Acoustic Properties of the Lake Sevan

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Abstract: The work is devoted to the studies of the acoustic properties of the Lake Sevan located on the territory of the Republic of Armenia. The dependences of acoustic properties on the underlying multilayered stratums structure and the form of the Lake Sevan were investigated. The characteristic background noise, the fundamental resonant frequencies and the coefficients of transmission of acoustic waves through layered structures with different orders of arrangements of the layers were found. Acoustic waves spread from artificial and natural sources were experimentally detected. The appropriate temporal and frequency spectra from different sources of acoustic waves were recorded. The phenomenon of reverberation of acoustic waves was registered. The measurements were conducted by means of specially developed unique registration systems of super week acoustic waves and vertical seismograph SM–3. Based on the comprehensive analyzes of the obtained experimental data and theoretical calculations, the utilization of the lakes and water cavities in areas with a certain geological structure as antennas and accumulating systems of super weak acoustic waves can be confirmed.

Keywords: acoustic waves, reverberation, water reservoir, multilayered stratum

1. Introduction

One of the actual problems of modern science and technology is identifications of the influence of super weak distortions on the processes proceeding in the medium on the assumption of coherent interaction. In this field of investigations the development and creation of registration systems of the acoustic waves propagating in stratified medium with rather small amplitude are of special interest. Since 1980 at the Institute of Applied Problems of Physics of NAS RA fundamental and applied researches of above mentioned problems have been carried out. Under the leadership of the academician of NAS RA A.R. Mkrtchyan new approach to solve these problems, by utilization of some methods of AcustoPhysics, was formed. During the investigation unique experimental and theoretical results were obtained. The theoretical approach and the bases of the experiment technique for the solution of this problem are given in papers [1-7].

2. Experimental setup

Various types of seismic receivers and hydrophones are utilized for registration of super weak low-frequency acoustic waves in water reservoirs and caves. However, they have a number of deficiencies, such as the dependence of sensitivity of hydrophones on temperature, limited sensitive registration frequency range, absence of reconfiguration of characteristic frequency, small term of operation, low sensitivity, etc. To overcome these difficulties, in the IAPP of NAS RA unique registration systems of acoustic waves operating on the basis of the phenomenon of modulation of Messbauer radiation under the influence of external acoustic fields were developed.

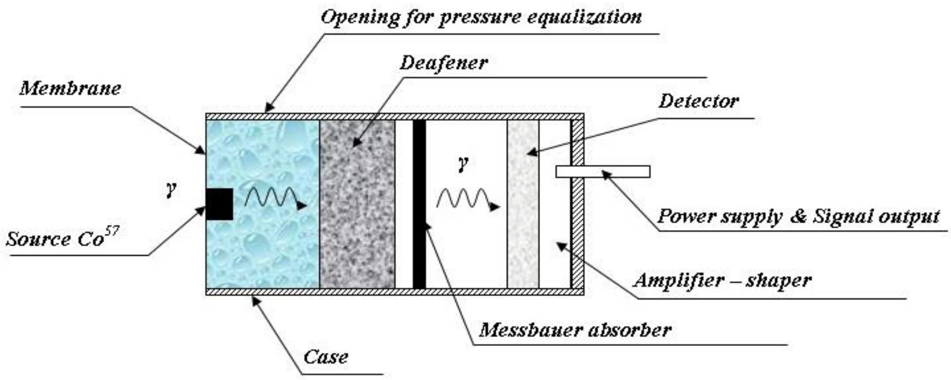


Fig. 1. Schematic view of the modulated Messbauer radiation phenomenon based detector.

The schematic view of the Mössbauer acoustic detector is presented in Figure 1. It consists of the following principal components: (1) a membrane on which the gamma quanta from the Mössbauer source Co^{57} (2) is fixed, (3) rigidly fixed Mössbauer absorber - a foil from stainless steel and (4) the detector of gamma quanta. The operation principle of the detector can be explained as follows: the variation of the gamma quanta energy as a result of acoustic vibrations influence on the condition of gamma-resonant absorption and, therefore, variation of the intensity of the quanta radiations registered by the detector.

The gamma quanta emitted by the Mössbauer source and passing through the Mössbauer absorber are absorbed by the Mössbauer nucleus. The gamma quanta passed through the absorber are registered with the gamma quanta detector. The intensities of the gamma quanta emitted by motionless source and absorbed by the motionless absorber have constant values. The influence of acoustic wave on the membrane generates vibrations with characteristic frequencies and the gamma quanta source fixed on it vibrates with appropriate frequencies. Due to the Doppler effect the energy of the gamma quanta falling on the absorber is changed. The resulting output of the Mössbauer acoustic detector after preliminary amplification and discrimination is directed to specially designed communications unit, which is connected to the computer where the obtained experimental data are saved and analyzed.

By means of registration of the temporal dependence of the variation of the intensity of gamma quanta the main characteristics of acoustic waves, causing these variations, can be determined:

$$N(t) = N_0\left(1 - \frac{\beta/2}{\left(\Delta x + \frac{V_0 \sin \omega t}{\lambda\Gamma/2}\right)^2 + 1}\right)$$

where $N(t)$ is the temporal dependence of the resonant gamma quanta count, N_0 is the gamma quanta count out of the resonance, V_0 is the maximum speed of the absorber movement, Δx – is the energy shift between the resonance emission and absorption, β is the effective thickness of the absorber.

The developed Mössbauer acoustic registration system allows to register acoustic waves in the frequency range up to $10^4\,Hz$, with sensitivity on the vibration speed $10^{-6} \div 10^{-5}\,cm/\sec$, in the dynamic range of $80\,dB$. Characteristic frequency of the Mössbauer acoustic detector is tunable.

The amplitude-frequency characteristic of the Mössbauer detector determined during the researches is presented in Figure 2.

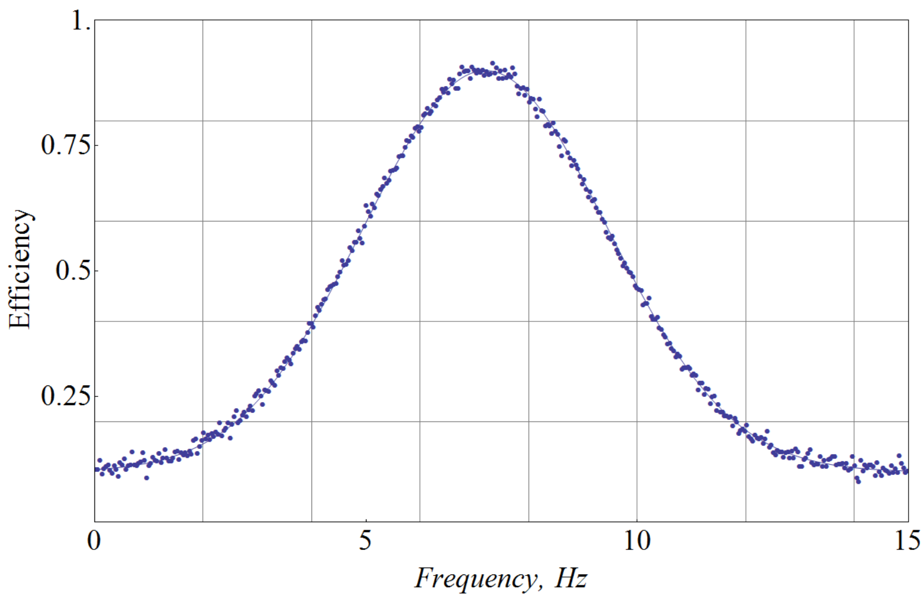


Fig. 2. The amplitude-frequency characteristic of the Mössbauer detector.

The experimental setup has also included temporary gamma acoustic spectrometer - GAS which is developed on the basis of the microprocessor with signal discrete processing, providing registration of weak non-periodic and periodic acoustic waves. The spectrometer registered signals in real time and at connection with the computer can operate in the mode of accumulation and information processing. Automatic control of the registration system GAS provides three-channel registration of periodic and non-periodic acoustic vibrations in three directions at the same time that gives the chance to utilize the spectrometer as a vector sensor, for the purpose of measurement of three-dimensional component of the vibration parameters that is very important in the acoustics and in hydrophysics researches.

For carrying out underwater measurements, in IAPP NAS RA sensitive sonar systems registering the acoustic waves propagating in liquid media are developed and created. As main elements of the hydrophones, radial polarized piezo-ceramic spheres from barium titanium are utilized. In comparison with flat and package piezo-converters, such design of the receiver increases the sensitivity at the expense of coefficient of the electromechanical transformation. These detectors have good phase identity and stability. For calibration of utilized acoustic sensors underwater and ground based low-frequency radiators with controlled output power were developed and created.

On the basis of results of laboratory investigations and the carried-out theoretical calculations, the necessary optimal conditions for conducting experimental studies in field conditions were revealed. It should be noted that for conducting experimental field studies the following experimental conditions were provided:

1. The reservoir must have a certain configuration and must be located in the regions where the geological layers under its bottom met conditions of accumulation and amplification of acoustic energy,
2. Underwater devices for measurement of amplitude, profile and duration of an acoustic response of the resonant system must operate independently at certain depth,
3. For comparative analysis of the obtained results ground based measurements with vertical and horizontal seismic sensors and underwater measurements with developed registration systems in parallel must be carried out.

Taking into account the conditions mentioned above and the fact that the resonant systems of corresponding theoretical models must have accumulating and amplifying characteristic of acoustic waves propagating through the multi stratum system, containing heterogeneity of certain geometrical forms, some natural and artificial reservoirs must be chosen. Thus, for carrying out experimental field researches to register weak and super weak acoustic vibrations Lake Sevan was chosen.

Lake Sevan, chosen as a seismic hydroacoustic antenna, is water basin of $1150km^2$ surface with maximum depth of $72m$, located at height $\sim 1900m$ above sea level. Bottom stratums of the Lake have schistose structure consisting of basalt, clay and volcanic rocks. The measurements were carried out in the deep-water part of the lake.

3. The results of experimental investigations

Experimental investigations to solve the main objectives and to confirm our proposition on utilization of certain water reservoirs and caves as supersensitive antennas of acoustic vibrations were conducted according to the following scheme (Figure 3).

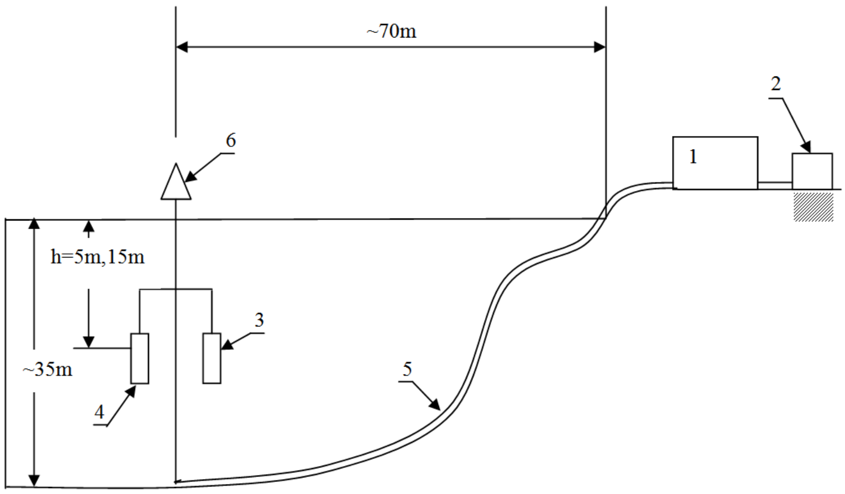


Fig. 3. The schematic view of the experimental setup: 1 - center of obtained data collations; 2 – seismic sensor; 3 - Mössbauer acoustic detector; 4 - hydrophone; 5 - feed cable; 6 - buoy.

Seismic sensors SM-3 (2) for registration of horizontal and vertical components of vibration process were placed on the shore of Lake Sevan on the special pedestal having surface area of $52\times52cm^2$. The sensors are attached by the protected cable with multichannel recording unit and with the computer. The hydrophones (4) were placed in the Lake in suspension and are kept by buoy (6) under water in vertical position. Such installation of hydrophones provides homogeneous contact with the surrounding medium and free from the strays originated by the surface waves.

The Mössbauer acoustic detector (3) is placed in the Lake together with hydrophones and by means of special cable enclosed under water is connected to GAS and to personal computer which provides saving, processing and interpretation of the registered temporary and modulated Mössbauer spectra of hydroacoustic signals. Simultaneously, the acoustic vibrations were registered by seismic detectors located on the shore of the Lake and under water at depths of 5 and 15 meters by means of hydrophones and the modulation Messbauer sensor.

During the experimental investigations the main characteristics of the utilized detectors of acoustic vibrations were defined and they are presented in Table 1.

Table 1: The main characteristics of the utilized acoustic sensors

Type of sensor	Frequency range	Dynamic range	Characteristic frequency
Hydrophones	0.1÷1 kHz	70 dB	10Hz, 100Hz, 250Hz, e.t.c.
Seismic sensor	0.5÷0.03 kHz	60 dB	100Hz
Messbauer acoustic detector	0.0÷10 kHz	80 dB	7,5Hz*

* The characteristic frequency of the Mössbauer acoustic detector is tunable

To determine the characteristic frequency of the resonant antenna system, Lake Sevan, measurements in the presence of artificially excited hydroacoustic vibrations of different forms, amplitude and frequency have been done. The measurements were conducted for the frequency range of $0.1 \div 30 Hz$ under identical conditions of excitation. In the frequency spectra registered by the hydrophone the increase is observed in the ratio of signal to noise around $7.5 Hz$ (Figure 4). This frequency matches the calculated characteristic frequency of Lake Sevan. In this range the maxima corresponding to frequencies of artificially excited hydro-acoustic vibrations from the underwater acoustic radiator with frequency of $15 Hz$ and the ground based radiator with frequency of $30 Hz$ are also observed.

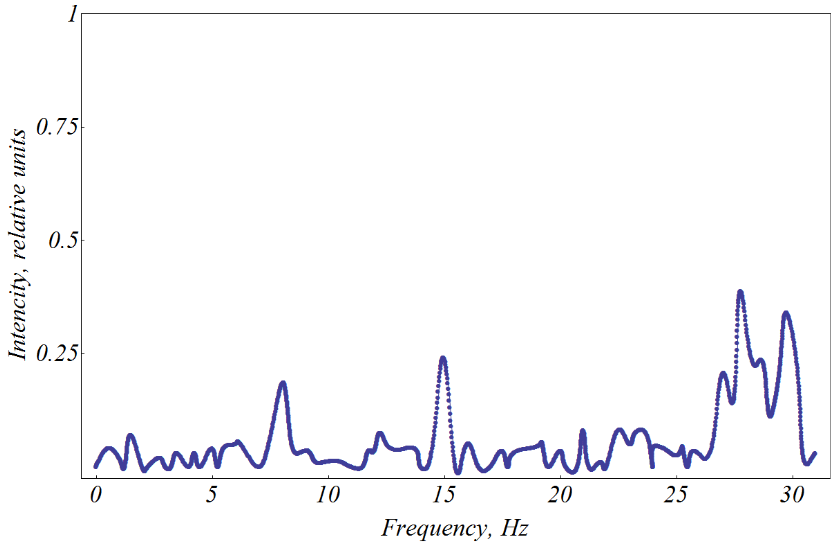


Fig. 4. The characteristic frequency distribution spectra of the noise of Lake Sevan registered by the hydrophone.

The temporal spectra of the acoustic vibrations from the underwater acoustic radiator, registered by the hydrophone, are given in Figure 5. It is seen that at registration in the time spectra sinusoidal forms of artificially excited acoustic vibrations are present.

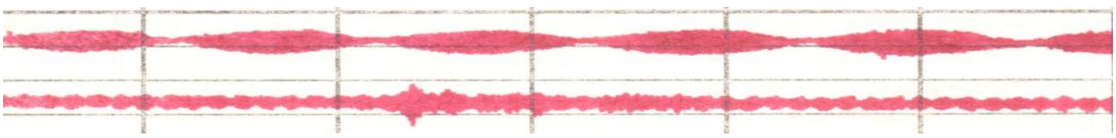


Fig. 5. The temporal spectra from artificial source generating sinusoidal acoustic vibrations of different frequencies.

It should be noted that in the frequency distribution spectra, registered by the seismic sensors located on the shore, maxima corresponding to the characteristic frequency of Lake Sevan and of the underwater calibrating radiator were not observed (Figure 6). This sensor has registered only the presence of the ground based calibration radiator and other artificial sources of low-frequency acoustic vibrations. Apparently, from the comparison of these spectra with the similar spectra obtained by means of hydrophones and Mössbauer acoustic detectors in the lower frequency range it is seen that there are no maxima around the frequencies of $7.5Hz$ and $15Hz$. This circumstance, first, can be explained by the technical parameters of the sensor determined during the experimental studies and specified in Table 1, and secondly, it means that the whole water reservoir is a resonant antenna system for registration of super week acoustic signals.

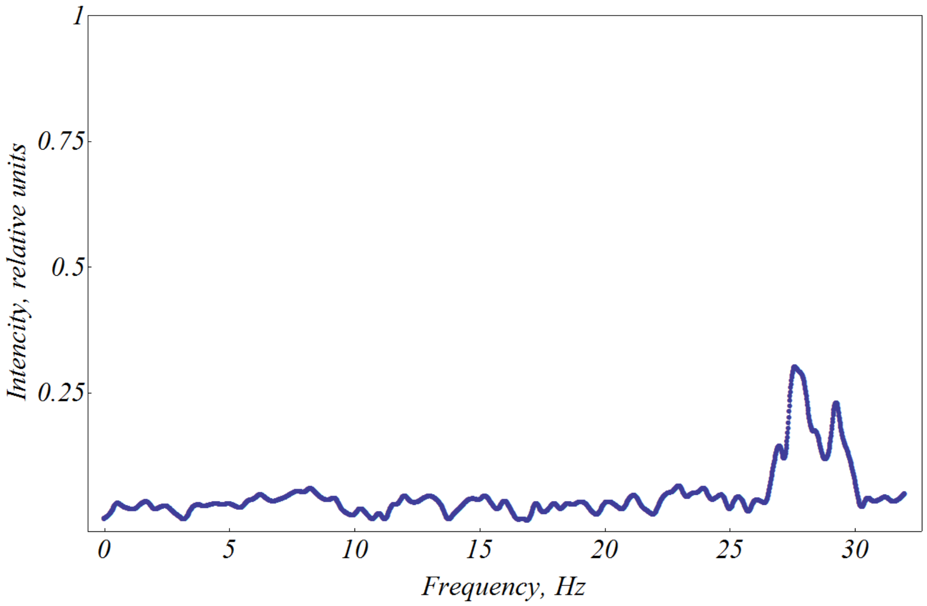


Fig. 6. The characteristic frequency distribution spectra registered by the seismic sensor located on the shore of Lake Sevan.

In all frequency distribution spectra, registered by Mössbauer acoustic detectors and hydrophones, maxima near $7.5Hz$, corresponding to the characteristic frequency of Lake Sevan and the calibration maxima, caused by the excited artificial sources of acoustic vibrations of different frequency, amplitude and form, are present.

One of the features registered during the experimental studies is the phenomenon of reverberation of acoustic signals in the resonant antenna system - Lake Sevan. Due to utilization of artificial underwater and surface sources of acoustic vibrations of certain temporal and frequency characteristics, in the registered temporary and modulation spectra repeated excitations of primary vibration frequency and lowered amplitude is observed. The temporal spectrum registered by the hydrophone with observed phenomenon is presented in Figure 7.

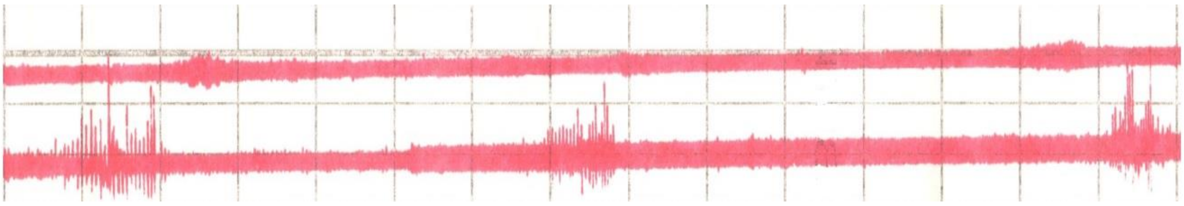


Fig. 7. The temporal spectra registered by hydrophone including the phenomenon of reverberation of acoustic vibration.

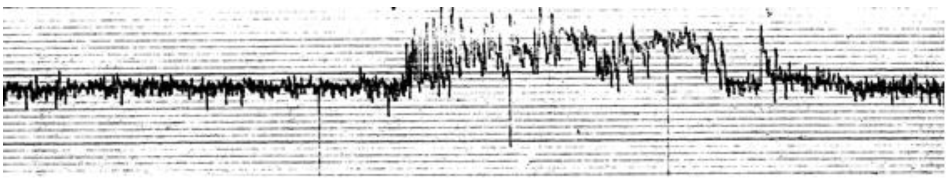
The analysis of characteristics of the frequency-amplitude spectra of noises of Lakes Sevan, based on the measurements of acoustic vibrations by Mössbauer acoustic detectors, hydrophones and seismic sensor, shows that the frequency range is separated into three main ranges. In the first range, $0 \div 5 Hz$, the main contributions to the frequency distribution spectra of the lakes come from the surface noises of the lakes. In the range of $5 \div of\ 20\ Hz$, generally the responses corresponding to micro-seismic and resonance characteristics of the spreading stratums and lakes are observed. For the frequency range higher than $20 Hz$, the maxima in frequency distribution spectra, caused by artificial sources of acoustic vibrations, were observed.

In the first frequency range the registered spectra almost are not changed. In the second range there are irregular separate peaks at various frequencies which can be explained by variations of seismic, biological, structural and resonance characteristics of the area of registration. In the upper range both irregular and regular variations are observed.

Aiming to determine the unknown irregular and regular sources of low-frequency vibrations, the area of registration was monitored. Analyzing the registered frequency distributions spectra, it was established that some regular changes in the frequency and temporal spectra match the frequency of trains passing near the area of registration, the frequency and the amplitude changes due to the characteristics of the trains.

The temporal characteristic spectrum of the acoustic vibrations, originated from the cargo train and registered by the Mössbauer acoustic detector is given in Figure 8.a, and the temporal characteristic spectrum of the same cargo train at the same time registered by the hydrophone is given in Figure 8.b.

a)



b)

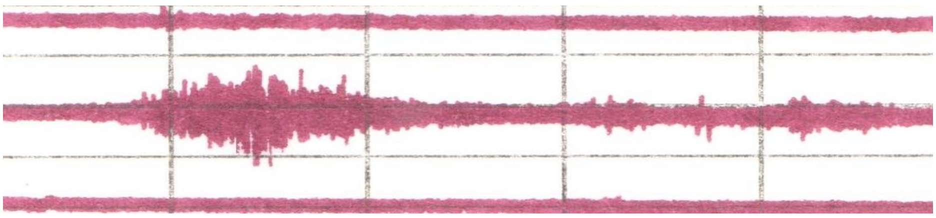


Fig. 8. The temporal frequency spectra of the cargo train registered by the Mössbauer acoustic detector (a) and hydrophone (b).

During the investigations, for determining unknown irregular sources of acoustic vibrations, temporal spectra from the compressor (Figure 9.a) and from the floating boat (Figure 9.b) were registered.

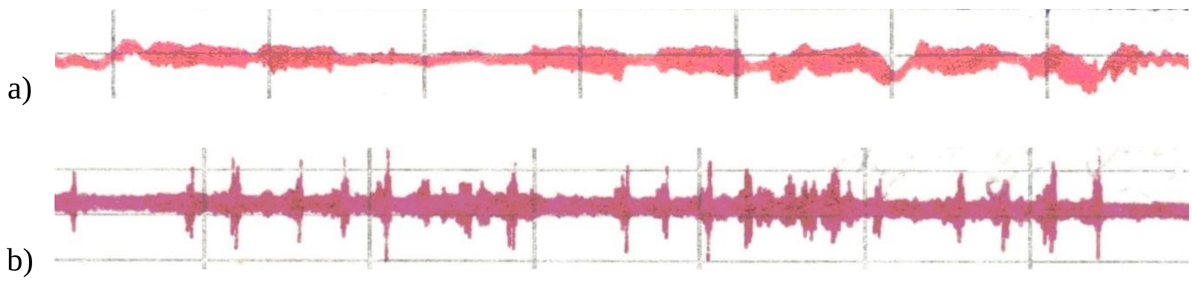


Fig. 9. The temporal spectra of the compressor (a), truck (b) and boat (c) registered by the hydrophone.

On separate spectra sharply allocated signals with frequency about $10 Hz$ were observed (Figure 10). These signals, as it has been shown by further investigations, correspond to supersonic airplanes upon transition of the sound barrier. In the registered spectra the maxima corresponding to flights of passenger airplanes on the horizon over the Lake were observed as well. The different intensity of signals from supersonic airplanes with frequency $\sim 10 Hz$ is explained by the different height and distance for which the transition of the sound barrier takes place.

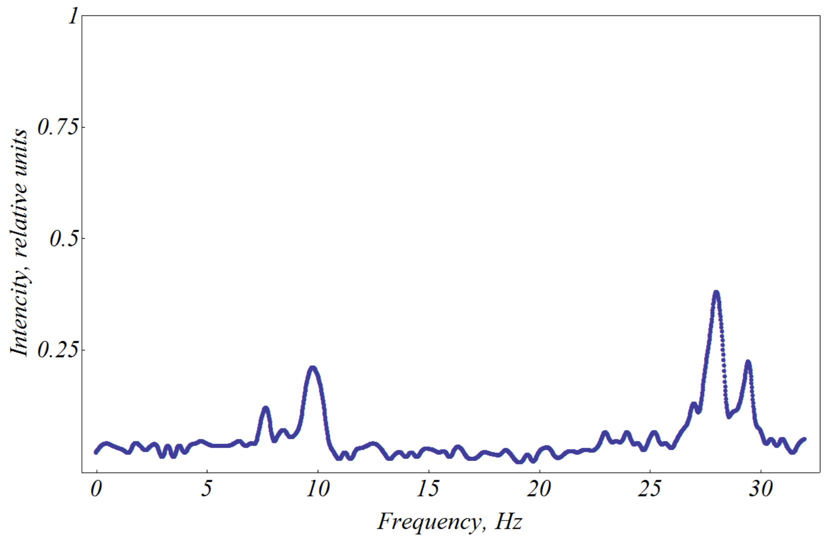


Fig. 10. The characteristic frequency distribution spectrum of upon transition by airplane of a sound barrier registered by the Mössbauer detector.

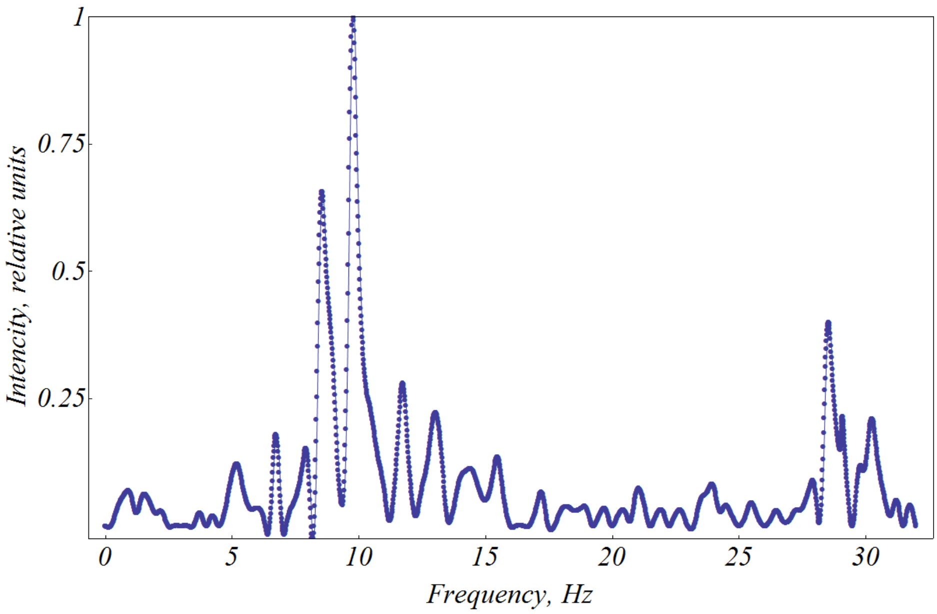


Fig. 11. The frequency distribution spectra from artificial source registered in Lake Sevan.

We also have conducted experiments for registration of hydroacoustic waves originated from the artificial sources located at distances $\sim 10km$ and $\sim 20km$ from the area of registration. Artificial sources were located at depth of $20m$ and $50m$. The frequency distribution spectrum of the signal registered by Mössbauer acoustic detectors is given in Figure 11. It is also possible to separate the spectrum into three regions where the maxima corresponding to the characteristic frequency of Lake Sevan, the maxima of the calibration radiators at $15Hz$ and $30Hz$, and the maxima corresponding to acoustic vibrations from artificial sources are allocated. Time slot between the beginnings the first and second strips is about $5\sec$, and between the beginnings of the first and third strips – about 8 sec. The two front ranges can be interpreted as longitudinal (P) and transverse (S) components of the wave, propagating through the lower basalt stratum with speeds $V_p = 4000\, m/\sec$ and $V_S = 3100\, m/\sec$ respectively, and the third range as the longitudinal component of the wave passing through the top clay stratum with speed $V_p = 2000\, m/\sec$ (the transverse component of the wave in clay stratum is strongly absorbed). Similar spectra were observed for signals registered by hydrophones.

The obtained results for seismic and hydro-acoustic signals from the artificial sources, registered by seismic sensors, hydrophones and Mössbauer detector, showed that the signal/noise ratio for the seismic sensor is 2.5 times smaller, than for the hydrophone, and for the latter it is 2.5 times smaller compared with the Mössbauer detector. This shows the high sensitivity of the Mössbauer method of registration.

4. Conclusion

The results of the experimental studies confirm the possibilities of utilization of lakes, water reservoirs and cavities in areas with certain geological structure as sensitive receivers and accumulating systems for registration of super week acoustic vibrations. The developed new acoustic detectors can be utilized for registration of acoustic vibrations excited from natural and artificial sources.

Conflict of Interest

There is no conflict of interest.

References

[1] A.R. Mkrtchyan, H.A. Aslanyan, L.A. Kocharyan, A.H. Mkrtchyan, Kh.V.Kotanjyan, E.G. Baghdasaryan, G.R. Harutyunyan, N.A. Barseghyan"Lakes and waterfilled cavities as sensitive antennas and memory devices for acoustic vibrations of infrasonic frequencies" – International Symposium "Monitoring and Discrimination of Underground Nuclear Explosions and Earthquakes", Moscow in November, 17-21, 1997.

[2] A.R. Mkrtchyan, A.H. Mkrtchyan, A.S. Baghdasaryan, A.K. Atanesyan, V.V. Nalbandyan, T.G. Dovlatyan, V.N. Agabekyan, H.R. Muradyan, E.A. Mkrtchyan, S.A. Mirakyan, H.T. Hovhannesyan. Influence of Acoustic Fields on Main Parameters of Resonance Systems. Proceedings of the International Conference on Electron, Positron, Neutron and X-ray Scattering under External Influences. Yerevan-Meghri 2011, Armenia, ISBN 978-99941-2-710-8, p.149, 2012.

[3] A.H. Mkrtchyan, A.R. Mkrtchyan, Kh.V.Kotanjyan, H.A. Aslanyan, E.M. Harutyunyan, A.S. Harutyunyan, G.A. Ayvazyan, H.R. Muradyan, V.N. Agabekyan, S.A. Mirakyan. About possibility to the determination of parameters of seismic-acoustic waves by solving the reverse problem. Fundamental Research, №8, pp. 51-54, 2014.

[4] A.H. Mkrtchyan, A.R. Mkrtchyan, A.S. Baghdasaryan, V.K. Saryan, Kh.V.Kotanjyan, H.A. Aslanyan, G.A. Ayvazyan, H.R. Muradyan, V.N. Agabekyan, S.A. Mirakyan. Determination of parameters of acoustic vibrations by inverse problems method. Non Linear World, №6, v.12, pp. 42-47, 2014.

[5] A.H. Mkrtchyan, A.R. Mkrtchyan, A.S. Baghdasaryan, V.K. Saryan, Kh.V.Kotanjyan, H.A. Aslanyan, H.R. Muradyan, S.A. Mirakyan. Accumulation of acoustic waves propagated in stratified medium. Non Linear World, №8, v.12, pp. 16-22, 2014.

[6] [6] S.A. Mirakyan. Propagation of acoustic waves through elastic stratified medium with heterogeneity in the form of rectangular reservoir. Armenian Journal of Physics, 2014, vol. 7, issue 2, pp. 102-105.

[7] A.R. Mkrtchyan, A.H. Mkrtchyan, E.M. Harutyunyan, S.A. Mirakyan. Detectors of acoustic waves. Patent №2864 A, 2014.

[8] A.R. Mkrtchyan, A.H. Mkrtchyan, E.M. Harutyunyan, S.A. Mirakyan. Method of registration of acoustic vibration parameters. Patent №2863 A, 2014.