Spatial and time spectra of stochastic oscillations in a convective cell

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It was found that stochastic oscillation regimes with a dominant spatial frequency and regimes with spatial mode intermittence differ in their sequence of peaks in the time spectrum of the amplitude of the lowest spatial mode.

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The stochastic flow regimes arising after the critical point of a stationary or oscillatory fluid motion can be studied by measuring the time energy spectra of local velocities. The spectra have been measured for a Couette flow in cylindrical[1,2] and spherical[3] fluid layers and also for certain natural convection problems.[4]

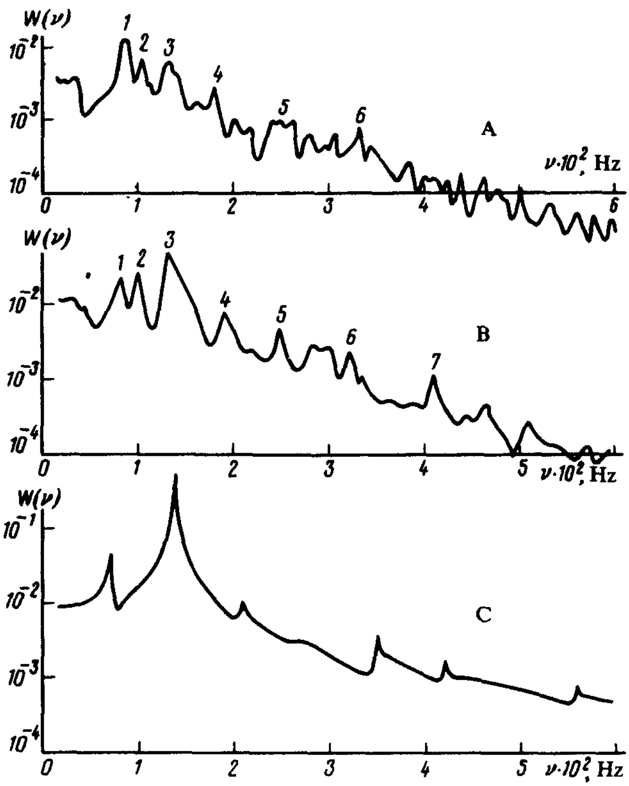

FIG. 1. Time energy spectra $W(\nu)$ of the amplitude of the b_1 spatial harmonic for $R = 75$. (A) $\alpha = 0$; (B) $\alpha = 15'$; (C), $\alpha = 20'$.

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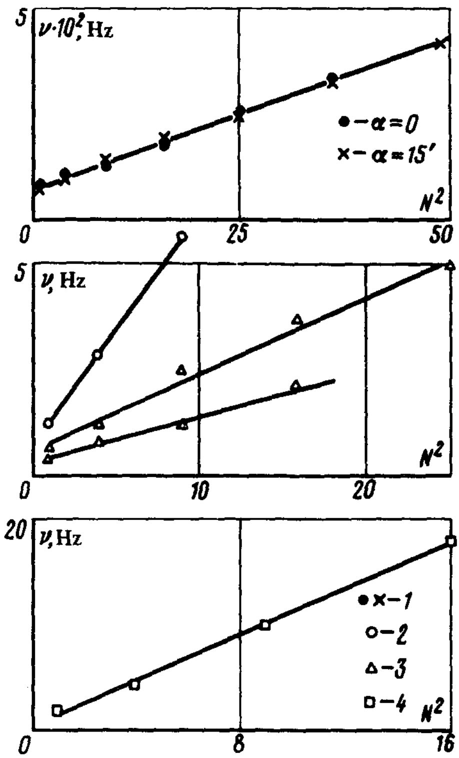

FIG. 2. Dependence of the frequency ν_N on the peak number. 1, Our results; 2, the results of Ref. 2; 3, the results of Ref. 6; 4, the results of Ref. 1.

Since a small number of spatial modes are excited near the critical point, it is of interest to measure the spatial and time spectra of the flow. The time spectra of the velocity in rotating fluid layers[1–3] partially reflect the spatial structure of the flow, since the measurements are made at a point that is motionless with respect to the laboratory coordinate system. The velocity spectra in problems of natural convection refer to the collective behavior of the spatial modes. Such spectra are difficult to interpret in the region of stochastic oscillations.

In this paper we perform a space and time Fourier analysis of stochastic oscillations for the natural convection of a fluid in a closed cavity that is heated from below. The cavity, which was filled with distilled water, had the shape of a short, horizontal cylinder with a diameter $D = 30.9$ mm and length $d = 4.7$ mm. A homogeneous temperature gradient $\overline{A}$, directed downward at an angle α to the vertical, was generated at the ends of the cylinder.

For the specified cavity geometry the spatial structure of the steady-state supercritical motions is uniquely determined by the temperature profile in the central horizontal cross section.[5] The temperature in this cross section was measured with thermocouples where junctions were spaced at 3-mm intervals along a line passing through the center of the cavity. The signals from the thermocouple were fed to the input of an analog circuit that performed a discrete Fourier transformation. In the experiments we

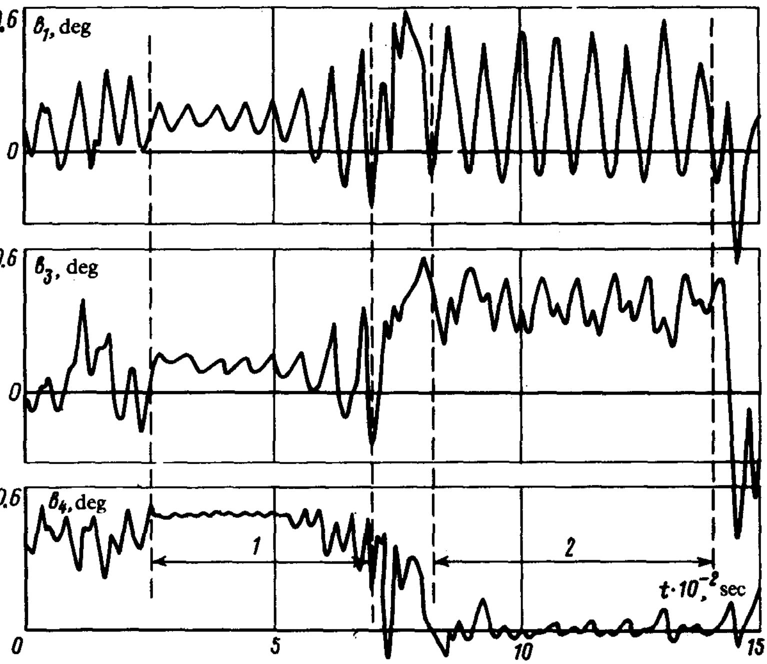

FIG. 3. Time dependence of the amplitudes of the spatial harmonics b_n for $R = 75$, $\alpha = 0$.

recorded the $b_n(t)$ amplitudes of the four lowest spatial harmonics $\sin \dfrac{\pi(n+1)x}{D}$ $(n = 1,2,3,4)$. Each spatial harmonic corresponds to a steady-state supercritical motion which can be observed in pure form under certain conditions. The number n determines the number of convective cells.

For $0 \leqslant \alpha < 30'$ a succession of alternating steady-state motions b_n is observed with an increase in the Rayleigh number $R = \dfrac{\rho g B}{\eta \chi}(d^4/2)A$. In the interval $R = 70 \pm 2$ the four-cell motion b_4 is replaced by stochastic oscillations whose nature depends on the parameters R and α and on the previous history of the process.

A series of peaks with two types of dependence of the frequency ν_N on the peak number N can be identified in the spectra of stochastic oscillations (Fig. 1). In both cases the oscillation spectrum is continuous. The first type of oscillations (curve C in Fig. 1), which resemble regular oscillations, are characterized by a dominant spatial mode. The peaks in their time spectrum correspond to the multiple frequencies $\nu_N = N\nu_1$. The second type of oscillations (curves A and B in Fig. 1 are characterized by an intermittence of the spatial modes. The dependence of ν_N on N in this case is quadratic (Fig. 2). The transition from one type of oscillation to the other occurs in a critical manner as the parameters R and α are varied.

The position of some peaks can be easily identified by the oscillation frequency of the amplitude b_1 on different segments of the $b_n(t)$ trace (Fig. 3). Segment 1 has a large constant component of b_4 and the frequency of the b_1 oscillations corresponds to the peak $N = 4$. The b_3 spatial mode predominates in segment 2. The b_4 motion is suppressed, and the frequency of the b_1 oscillations corresponds to the peak $N = 3$.

In conclusion, we note that several groups of peaks, for which a quadratic dependence of the average frequency of a group on the group number exists, can be isolated in the spectra of the Couette flow. To obtain the average frequency of a group, the spectra[1,2,6] were smoothed out. The results of the analysis are shown in Fig. 2.

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