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Theoretical and Experimental Investigations of Flow Induced Vibrations of Long Slender Structures Partially Immersed in Sodium Pool of LMFBR

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ABSTRACT: In this paper, the sources of excitation mechanism of vibrations of long partially immersed structures in a liquid are investigated. The experimental tests carried out on mockup level probes are described. From the experiments, the excitation force has been found as a function of the flow rate which is used for the theoretical investigations. The theoretical formulation of the problem has been carried out using random vibration theory. The amplitude of vibrations of the level probe is computed from the analysis.

1.0 Introduction

The reactor vessel of FBTR contains four discontinuous level probes as indicated in fig 1. Under normal operating conditions, two of the probes are under sodium. The shorter probe has a total length of 1015 mm, with 100 mm under sodium. The longer probe has a total length of 1565 mm with 650 mm under sodium. During the shutdown condition, the two probes were found vibrating, with the shorter probe vibrating more. The vibrations showed a certain periodicity with some time duration of no oscillations. Details of the observations can be seen in ref [1].

The fundamental concern regarding the vibration of the level probes is of the failure of the probe due to random fatigue loading. This would have widespread implications, loss of function being just the beginning. Hence detailed experimental and theoretical investigations have been carried out to understand the mechanism of vibrations.

2.0 Experimental investigations

2.1 Details of test setup

To understand the mechanism of the vibrations of the probe, experimental investigations were undertaken on a specially fabricated mockup. The mockup consists of a vessel of about 1/3 scale of the reactor vessel in which two mockup probes were placed along a overflow pipe and control plug in the proper locations as in the reactor vessel. There are one inlet pipe and two outlet pipes for circulating the flow. The control plug (CP) deflects the flow which comes through the core. The overall experimental setup is shown in the fig 2 and fig.3

The mockup probes are designed to have the same fundamental frequencies as that of the actual probes. This is achieved by using aluminium tubes of nearly the same diameter (10 mm OD and 6 mm ID), filled with lead shots, and with the lengths adjusted to obtain the same fundamental natural frequencies (~ 3 Hz and 7.5 Hz for longer and shorter probes respectively). The longer probe is of length 1350 mm and the shorter probe of length 875 mm which are held vertically and clamped at their upper ends to suitable supports. In the reactor, they are fixed to the Large Rotating Plug (LRP) which is an annular disc over the reactor core. The free, unsubmerged portion of each probe is 800 mm. This means that the longer probe has 550 mm and the shorter probe has 75 mm submerged under the water surface . The coolant itself enters the core from a bottom inlet, and at the upper end, shoots up from the 91 fuel pins. It hits the CP and gets deflected, reaches the surface and then flows out through the outlet valves located on the sides of the vessel. This creates turbulence in the free surface. Water is used to simulate sodium coolant.

2.2 Experimental results

Basically the vibrations are measured on the two mockup probes at various locations of CP for the different flow rates ranging from 0 - 10 m^3/s. The vibrations are measured using modal analyser. The vibrations are random in nature. However there are peak at the natural frequencies of the probes. The vibrations are not continuous. During certain intervals of time, vibrations are absent as observed in the FBTR. Vibrations are significant only at some specified locations of CP. The level of oscillations is increasing with flow. However at the other locations of CP, particularly at the location during normal operation, vibrations are absent whatever may be the flow rate. This is an important observation.

3.0 Theoretical Investigations

3.1 Assumptions

- The excitation mechanism is assumed to be resulting from free surface turbulence and hence the probe is subjected to this excitation only in the vicinity of the free surface of the water. The turbulence is due to the impingement of the liquid jets ejecting from the subassemblies directly on the free surface as well as the deflected jets after hitting on the internals and side walls. The fluid oscillations contain a wide frequency band and hence a white noise characteristics can be applied with proper correlation lengths.

- The probes are modelled as a uniform cantilever beams.
- Damping values are taken as 3% for the smaller probe and 8% for the longer one, since maximum portion of the longer probe is immersed in the water. The damping values are obtained using half-power method on the acceleration frequency spectrum obtained from the experiment.

3.2 Definition of exciting force history

The forces that act on the probes are mainly pressure forces due to surface oscillations. The origin of such a surface disturbance may be described thus. The coolant emerges as a jet from the fuel pins towards the CP, hitting the bottom of the CP with great force. The flow is directed randomly in all directions after the impact. This results in turbulence and random surface disturbance components. When the CP is placed eccentrically, the fluid rises beyond the mean surface level on one side of the CP, hence causing more surface disturbance on one side. As a result, the pressure forces on the probes are random. The surface disturbance could also amplify or annihilate itself by getting reflected from the reactor walls, depending on the frequency and geometry. These forces depend strongly on flow rate. These sort of exciting forces for causing flow induced vibrations are addressed in ref [2].

3.3 Random response analysis

The theoretical analysis that follows is of the random vibration response of a cantilever beam subjected to randomly varying forces uniformly distributed over a certain length near the free end. The references [4, 5, 6, 7 and 8] are followed for solving this problem.

3.4 Computer implementation

A computer program has been written based on the above formulations. Typical acceleration PSD's are plotted for both the probes on same axes with various parameter values. The parameters studied included the shape of the pressure PSD curve, the submerged length of the beams, effective depth of the fluid loading, and the region on the beams on which fluid pressure forces due to surface oscillations are felt, called here Effective Loading Region (ELR).

4.0 Results & Discussion for the analysis of the mockup probes

Based on literature, the characteristic of the fluid induced forces on the level probe is of a white noise, consisting of wide range of frequencies. The amplitude was estimated from the experimentally obtained displacement values as a function of specified flow rate. The PSD corresponds to the flow rate of 9 m^3/s, with the CP positioned at the worst location, where maximum vibration of the level probe is observed, as fitted in the program from known displacement values. The power spectral displacement of the probes shown in fig 4. The measured displacement response of the probe is shown in fig.5. Parametric studies are carried out varying the effected loading region and the correlation length (CL). Table-1 gives the details of the parametric study carried out.

Table-1

Effective loading region (mm)	RMS displacement (mm)		RMS Acceleration (g)	
	Short probe	Long probe	Short probe	Long probe
25	3.725	0.062	1.434	0.803
35	4.68	0.078	1.812	1.009
45	6.724	0.114	2.659	1.446

5.0 Results & Discussion for the analysis of the FBTR probes

The input forc function is expressed as a function of the ratio of the flow rate to the free surface area (cross-sectional area), since the excitation is caused by the surface wave fluctuations. For the prototype Q is 200 m^3/h and A is 4.337 m^2, giving Q/A as 46.1. The corresponding values for the model are Q = 9 m^3/h, and A = 0.384 m^2, giving Q/A as 23.4. From the above data, the analysis gives the vibration levels of the shorter probe to be ±7.5mm

6.0 Conclusions

The present approach using random vibration theory is able to explain some of the experimental observations on the vibration of the level probes, viz. vibrations at the natural frequencies, relative amplitudes of the shorter and longer probes and damping characteristics. Towards this, an expression has been defined in the form of white noise involving a characteristic constant depending upon the flow rate. The characteristic constant has been estimated using the measured displacements on the mockup.

With the present analytical approach, the displacements of about ±7.5 mm for the prototype at the flow rate corresponding to shutdown condition has been predicted satisfactorily. Vibration amplitudes have been obtained also at various flow rates to understand its effects. It is confirmed that the vibrations are absent when the control plug is in its position during the normal operation.

References

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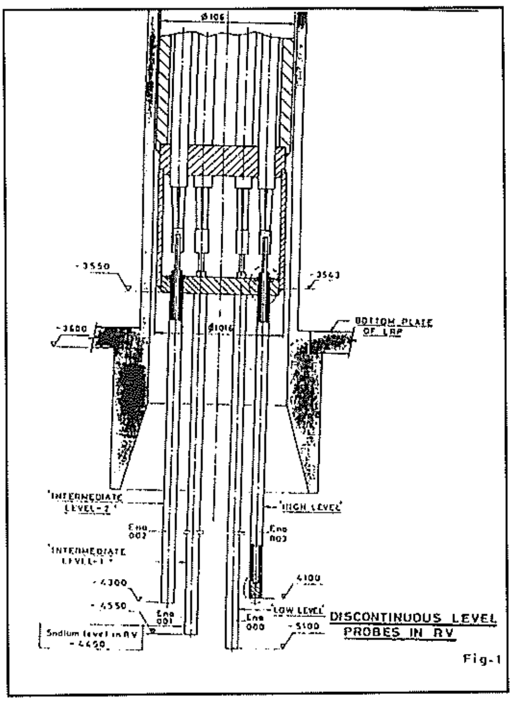

Fig.1 Discontinuous level probes

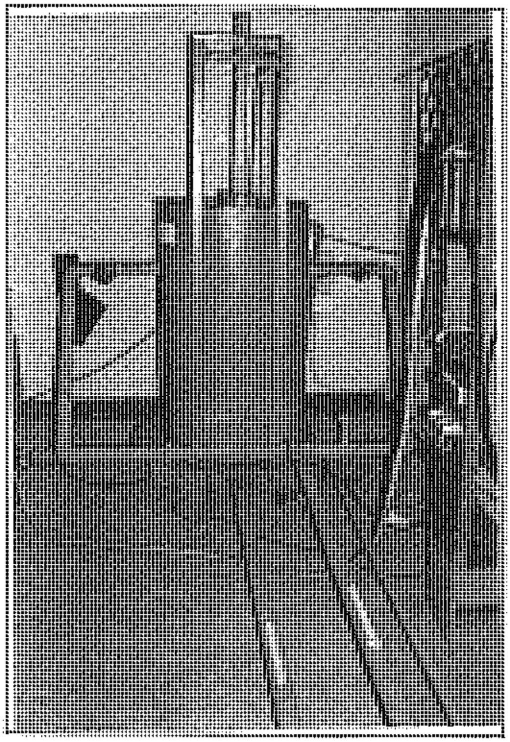

Fig.2 Experimental setup showing inlet,outlet,reactor vessel,control plug, overflowpipe and level probes

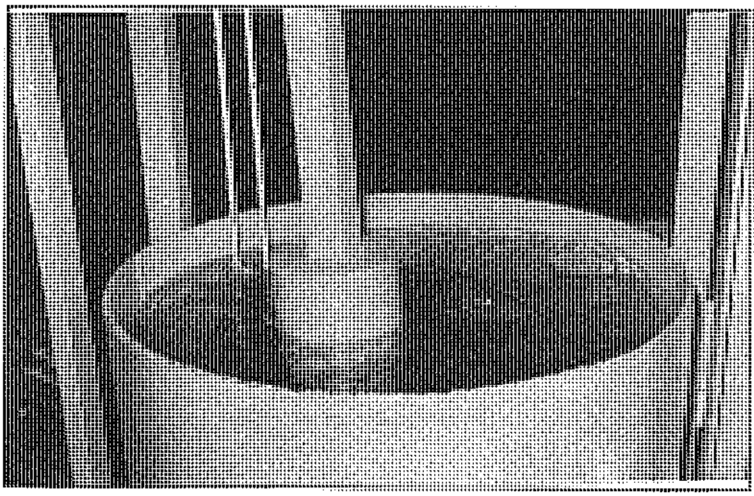

Fig.3 Shorter and longer level probes adjacent to the overflow pipe

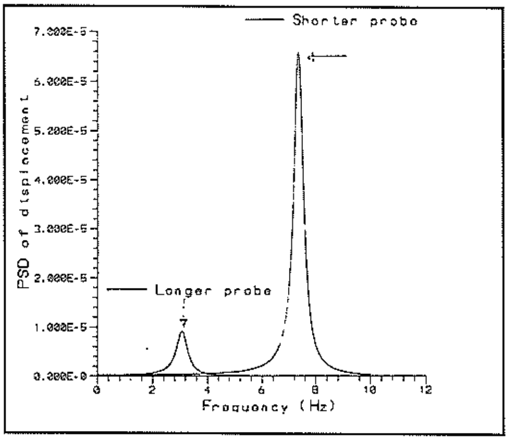

Fig. 4 Power Spectral Density of Displacement Response of Probes

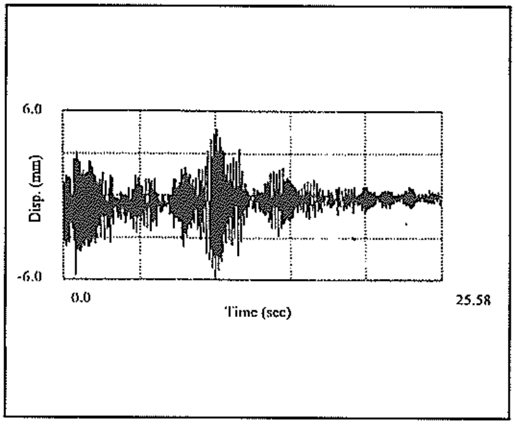

Fig.5 Measured Displacement of Shorter Probe