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STABILITY OF OPERATION OF A STEAM-GENERATING CHANNEL FROM LOW-FREQUENCY PRESSURE FLUCTUATIONS

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The onset and development of vibrational instability in a steam-generating channel is investigated by an analysis of the fluctuations of pressure and temperature of the transfer fluid.

Experience in the operation of heat-power installations of the channel type shows that the flow of transfer fluid can become unstable, with concomitant fluctuations of the flow rate, pressure, and channel wall temperature [1, 2]. Depending on the hydrodynamic characteristic of the channel, the heat load, and the parameters of the transfer fluid the instability can be aperiodic, manifested in a variable hydrodynamic characteristic of the channel, or oscillatory.

Aperiodic instability arises in a channel with low hydraulic resistance and it can usually be eliminated by increasing the channel resistance by the installation of baffle plates. Oscillatory instability is characterized by quasiperiodic changes in the thermophysical parameters of the flow, occurs more often than aperiodic instability, and is not always eliminated by simple throttling [3]. Flow instability adversely affects heat transfer and promotes the onset of the heat-transfer crisis.

An important factor for improving the reliability and safety of operation of channel-type heat-power installations is early prediction of hydrodynamic instability of the steam-generating channels. For instance, it was shown in [4] that the spectrum of steam-content fluctuations completely determines the stability reserve of the channel and can serve as an indicator of the onset of hydrodynamic instabilities. Our investigations of oscillatory instability were made on a laboratory apparatus consisting of a closed circulation loop with a constant-level tank containing outgassed distilled water (Fig. 1a). Pump 1 drives water from the thermostat 2 through a flowmeter 3, the working channel 4, and a glass inspection tube 5. Power from an ac line, monitored by the measuring unit 8, is delivered to the working channel 4 through an autotransformer 6 and power transformer 7. During the measurements the temperature of the fluid at the entrance and exit of the working channel, and also the pressure at its exit, were recorded.

The temperature-measuring circuit includes a Chromel – Copel thermocouple 9 with time constant 0.2 sec, placed in the flow of fluid, a dc amplifier 10, and a compensator 11 for the constant component of the signal, which increases the sensitivity of the system.

The pressure is measured with a specially designed mechanotron transducer 12 (Fig. 1b), based on a 6MKh2B mechanotron, with a power unit 13. The wide dynamic range (from 10 N/m^2 to 10^4 N/m^2) and the 0- to 100-Hz transmission band allow this transducer to be used for measurement of static pressure or pressure fluctuations.

The signal of the measuring circuits was recorded by a multichannel recorder 14.

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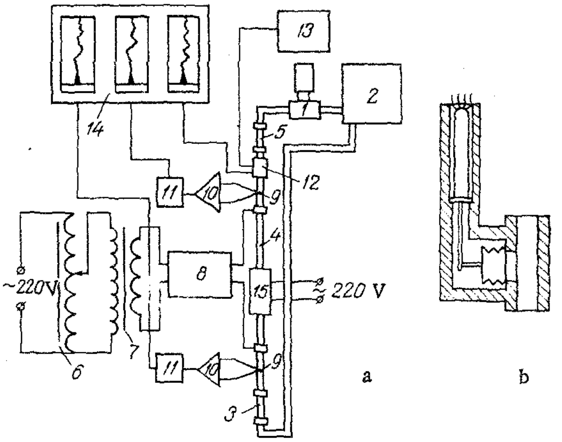

Fig. 1. Apparatus for investigation of stability of steam generation.

The investigations were made on two circulation systems: 1) with the pump at the entrance to the working channel and 2) with the pump at the exit of the working channel. The fluctuations were recorded at constant flow rate and different power inputs, corresponding to different boiling regimes. The temporal realization of the pressure fluctuations, represented in discrete form, was decomposed into a spectrum by means of a fast Fourier transform. We then calculated the statistical characteristics [5]:

1) the fluctuation amplitude – rms deviation

$$\Delta p = \sqrt{\int_0^\infty x^2(t)\,dt};$$

2) the integral power of the fluctuations – the energy characteristic of the fluctuations

$$W = \int_0^\infty S(\omega)\,d\omega;$$

3) the Rice frequency

$$f_R = \sqrt{\int_0^\infty S(\omega)\,\omega^2 d\omega \Big/ \int_0^\infty S(\omega)\,d\omega.}$$

The obtained results are shown in Figs. 2-4 for both circulation schemes.

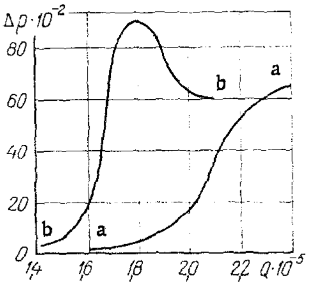

Fig. 2

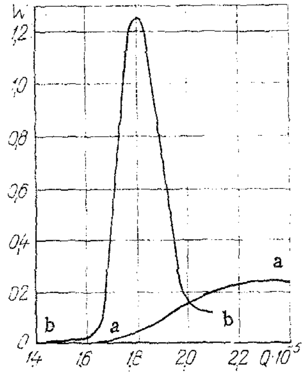

Fig. 3

Fig. 2. Amplitude of pressure fluctuations at channel exit as function of specific heat input for two circulation schemes: aa) scheme 1; bb) scheme 2. $\Delta p \cdot 10^{-2}$, N/m^2; $Q \cdot 10^{-5}$, kJ/m^3.

Fig. 3. Integral power of pressure fluctuations W, N/m^2 · sec, as function of specific heat input Q, kJ/m^3.

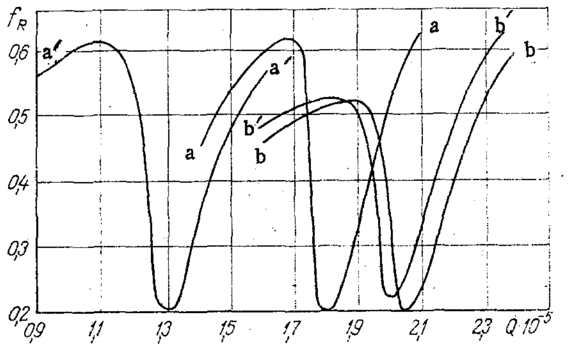

Fig. 4. Rice frequency f_R, $\sec^{-1}$, as function of specific heat input Q.

With increase in the power input the fluctuation amplitude (Fig. 2) (for circulation scheme 1) increased steadily from $\Delta p = 2 \cdot 10^2$ N/m^2 at specific bulk heat input $Q = 1.6 \cdot 10^5$ kJ/m^3 (ratio of total power input to channel to volume flow rate of fluid) to $\Delta p = 6.5 \cdot 10^3$ N/m^2 at $Q = 2.4 \cdot 10^5$ kJ/m^3. For scheme 2 the situation was different. It was characterized primarily by the onset of the fluctuations at lower heat loads, i.e., scheme 2 was less stable. A large peak appeared at $Q = 1.8 \cdot 10^5$ kJ/m^3, where the fluctuation amplitude was about $9 \cdot 10^3$ N/m^2. This peak was associated with the appearance in the channel of low-frequency (period 9 sec) pressure fluctuations and synphasic temperature fluctuations of up to 3-4°C at the channel outlet. The fluctuation amplitude then decreased sharply and leveled out: $\Delta p = 6 \cdot 10^3$ N/m^2 at $Q = 2.1 \cdot 10^5$ kJ/m^3.

The described situation occurred only when the subcooling of the fluid entering the channel was sufficiently great. At subcooling of less than 10°C the oscillatory instability was converted to an aperiodic instability with a developing boiling crisis and frequently burnout of the channel.

The integral power of the fluctuations (Fig. 3) in circulation scheme 2 was characterized by a large peak at $Q = 1.8 \cdot 10^5$ kJ/m^3.

Like the peak of the pressure fluctuation (see Fig. 2) this feature was associated with the onset of periodic low-frequency instability. In scheme 1 the integral power of the fluctuations increased steadily.

The Rice frequency (Fig. 4) characterizes the rate of change of the function and, hence, the frequency–energy structure of the considered process. All the experiments were characterized by the same kind of relation: steady growth with increase in specific heat input, passage through a maximum, a sharp decline due to low-frequency oscillatory instability, followed again by a steady increase. This behavior of the Rice frequency was not greatly affected by the distribution of the heat load along the channel. The shape of the curve was not altered (a'a', b'b') by the inclusion of an additional local heater providing a heat flux of up to 300 kW/m^2. Hence, the passage of the Rice frequency through a maximum can serve as a reliable index of the onset of flow instability in the channel.

NOTATION

$x(t)$, value of function at time t; Δp, amplitudes of pressure fluctuations; ω, frequency; $S(\omega)$, energy spectrum of fluctuations; f_R, Rice frequency.

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