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Analysis of Seismic-Acoustic Data of an Active Space-Time Monitoring of a Geological Hierarchic Two Phase Medium from the Point of View of an Open Dynamical System

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Summary

That chapter is devoted to use the approaches of the theory of open dynamical systems to research and analyze the behavior of the rock massif and oil saturated inclusions in it. The method of construction phase diagrams, using data of an active seismic and an electromagnetic monitoring, shows its effectiveness for the reflection of the changing of the massif state and oil mobility. That is a significant information for the action managing on rocks and oil saturated massifs. All the discussed data had been obtained in real natural mines or boreholes.

11.1 Introduction

It is hold an empirical fact about the influence of a vibration on the acceleration of oil extraction processes. The physical explanation can be that model. The active medium has a high inner energy and often no equilibrium state. Therefore, the influence signal can synchronize or have a synergetic effect on the meso processes in the zones of a maximum instability, a low strength and a high fatigue of the medium on the meso level. On these levels, the action energy can accumulate in meso structures and initiate mechanical effects, which lead to mechanical movements and a medium fragmentation (Lavrov and Shkuratnik, 2005).

For crack-porous collectors, which are in the process of operating by the method of a high liquid head water displacement of oil, the possibility of intensification of ultra sound oscillations can be a technique of large importance. Even a very weak ultra sound can destroy, during a long time, action viscous oil films, occuring in cracks among the blocks, and which can be a reason of a decreasing layers permeability and an increasing extraction of oil (Alekseev et al., 2001, chapter 9).

To describe these effects, we need to consider the wave process in a hierarchic block medium and to theoretically study the mechanism of self-oscillations origin by the action of relaxation shear stresses (Hachay and Khachay, 2008, chapter 9).

From the other side, the oil layer, which is acted by a periodic vibration effect, is an open dynamical system. The latter acted by a natural and an artificial influence on different scale levels, which changes its state, and leads to a complicated varied ranked hierarchic evolution. It is known that the most geological systems are open and non equilibrium, which can long exist only in the regime of the energy through circulation. The closing of the energy flow makes_the system transfer in a conservation stage, when the duration of its existence depends on its energy potential due to an accumulated energy on the previous stage (Letnikov, 2007). On a certain stage of an open dynamical system evolution, the exchange by the matter and energy with the surrounding medium, decays on a set of subsystems, which in their turn can decay on smaller systems. The criterion of defining boundaries of these systems is one of the synergetic laws: macroscopic processes in the systems, that exist in a nonlinear area with a self-organization processes, are cooperative, coordinated and coherent. The base of the processes of self-organization in the open non equilibrium geological systems is the energetic origin. If the energy potential does not achieve its threshold value, the processes of self-organization do not begin. If it is sufficient to compensate losses to the outer medium, the processes of self-organization will begin in the system and form space-time or time structures. The transition from the chaos to a structure is performed by a jump. If the income of the energy is too much, the structurization of the medium finishes and the transition to the chaos begins.

In any arbitrary open dissipative and nonlinear systems, self-oscillating processes are generated. They are sustained by outer energy sources, due to the self-organization existence (Letnikov, 2007).

The paradigm of physical mesomechanics, formulated by the academician V.E. Panin and its school (Panin, 2005, chapter 9), which includes the synergetic approach, is a constructive tool for research the state and its variation of heterogenic materials. That result was obtained on specimens of different materials. In our research of no stationary geological medium, in the frame of natural experiments in a real rock massifs, which are under a heavy man-made action, we showed that the variation of the state can be distinguished with the use of a synergetic approach in hierarchic media (Hachay and Khachay, 2005a; Hachay, 2007, chapter 9). The combination of the active and passive geophysical monitoring plays a significant role for the study of dynamical geological systems. That can be realized with the use of the electromagnetic and seismic fields. The change of the system state on the used space bases and times can be observed on the parameters linked with the structure medium peculiarities of the second or higher rank._Thus, the research of the state dynamics, its structure and effects of the self-organization in the massif can be provided by geophysical methods, set on a many ranked hierarchic non-stationary medium model.

From the mathematical point of view, a dynamical system is an object or process, for which the concept of a state is defined as a set of values in a given time and an operator that defines the evolution of the initial state in time (Tshulichkov, 2003, chapter 10). If for the description of the system state evolution, it is sufficient to know its state in a given moment of time, that system is denoted as a system with discrete time. Let the set of numbers be defined as $\mathbf{x}=\{x_1,x_2,..x_N\}$in a time moment describing the state of a dynamical system and the different sets $\{x_1,x_2,..x_N\}$ correspond to different states. Let us define the evolution operator, indicating the velocity of each system state change, as:

$$\frac{\partial x_i}{\partial t}=F_i(t,x_1,x_2,...,x_N),i=1,...N \qquad (1)$$

x - a point of the Euclid space $\mathcal{R}_N$, which is named as the phase space, x - the phase point. The system (1), for which the right part does not depend on time, is named autonomous. By investigating the dynamical system, which describes the change of oil layer state by the vibration action, the right parts of equations (1) will depend on time, and the system will not be autonomous. If the system (1) completes with the initial conditions x(0)=x0, we shall obtain an initial conditions problem (problem Koshi) for (1). The solution {x(t), t>0} belongs to a set of points of the phase space $\mathcal{R}_N$, which forms a phase trajectory; the vector-function F(x) specifies the vector field of velocities. The phase trajectories and vector field of velocities give a descriptive representation of the system behavior character over time. The set of phase trajectories corresponds to different origin conditions, and forms a phase portrait of the dynamical system.

The dynamical systems can be divided on conservative and dissipative systems. For the first type, the whole energy of the system is conserved, while for the second type, there can be energy losses. As regards to our problem dealing with the study of the massif state, which is in a state of oil recovery, the best model is a heterogeneous and no stationary dissipative system. Nevertheless, there can occur in the massif such local places, that will be described by a conservative dynamical model, i.e. a energetic equilibrium model.

11.2 Analyses of the Phase Portrait of an Open Dynamical System

The analyses of the phase portrait of the dynamical system allow us to make a conclusion about the system state during the period of observation. So, in conservative systems, attracting sets do not exist. The set of the phase space $\mathcal{R}_{\mathrm{N}}$ is named attracting; and its trajectories tend with time and begin in its neighborhood. If in conservative system, a periodical movement exists, thus such movements are infinite and defined by the initial value of the energy. In dissipative systems, the attracting sets can exist. Stationary oscillations for dissipative dynamical systems are not typical. However, in nonlinear systems, a periodic asymptotic stable movement can exist. Its mathematical image can be described by a limited cycle represented in the phase space as a closed line, and to which all the trajectories from some neighborhood of that line tend in time. We can investigate the characteristic behavior of the system by analyzing the form of the phase portrait. As a remainder, the “smooth” deformations of the phase space do not lead to quality changes of the system dynamics. That property is called a topologic equivalence of phase portraits. It allows analyzing the behavior of different dynamical systems from the unique point of view; on that base, the set of dynamical systems can be divided into classes inside of which the systems show an identical behavior. Mathematically, a “smooth deformation” of the phase portrait is an one-to-one and a bicontinuous transformation of the phase coordinates, for which new singular points can not occur, and on the other hand, singular points can not vanish.

The results of the rock massif phase state researches obtained earlier (Hachay, 2004, chapter 9, 2005, 2006; Hachay and Khachay, 2005 a,b, 2006, chapter 10; Hachay et al., 2001, 2003, chapter 9) testify that the classification of the massif by its stability and further control can be effectively performed, using the parameter *Spint* (the interval intensity of the second rank heterogeneities, according to the obtained geomechanical terminology), and allows to locate the zones of the disintegration. Besides, by using the parameter of the integral intensity *Sp,* we can see a good agreement with data of the seismological monitoring provided in the same research space such as the active electromagnetic monitoring. Therefore, for constructing the phase portrait of a massif state on different horizons and holes, located on different distances from the production face, we use as phase coordinates: the parameters *Spint* and d/dt*(Spint)*, and also *Sp* and d/dt(*Sp*), defined by the interpretation of data corresponding to seven cycles of an active electromagnetic monitoring (chapter 9). Under symbols *d/dt(Spint)* and *d/dt(Sp)*, we shall understand the difference of successive (in time) values, the time interval is one year. In our case, the phase trajectory denotes the discrete set of points on the phase plane defined by phase coordinates in the given time sequence corresponding to the observation cycles. All phase trajectories can be divided into three groups according to the area on the phase plane and to its location on the centroid (fig. 1). Under the area which belongs to the phase trajectory on the phase plane, we shall understand the exact low boundary of the areas set of the convex polygons containing that phase trajectory.

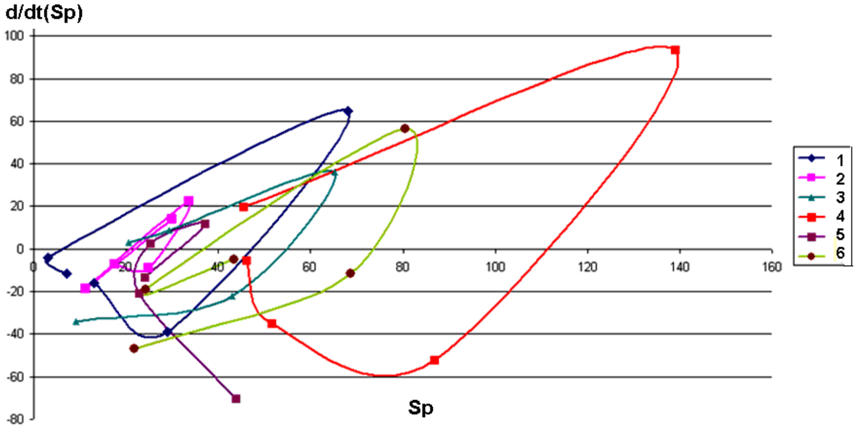

Figure 1. *Phase portrait of the massif state down the near hole space of different holes. The frequency of observation is 20 kHz. 1- horizon - 210, ort 8-7, 2- horizon-210, ort 4, 3 - horizon-350, ort 18, 4 - horizon -350, ort 19, 5- horizon. -350, ort 20, 6- horizon-210, ort 2.*

The constructed centroid can also occur at a point of attraction, but due to the lack of sufficient data, the so-called centroid, cannot describe that phase trajectory.

The extracted three groups by new signs as a whole coincide with the earlier classification, using the parameter *Sp int* (previous two chapters):

- A stable massif (horizon -210, ort 4) -the smallest area of the figure of the phase plane.
- A quasi stable (horizon. -210, ort 2), (horizon -350, ort 18) - the intermediate area corresponding to phase trajectories.
- And a non stable massif (horizon -350, ort 19) -the maximum area, described by the phase trajectory.

From the developed result, the phase trajectory for the massif (horizon -350, ort 20, fig. 1) is strongly deviated, according to the data of the year 2005, from its previous localization during five cycles of observation. This can testify about the activisation of the massif and about the massif state transition to the class of quasi stable. The analysis of the phase trajectory for the massif horizon -210, ort 7-8 using the phase coordinates *Sp* and *d/dt (Sp)* is of a special interest. The area, which is described by the phase trajectory of that massif, insignificantly differs from the corresponding areas for quasi stable massif (Fig. 1). At the same time in the area limits of that ort, extensive energetic dynamical events-tectonic rock shocks occurred. From the other side, according to the classification using the parameter *Spint*, that massif was classified as non stable massif.

Let us consider phase portraits, constructed using an interval distribution of the intensity *Spint* (Figs. 2a-c).

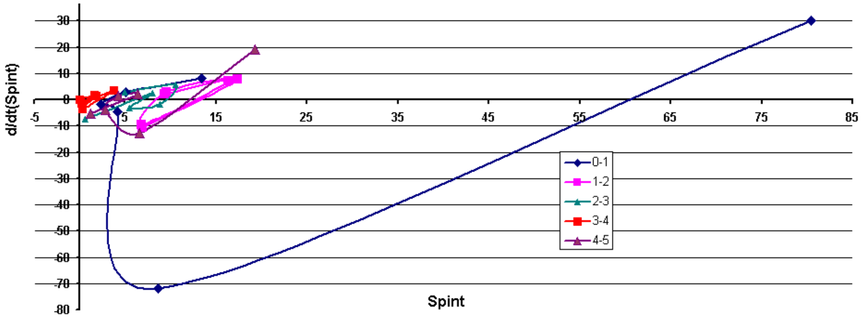

Fig.2a

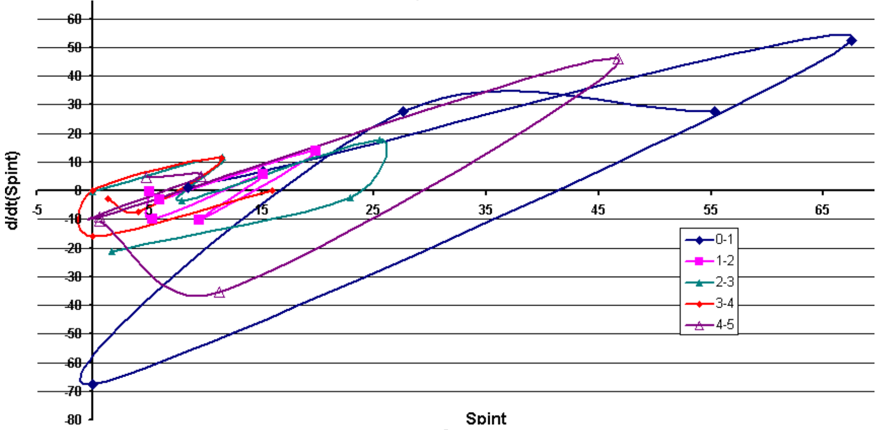

Fig.2b

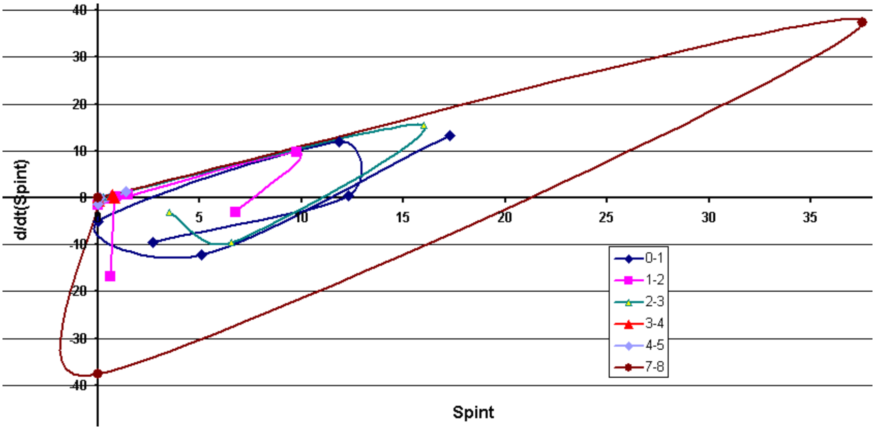

Fig.2c

Figure 2. *Subinterval phase portraits: a - horizon -350, ort 20, b - horizon -350, ort 19, c - horizon -210, ort 7-8. The frequency of observations is 20 kHz. The intervals down from the hole contours are given in the legends in meters.*

As regards the massif ort 20 (horizon -350), we can see, that the sharp increasing of the phase trajectory area is observed in a layer, located near to the contour of the hole during the two last cycles(fig. 2a). The phase subinterval portrait of the massif ort 19 (horizon -350) demonstrates the difference of the areas, which are described by phase trajectories on different levels of the hole contour (fig. 2b). So, on the first interval and on the fifth interval, the areas have the largest values. Since the chosen phase coordinates characterize the subinterval activisation and the subinterval velocity of the activisation, we can connect the effect of areas, described by increasing phase trajectories with the increase of the intensity of dissipative processes in the massif in the corresponding depth intervals. That assumption must be verified by a more wide material. The centroid, depicted by the phase trajectory for the fifth interval, is strongly shifted to the area of large phase coordinates, and can characterize the larger potential tendency to dissipative processes. This can lead to a destruction in the massif.

On intermediate intervals, the phase trajectories are similarly located in the quasi stable massif. At last, the analysis of the phase subinterval portrait of the massif state ort 8-7, horizon. -210 shows that the significant non stability of the massif was a consequence of a sharp heterogeneity of the subinterval tendency to an energy dissipation. On the interval from 3 to 7 m, the phase trajectories are almost located near zero of the phase plane. At the same time on the intervals 7-8 m, significant dissipative processes occured, and practically stopped during the last 2-3 cycles. It can be noted that the phase trajectory also came near to zero.

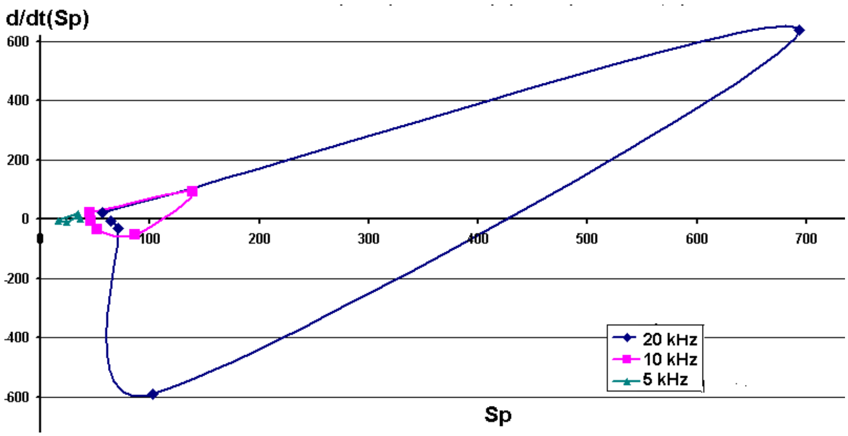

Fig. 3a

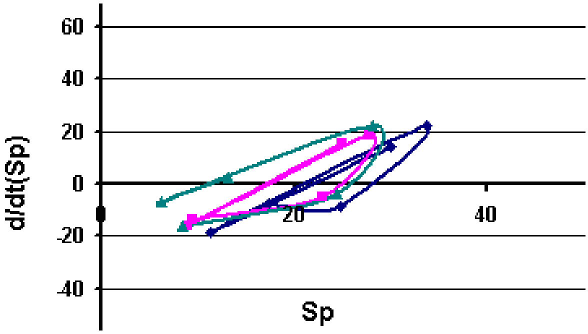

Fig. 3b

***Figure 3.** The frequency dispersion of the massif state phase portrait. a) Horizon -350, ort 19., b) Horizon -210, ort 4, the legend is the same to a).*

We can see that the stable massif (fig.3b), unlike the unstable massif (fig.3a), shows the absence of a frequency dispersion of the phase portrait, but the unstable massif illustrates a significant frequency dispersion in his phase portrait. It can also be used as criterions of the stability state of the massif.

11.3 Algorithm of the Phase Portrait (or the Diagram Construction) Using Data of a Seismic- Acoustic Monitoring and Its Results

Let us consider the algorithm of the phase portrait (or the diagram construction) using data of a seismic- acoustic monitoring. As a result of borehole monitoring, we have three sets of the intensity of the seismic-acoustic radiation: phone $I(t,z)_f$, after the first excitation $I(t,z)_{V1}$, and after the second excitation $I(t,z)_{V2}$ .These three functions for a fixed z are observed on a time interval of 14 seconds with a discretization frequency of 44100Hz and a step along the borehole of 0.5m. The whole time interval is divided into 14 subintervals with a 1- second length. In the range of each second, we smooth the observed data $I(t,z)_f$, $I(t,z)_{V1}$, $I(t,z)_{V2}$ in the intervals 0-0.1sec., 0.1-0.2 sec, 0.2-0.3 sec, 0.3-04 sec, 0.4-0.5 sec, 0.5-0.6 sec, 0.6-0.7 sec, 0.7-0.8 sec, 0.8-0.9 sec., 0.9-1. sec. Thus, we obtain a new base of the averaged data $I_s(t,z)_f$, $I_s(t,z)_{V1}$, $I_s(t,z)_{V2}$, for which phase diagrams on the planes are constructed:

$$\begin{aligned}&I_s(t,z)_f, \frac{\partial}{\partial t} I_s(t,z)_f; I_s(t,z)_{V1}, \frac{\partial}{\partial t} I_s(t,z)_{V1};\\&I_s(t,z)_{V2}, \frac{\partial}{\partial t} I_s(t,z)_{V2};\end{aligned} \tag{2}$$

Then, we determine:

$$\max I_s(t,z)_f, \min I_s(t,z)_f, \max\left|\frac{\partial}{\partial t} I_s(t,z)_f\right|,$$

Similarly, we perform for functions $I_s(t,z)_{V1}$ and $I_s(t,z)_{V2}$. After that, we calculate the areas of three figures (rectangles including the phase portraits of three sets of functions (2)), for example:

$$\begin{aligned} &A_f = (\max I_s(t,z)_f - \min I_s(t,z)_f) \times \\ &(\max\left|\frac{\partial}{\partial t} I_s(t,z)_f\right|, \frac{\partial}{\partial t} > 0 + \max\left|\frac{\partial}{\partial t} I_s(t,z)_f\right|, \frac{\partial}{\partial t} \le 0) \end{aligned} \quad . \tag{3}$$

The value (3) for each time interval equals to 1 sec, are designated by A_f, A_{V1}, A_{V2}, respectively. Then, we construct the phase diagrams on the planes: $A_f, \frac{\partial A_f}{\partial t}$; $A_{V1}, \frac{\partial A_{V1}}{\partial t}$; $A_{V2}, \frac{\partial A_{V2}}{\partial t}$; that will be analyzed for a description of the state of in a close proximity to a borehole oil saturated layer. This algorithm is realized using the Microsoft Excel Visual Basic language as a macro, allowing a fast smoothing with any arbitrary frequency and calculates the values (2) and (3). From the results of the processing using the developed algorithm, we can conclude that the phone phase diagrams before excitation highly differ by their morphology, their attracting point and the area under the phase trajectory for each point of observations along the borehole, corresponding to a high heterogeneity of the near borehole medium state. The phase diagrams before and after the first and the second excitation at the same point differ from each other for the similar criterions. That reflects the fact that near the borehole, the massif changes its state by the vibration action.

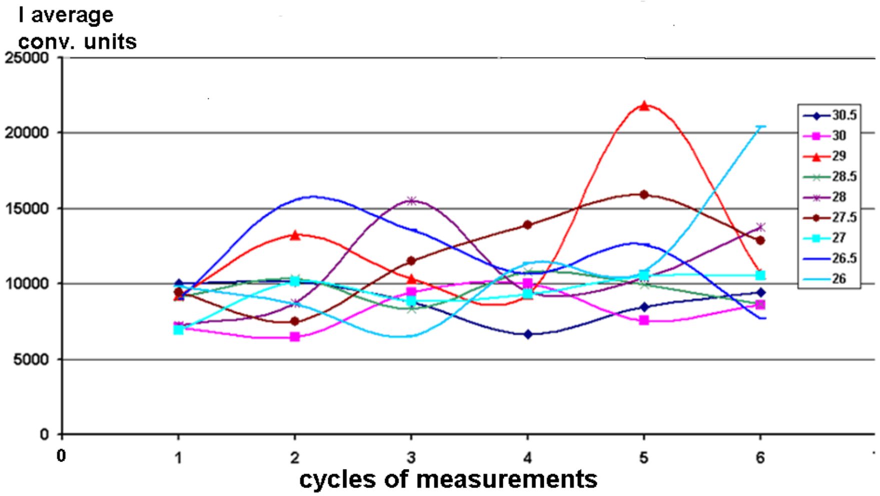

Figure 4. *Analysis of the processed results of seismic-acoustic monitoring data during 6 cycles of observation.*

Axis OX: 1-2-repeated cycles of phone observations, 3-4-repeated cycles of observations after the first excitation, 5-6-repeated cycles of observations after the second excitation. In the legend, the intervals of measurements (X(m) -2600(m)) are presented in meters in the borehole.

If the area under the phase diagram, after the first excitation, becomes larger, then the similar value before the excitation or the value $A^c_{V1} = (\max A_{V1} - \min A_{V1})$, becomes larger, than $A^c_f = (\max A_f - \min A_f)$.

That corresponds to a fact that the intensity of the seismic- acoustic radiation becomes larger, which is the situation of closing cracks and pores and reducing the liquid phase influence. If these parameters diminish, that means that the seism-acoustic radiation decreases, which corresponds to a larger flow of the liquid phase and an increase of its mobility in the given time interval and in the given point of observation. Similarly, we provide the phase diagram analysis after the second excitation.

Additionally, for the estimation of the results of an action on the near borehole massif, we introduced for each cycle of observation the parameter I (conditional units), calculated as an average of A_f, A_{V1}, A_{V2} and named as $\bar{A}_f, \bar{A}_{V1}, \bar{A}_{V2}$, respectively. That is performed for 6 cycles of observation (2 for each of the following data types: phone observations, the first and the second excitations).

From the results of the natural data processing on a space interval of 4m along the borehole (fig.4), the values of the seismic-acoustic intensity I change in the interval 6000-10000 (conventional units) for all the points of observations, except for the points 2629 m and 2626.5 m. Practically very low changes in the value I for the point 2627m, and they are bit larger for the points 2628.5m., 2630m., and 2630.5m. Only for two points 2627.5m and 2626m, a stable increase of the value I after two excitations is observed.

11.4 Conclusion

So we can testify that the rock massif of different matter contents is an open dynamical system. And we can analyze its state and structure, and their change by the use of an electromagnetic induction space-time discrete monitoring with an additional developed method of processing and interpretation described in all three chapters. The processing of the seismic-acoustic monitoring data using the developed algorithm leads to a point-to-point identification of the different degrees of the massif response on the excitation, which is linked with a complicated structure of three components (water, oil, and rock skeleton) near the borehole massif.

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