly dense layer of the soil

Source: author's working out

$$W_I = \frac{4Z_1 Z_2}{(Z_2 + Z_1)^2}. \tag{21}$$

These formulas of coefficients of transmission W_I and reflections V_I are valid as longitudinal and for shift (cross) waves.

On condition of full reflection of a flat wave, as in our case ($Z_1 < Z_2$), the coefficient of transmission W_I turns into zero (Figure 1), and the coefficient of reflection V_I is equal to unit on condition of flatness to zero of the cosine of one of corners falling. If the cosine of the corner falling of a longitudinal wave is equal to zero then the wave extends along limit of the section. And if the the cosine of the corner falling is equal to zero then the coefficient of reflection will be equal to zero. And the corner of refraction will correspond to a critical corner of falling. At such the corner of refraction the beam disappears and all energy which was in the falling wave passes into the reflected wave.

If the second soil layer is strongly condensed, that the formula of coefficient of reflection will be:

$$V_I = \left(\frac{Z_1 \cos\tilde{}_{2} - Z_2 \cos\tilde{}_{1}}{Z_1 \cos\tilde{}_{2} + Z_2 \cos\tilde{}_{1}}\right)^2 \tag{22}$$

If on limit of the section of environments the shift wave falls, then such wave does not create others a shift components on border. Such wave is reflected and refracts in the form of two purely shift waves. And this formula (22) is suitable for calculation of coefficient of reflection of such wave too.

4. Acoustic path and formation of echo signals

Assessment of physical and mechanical properties of layers of the soil is a main objective of acoustic control in work of the studied system of expeditious definition of a depth of the condensed soil layer. We applied active, more widespread, universal acoustic method to this purpose, namely – an echo method [2, p. 12–15].

Time of receipt of an impulse is the informative parameter of such method that characterizes a depth of strongly condensed soil layer. At this method the measurement mode pulse, a way of obtaining information – piezoelectric.

For exact measurement of a depth of the condensed soil layer have to such conditions will be satisfied:

1. $$l_t + l_r = 2\,\mathrm{H}\; tg\varphi_t \quad [4, p. 118], \qquad (23)$$

where l_t and l_r – the distance of passing of an impulse from the sensor to the condensed soil layer and back to the sensor, H – the distance from the sensor – converter to the condensed soil layer, φ_t – the corner of falling a beam.

2. $$t = \frac{2H_{max}}{c} \quad [3, p. 35], \qquad (24)$$

where t – the time of passing of an impulse to a dense layer and back, H_{max} – the maximum depth of sounding, c – the acoustic speed in the top layer of the soil.

3. $$\mathrm{F} = \frac{1}{T} = \frac{c}{N\,2H_{max}} \quad [4, p. 33], \qquad (25)$$

where F – the maximum frequency of receipt of the sounding impulses, T – the period of the sounding impulse, H_{max} – the maximum depth of sounding, N – the quantity of ultrasonic impulses.

4. The period of passing of impulses is formed in such a way that before receiving the signal reflected from depth the repeated radiation does not occur. Formula of the period of the probing impulse is as follows:

$$\mathrm{T} = \frac{2H_{max}}{t} \quad [3, p. 36], \qquad (26)$$

where T – the period of sounding impulse, H_{max} – the maximum depth of sounding, t – the time of passing of an impulse to a dense layer and back.

Let's consider the scheme of sounding of the soil with existence of strongly condensed layer (Figure 2). In this case the direct converter with the connected scheme serves as both the receiver and the emitter. This converter is at the same time connected to the generator and the amplifier of the device and serves both for radiation and for reception of ultrasound.

Taking into account that the condensed soil does not pass ultrasound and under any conditions is placed perpendicularly to the front of the falling waves, that such waves are flat. Then the waves reflected from the dense soil and accepted by the sensor are also the front of flat waves.

At the mathematical description of an acoustic path by definition of a depth of strongly condensed soil layer it is necessary to consider that it is absolutely sharp border (the absolutely rigid object). Acoustic characteristics of such environment are stable, their deviations with in a zone of sounding are absolutely small.

We will take a signal of radiation and reception of ultrasound for material points, which are placed in focus of the field of radiation and reception of a signal by the sensor – converter. In the drawing 1 point of P designates

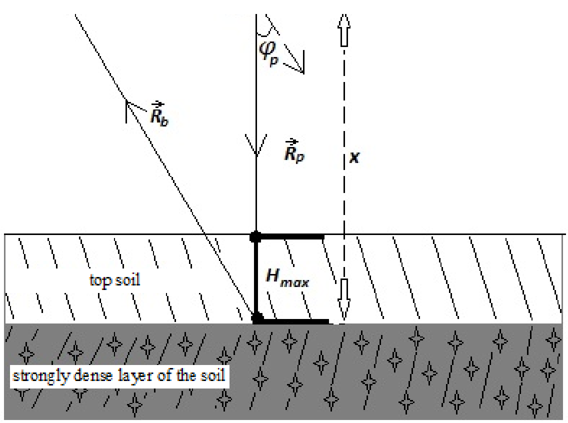

Figure 2. The scheme of a prozvuchivaniye of the condensed soil layer

Source: author's working out

the center of flat waves which are radiated by the sensor and the point B is a midfield of reception of a signal the sensor.

The ultrasonic sensor – converter forms the acoustic field in soil layers

by signal which arrived from point P which at the maximum depth of sounding is characterized by the chart of the direction $j_p(x_p)$. This function distributes amplitude of waves in the direction of a signal of radiation. Similar to a signal which accepted the sensor (point B) has the chart of the direction $j_b(x_b)$ which characterizes sensitivity of the sensor to signals which arrive.

As strongly condensed soil layer lies at a certain depth and is not the top layer that amplitude of sound waves the sensor passes distance x to the condensed soil layer from a signal which was radiated in point P. Amplitude of the radiated signal depends on the chart of the emitter of the direction j_p (x_p) and on distance x.

The amplitude falling waves is equal: $\frac{j_p(x_p)}{|\overrightarrow{R_p}|}$.

The amplitude of the reflected waves is equal: $\frac{j_b(x_b)}{|\overrightarrow{R_b}|}$.

The acoustic path is a way of an ultrasonic signal from the emitter to border which reflects ultrasound, and back to the emitter. To calculate an acoustic path – it means to determine amplitude of a useful signal depending on a depth of strongly condensed soil layer, from acoustic behavior of the top layer of the soil and frequency of fluctuations. The amplitude of reflection of a wave depends from that on how many the soil is strongly condensed: the soil is more dense, the wave will be reflected stronger.

When the same converter works for the radiation and acceptance of a signal, pressure on the converter will be:

$$P = \frac{K}{S} P_o j^2(x) \text{ [4, p. 115]}, \tag{27}$$

where P_o i P – the amplitude of the signals which the converter radiated and accepted, S – an area of the converter, K – the reflection coefficient from the condensed soil layer, $j(x)$ – the function describing spatial distribution of the field of radiation.

The divergence of beams is excluded for flat waves. Weakening of such waves is caused by attenuation in the environment. The coefficient of reflection K has uneven frequency characteristic. In case of limit of the section of two environments it changes with a frequency or from a long wave of radiation. But in our case, when absolutely rigid body is the reflecting environment, it is possible not to consider frequency properties and to use some simplification:

$$K = \alpha \cdot H_{max}, \tag{28}$$

where α – the coefficient of attenuation in the top layers of the soil, H_{max} – the maximum depth of sounding (the depth of strongly condensed soil layer).

With the maximum depth of sounding the function monotonously decreases behind the law:

$$j(x) = \frac{S}{lx} \text{ [4, p. 115]}, \tag{29}$$

where l – wavelength, x – the distance from the sensor – converter to strongly condensed soil laye, S – an area of the converter.

Therefore, the pressure on the receiver on the maximum depth of sounding will be:

$$\left|\frac{P}{P_o}\right| = \frac{\alpha H_{max}}{S} j^2(x) = \frac{\alpha H_{max}}{S} \times \frac{S^2}{l^2 x^2} = \frac{\alpha H_{max} S}{l^2 x^2} \text{ [4, p. 116]}. \tag{30}$$

The relation of the maximum depth of sounding to a square of wavelength characterizes the reflecting properties of the condensed layer (the coefficient A_σ):

$$A_\sigma = \frac{H_{max}}{l^2} \text{ [4, p. 116]}. \tag{31}$$

And so, through coefficient we will write down a formula an echo – signal which arrives to the sensor with the connected scheme:

$$\left|\frac{P}{P_o}\right| = \left|j^2\right| A_\sigma \frac{l^2}{S} \text{ [4, p. 116]}. \tag{32}$$

The echo signal received in in the form of temporary dependence is as a rule. It is inconvenient for definition of a depth of the condensed soil layer, therefore we will carry out transition from time to length of a run of waves scaling on acoustic speed:

$$c : l = c \cdot t.$$

Formulas (30) and (32) establish connection of a subject to control (the condensed soil layer) with an echo – signals which arrive to the sensor receiver. The information on subject to control is encrypted in an echo – signals thus:

1. The function $j(x)$ is modelled by reflection coefficient (31), and the scheme of sounding perceivs subject to control $\boldsymbol{O_c}$ as function of a look: $O_c = j(x) \cdot K$;

2. Subject to control $\boldsymbol{O_c}$ is modelled by keenness of the scheme of sounding and integrated by wave run length l;

3. Function of distribution of the reflecting surfaces gives in to turning with function of a response at the maximum depth of sounding and distribution of echo – signals is formed.

5. Conclusions

It turns out that the question ultrasonic fluctuations with the soil was not considered in geolocation earlier. Was considered that it is impossible to probe the soil deeply. But considering that strongly dense soil lies at most at a depth of 36 cm (depth small) and we do not need to define what subject it is placed underground. And are interested for we only such qualities as: the subject density, its ability to contract, that is deformation processes in it.

Having studied acoustic behavior of strongly dense layer of the soil, came to a conclusion that it behavior it is absolutely close to behavior of absolutely rigid body. But all problem is in that, what absolutely rigid bodies do not consider in acoustics at all, as in them deformation processes are impossible.

Taking this fact in attention, considering that the soil the layered environment, we decided to be the basis for our researches, at first sight – paradoxical situation: the ultrasonic wave will never pass through absolutely rigid body.

Theoretically we understood that the ultrasonic wave surely must to be reflected from a dense layer of the soil. It was necessary to simulate interaction of ultrasound with the layered environment where the lower layer is strongly condensed. It was necessary to understand: as the acoustic signal will be formed in this case. Having considered all these nuances, having considered all these nuances, considering that works on cultivation of the soil are carried out in the environment, taking into account the strong absorbing properties of soils, it was necessary to develop the special ultrasonic sensor, as the traditional sensor (as, for example, for the sonic depth finder) here is not suitable.

But it will not be possible to disperse in the solution of this question especially. Because if the soil has a dense vegetable covering, then level distribution of a sound can decrease in addition on 5-6 dB. The temperature of the soil or air gives the prize or loss to 5 decibels concerning attenuation or dispersion of a sound wave. But most of all renders wind and air on passing of a sound wave: acoustic speed develops with a wind speed. The wind can increase or reduce attenuation of a sound on the route of passing to the soil. The wind can increase sound level to 5 dB and also to lead to additional attenuation in 20 dB. If the sound wave moves in the direction of wind, then its speed increases (there is a concentration of sound energy) and if moves against wind – that decreases (the phenomenon of an "acoustical shadow" is observed).

It was necessary to minimize contact of the sensor with air. Completely it will not be possible to avoid this contact. Therefore it is necessary to reduce distance from the sensor to the soil. For this purpose both laboratory and field researches were conducted. Specially created models of soils were an object of researches in laboratory. In these models of soils at different depths the condensed material (wooden boards) was placed. The analysis of the received results of researches showed: if increases a depth of the condensed soil layer that the measurement error increases (for depth 0,25 m – from 4 to 14%, for depth 0,5 m – from 6 to 16%). The most exact measurements were reached at installation of the sensor at the height of 20 cm (the error made 4–6%), and with increase in height of installation of the sensor the error increased. Increase in contact of the sensor with air distorts measurements.

Similar results showed also field researches. Also it was established that within the speed of the tractor from 8 to 12 km/h systematic changes of measurements of a depth of strongly dense layer of the soil are not established. Indicators of measurements of our device differed from indicators of the hardness gage of Revyakin from -9,4 to +16%. Summing up the results, it is possible to claim surely that application of ultrasound for loosening of the soil with a height of sensor at no more than 20 cm and and at a tractor speed from 8 to 12 km/h.

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