Fig. 5. The vector field at the time t=0.96 ms.

and to build the stress-strain diagram. The stress-strain diagrams for three types of grains interaction are presented in Fig. 2. All diagrams are nonlinear and hysteretic. The hysteresis squares in the viscoelastic and elastoplastic cases are greater then in the elastic one.

The second part of the report is devoted to the propagation of nonlinear wave in structured media in gravitation field. The massif consists of 56000 elements with the elastic Hertzian contacts (Fig. 3). The wave is generated by the same procedure as in the first case. Averaged mass velocities are calculated at six distances away from the piston by averaging the velocities of particles in thin layers. The dependences of the averaged velocities on time are presented in Fig. 4. The propagating wave rapidly decays being transformed then into a periodically one. Fig. 5 shows that in the massif periodical wave structures are formed. If the massif is in a prestressed state the wave attenuates slowly and the wave structures do not arise. The prestressed state is created by the z-direction weighting.

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Efficient method for solving the resistivity sounding inverse problem

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The aim of electromagnetic sounding including the logging is to determine medium parameters on the base of measurement data. In other words, it is necessary to associate each vector **g** from the measurement space **G** to vector **p** from the space of model parameters **P**. The finding of such correspondence determines the essence of solving the inverse problem.

Traditionally in solving the logging inverse problem, it is accepted to use a minimization of the functional:

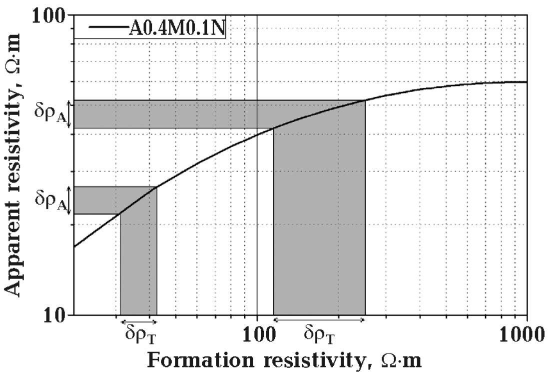
$$F\left(\rho_1^T,\ldots,\rho_n^T\right)=\sqrt{\sum_{i=1}^{n}\left(\frac{\rho_i^T-\rho_i^P}{\delta_i\rho_i^T}\right)^2}\,, \qquad (1)$$

where: n is the number of sounds in the equipment, ρ_i^T are computed theoretical values of apparent resistance (AR) of the model under consideration, ρ_i^P are values obtained really in AR measuring and δ_i is the value of error for i-th sound. The values of model parameters, to which computed ρ_i^T correspond at each step of the iterative process of minimization of the functional (1) shall be the solution of the inverse problem. This approach was devised and described in details in many articles (L. E. Kneller, A. P. Potapov, M. I. Epov, G. K. Gorbik, S. M. Zundulevich, A. E. Kulinkovich, M. D. Krasnogon etc.). At the present time this method is commonly used in practice (for example in programs: Mikar, Electra, VIKIZ etc.), we shall refer it to as “now used method”.

In the present work, it is shown that practical use of such approach is not quite correct since instead of vector $\mathbf{g}$ the spatial domain $\mathbf{g}+\delta\mathbf{g}$ should be our initial condition (taking into account an error, a result of any variation is non-numerical, a confidence interval (CI)). Accordingly, the inverse problem solution shall be not $\mathbf{p}$ vector, but a $\mathbf{p}+\delta\mathbf{p}$ spatial domain. The results of minimization (1) reflect only the relationship between vectors $\mathbf{g}$ and $\mathbf{p}$, but do not reflect any relationship between $\mathbf{g}+\delta\mathbf{g}$ and $\mathbf{p}+\delta\mathbf{p}$. For example, Figure demonstrates the dependence of apparent resistivity ρ_A on formation resistivity ρ_T for resistivity logging sound A0.4M0.1N. As it is shown in the figure, the values of $\delta\rho_T$ corresponding to the same value of $\delta\rho_T$ can change substantially depending on a part of range. And in accordance with the above-stated, in this case the interval of $\delta\rho_T$, but not the value of ρ_T itself, is the solution of inverse problem. Thus, the method of inverse problem solving should primarily minimize the domain of $\mathbf{g}+\delta\mathbf{g}$. As was found, it can be easily realized. The idea of the proposed method consists in the replacement of functional (1) by functional:

$$F\left(\rho_1^T,\ldots,\rho_n^T\right)=\sqrt{\sum_{i=1}^{n}\left(\frac{\rho_i^T-\rho_i^P}{\lambda_i\rho_i^T}\right)^2}\,, \qquad (2)$$

where: λ_i are weighting coefficients determined from the condition $\inf\limits_{\lambda_1,\ldots,\lambda_n}\left(\left\|\delta\mathbf{p}(\delta\mathbf{g})\right\|\right)$ and in solving the inverse problem determining the measure of influence on the confidence interval of every of model parameters, respectively.



Apparent resistivity (ρ_A) as a function of formation resistivity (ρ_T).

Table 1. Parameters of different bed models

Type of bed	Fluid content	ρ_T, Ω·m	ρ_{x0}, Ω·m	D/d
1	water-saturated	4.5	20	5
2	gas-saturated	50	30	5
3	oil-saturated	8.5	30	4

Table 2. Compared error in solving the inverse problem with using two methods (I — now used, II — proposed) for 7IK equipment

Type of bed	I			II		
	ρ_T, %	ρ_{x0}, %	D/d, %	ρ_T, %	ρ_{x0}, %	D/d, %
1	37.1	12.0	23.7	5.4	2.5	5.3
2	15.6	16.3	23.1	6.4	4.1	6.4
3	41.5	42.8	34.0	3.7	6.1	3.1

Table 3. Compared errors in solving the inverse problem with using two methods (I — excisting, II — proposed) for MEK equipment

Type of bed	I			II		
	ρ_T, %	ρ_{x0}, %	D/d, %	ρ_T, %	ρ_{x0}, %	D/d, %
1	19.4	32.4	72.1	13.3	15.2	13.1
2	14.1	26.1	51.6	4.9	13.0	12.7
3	17.8	29.2	47.4	5.3	14.1	18.2

To estimate the efficiency let us give some examples of comparing the proposed method of solving the inverse problem with the now used method. For that end, let us consider models of typical invaded beds corresponding the conditions of the Dnieper-Donetsk depression (model parameters of considered beds are given in Tabl. 1; where: ρ_T is the formation resistivity, ρ_{X0} is the invasion zone resistivity, D is the diameter of invasion zone, d is the rated well diameter). The 7IK seven-sound equipment for induction logging (a modified analogue of AIT Schlumberger) and the MEK multisound equipment for electric logging (a modified analogue of HRLA Schlumberger) were chosen as the sounding equipment.

The results of comparison between these methods for 7IK are given in Tabl. 2, and the ones for MEK are given in Tabl. 3. It is evident that the proposed method is significantly more precise than the one used traditionally. Similar calculations were performed for all spectrum of models of payout beds relating to the Dnieper-Donetsk depression and Western Siberia. It shall be noted that effective practical use of the proposed method has become possible owing to the development of computers since it require considerable computer resources: actually to determine the confidence interval for each of determined parameters of every concrete bed it is necessary to solve the inverse problem for several different values of initial data.

The following conclusion was made on the base of conducted study: the solution of inverse problem based on the minimization of functional (2) is more correct and accurate than in case of use of the minimization of functional (1).

Method for improving the spatial resolution of resistivity logging

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The main aim of resistivity logging is to determine geometric and electrical parameters of a model of borehole environment. Subsequent problems of geophysical investigations of well, such as determinations of fluid saturation, daily flow of fluid production and others will be solved the more precisely, the more precisely these parameter are determined. Sounds in the complex differ each from other as to the depth of investigation and the vertical resolution (along the axe of well). Naturally, the vertical resolving power is worse for sounds with larger depth of investigation. In this connection, the necessity to build sounding system for logging with the maximum high vertical resolution of all sounds including the most subsurface ones.

A creation of such equipment based on traditional principles is complicated by the necessity to use frequency, spatial or time separation, what complicates considerably the design (a creation of effective equipment with more than two sounds was found practically impossible). A creation of such equipment for induction logging are also complicated because of fundamental design limitations.

A factorization is believed an affective approach to create sounding system for logging with the maximum high vertical resolution of all sounds including the most subsurface ones. The factorization permits to solve separately the inverse problem along the axe of well and along a normal to it. It means that in each point of sound's position we can believe that the bed has infinite thickness (is free of shoulder effect). In this case, the conductivity values will change only along the normal to the axe of well.

The following methodical approach was used for induction logging: to determine the resistivity according to the apparent resistivity measured within the frame of the linear Doll theory using a solution of the first kind Fredholm equation of convolution type. The present method was tested on model material from various complexes (4IK, 7IK, AIT Schlumberger). The example of application of such method to data of 4IK equipment is shown in Fig. 1 (sounds: I0.5; I0.85; I1.25; I2.05. The numbers corresponds to the length of each sounds). It is evident that using the proposed approach permits to factorize the problem with high degree of accuracy. In the work, it is also shown that after such factorization the vertical resolution of each sound is limited only by the error of measurement and the value of recording step along the axe of well.