Problems of acoustic monitoring of extensive concrete building structures are considered. The disadvantages of existing methods of measuring the thickness of concrete articles are demonstrated. A new resonance-multiplicative method is proposed that increases measurement accuracy and reliability. Results are provided for a test model of a thickness meter.

Key words: resonance-multiplicative method, thickness meter, concrete.

In using the traditional pulse-echo method for monitoring building structures (BS) made of concrete [1] as a result of anomalously high attenuation of acoustic signals in the material it is not possible to monitor an object with a thickness of more than 1 m even with a reduction in the frequency of the probing signal confidently to limiting values of 50–80 kHz for the echo method. Use of radio engineering methods for processing echo signals with the use of comprehensively modulated signals followed by optimum filtration [2] makes it possible to increase a little the maximum monitoring depth to about 1.5 m. For this reason, the impact-echo method [3] is used in order to measure the thickness of extended concrete BS at depths exceeding this limit. A diagram illustrating this method for cases of uniform (a) and nonuniform (b) objects is shown in Fig. 1.

A short but strong mechanical shock is applied to the surface of the object being monitored by means of a special device, i.e., an impactor. This shock initiates in the object being monitored a short acoustic delta-pulse having a broad frequency spectrum. The acoustic wave, caused by the impactor, is reflected repeatedly from the boundaries of the monitored object and recorded by the receiving piezotransducer. Here there is always some component of the spectrum \( f_j \) of the broadband probing signal within which a natural resonance of the object being monitored arises. The period of these resonance vibrations \( T \) will equal the ratio of the distance \( 2h \) through which the wave passes to the reflection surface and back, to the velocity of the wave \( c \). The thickness of the object being monitored is determined by the equation

\[
h = c/(2f_j).
\]

For precise determination of object thickness, it is necessary to know wave velocity and natural frequency \( f_j \). As a rule, velocity is either considered to be known beforehand, or measured by special equipment before thickness measurement. For this, in order to find the value of the natural frequency \( f_j \) the frequency spectrum of the signal received is determined by a Fourier transform. The resonance characteristic obtained as a result of transformation in the simplest case only has one “thickness” resonance whose frequency in monitoring extended objects does not normally exceed 20 kHz. Thickness \( h \) of the
object being monitored is determined from the frequency $f_j$. Attenuation of acoustic signals in concrete is small for these low frequencies and this makes it possible perform monitoring at depths markedly exceeding the possibilities of the echo-pulse method. Recently, instruments have been produced that make it possible to monitor extremely large thicknesses up to 15 m (dam embankments at hydroelectric stations), and under laboratory conditions a method has been developed for measuring the length of pile up to 27 m [4].

As a rule, by means of the impact method it is possible to monitor the quality of objects using comparison of spectra of a previously known defect-free object with spectra of the object being monitored. Existence of a defect is assessed by the shift in resonance frequency with respect to a standard spectrum. Here these shifts may be very insignificant, i.e., several hundred, and sometimes tens of hertz.

A disadvantage of the impact method is the fact that for two different "shocks" it is impossible to provide repeatability of the probing signal: their spectra differ, and this affects the reliability of measurements. In addition, the Fourier transform, used for the transfer from a time region into frequency, is inevitably performed in a wide frequency range, and in order to provide the required discreteness with respect to frequency in a narrow region, it is necessary to analyze a very lengthy selection of the signal received. This markedly reduces monitoring productivity that is important under series production conditions and increases the cost of an installation.

These disadvantages do not exist in the resonance method [5], distinguished by the fact that impactor is replaced by a piezotransducer that studies the harmonic signal in an object with increasing frequency. The resonance signal arrives at the receiving transducer, and in fact the frequency component for which there is emission at a given instant. Therefore, the requirement for Fourier transformation becomes superfluous. In order to construct the resonance characteristic for the object being monitored, it is sufficient to record the amplitude of the signal received at each frequency. This makes it possible to perform a detailed study of the characteristic just for the frequencies of interest, and this leads to an increase in measurement accuracy.

Another advantage of the resonance method is a marked increase in signal energy compared with the impact-echo method. In the case with an impactor, all the pulse energy is distributed in a very broad spectrum (from several hertz to a hundred hertz), and there is only a small part of this energy in a fraction of each separate spectral component. With the resonance method, it is possible to concentrate signal energy at each separate frequency. In addition, measurement repeatability is guaranteed and the possibility is provided of correcting the amplitude-frequency characteristic (AFC) of the receiving-transmitting path of the monitoring instrument. The latter is particularly important since creation of broad-band low-frequency receiving

![Diagram of the impact-echo method in thickness measurement for uniform (a) and nonuniform (b) concrete objects.](image)