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Experimental Study of the Fuel Rod Behaviour under Baffle Jetting

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ASBSTRACT

High velocity jets going through the narrow baffle slots that run the length of the baffle plates in nuclear reactor cores may cause large amplitude vibration of the fuel rods when a critical jet velocity is exceeded.

The purpose of this paper is to present the experimental studies performed by FRAGEMA to develop and qualify design which can withstand the baffle jetting effect.

1 INTRODUCTION

In a pressurised water reactor, the core is surrounded by vertical plates called baffles. These baffles are joined to each other but the joints are not completely leaktight. So, due to increasing temperature and pressure during power escalation, the gap width increases and crossflows are jetted through the joints towards the inside of the core. In some reactors, the jet flows are so strong that they could damage the fuel rods located in the vicinity of the joints.

FRAGEMA in collaboration with TECHNICATOME has developed an experimental program to investigate this problem. The purpose of this study was to acquire a data bank of data on the behaviour of the maximum number of fuel rods facing to the baffle jets and also to find a way to avoid fuel rod damage.

This paper describes the testing installation and conditions and then explains the main results. The first part shows how the testing installation is constituted, how it operates, what kind of possibilities it offers and also how vibration measurements are made. The other part concerning results, submits the comparative test data between the four different types of fuel assembly configurations tested and presents the comments on the fuel rod instability problem.

2 TEST FACILITIES AND PROCEDURE

2.1. Description of test apparatus

The tests were performed by TECHNICATOME on the VICHY facility (see figure 1).

The test assembly is loaded into a square basket with four cavities which generate a crossflow jet distributed over the entire fuel assembly using special slots.

The assembly is positioned in the basket by means of adjustable stops at the nozzle and grid locations and the assembly holddown springs are compressed to their nominal position.

The test apparatus contains a main flow loop capable of an axial flow of 125 m^3/s at a 4 bar pressure and at a 40°C température.

An injection line supplies water to the four cavities which characteristics can be adjusted as follow.

cavity 1 : non supplied

cavity 2 : $0.50 \times 10^{-3} < Q < 5.56 \times 10^{-3}$ m^3/s P < 10 b

cavity 3 : $0.30 \times 10^{-3} < Q < 3{,}33 \times 10^{-3}$ m^3/s P < 7 b

cavity 4 : $0.30 \times 10^{-3} < Q < 3{,}33 \times 10^{-3}$ m^3/s P < 5 b

The injection slot widths are calibrated by contact with controlled thickness gages, and the distance from the baffle and the lateral position of the rod (n°3) facing the jet can be adjusted by moving the assembly.

2.2. Vibration instrumentation

To avoid the problem arising from the use of standard techniques which create flow and structural behaviour modifications, vibration measurements were taken by LASER VIBROMETER TECHNIQUE.

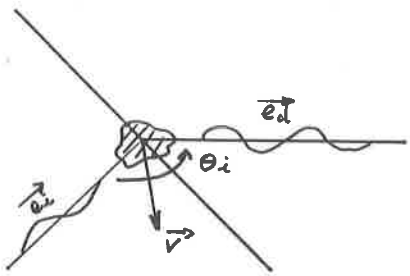
Instant velocity is measured by detection of the DOPPLER frequency by heterodyning on photo-detector elements.

The DOPPLER frequency is given by :

$$F_D = f_1 - f_d = \frac{1}{\lambda i} (\vec{e}_D - \vec{e}_1) \vec{V}$$

and the instant velocity

$$V = \frac{FD \ \lambda i}{2 \sin \frac{\emptyset i}{2}}$$



This type of measurement allows :

- a high level of resolution, dynamic measurements,
- ease of multiplication of data points by simplifing rod instrumentation and measurements from the outside.

Glass windows and glass cylinders provide access in two directions to the special small reflectors attached to the instrumented rods.

Sixteen rods facing the jet were instrumented between grids 5 and 6 and two rods (2 and 9) were also instrumented at the bottom of the assembly between grid 1 and 2.

2.3. Vibration data processing

Three laser guns are used simultaneously :

- two, measure the vibrations of the sixteen rods in two directions,
- the third one, measures the reference vibrations of the first rod coming into instability.

The figure 2 shows the frequency processing and the time history processing.

For this last processing, a special soft ware has been developped.

The analog signals are sampled after passband filtering through a computer based system HP 1000 F.

Then the following processings are realized :

- integration of velocity,
- search for maximum peak displacements,
- plotting of peak displacement curves versus time and detection of impact,
- calculation and plotting of rod trajectories and of the displacement amplitude distribution for 10 s,
- calculation of characteristic parameters of the rod vibrations.

2.4. Hydraulic measurements

Measurements and display of jet impingement into the test flow lane were performed using LASER ANEMOMETERS ANALYSER STROBOSCOPES.

For these tests the assembly was removed.

These tests showed the extend of jet impingement into the flow lane without the fuel assembly (up to 100 mm) and the presence of whirling.

3 TEST CONDITIONS

3.1. Jet profile representativity

Baffle gaps measurements were taken on different reactor internals affected by the baffle jetting problem. The values were then extrapolated under hot conditions. The choice of the slot width for each cavities of the loop, based on this evaluation, is representative of the typical in reactor gap geometry.

Then hydraulic data were used to calculate a jet profile considered as representative of baffle jetting during normal operation (see figure 3).

3.2. Test procedure

The initial configuration for water supply of to the cavities was as follow :

Cavity	1	2	3	4
Slot whidth (mm)	0	0.15	0.10	0.22
Flow rate (l/s)	-	0.92	0.39	0.54
P (bar)	-	1.25	0.77	0.30

Based on this configuration the rods were subjected to homothetic jets which were increased by a factor K until instabilities occured.

3.3. Test configurations

Four fuel assembly configurations were tested (see figure 4) :

- a normal assembly as reference,
- a "waterhole" assembly with the rod facing the jet removed,
- an assembly with on stainless steel rod facing the jet,
- an assembly with three stainless steel rods facing the jet (see figure 5).

4 *TEST RESULTS*

4.1. Reference assembly

Under the effect of axial flow only, rod vibration amplitude were very slight (0.03 to 0.05 mm) and the natural frequencies of the rod are ill defined (figure 5a) and the trajectory is also random.

Then under the effect of cross flow the rod behaviour changes and predominant modes gradually appear (61 and 75 Hz - figure 5b) corresponding to the second and seventh mode shapes.

The first rod affected by the instability is rod 2 and not the rod facing the jet. This is probably due to the fact that rod 3 is off center, and the jet is transfered to rod 2.

Maximum rod amplitude increases to about 1.3. mm at the instability where interaction between the rods becomes evident at 75 Hz (figure 6 and 7).

Note that rods have a "quasi circular" (figure 7) trajectory and rod 2 sustains a static load which brings it to the loop wall (figure 8).

4.2. "Waterhole" assembly

The main result of this test are the following. Under the effect of axial flow only, overall rod behaviour at level 5 is the same as in the previous phase. At rod instability first appears at level 1 (K = 1.9) on rod 9 at a frequency of 42 Hz and then at level 5 at 56 Hz (K = 3.0).

4.3. "One stainless steel rod" assembly

The effect of axial flow on rod vibrations were the same as in the reference phase and for the configuration of instability in the reference phase (K = 3.7), the rods were stable at level 1 and 5.

Instability occurs for a wery high intensity crossflow jets (K = 5.1).

4.4. Three "Stainless steel rods" phase

In general, the insertion of 3 stainless steel rods had a stabilizing effect on the rod bundle and constituted an effective barrier against baffle jetting problems.

The instabilities were induced on a non reproductible basis at level 1 by providing a large water supply to the bottom cavity. The most important vibrations occur on rods located behind the stainless steel rods.

5 COMMENTS

5.1. Description of phenomenon

The test runs clearly showed that the phenomenon of rod instability due to crossflow jetting is characterized by thresholds as illustrated in figure 6. As long as the threshold is not exceeded the vibration amplitude is not excessive. However the vibration amplitude slightly increases with jet intensity, near to this thershold, a slight increase in jetting causes a considerable increase in rod vibration amplitude.

5.2. Jet intensity characterisation

To characterize jet intensity the quantity hV^2 can be used, defined by the formula :

$$(hV^2)\ \text{mode}\ n = \frac{\int_0^L \left\{ h(z)^2 \phi N(z)\ V(z)^2 \right\} dz}{\int_0^L \phi_N^2 (Z)\, dZ}$$

Where :

h : slot width

V : jet velocity

Ø : mode shape at level = for mode N

Z : coordinate along rod axis.

For K = 3,7, the effective hV^2 values for the first seven modes are as follow.

MODE	1	2	3	4	5	6	7
HV^2	9,5	15,2	7,8	10,3	10,0	9,2	14,5

Note that the more sollicitated modes are those highlighted by previous vibratory tests and it seems logical, based on the mode shapes :

. that 1st span instability occurs at the frequency corresponding to the first mode (gross mode shape only at the bottom of the assembly).

. that 5th span instability occurs for a frequency corresponding to the last mode for which the 6 equal-length levels behave as if they were independent (fuel rod clamped at each grid locations).

5.3. Instability threshold

Under the conditions existing during our hydraulic and mechanical tests, we consider that the effective hv^2 causing instability during the reference phase is about 14 ft^2 in/s^2 for mode 7.

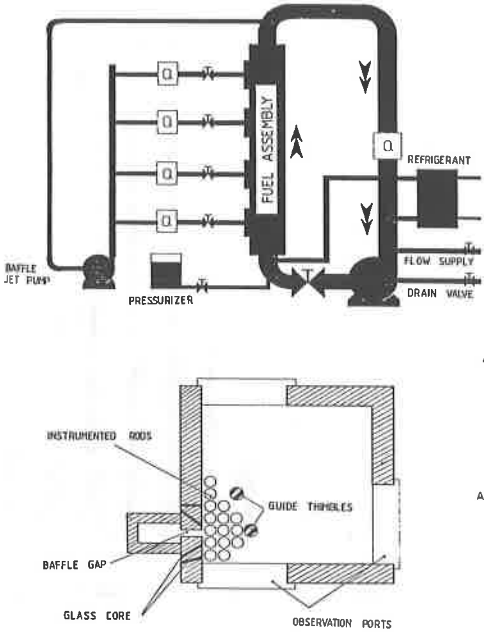


FIGURE 1 - VICHY LOOP FACILIY

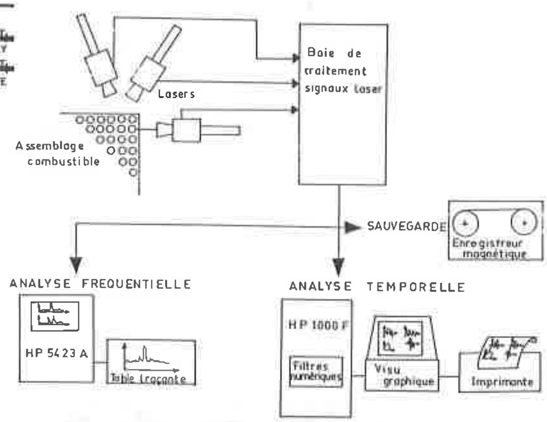


FIGURE 2 - ANALYTIC PROCESSING

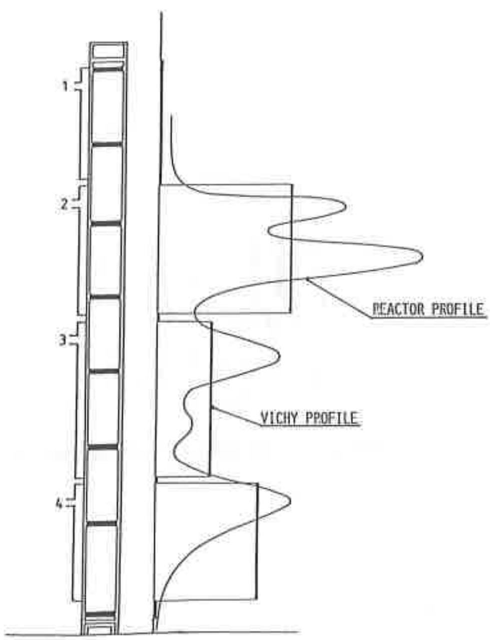


FIGURE 3 - DOWNFLOW REACTOR AND VICHY BAFFLE JETTING PROFILES

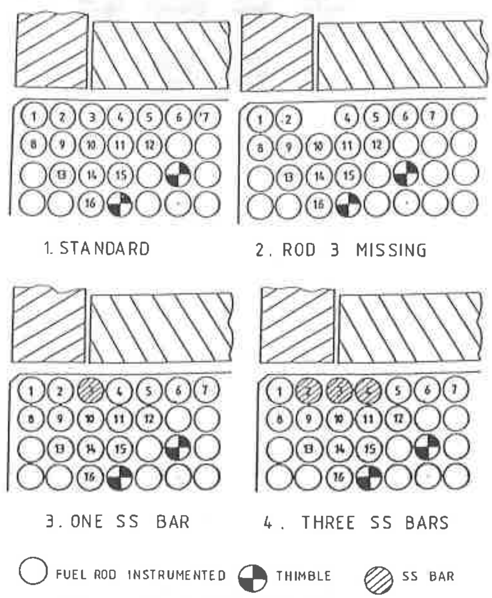


FIGURE 4 - FUEL ASSEMBLY CONFIGURATIONS TESTED

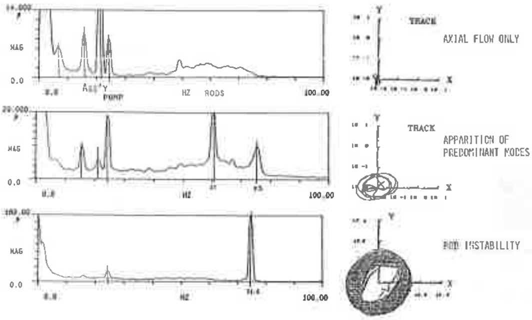


FIGURE 5 - EVOLUTION OF ROD NATURAL FREQUENCIES

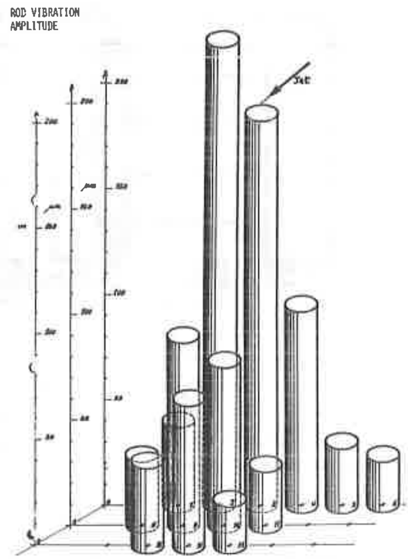


FIGURE 6 - RODS VIBRATION AMPLITUDE DISTRIBUTION

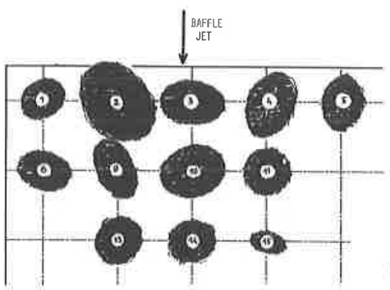


FIGURE 7 - RODS WHIRLING INTERACTION

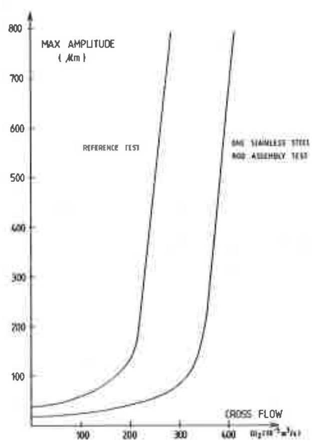


FIGURE 9 - ROD NR2 INSTABILITY THRESHOLD

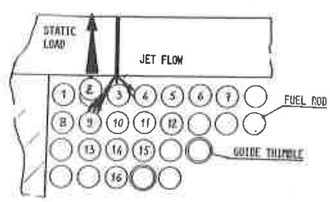


FIGURE 8 - STATIC DEFLECTION OF FUEL ROD NR2