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ON SEISMIC SIDE-LOOKING LOCATION WITH ANTENNA APERTURE SYNTHESIS

G.Ya. SHAIDUROV, V.V. SUHOTIN, D.S. KUDINOV AND M.A. KOPYLOV

This article has given an assessment of implementation possibilities of the method of seismic location using pulsed non-explosive sources and receivers that are placed in one transport base during the side looking of the geological environment and the synthesis of an equivalent aperture of transceiver antennas.

Keywords: seismic, location, aperture, synthesis, interface.

Nowadays radiolocation method of side looking (RMSL) with the synthetic antenna aperture is the classic way to increase the resolving power of the mapping systems with the location of transmitter and receiver on one carrier - airplane or satellite. [1] This method is also used in the technique of mapping of the sea floor, but with the usage of acoustic excitation and reception with the placement of all the complex on the submarine or surface vessel.

Essence of the method RMSL (Fig. 1) consists in the probing of the ground surface or sea floor with the sequence of pulses and receiving of the reflected signals from the profile plane relative to the transport base. As the transport base is moving, the received signals are stored and summarized, so that along the line of motion there is a synthesis of virtual antenna with the length equal to the summarized section of the transport base trajectory.

Since the length of the section of this trajectory is much higher than the base of transport base, as a result the equivalent length of the synthesized antenna determines the high resolving of the method RMSL.

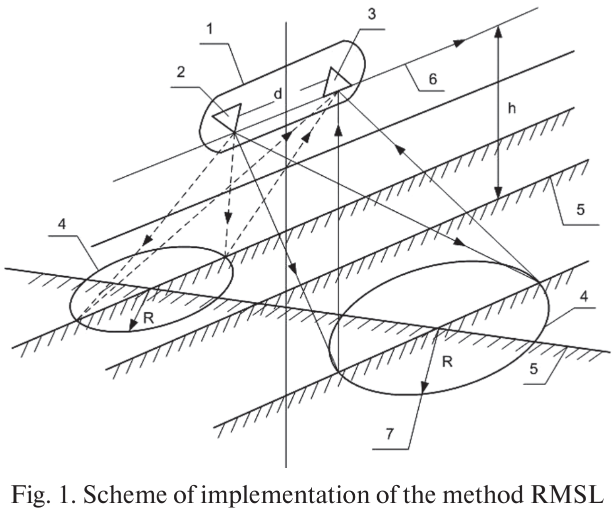

Fig. 1. Scheme of implementation of the method RMSL on one transport carrier: 1 – the transport base (carrier); 2 – the pulse non-explosive emitter; 3 – the geological receiver; 4 – the reflective spot; 5 – the surface of the reflective layer; 6 – the motion line of carrier; 7 – the radius of the first Fresnel zone; h – the depth of the reflective layer position; d – the system base

It is known that during the synthesis of the antenna aperture with the length L, the resolving power of the mapping of soil elements increases by $(L/\lambda)^2$ times, where λ – the length of the used wave.

Concerning the exploration seismology, this method is equivalent to the interference method of signal processing using groups of emitters (sources) and seismic receivers, but with the difference that both of them move together with a fixed distance between them.

This method is known in seismic exploration [2] of the high resolution as the term seismic locator of side looking (SLSL) with the usage of scattered waves. It's advantage is in the opportunity to study the fissuring of geological environment.

Implementation of the method RMSL in motion is possible both on land and water. In the first case, the aperture synthesis is performed simultaneously with the ordinary signal-processing technique, with the difference that geological profile is based on the indications of the seismic receiver or their "cables" that are the nearest to the source.

This technology is particularly relevant for marine exploration seismology with the work of one ship-carrier without the usage of seismometer cable assemblies under tow, as well as with the work on the rivers.

It is known that the work of exploration seismology in the mountain and taiga areas like East Siberia, is very difficult because of the need for heavy equipment, so the implementation of the method RMSL in the motion would solve many problems of exploration seismology that are not realized by other technologies.

For the scientific and technical justification of the method it is necessary to solve the following problems:

- To evaluate the loss in the ratio signal/interference by reduction of the frequency of processing;
- To determine the optimal length of the synthetic aperture taking into account the heterogeneity of the geological environment;
- To solve the technical problem of the simultaneous work of the source and seismic receivers on one transport base;
- To design the project of hardware complex of seismic locator and create a prototype of the water version;
- To carry out experimental and methodological work in the field conditions on the ground, as well as by the cameral treatment of prepared records on well-known deposits.

We will consider the problem of geological mapping in motion by the method RMSL of the two-layer profile including some heterogeneity in the first layer (Fig. 2).

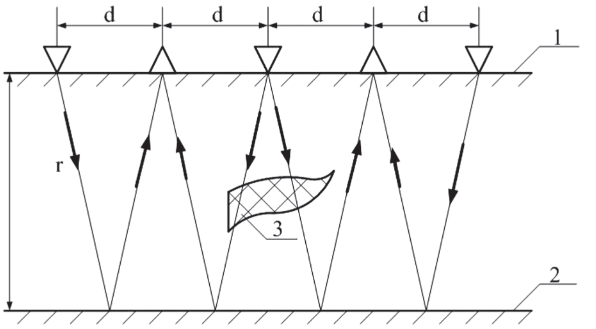

Fig. 2. The problem of geological mapping of the two-layer profile by the method RMSL: 1 — the first layer boundary; 2 — the second layer boundary; 3 — geological heterogeneity

Reflected signals along the line of motion can be written as the following:

$$u_i(t) = U_{mi} e^{-\alpha_i t} \sin(\omega t_i + \varphi_i) \qquad (1)$$

where i = 1,2,3 ... — the serial numbers of points of reflection; U_{mi} — the initial amplitude; α_i — the attenuation factor; ω — the operating frequency; t_i — the delay time on the path 2 r_i; φ_i — the initial phase.

Remembering and summation gives the following:

$$u\Sigma(t) = \sum_{i=1}^{n} U_{0i} e^{-\alpha_i t_i} \cdot \sin(\omega t_i + \varphi_i) \qquad (2)$$

If in the section of the synthetic aperture *L* there is *m* acoustic inhomogeneities with the speed of seismic waves v_j, while the average speed of homogeneous sections is v_{i-j}, then the total signal (2) can be written as the following:

$$\begin{aligned} u\Sigma H(t) = &\sum_{i=1}^{n-j} U_{0i-j} e^{-\alpha_{i-j} t_{i-j}} \cdot \sin(\omega t_{i-j} + \varphi_{i-j}) + \\ &+ \sum_{i=1}^{m} U_{0j} e^{-\alpha_j t_j} \cdot \sin(\omega t_j + \varphi_j). \end{aligned} \qquad (3)$$

Assuming that the parameters of the inhomogeneities are random, then the sum (3) will have the following limit:

$$\begin{aligned} u\Sigma(t) = &(n-j) U_{0i-j} e^{(n-j)\alpha_{i-j} t_{i-j}} \cdot \sin(\omega t_{i-j} + \varphi_{i-j}) + \\ &+ \sum_{i=1}^{n} \sqrt{U_{0j}^2 e^{-2\alpha_j t_j} \cdot \sin^2(\omega t_j + \varphi_j)}, \end{aligned} \qquad (4)$$

i.e. the second term (3) is summarized by the law of random quantities.

In this case, the ratio signal/interference will be the following:

$$\frac{u_c(t)}{u\ \ (t)} = \frac{(n-m) U_{0c-m} e^{-(n-m)\alpha_{i-m} t_{im}} \cdot \sin(\omega t_{i-m} + \varphi_{i-m})}{\sqrt{m}\sqrt{U_{0j}^2 e^{-2\alpha_j t_j} \cdot \sin^2(\omega t_j + \varphi_j)}} \qquad (5)$$

The ratio of the initial amplitudes:

$$\frac{u_{c0}}{u_{n0}} = \left(\frac{n-m}{\sqrt{m}}\right) \cdot \frac{U_{0i-m}}{U_{0j}} \qquad (6)$$

If n >> m, then:

$$\frac{u_{c0}}{u_{n0}} = \frac{n}{\sqrt{m}} \cdot \frac{U_{0i-m}}{U_{0j}}. \qquad (7)$$

Noises (microseisms) that are uncorrelated with the signal will be summarized despite of their independence also as the random quantities, i.e. there will be summarization of their two dispersions:

$$u\Sigma N = n \cdot U_{Nn}. \qquad (8)$$

If the total length of the synthetic aperture *L* will contain $n = \frac{L}{d}$ signal reference points, then the multiplicity of the method RMSL will match this quantity.

Next, we will give an assessment of the reasonable length of the synthesized amplitude L, based on the spherical symmetry of the diagram of the radiation source direction (Fig. 3).

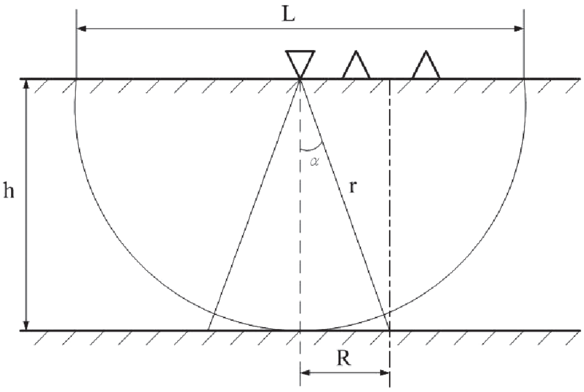

Fig. 3. For the assessment of the reasonable length of the synthesized aperture

We will assume that the area of the active zone of the reflective layer is determined by the radius of the Fresnel zone:

$$R = \sqrt{\frac{\lambda h}{\cos\alpha}}, \qquad (9)$$

where λ — the average length of the radiated seismic wave.

In this case, the length of the coherent section of the reflective layer will be the following:

$$L = 2R. \qquad (10)$$

For example, when *h* =4000 m; λ=100 m; cos α=1:

$$L = 2\sqrt{4 \cdot 10^5} \approx 1400\,\text{m}.$$

When *h*=100 m; λ=100 m ; *L*=200 m.

During the motion of carrier at a speed *v* and the count interval between the operating points Δ*t*, the number of summarized signals on the section of aperture *L* will be the following:

$$h = \frac{L}{v \cdot \Delta t}. \qquad (11)$$

For example, during the motion of the ship at a speed of $v = 10$ km/ $h \approx 3$ m/ s , the number of counts for *L*=1400 m will be the following:

$$n = \frac{1400}{3 \cdot 10} \approx 46 \,. \qquad (12)$$

This quantity will be the summation factor, and the ratio signal/interference increases in amplitude by $\sqrt{h} \approx 7$ times.

The given calculations are made for the case of specular reflection.

With the small transport base, i.e. separation between emitter and receiver, it is difficult to implement the alternative of reflection specularity because of the influence of reverberations. For this reason, it is necessary to use the side looking that naturally reduces the level of useful signal. The problems of the method implementation for solving problems of exploration seismology in the Arctic basin are presented in [3].

It should be noted that with the small separation between emitter and receivers there is elimination of the problem of low-speed interference reduction, because they disappear almost instantly after the generation of the next pulse of radiation. However, in this case, at the moment of radiation it is necessary to damp, i.e. to “brake” the seismic receivers in order to avoid their damage and the nonlinear saturation.

With a significant linear dimension of the vehicle, in particular ships or submarines, the emitters and receivers can be placed in various parts of the ship, i.e. at the stern and the bow. It is equivalent to the realization of the method of scattered waves with side looking that is used in the practice of land exploration seismology.

CONCLUSION

- For the work in the mountain and taiga area of East Siberia one of the options of exploration seismology is the usage of rivers and other water basins as the exploration profiles using water options of the pulsed non-explosive sources “Yenisei”.
- The estimations given in the article substantiate the reasonability of the technology development of side looking with the synthesized aperture and deployment of all the seismic complex, including the source and receiver based on one transport base without the usage of seismographs.

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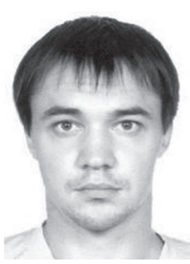

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В статье дана оценка возможности реализации метода сейсмической локации с помощью импульсных невзрывных источников и приемников, которые расположены на единой транспортной базе во время бокового обзора геологической среды и синтеза эквивалентной апертуры антенны трансивера.

Ключевые слова: сейсмическая локация, апертура, синтез, интерфейс.

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Сейсмічна локація бокового огляду з використанням синтезу апертури антени / Г.Я. Шайдуров, В.В. Сухотін, Д.С. Кудінов, М.О. Копилов // Прикладна радіоелектроніка: наук.-техн. журнал. – 2013. – Том 12. – № 1. – С. 172–174.

У статті дана оцінка можливості реалізації методу сейсмічної локації за допомогою імпульсних невибухових джерел і приймачів, які розташовані на єдиній транспортній базі під час бокового огляду геологічного середовища та синтезу еквівалентної апертури антени трансивера.

Ключові слова: сейсмічна локація, апертура, синтез, інтерфейс.

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