PARALLEL-FLOW-INDUCED VIBRATION OF FUEL RODS

S.-S. CHEN, M.W. WAMBSGANSS,

Theoretical and Applied Mechanics Section, Engineering and Technology Division, Argonne National Laboratory, Argonne, Illinois, U.S.A.

The vibration of nuclear reactor fuel rods is an important design consideration since it may cause failure by fretting and fatigue, or may cause malfunctioning of the plant. In recent years, extensive studies have been performed to determine the response of fuel rods in parallel flow.

In a previous paper [1] , an analytical solution is obtained for the displacement statistics of a simply-supported rod in parallel flow. However, in many cases of practical interest the assumption of simply-supported end condition is not acceptable, indicating the need for a more general treatment. In the present paper, the theory has been extended to account for a rod with arbitrary end conditions. Also, new experimental data for the turbulent-boundary-layer pressure [2] is incorporated into the theory and the mechanism of damping and the virtual mass are studied.

The motion of the fuel rod is postulated to be excited by the turbulent-boundary-layer pressure fluctuations. The equation of motion is first derived to incorporate the drag forces, damping, axial force and fluid forces. Since the system does not possess classical normal modes, Galerkin's method is employed to reduce the equation to a system of ordinary differential equations. The displacement statistics are expressed in terms of the power spectrum of pressure, the rod transfer function and joint acceptance. The power spectrum of the pressure is based on the experimental data obtained from pressure measurements on the surface of a cylindrical element in water flow [2]; these measurements give the nearfield mean-square spectra in the low-frequency range of interest. The evaluation of the transfer function requires a knowledge of damping, consequently the mechanism of damping is investigated.

Numerical computations were carried out for several support conditions. For the assumed forcing function, the response of a fixed-fixed rod is lower than that of a simply-supported rod; thus, increasing the end restraint can reduce the vibration.

A comparison of theoretical rms rod displacements with experimentally-determined values reveals that the theory satisfactorily predicts the essential features of parallel-flow-induced vibration. The measured rms displacement of a fixed-fixed rod is in good agreement with the theoretical result.

REFERENCES

1. S.S. Chen and M.W. Wambsganss, "Response of a Flexible Rod to Nearfield Flow Noise", Proc. of the Conference on Flow Induced Vibrations in Reactor Components, Argonne National Laboratory, Argonne, Ill., May 14-15, 1970, pp. 5-31

2. M.W. Wambsganss and P.L. Zaleski, "Measurement, Interpretation and Characterization of Nearfield Flow Noise", Proc. of the Conference on Flow Induced Vibrations in Reactor System Components, Argonne National Laboratory, Argonne, Ill., May 14-15, 1970, pp. 112-140

* Published in *Nuclear Engineering and Design* 18 (1972) 253-278.

DISCUSSION

Q L. CEDOLIN, Italy

Has the assumption that the spacial correlation of pressure fluctuations been investigated ?

This question arises because some experimental results, reported in paper E4/5, seem to indicate a strong frequency dependent effect in two phase flow.

A S. S. CHEN and M. W. WAMBSGANSS, U. S. A.

The spatial pressure correlations were represented by the phenomenological model proposed by Corcos (31); empirical constants in the model were based on data obtained by Bakewell. We have measured longitudinal and circumferential correlations and, while these data were not used in the calculation, they were in agreement with Corcos' model and Bakewell's results. We agree that the rms response depends on the pressure correlation, and accept that the pressure correlations in single-phase flow are different from those of two-phase flow. While we did not study the sensitivity of the spatial pressure correlation on the rms response, Crocker M. J., "The Response of a Supersonic Transport Fuselage to Boundary Layer and to Reverberant Noise", J. Sound Vib. 9 (1969) 6-20, found that the response of an aircraft fuselage was relatively insensitive to the spatial correlation of the turbulent boundary layer pressure; we expect this to be true in the case of fuel rods.

Q J. KADLEC, Germany

According to your paper the damping quotient ξ is linear proportional to the mean flow velocity V. $\xi \sim V$. On the other hand, the spectral function of pressure fluctuation is proportional to V^3. As a result, could it be expected that the rms value of amplitude of displacement $\sqrt{\bar{y}^2}$ would be approximately linear proportional to V. But the experimental results show the dependency $\sqrt{\bar{y}^2} \sim V^n, n > 1$. Can you explain this ?

A S. S. CHEN and M. W. WAMBSGANSS, U. S. A.

The rms response depends on the damping ratio ξ_n, frequency Ω_n, pressure spectral density $\Phi(\Omega)$, and acceptance J_{nm}, all of which are functions of mean axial flow velocity. If we neglect the effects of flow velocity on the frequency and acceptance, take as having a "white-noise" spectrum, and use a one-mode approximation, then, the rms displacement will be approximately proportional to the flow velocity V. However, as we include the effects of flow velocity, the rms displacement becomes approximately proportional to V^n where n ranges from 1 to 2. This is based on the assumption that the spectral density of the pressure fluctuation is proportional to V^3. However, the behavior of the fluctuating pressure field in the low-frequency range has not been firmly established and this assumption remains to be verified.

Q E. OHLMER, JRC Ispra, Italy

Our paper has shown the advanced state of our analytical and experimental work in this field. But it remains the "crucial point", as you have said, concerning a realistic determination of pressure fluctuation fields influenced by an actual flow loop. Do you think that the analytical model prediction of rod displacement will also be applicable to the realistic case of rod displacement under e. g. , reactor-flow conditions assuming that we can determine experimentally the pressure fluctuations field ?

A R. A. VALENTIN, U. S. A.

It is hard to believe that, at this time, the far field noise, structural conducted vibrations, etc. , that one would expect in a real reactor could be modelled a priori in any realistic analysis - that is, in a mathematical analysis. If one examines the literature on the characteristics of far-field acoustic pressures as they relate to their origin, one finds it very difficult to identify source properties (e. g. geometry, vibration modes, etc.). Therefore, to take a preliminary design, look at the components, predict what their far-field spectra would look like, and then use this to predict fuel pin response, seems an almost impossible task. What is possible and necessary is to seperate out each possible source in an idealized experiment and to truly understand its physic response by finding a suitable analytical treatment. The total problem as a design question, reduction to handbook-type computations is not feasible. A careful study of each isolated effect, however, gives the designer some hope of knowing what things to safely ignore. The question of separability of phenomena is, however, itself a matter for serious study.

Q R. J. SCAVUZZO, U. S. A.

In your lecture you referred to a critical flow velocity associated with a cantilever rod. Could you discuss this phenomenon ?

A R. A. VALENTIN, U. S. A.

The critical flow velocity associated with a cantilever rod in parallel flow is somewhat analogous to that observed in flow over flat plates fixed at the flow inlet end but free down-stream. As noted by Prof. Boresi, it has been observed experimentally that such "flutter" - in particular the critical flow velocity at its onset - is dependent on the shape of the rod end. One would expect that this end shape would determine the state of turbulent flow at the very end of the rod and through this, the local pressure spectra - hence the end forcing function. Dr. Chen has done extensive work on a similar problem associated with the stability problem associated with a cantilever tube having fluid flowing through. An analytical solution for the flutter problem of a solid, cantilevered rod in parallel flow has been presented by Paidoussis (4).

Q

K. OMATSUZAWA, Japan

One of the differences between experimental and actual core rod is the temperature of fluid. What is your idea if the results of experiment would be developed to the actual core design ?

A

R. A. VALENTIN, U. S. A.

It would be my opinion that the most important temperature effect to be considered in parallel flow would involve heated rods, - preferably internal heating by an in-reactor closed loop experiment. This would certainly affect the size of the turbulent boundary layer and, hence, the spectral characteristics of the pressure field. It would be my intuitive answer that such heating would increase the rms displacement in any given case when compared to an equivalent uniform temperature experiment.