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Flutter of Rods with Artificial Roughness in Axial Flow

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Abstract

The experimental investigation results on the vibration characteristics of the rods with artificial roughness in the axial flow are presented. It is shown that the roughness plays an important role in the mechanizm of vibrations excitation. For the rods having artificial roughness with a relative size of 0.075 ÷ 0.2 the phenomenon of dynamic instability has been revealed at the flowrates being by the order of magnitude smaller then those predicted by the Paidoussis theory. It is experimentally obtained that for the rods similar to those used as a nuclear reactor fuel element and heat exchanger tubes the critical velocities resulting in the vibration amplitude increase by the one or two order of magnitude are the values as much as 6-12 m/s. It is shown that the phenomenon revealed differs from a classic flutter by a number of attributes.

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The perspectives of power engineering development connected with creating the reactors of high power density put forward as one of the important problems the intensive heat removal in the core fuel assemblies and the heat exchangers.

The widely used method of heat transfer intensification is based on the turbulization of a coolant flow by means of artificial roughness manufactured in the form of circular grooves and protrusions, spiral ribbing, spiral wire windings, cross and spiral crimps and some elements of this king placed on the heat transfer surfaces. In this case the hydraulic resistances of the channels and the power required for coolant pumping are substantially increased. Moreover, the use of artificial roughness results in increasing the intensity of flow induced vibrations of the rods and tubes.

It is customary to assume that the amplitudes of vibration of the rod elements in axial flow are smaller that those in cross flow and do not present a danger of vibration induced.

The main cause of the forced vibration of the rods in the axial flued flow is turbulent pressure fluctuations. The other mechanizms of excitation(the parametric and self-excited vibrations) that have been studied and published are not realized practically at the flow velocities typical for the atomic power plants. So, in particular, the theory of a classic flutter developed as applied to the elastic rod elements in the axial flow [1-3] shows that for the rods having geometric dimensions and stiffness typical for the fuel elements and the heat exchanger tubes, the critical velosity at which the vibration amplitude is sharply increased exceeds 100 m/s. According to this theory the artificial roughness of the rod surfaces is not an important factor. In the present report the results of experimental investigations are given that show an extremely important role of artificial roughness in the mechanizm of exciting these intensive vibrations.

The investigations of the flow induced vibrations have been carried out on the experimental installation which represents a concentric annular channel formed by the rigid cylindrical body and the coaxial elastic cylindrical rod which is hinged on both ends. The surfase of the investigated rods has possessed the artificial roughness representing in different variants the spiral wire windings, ring ribs and sandy surfaces with a relative protrusion height of $d/(R-r) = 0.075 - 0.2$.

In these experiments the geometric and structural parameters of the rods and the body have been varied too.

The main characteristics of the investigated versions of this system are given in the table.

For the investigation of dynamic characteristics (natural frequencies and damping factors) of the rods being flowed around by a fluid flow the electrodynamic method of exciting vibration has been used in these experiments. The spectra of pressure fluctuations have also been measured on the wall of a channel by means of the straine sensors.

The results of experimental investigations [4-6] carried out on the rods with artificial roughness have shown that on reaching a definite critical velocity of a flow the amplitude of vibration has been sharply increased by the 1-2 orders of magnitude. In the figure 1 are shown the dependencies of vibration amplitudes attributed to the width of a annular gap with taking into account the roughness elements for several versions of the rods. As it is seen from the figure at the velocities of 6-12 m/s the amplitude of vibration has become comparable with the width of an annular gap. It is also established that the natural frequencies of rod vibration are essentially independent of the flow velocity as the hydrodynamic damping undergoes significant changes. In the fig.2 the relative damping factor is shown versus the flow velocity. It is seen that as the flow rate is increased the damping is strongly increased at the first time and then it is decreased.

On reaching the critical velocity the damping is turned to be zero. This means that the energy transmitted from the flow to the rod has become equal to the dissipative losses in the system and thus the conditions for appearins some self-exciters vibrations take place. For comparison in the figures 1, 2 are given the results of experiments for the smooth rod that show the monotonic increase of a damping coefficient and the relatively small intensity of vibrations within the investigated range of velocities (0-20 m/s), The calculated velocity of a flutter for the smooth rod [1] has a value of 130 m/s. Thus, the experimental data show that the critical velocities exciting vibration of a flutter type for the rods with artificial roughness can differ from the critical velocities of a classic flutter by the order of magnitude and upwards, the mechanizm of these vibrations seems to be of quite another nature.

It is possible that in this case the flutter is caused by a specific character of interaction between a vibrating rod and a flow in the channel having a substantially high hydraulic resistance as compared to a smooth one.

In the fig.3 are given the experimental data on the intensity of pressure fluctuations in a channel normalized to the dynamic pressure against flow rate. It is seen from the figure that at the sub-critical flow rates the intensity of pressure fluctuations having the wide spectrum of frequencies accounts for only some per cent of dynamic pressure. This corresponds to the turbulent fluctuations of the flow in the channel and, respectively to the forced vibrations of the rods with the relatively small amplitude. When the critical velocity of a flow is reached the random pressure fluctuations became harmonic vibrations with the frequency being equal to the natural rod vibration frequency and their amplitude is sharply increased. At the same time the amplitude of the rod vibrations is grown.

The analysis of given experimental data and their comparison with those prediction by the known theory demonstrate that the revealed phenomenon differs from a classic flutter.

Firstly, the critical velocities are smaller by the order of magnitude as compared with those predicted by the theory.

Secondly, the classic flutter of the rods is preceded by the loss of static stability (a divergence) at which the natural frequency of vibrations over the first mode is turned into zero.

In our experiments not only divergance but as well even any appreciable change of frequency were absent.

Thirdly, in these experiments it is essential the lack of the interaction of vibrations typical for the classic flutter over several modes. On reaching the critical velocities the vibrations of rods have been occured only over the first mode of a hinged beame.

Thus, the flutter of rods with artificial roughness differs from a classic one and represents a new phenomenon in the field of hydroelasticity.

The type of flutter mentioned above can be arise practically when using artificial roughness, e.g., for the heat mass-transfer processes intensification.

Therefore, on the development of the optimal designs of cores and heat exchangers with the use of artificial roughness on the heat transfer surfaces, it is necessary to take into consideration not only undesirable increase in hydraulic resistances but also the extreme growth of the amplitudes of vibrations, which can result in the fatigue failures of fuel elements and heat exchanger tubes.

References

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Construction and Dimensions Parameters of System and Critical Velocities of Flutter

№ number of version	Type of roughness	Length of rod l, mm	Radius of rod r, mm	Inner radius of shell R, mm	Mass of rod per unit length kg	Natural frequency of rod vibrations Hz	Coefficient of hydraulic resistance of channel	Critical velocity of flutter m/s
1	2	3	4	5	6	7	8	9
	Double wire winding on rod							
1	d = 0,1 mm s = 3 mm	800	5	9	0,164	33,5	0,031	-*)
2	d = 0,3 mm s = 5 mm	800	5	9	0,175	35,0	0,082	11,9
3	d = 0,5 mm s = 5 mm	800	5	9	0,185	34,0	0,090	10,4
4	d = 0,8 mm s = 5 mm	800	5	9	0,219	29,4	0,180	7,8
5	d = 0,8 mm s = 5 mm	1534	11	16	0,633	13,6	0,140	5,7
6	d = 0,8 mm s = 5 mm	1534	11	20	0,633	15,6	0,095	10,4
	Ring protrusions on the rod							
7	d = 0,5 mm s = 4 mm	800	5	9	0,164	34,1	0,090	9,4
	Sandy roughness = 0,9 mm							
8	on the rod and the shell	800	5	9	0,179	30,6	0,200	-*)
9	on the shell, the rod is smooth	800	5	9	0,164	36,1	0,019	130**)
10	the rod and the shell are smooth	800	5	9	0,164	36,1	0,019	130**)

*) Critical velocity is not attained in the experiment

**) Calculation is carried out according to the theory of a classic flutter [1]

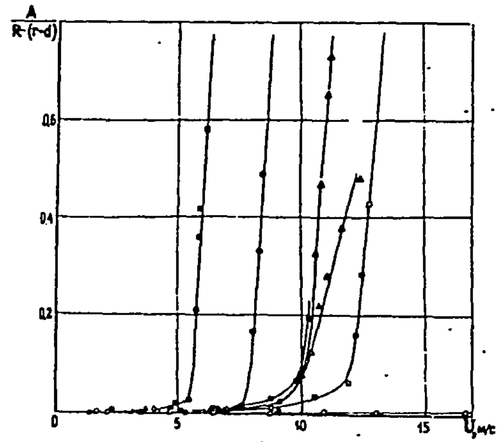

Fig.1. The relative amplitudes of bending vibrations of rods against the flow rate (the designations are in the fig.2)

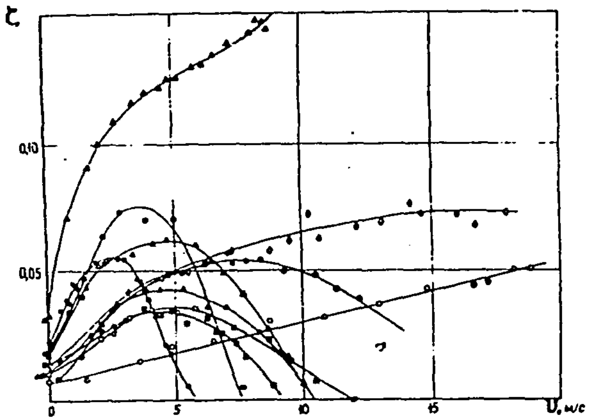

Fig.2. The relative damping against the flow rate ● -1, □ -2, ▲ -3, ◑ -4, ■ -5, △ -6, ◪ -7, Δ -8, ◊ -9, ○ -10 (the figures correspond to the numbers of versions in the table).

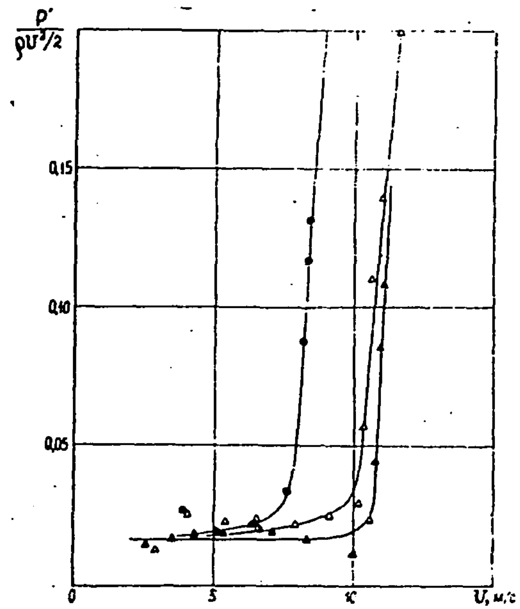

Fig.3. Ratio of the amplitudes of pressure fluctuations in flow to the dynamic pressure (the designations are in the fig.2.).