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GEOPHYSICS

STUDIES OF GRID-INDUCED TURBULENCE BY THE METHODS OF CORRELATION AND SPECTRAL ANALYSIS

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A series of experiments using correlation and spectral analysis has been performed to study the spatial structure of a liquid, in which turbulence is set by a vibrating grid. The experiments have shown that there are three regions of motion in such a liquid: jet flow, transition, and random (turbulent) zones. Turbulence intensity in pure water and in suspension has been estimated and the vertical scale of turbulent formations has been determined. In suspension, part of turbulent energy of a liquid is absorbed by suspended particles.

To simulate the effect of turbulence on a density jump layer, various vibrating systems, e. g., grids, disks with round holes or vibrating rods, have been used recently in Russia and in other countries. Suspensions as a material for this purpose have not virtually been studied and, as a rule, the nature of vibrations set in a liquid in different parts of a basin has not been discussed. This study is an attempt at making up for this deficiency.

In an experimental plant described in [1], turbulence in the liquid was produced by a vibrating grid. Measurements were made in pure and turbid water with grid vibration frequencies of 0.5 to 1.8 Hz. Natural silt particles of up to 30 μm in size and 2.5 g/cm^3 density were used as a suspension.

The experiments furnished information on bulk distribution of the dispersion of frequency of vibration of a liquid [2]. A distinct horizontal periodical structure of frequency of vibration of jet nature is observed near the grid. The flow velocity maxima are located over the mesh centers, and its minima, over the centers of the grid bars. The ratio of the grid free surface to its total area is 0.34. In this case, turbulence generated by the vibrating grid, can be considered to be the result of interaction of liquid jets moving through its windows. Similar processes were reported by other authors [3]. Jet motion dampens with distance from the grid giving rise to a zone, where the nature of motion is close to natural turbulence. This information was used for tracing the transition of jet vibrations to turbulent motion. Besides the dispersion analysis, this transition was also studied by analyzing autocorrelation and spectral functions for the liquid velocity modulus. Figure 1 illustrates autocorrelation functions for the grid frequency of vibration of 0.6 Hz calculated for two horizons. The autocorrelation function obtained in the immediate vicinity of the vibrating grid, where the jet velocity is higher, is of obvious vibrational nature. A 3-cm distance away from the grid (curve *1*), the jet motion is still partially vibrational, however, the amplitude of vibration is much smaller. Finally, at a distance of 7 cm from the grid (curve *2*), the form of the autocorrelation function is similar to that of the functions for a random process [4]. Thus, judging from the autocorrelation functions, a zone close in parameters to a turbulence zone exists in horizons starting from 7 cm and higher.

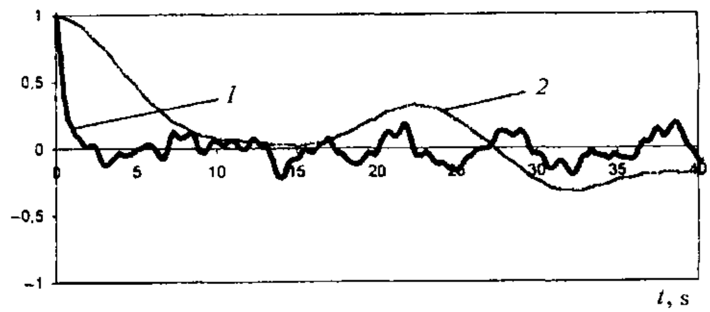

Fig. 1

Autocorrelation functions for 0.6 Hz frequency of grid vibration at distances: *1*—3 cm from the grid top position; *2*—7 cm from the grid top position.

A similar result confirming that different types of motion occur in a turbulent liquid at different distances from the grid vibrating in this liquid can be obtained by analyzing a spectral function for the modulus of velocity at different distances from the grid. Figure 2 (curve *1*) is a plot of a spectral function for the velocity modulus 0.2 cm away from the top position of the grid vibrating with a frequency of 0.6 Hz. The abscissa represents the grid vibration frequency in Hz, and the ordinate, the squared amplitude in units of a squared liquid velocity; the confidence interval for 75-% probability is shown by a vertical segment.

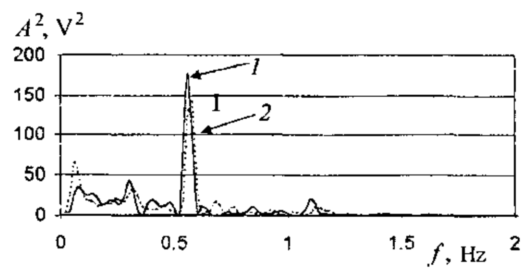

Fig. 2

Spectral function for the velocity modulus for a 0.6 Hz frequency of grid vibration at distances: *1*—0.2 cm from the vibrating grid top position; *2*—2.7 cm from the grid top position.

Curve *1* displays a confidence peak of a spectral function corresponding to the carrier frequency of grid vibrations. Curve *2* represents a spectral function for the velocity modulus at a distance of 2.7 cm from the grid top position. Comparison of curves *1* and *2* shows that the confidence peak amplitude corresponding to the frequency of vibration of 0.6 Hz decreases sharply with distance from the vibrating grid, and that confidence peaks appear at lower frequencies, which evidence motion different from the jet one. It can be stated that in this region, the availability of jets does not play a decisive role for the motion of the liquid, i. e., here the nature of a liquid flow is a transition from a periodic motion to a random one. With allowance for the confidence interval, the spectral function peak corresponding to a frequency of 0.6 Hz virtually disappears at distances more than 6 cm away from the grid top position, which indicates that there is no periodic motion in these horizons.

So, the study of the dispersion field of the liquid velocity modulus and analysis of the autocorrelation and spectral functions have shown that there are three zones of motion in a liquid with turbulence produced by a vibrating grid: jet, transition and random, i. e., turbulent, zones.

Samples of the suspension were taken at different frequencies of grid vibration. Prior analysis of these samples has shown that at all levels the velocity of particle precipitation slows down as compared with the Stokes velocity [5, 6]. Large-size particles accumulate in the lower zone (near the grid), whereas an obvious growth of concentration of fine particles occurs in the eddy zone. The mechanisms of these phenomena are different. Accumulation of particles in the vibration zone, where the jet flow prevails, seems to be conditioned by a nonlinear interaction of the flow with a suspended particle. As to the upper (eddy) zone, fine suspended particles are captured and held there by turbulent formations.

The data obtained in the experiments are unique for such plants, because they enable one to study energy exchange in liquids and suspensions both in the vibrational and turbulent conditions of liquid flow. Besides, the conditions of liquid flow can be determined by measuring the distance of the respective zone from the vibrating grid.

With a view to investigating energy exchange in liquids and suspensions in turbulent liquid with a vibrating grid, a number of other experiments were also performed to determine the turbulence level of a liquid. The turbulence level is calculated by the formula

$$K = \sqrt{\overline{u'^2}} \Big/ \overline{u},$$

where u is the characteristic velocity, and u' is the pulsation of flow velocity, which is used to obtain a quantitative estimate of the integrated turbulence intensity and characterizes the degree of the total disturbance of the flow velocity field [7].

The experiments were made in pure water and in suspension for frequencies of 0.5, 1, and 1.5 Hz. The velocity of vibration of the grid itself was taken as the characteristic velocity. Figure 3 illustrates one of the results obtained for the 1.5 Hz frequency of grid vibrations. Here, the axis of ordinates represents turbulent flow intensity I, and the axis of abscissas, the distance from the vibrating grid. Curve *1* was obtained after approximation of the experimental results in pure water by a second-degree polynomial; curve *2* represents the results of approximation in a suspension. One can see from the plot that turbulence intensity diminishes with the distance from the grid both for pure water and for suspension. The turbulence intensity as a function of the distance from the grid at a frequency of 1.5 Hz for pure water differs obviously from that for suspension, the turbulence intensity for pure water being higher than that for suspension.

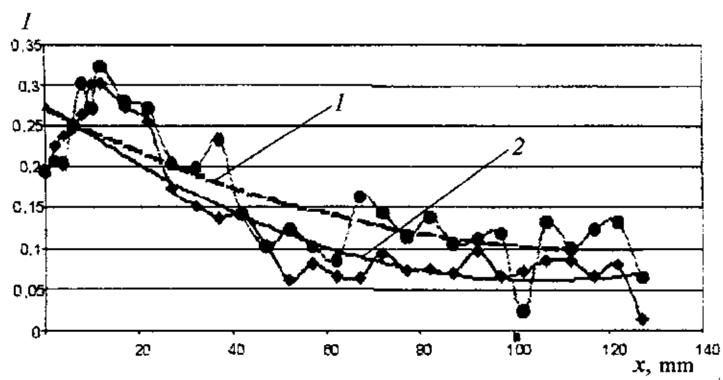

Fig. 3

Turbulent flow intensity I (approximated by the second-degree polynomial) versus the distance from the vibrating grid in pure water (*1*) and in suspension (*2*) at a 1.5 Hz frequency of grid vibration. The circles represent the experimental data in pure water and the squares, in suspension.

Generally, as a number of experiments have shown, the difference between turbulence intensity for pure water and that for suspension increases with the increase of the frequency of vibration of the grid and, accordingly, turbulent flow energy.

Based on the experimental results, it can be concluded that the intensity of turbulence in suspension decreases as compared with that for pure water due to the absorption of some energy by suspended particles.

A good illustration of the process when some energy of a turbulent flow is absorbed by suspended particles is a plot in Fig. 4 showing the energy spectrum of the velocity pulsation modulus in pure water and in suspension with a 0.5 Hz frequency of grid vibration 8 mm away from the vibrating grid. The abscissa represents the frequency of grid vibration in Hz, and the ordinate, the squared amplitude in units

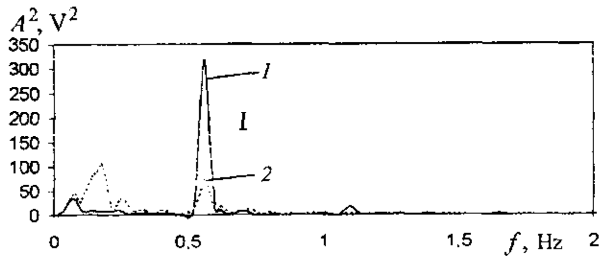

Fig. 4

Spectrum of velocity pulsations in pure water (*1*) and in suspension (*2*) at a 1.5 Hz frequency of grid vibration at a distance of 8 mm from the vibrating grid.

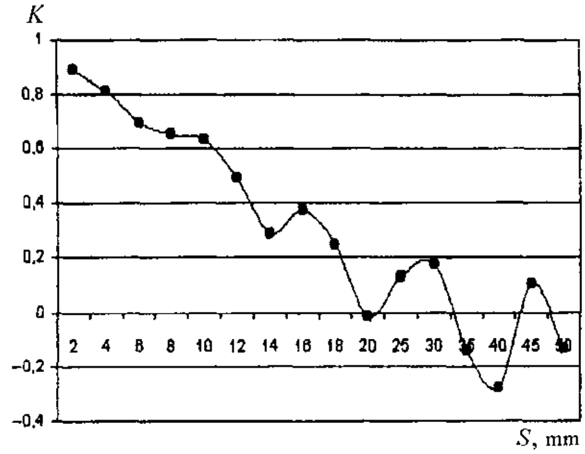

Fig. 5

Spatial correlation factor versus the distance between the sensors.

of squared velocity of the liquid flow; a confidence interval for 75-% probability is shown by a vertical segment. Here, curves *1* and *2* characterize the spectrum of the velocity modulus in pure water and in suspension, respectively. A confidence peak at a carrier frequency, which shows regular motion in liquid at this frequency for pure water is found to be higher than a confidence peak at the frequency of grid vibration for water with suspended particles. This fact may be accounted for by the absorption of some energy (about 10–12%) of turbulent flow by suspended particles. A similar phenomenon is observed in all horizons at other frequencies of grid vibration. This can be seen distinctly in the plots of energy spectra, where a certain peak corresponding to the carrier frequency is still preserved.

When analyzing processes in a liquid, where turbulence is produced by a vibrating grid, we used not only time autocorrelation functions, but also space autocorrelation functions. Time autocorrelation functions make it possible to estimate the degree of connection between flow velocities at different instants and thus to assess time scales of velocity variations, whereas space correlations help in evaluating the spatial structure of a turbulent liquid [7]. A series of experiments with two sensors were performed for pure water and suspension in a turbulence zone. The lower sensor was positioned over the vibrating grid outside the jet flow zone, and the second sensor moved up from the first one with a step of 1 to 5 mm. Figure 5 exemplifies one of the relationships of the spatial correlation factor versus a distance between the sensors. The point where the spatial correlation factor intersects the abscissa is called a “cutoff point”. This point characterizes the spatial scale of a turbulent formation [7]. The spatial correlation functions helped us determine the scale of turbulent eddies for frequencies of grid vibration of 0.5, 0.8, 1, 1.2, 1.6, and 1.8 Hz in pure water, and at frequencies of 0.5, 0.8, and 1.0 Hz in suspension. As the frequency of grid vibration increases and, hence, the turbulent flow energy, the size of turbulent formations grows both for pure water and for suspension. Besides, the comparison of the size of turbulent formations in pure water and that in suspension for frequencies of 0.5, 0.8, and 1.0 Hz has demonstrated that the size of eddies in turbid water is much larger than that in pure water. The ratio of size of these formations in pure water to that in suspension is approximately 1 : 2.5. We believe that as the presence of suspended particles in a turbulent liquid increases the liquid density (its inertia), the result is that with the same flow velocities, a larger centrifugal force acts on the bulk of water with suspension and, therefore, eddies in suspension are larger in size than those in pure water.

The correlation and spectral analyses adequately depict the vertical structure of a liquid, where turbulence is set up by a vibrating grid. The presence of suspended particles in such a liquid causes part of turbulent energy to be used for maintaining solid particles in suspension, in other words, it is virtually absorbed by suspended particles.

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