Experimental study of the vibration of vertical rod in liquid flow

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Abstract. Vibration of the vertical tube, induced by an axial flow, were studied experimentally. Experiments were carried out using the sensors based on the electrical impedance. The time chronology of the pass of the tube axis was reconstructed using four sensors. For various flow rates different modes of fluctuations were found. The amplitude, shape, and characteristic frequencies of signals were found to change depending on the liquid flow rate.

1. Introduction
The flow induced vibration (FIV) is a negative factor that can cause emergency situations in heat transfer loops of promising power equipment. For example, this process can lead to the fretting corrosion of the fuel pins in the core of nuclear reactor power plants. Possibly, the most dangerous place is a contact between the fuel pins and the spacer grids, used in order to keep the distance between fuel pins. Damage and leaks of a fuel pin may occur at this location. This can lead to the leaks of radioactive substances into the coolant and then beyond the limits of the circuit. That is why the investigation of fluid structure interactions (FSI) is very important for nuclear industry at nowadays [1,2].

The use of heavy liquid metal coolants (eutectic lead-bismuth alloy, lead) for cooling the fuel elements of fast nuclear reactor power plants with a closed fuel cycle leads to the aggravation of this problem because the density of coolant is comparable to the density of materials of structural elements. Therefore, detailed studies of this problem should be carried out using numerical and experimental methods.

In this regard, a number of works dealt with the experimental and computational studies of the flow of liquid metal coolants in the elements of reactor installations have recently appeared [2–5]. The results of both experimental and numerical investigations can give useful information about processes causing flow induced vibration, frequencies and amplitudes of vibration of fuel pins; this is why the further development of experimental and numerical methods used for investigation of FIV in the elements of nuclear reactors is necessary.

The purpose of this work is to carry out measurements of FIV of the central tube in the annular channel, which is a preliminary task for experimental investigations of flow characteristics in rod bundles.
2. Experimental setup
The experimental stand was a closed loop stand. Distilled water with a temperature of 25°C was used as the test liquid. During experiments, the liquid from the tank was fed into the pressure line using a centrifugal pump. The flow rate was measured using an ultrasonic flow meter (the uncertainty in determining the flow rate is within ±1% of the measured value according to the manufacturer instructions). Next, the liquid entered the test section of the experimental setup.

The scheme of the test section is shown in figure 1. It was a vertical tube, in the center of which an aluminum tube was installed. The inner diameter of the tube was 10 mm, the outer diameter was 12 mm. The inner diameter of the outer tube was 26 mm. The flow was supplied to the test section through three nipples located at an angle of 120 degrees relative to each other. From nipples, the flow entered the cavity of the inlet manifold, in the center of which a sleeve preventing the effect of transverse liquid flows on the inner tube was placed. To reduce the irregularity of the flow at the entrance to the annular channel, a honeycomb was installed at the end of the cylindrical part of the collector. Behind the honeycomb there was a smooth transition from the cylindrical part of the collector (80 mm) to the diameter of the external tube of 26 mm. Then the main grid was set up. The distance from the location of the upper edge of the main grid to the entrance of the annular channel was 200 mm. The fuel rod simulator was rigidly attached to the grid. Fastening of the simulator was carried out both in the main grid and in a protective sleeve.

![Figure 1. The CAD model of the test section.](image)

3. Experimental results
The measurements were carried out using a rod-shaped vertical sensor installed inside the inner tube of the annular channel. Four sensors located at the corners of the square were used.

The sensor tip had a square cross section; each corner of this square was supplied with one electrical impedance sensor. The measurement area of the sensor was at a distance of 50 mm from the upper end of rod-shaped vertical sensor.

An example of signals received simultaneously using four sensors is shown in figure 2. The measurements can be converted into a time chronology of the position of the axis of the central tube in two-dimensional coordinates.

The liquid flow rate was \( Q_l = 3.3 \) t/h and the length of the rod \( L \) was 400 mm. The data for each sensor was given in volts. Calibration was used to convert the sensor signal into the length units. We
can see that the amplitude of oscillations was not constant in time and shape. Signal processing allowed us to determine the deviation of the tube axis from the vertical line at a given time. The data on the oscillation frequency of the tube were obtained.

**Figure 2.** The time dependences of signals from different sensors, L = 400 mm, Ql = 3.3 t/h: a - sensor 1, b - sensor 2, c - sensor 3, g - sensor 4.

The characteristic of oscillation forms is shown in figure 3. It demonstrated short sections of the restored trajectory of the rod axis, with duration of 0.1 s. The liquid flow rate was 2.4 t/h and the length of the central tube was 400 mm. Vertical and horizontal coordinates are shown in the figures in millimeters.

**Figure 3.** The position of the tube axis for different time intervals. L = 400, Ql = 2.4 t/h
Figure 4. The position of the tube axis for different time intervals. $L = 400$, $Q_l = 5.1 \text{ t/h}$.

The movement became more chaotic at the liquid flow rate $Q_l = 5.1 \text{ t/h}$ (see figure 4). In this case the amplitude of vibration was much smaller than at the previous one. This effect was caused by the resonance behavior of the central tube in the first case. The resonance frequency was not caused by the rotation frequency of the pump; this fact was revealed by using bypass.

Conclusions
Experimental investigation of flow induced vibration of the central tube of the annular channel was carried out. The method based on the electrical impedance was used in order to obtain the position of the central tube axis. The different time chronologies of the pass of the central tube axis were found; they depended on the rod length and the liquid flow rate. The resonance was shown to occur at different frequencies for different flow rates and the length of the central tube. In our experiments, these frequencies were in the range of about 6-50 Hz.

Our future plans are to use the presented experimental technique in order to obtain the characteristics of vibration of the rod in an experimental model of rod bundle.

References
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