Study of Propagation of Long-Duration Vibrational Signals Through Geophysical Medium

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A model of the geophysical medium in which it behaves actively relative to elastic signals propagating in it has now come into wide use: it is capable of accumulating and then freeing the energy of elastic waves and elements of its microstructure are restructured under their influence. Hopes for success in active methods for modifying its state, such as an increase in the oil yield of reservoir strata as a result of weak but prolonged elastic irradiations, are based on this property of the medium.

Such a medium is called "active." It is evident that the properties of such a medium are dependent on the prehistory of its state, such as on the time of its irradiation by elastic waves. Accordingly, an active medium can be regarded as the same as a medium "with a memory."

A very simple phenomenon which can be observed in the geophysical medium with its elastic irradiation is the activation of seismoemission processes. In actuality, the processes of internal restructuring caused by the propagation of signals and accumulation of their energy, result in the redistribution of stresses, the appearance of microcracks, which causes the radiation of noiselike oscillations in a broad frequency range.

The principal ideological references pertinent to the possible transpiring of processes in a geophysically active medium are given in [1]. Some theoretical models of activity have been proposed. In [2] it is proposed that the tools from related fields of mathematical physics be used for its description; a model with internal oscillators is used in [3] as a model of an active medium.

There are individual communications on observations of stimulation of emission activity under the influence of prolonged vibration. For example, the authors of [4] described how under the influence of vibrator operation the medium emitted strong narrow-band noise at frequencies which were not registered prior to vibrator activation. It was noted in [5] how a medium, gradually being "pumped" by a vibrational signal, began to "emit noise" intensively.

In any case, at present there are only individual communications on registry of manifestation of the activity properties of the geophysical medium; accordingly, the volume of experimental observations must be built up.

It seems especially interesting to investigate the behavior of the medium at transitional times in activation and deactivation of the elastic field irradiating it. Proceeding on this basis, it is possible to visualize the following scheme for an *in situ* experiment for checking the property of activity of a studied medium. Activating the seismic recording apparatus at an appropriate time in advance, a prolonged background is recorded; then the vibrator is activated, the prolonged seismic process caused by its operation is recorded, the vibrator is cut off and the apparatus over some additional time records the residual background. The overall observation process must evidently extend over tens of minutes. The seismic "response" of the medium must be recorded in a broad frequency range so that it is possible to estimate the intensity of the noise component in different spectral windows.

Approximately this same scheme should be used in carrying out "ideal" field experiments. We made observations in a somewhat simplified form. This article describes the results of recording of a prolonged vibrational signal together with the moment of its "cutoff" and transition of the medium to a quiet state.

The scheme for our experiment was as follows. The work region consisted of a thick sedimentary mantle with a depth to the top of the crystalline basement about 3-4 km. A 50-ton vibrator was set up at the surface of the medium; it radiated prolonged monochromatic oscillations at a frequency 12 Hz for a period 10-15 minutes.

After the vibrator had operated for 7-8 minutes the recording apparatus was switched on and data were recorded for about 10 minutes. During this time the vibrator continued to operate for 6-7 minutes; then it was switched off and for 3-4 minutes the apparatus recorded the residual background.

A "Progress" digital seismic prospecting station with 24 recording channels, a quantization step of the records 2 ms and a recording frequency range 10-125 Hz, was used in recording. The oscillations were received by SV-10Ts seismic detectors.

The described observations were made at four points 2, 5, 8 and 14 km distant from the vibrator. The quiet time of day was selected for the observations. The registered vibrational signal

Table 1

Distance from vibrator, km	2	5	8	14
$\bar{a}$	$0.11 \cdot 10^9$	$0.12 \cdot 10^9$	$0.95 \cdot 10^7$	$0.91 \cdot 10^7$
σ_{n-1}	$0.31 \cdot 10^7$	$0.76 \cdot 10^7$	$0.24 \cdot 10^7$	$0.27 \cdot 10^7$
$(\sigma_{n-1}/\bar{a}) \cdot 100\%$	2,8	6,2	25,1	30,0

Note: The values of the spectral amplitudes are given in nominal units.

Table 2

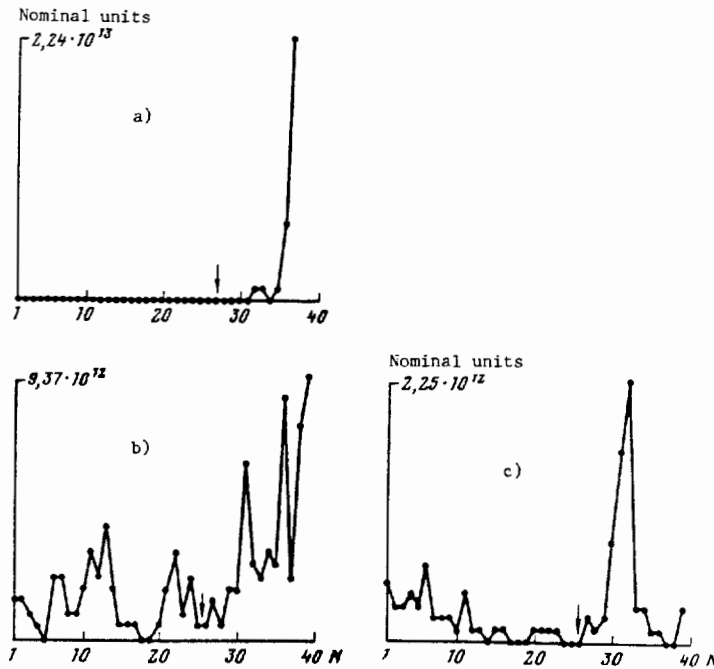| Distance of vibrator, km	2	5	8
$\dfrac{24 \text{ Hz}}{12 \text{ Hz}}$	1,39	1.98	—
$\dfrac{36 \text{ Hz}}{12 \text{ Hz}}$	0,26	0.38	—
$\dfrac{36 \text{ Hz}}{24 \text{ Hz}}$	0,19	0,19	1,03

Fig. 1. Dependence of spectral intensity of noise component of seismic field on position of segment of analyzed record in time. Range 64-128 Hz. a) 2 km from vibrator, b) 8 km, c) 14 km.

on the seismograms at all distances was discriminated visually with a signal-to-noise ratio not less than 10.

Data processing involved the following. The amplitude spectrum was computed on a computer in a "moving" 15-second window from the recorded

10-minute wave field records. The spectra usual-
ly contained several harmonics of the vibrational
signal, expressed by narrow peaks, between which
a noise spectral component was situated. Two
aspects were of interest: first, how does the
power (square of amplitude) of the noise spectral
component react to vibrator operation and "deac-
tivation," and how stable are the amplitudes of
the vibrational signal harmonics with time during
prolonged vibrator operation.

At a distance of 2 km from the vibrator
there was reliable discrimination of the harmon-
ics of the vibrational signal to the 5th-6th
harmonic inclusive; at individual distances it
was possible to discriminate the first three har-
monics reliably. The time-averaged amplitudes of
the discriminated harmonics $\bar{a}$, standard devia-
tions from the mean σ_{n-1} and deviations relative
to the mean in percent $(\sigma_{n-1}/\bar{a})$ 100% were com-
puted for all the "current" spectra of a 10-
minute record at each of four observation points.
Table 1 gives these data for the harmonic 24 Hz,
which was discriminated reliably at all distances.
The table clearly shows that the scatter of the
amplitude of the registered harmonic increases
substantially in time with increasing distance
of the registry point from the vibrator.

Table 2 gives the reciprocal ratios of the
time-averaged amplitudes of the first three har-
monics at different distances from the vibrator.
Since at a distance 14 km it was possible to
determine reliably only the harmonic at 24 Hz,
such ratios were not computed for this distance.
Table 2 shows that the ratio of the higher to
the lower harmonics increases with increasing
distance of the observation point from the vibra-
tor, which contradicts ordinary concepts concern-
ing stronger absorption of high frequencies in a
linear medium. The nonlinear mechanism of "pump-
ing" of the energy of high-frequency harmonics
at the expense of low-frequency harmonics, which
confirms the results given in [6], evidently
exerts an influence here.

Study [7] was recently published in which a
nonlinear character of propagation of harmonics
of a vibrational signal is denied. The results
cited here, obtained in a source other than in
[6], demonstrated that the ratios of the ampli-
tudes of the higher to the lower harmonics in-
crease with an increase in distance. In our
opinion this is additional evidence supporting
the appearance of nonlinear properties in the
medium.

Now we will examine the behavior of the
field noise component during the time of vibra-
tor operation and after its deactivation at each
of the observation points. Here the scheme for
processing the results involved the following.
The total intensity of the noise component (sum-
mation of the squares of the spectral amplitudes
of noise for a particular frequency range) was
computed in the spectrum of each successive 15-
second "window" of the 10-minute record in three
frequency ranges (16-32, 32-64, 64-128 Hz).
Then a graph of the dependence of this value on
the number N of the next record "window," that is,
position in time, was constructed. Such curves
for distances 2, 8 and 14 km are given in the
figure. The arrows denote the times of vibrator
"deactivation." The spectral intensity of the
noise in nominal units is plotted along the y-
axis. The following overall picture can be seen
from the curves. The intensity of the noise com-
ponent during the time of vibrator operation does
not exhibit any regular variation in time. How-
ever, all the curves reveal an increase in the
noise background with some lag after vibrator
deactivation. The curves in the figure apply to
the frequency range 64-128 Hz. Such a stable
effect was not discovered in the two other lower-
frequency ranges.

Thus, experimental research confirms the con-
clusion that the propagation of a seismic vibra-
tional signal causes a "response" of the geophysi-
cal medium. However, there are still few reliable
experimental results and they are quite contradic-
tory. For example, in [5] we observed how the
medium begins to "emit noise" some time after
vibrator activation. In our study this phenom-
enon was not observed as such but a noise res-
ponse of the medium to cutoff of the irradiating
elastic field was registered. On the other
hand, the authors of [4] noted a noise increase
after vibrator activation in the neighborhood
of several narrow spectral peaks. All this in-
dicates that the stage of accumulation of
reliable experimental facts has still not been
completed and further research will help in
analysis of the contradictory picture of ob-
served phenomena.

The second result of the experiments which
we described was an intensification in instabil-
ity of the vibrational signal with time with in-
creasing distance of the reception point from the
vibrator. If it is taken into account that within
the framework of an active medium model the signal
can exchange energy with the medium, it becomes
clear that the greater the path traversed by the
signal the more actively will such exchange pro-
cesses exert an influence on its characteristics.
Since energy exchange itself is nonstationary and
is essentially dependent on the time of "pumping"
of the medium by a source, the more distant the
observation point the more substantially will
this nonstationarity be expressed. These, to be
sure, are qualitative considerations, but they
are supported by the collected experimental data,
although we allow that these data may also have a
different explanation.

In conclusions the authors express apprecia-
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