FLOW INDUCED VIBRATIONS OF LMFBR STRUCTURES

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1. Introduction

The vibrations of a structure subjected to an irregular flow can be estimated through the following steps : on one side the random pressure field associated with the flow is characterized by measuring the power spectral densities and the correlation lengths of the fluctuating pressure. On the other side the coupled fluid-structure system is characterized by its acoustical-mechanical transfer function, obtained from a modal computation. In most practical cases this implies the use of large structural computer codes which take into account the fluid structure interaction.

Experimental tests on simple models are needed in order to validate the codes and to provide data about the damping of fluid-structure coupled systems.

Here we present some results, recently obtained at C.E.A./D.E.M.T., concerning the experimental aspect of these two steps. Data to be discussed are more specifically related to L.M.F.B.R. structures : large axisymmetric shells (vessel and baffles), and elongated cantilevered structures (heat exchangers and pumps).

2. Modal Measurements on Axisymmetric Shell Structures

L.M.F.B.R. internals include large axisymmetric thin shells in contact with sodium. Strong fluid coupling effects occur for some of them which are separated only by a small sodium annular gap. Such fluid-structure configurations are quite conveniently computed by the AQUAMODE Code (see /1/, /2/).

An experimental program has been achieved on models in air and in water in order to validate the computation by the code of fluid-structure strongly coupled systems. Two coaxial axisymmetric shell models have been used : first model consists of two concentric cylindrical steel shells (Height : 1 m, diameters : 1.17 and 1.27 m, thickness : 1 mm). Each shell is solded at its base to a circular plate 50 mm thick. The model is simply lying on a neoprene sheet, stretched on the ground. The second model consists of two concentric conical shells (Height : 1.5 m, inner shell base and upper diameters : 0.228 and 1.03 m, thickness : 1.5 mm, gap width : 15 mm), which are solded to a circular plate 20 mm thick. Figure 1 gives the frequency diagram, in air and with water inside the gap, for resonances below 100 Hz on each model, as computed by AQUAMODE. Shell modes are classically identified by their axial "m" index and their azimutal "n" index. Because of the coupling of the two shells by the plate, each pair of (n, m) values corresponds to two resonances, the shells vibrating either in, or out of phase. Coupling by the fluid leads to a similar situation.

The models have been harmonically excited by a single shaker, with a slow frequency sweep. Vibrations have been measured by piezoelectric accelerometers and transfer functions obtained by measuring the force delivered to the structure. It can be noted on Fig.1 that several resonances occur at nearly the same frequency. This is true in particular for the lowest frequency modes on the cylindrical model, situation growing worse in the presence of water. This led to some experimental difficulties for recognizing unambiguously some modes.

1) In air fairly good agreement between experiment and calculation is found :
For all the analysed modes ($m = 1$; $n = 3$ up to $n = 12$ for the cylinders and $m = 1$; $n = 2$ up to $n = 7$ for the cones) the relative error between measured and computed frequencies is less than 10 %. Experimental values are systematically less than the computed ones, by an amount which is a decreasing function of the azimutal "n" index. This probably is due to an insufficient description of the connection between the shells and the plate, in each model.
On the other hand azimutal modal shapes are in close agreement with the calculated shapes.

2) In water results obtained are illustrated by figure 2 which gives the computed and measured evolution of the $m = 1$, $n = 7$ modes (cylinders) and of the $m = 1$, $n = 3$ modes (cones) with the water height in the annular gap. Natural frequencies are decreasing functions of the water height for both modes, the out of phase mode being much more affected than the in phase mode. On the cylinders, above 200 mm water height, only the out of phase mode has been analysed. On the cones, measurements for the two modes have been made of each level. In both models when fluid coupling entirely dominates the mechanical coupling (i.e. above a critical height) no significant differencies are found between the experimental and computed frequencies. This clearly shows that the fluid-inertial coupling effect is correctly treated by AQUAMODE.

Finally the tests have provided interesting data concerning the model damping rates. Structural damping in the two models is quite small, leading to modal damping rates in air of a few 10^{-3}. Presence of water in the annulus leads to higher damping rates, up to a few 10^{-2} for the out of phase modes.

3. Excitation of I.H.X Beam Resonances by the Flow

The L.M.F.B.R. intermediate heat exchangers (I.H.X) are elongated structures, supported at their upper part on the reactor floor. Their first beam resonances occur at a few Hertz. Primary sodium flowing through the I.H.X. reaches its highest permanent velocity at the exit from the tubes bundle. A highly turbulent flow takes place in this area, giving rise to pressure fluctuations able to excite the first I.H.X. beam modes.

A parametric model inserted in a water loop has been made in order to study the gross characteristics of the fluctuating forces induced by such a flow pattern on elongated structures supported only at their upper end.

The model is essentially made up of a vessel containing water with a free level, which simulates a quarter of the Super Phenix cold collector, and of three tubular structures which simulate one pump and two I.H.X. These components are supported at their upper end to a cover plate clamped to the vessel. Modelisation of the components has been highly simplified (see Fig.3).

Stiffness of the I.H.X. supports may be parametrically changed and the flow rate in the loop may be varied by a factor from 1 to 6. Water outflow from the I.H.X. models occurs across two concentric circular rod arrays. Vibrations are measured by piezoelectric accelerometers, located at various places along the two I.H.X. models.

Data are then numerically processed in order to obtain direct and cross power spectral densities of acceleration.

1) For several support configurations the first beam mode of the I.H.X.s has been analysed, in air and in still water by experiment and computation using the TEDEL code /3/. This resulted in a very good agreement as frequencies and modal shapes are concerned. However experiment reveals the existence of other modes at higher frequency which involve a mechanical coupling of the two I.H.Xs by the cover plate. Such a coupling effect always remains quite negligible for the first beam mode.

In water first beam mode frequency has been varied over the range 1 to 10 Hz. In addition a practically clamped free configuration using a very stiff cover plate has also been analysed (first mode near 24 Hz).

In air modal damping rates are a few 10^{-3}. Presence of water leads to higher values of a few 10^{-2}.

2) Each support configuration has been tested in flowing water : in comparison with still water tests a small rise in damping is observed when increasing the flow rate. Other modal characteristics remain practically unchanged.

Random vibrations of the I.H.X.s excited by the flow have been analysed in order to derive the spectral properties of the fluctuating forces acting at their lower part. Density power spectrum of an equivalent source located at the flow exit is derived by using the computed transfer function and the observed acceleration spectra. Analysis has been limited to the resonance peak corresponding to the first beam mode. Near this resonance the two I.H.X.s are excited to a similar level and coherence between their motions is quite small.

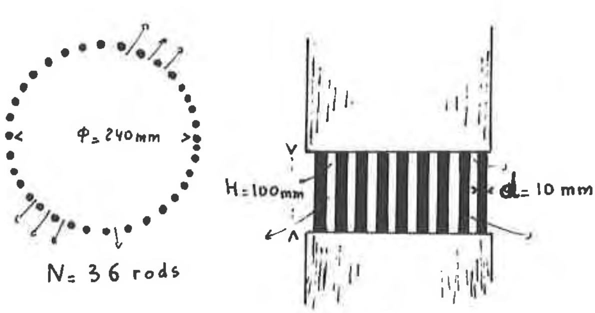
Figure 4 gives the spectrum of the excitation source. This has the classical shape of a turbulent spectrum, similar to others which have been previously measured on various flow singularities (sudden enlargements, bends, etc...).

Results are presented on a non dimensional form :

the non dimensional spectrum $\quad F(s) = \frac{V}{H}\left(\frac{1}{2}\rho V^2 S\right)^{-1} \varphi(\nu)$

the Strouhal number $\quad s = \frac{\nu H}{V}$

V, H, S are scaling parameters which are chosen according to general methods previously developed and applied to various flow singularities (see /3/, /4/). Geometry of the present singularity is sketched below.



S = N x d x H

V is generally chosen as the maximum permanent flow velocity through the singularity. Here V is the mean permanent velocity in the inter-rods space. The geometrical parameters H and S are chosen in analogy with the sudden enlargement case. This choice leads to :

Cut off Strouhal number $s_c \simeq 0.2$

Mean square value of fluctuation $\sigma^2 = \int_0^\infty F(s)\, ds \simeq 10^{-2}$

Such values are quite similar with the results obtained for other singularities, in particular sudden enlargements.

4. Conclusion

Concerning the experimental modal analyses fairly satisfactory results have been obtained. Further experimental tests are in progress or planed for a near future, which are devoted to the study of :

1) Some other typical geometries in still water, involving fluid gaps of variable width.

2) Fluid flow effect on modal shapes and damping rates on cylindrical shells.

Concerning the excitation sources studies, the results presented here show that the first beam modes of cantilevered I.H.X.s in L.M.F.B.R. are excited mainly by a turbulent source located at the I.H.X. exit, and that no strong fluid-structure coupling between pairs of I.H.X.s are likely to occur. Further experiments are in progress in order to study the excitation of the large thin shell structures by the primary sodium flow.

References

/1/ LIVOLANT, M., JEANPIERRE, F., "Experimental and Theoretical Methods for assessment of flow induced vibrations of nuclear reactor internal structures", Third SMIRT Conference, London 1975.

/2/ LIVOLANT, M., JEANPIERRE, F., "Vibrational analysis of the SUPER PHENIX internal shells", 4th SMIRT Conference, San Francisco 1977.

/3/ AXISA, F., GIBERT, R.J., "Flow Induced Vibrations of piping", 4th SMIRT Conference, San Francisco 1977.

/4/ AXISA, F., GIBERT, R.J., VILLARD, B., "Flow Induced Vibrations of piping system - Vibrations sources - Mechanical Response of the Pipes", BNES Vibration in Nuclear Plant, Keswick U.K. May 1978.

FIG. 1 RESONANCE FREQUENCIES AS COMPUTED BY AQUAMODE (m = 1)

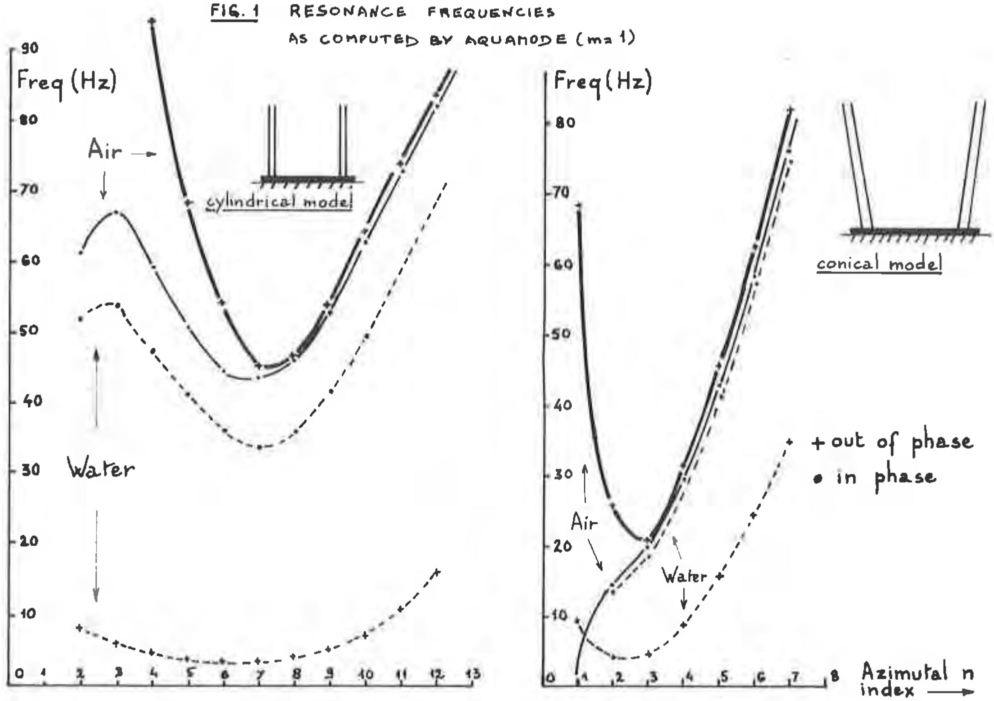


Figure 2 Evolution of resonance frequencies with the water level

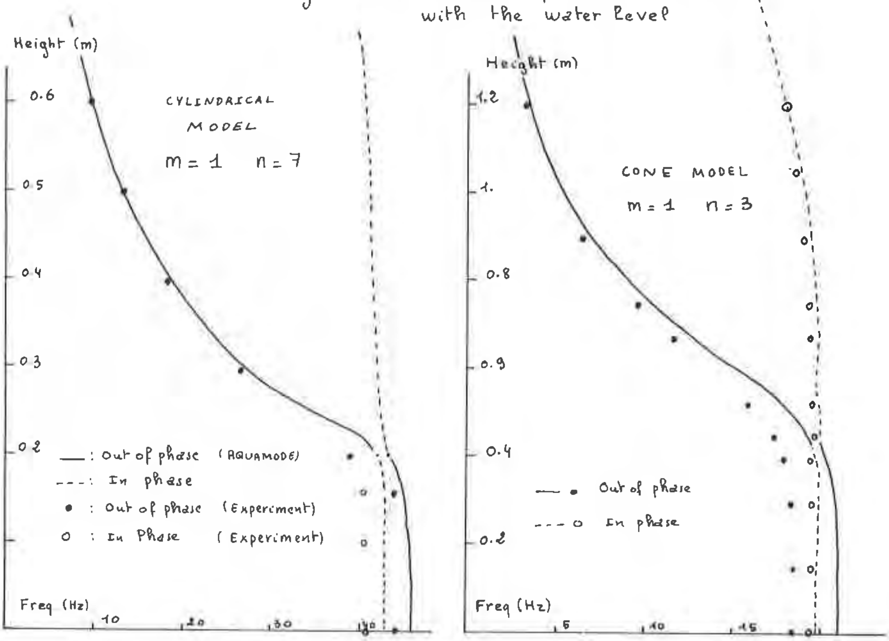
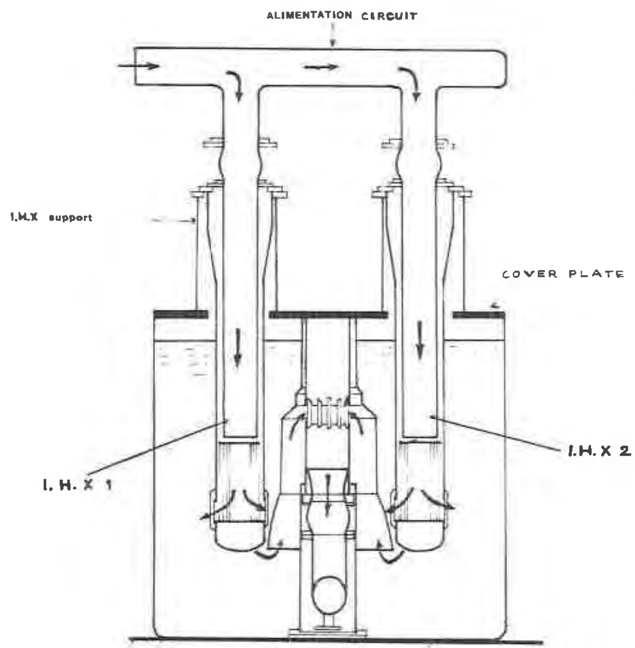


Fig. 3 MODEL FOR FLOW INDUCED I. H. X VIBRATIONS STUDY



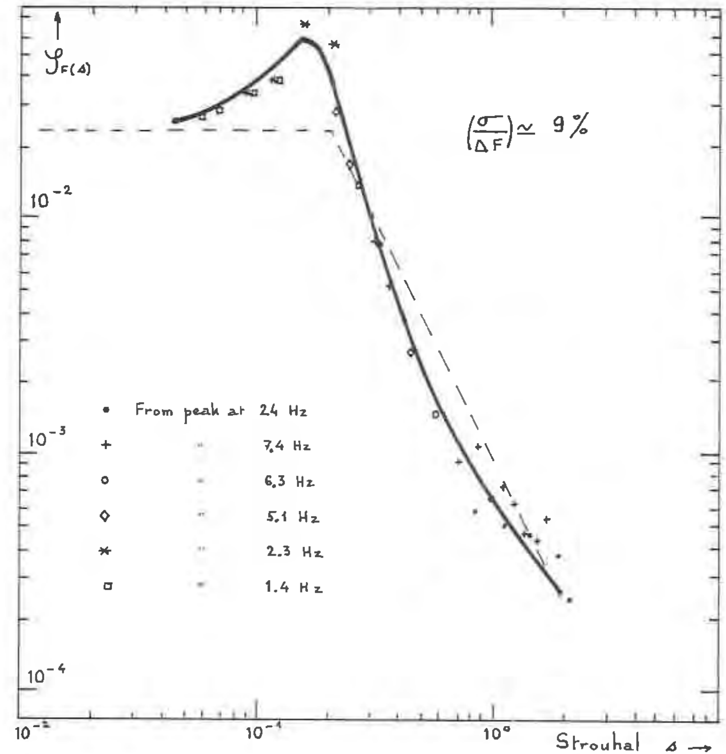


Fig. 4 ADIMENSIONAL SPECTRUM OF THE FLUCTUATING FORCES ON THE I. H. X