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Vibration Signature of PWR Internal Structures in Various Abnormal Conditions

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Summary

The SAFRAN test loop consists of an hydroelastic model at 1/8 scale of a three loop PWR.

This facility has been used for various vibrational studies concerning the main internal structures (thermal shield and core barrel).

In particular, an experimental program has been devoted to the abnormal vibratory behaviour of the hold down spring. Partial results of this study have been already presented at SMIRT 6 (papers F 1/2 and F 1/5).

In the present paper, a synthesis is given based on the whole of obtained experimental data. In particular, new results are discussed for various contact conditions between the lower part of the core barrel and the vessel. It is verified that the vibration signatures of the internals are very sensitive, both to the hold down spring status and to the contact conditions.

The whole of experimental signature then obtained will facilitate the diagnostic associated with the vibration surveillance of PWR reactors.

O. Introduction

0.1 - Objective

In service inspection of PWR reactors has shown that vibratory signature of internals fluctuates with the time, especially for the rocking movement of the internals. The results of tests performed on 1/8 scale models (SAFRAN tests) and on full scale structures show that the most remarquable variations are, in fact, connected with changes in the bundary conditions of the core barrel, that is :

- closing of gaps (locking of radial guides) at the lower level of the barrel
- bad clamping of the hold down spring (HDS) at the upper level of the barrel.

The first cause is mainly observed after the loading of the core. This phenomenon leads to an increase natural frequencies then to lower vibratory levels of the internals.

The second cause is connected with a degradation of the HDS which may be more progressive. This degradation may become dangerous from a vibratory point of view because of an increased flexibility of the internals.

The object of this study is to perform on the SAFRAN* mock-up an experimental analysis with parametric variation of these two kinds of modifications. This analysis mainly intends to precise how the vibratory signature of internals allows to distinguish the two causes of evolution and to establish on site a diagnosis related to the degradation of the HDS.

* SAFRAN : Three loops hydroelastic mock-up scale 1/8 PWR (see fig. 1).

0.2 - Description of the tests

The tests have been performed with the SAFRAN 2 mock-up (sectorised screens).

- Attachment conditions of the core barrel on the vessel

The core flange of the core barrel is clamped on the vessel by the compression of the HDS (see fig. 2). The SAFRAN mock-up simulates exactly this attachment condition. The study consists of measuring the flow induced vibrations of the internals and its evolution with this thickness of the HDS.

4 configurations have been tested.

	The reference	Clamping condition
Nominal HDS	+ 300	compression
Slightly damaged n° 1	+ 150	compression
More damaged n° 2	0	no compression
Completely damaged n° 3	- 150	150 µm gap

Internal, natural frequencies, vibration, amplitudes and damping coefficients have been measured. Test have been performed without core, with radial guides free or clamped with nominal flow conditions (three circulation pumps in operation).

I. Results of measurement with free radial guides

(Normal flow rate, 3 pumps operating).

I.1 - Study of the mode n = 1 of the internals

I.1.1 - Variation of the frequencies of the mode n = 1* of the internals for the different tested springs

* The n = 1 mode corresponds to the rocking mode of the internals.

Springs	Frequencies
Ref. + 300	64 Hz
Ref. + 150 Spring lightly damaged	2 orthogonal modes measured at : 54 and 60 Hz } depending on tests 56 and 62 Hz } with 54 Hz mode along direction 0-180° 60 Hz mode along 90-270° direction
Ref. 0 Damaged spring	2 orthogonal modes measured at : 40 and 46 Hz } depending on tests 42 and 48 Hz } with 40 Hz mode in 0-180° direction 46 Hz mode in 90-270° direction
Ref. -150 Highly damaged spring	After several tests,following results were obtained : First test In the 0-180° direction, we have obtained a spectrum with a frequency doublet measured at 34 and 46 Hz. On the spectrum in the 45-225° direction the amplitude at the 46 Hz frequency is much higher than the 34 Hz frequency. On the spectrum in the 90°-270° direction the 34 Hz frequency is very clear, the 46 Hz frequency is very damped. The identification of these two frequencies has shown that they correspond to 2 orthogonal modes. 2nd test 0-180° direction - table land between 25 and 35 Hz 90-270° direction - frequency at 34 Hz 3rd test 0-180° direction - 2 very damped frequencies at 25 and 40 Hz 90-270° direction - 34 Hz frequency 4th test 0-180° direction - 25 Hz frequency 90-270° direction - 34 Hz frequency

Conclusion on frequency analysis

1) It is observed a systematic variation of the frequency with the status of the spring. The variation between the normal spring and the most damaged spring is fairly 50 % to 60 % (see diagram fig. 3 and fig. 4).

2) It is observed that, for the most damaged spring where internals are applied only with their weight, the results are no more repetitive.

I.1.2 - Measured amplitudes - Associated mode shapes (mode n = 1)

With the most damaged spring the vibratory level is increased about by a factor three (fig. 3).

Nota : there is no significant differences between the mode shapes measured with the springs ref. + 300 and + 150. Theses ones correspond to the movement of a structure correctly clamped at its upper part. But with the springs ref. 0 and ref. - 150 show, as it was foreseeable, lateral movements of the upper part of the barrel are measured especially for the spring ref. -150.

I.1.3 - β damping coefficients (fig. 3)

It is observed the increase of β with the damage of the springs. This fact comes probably from the little shocks occurring at the level of the spring.

We underline that β characterises in fact the width band of the resonance peak. This width band may characterize as well an energy dissipation as little variations in natural frequency due to little variations in supporting conditions.

I.2 - Global rocking mode of the mock up (fig. 5)

The frequency of the global rocking mode of the mock-up is not significantly modified by the damage of the spring.

I.3 - In service inspection aspect - Correlation between internal-external measurements

During the operation of a PWR reactor, vibratory inspection is done by the mean of neutronic fluctuation chambers and external accelerometers (on the vessel).

Figure 5 illustrates for the 4 tested springs very good correlation between on internal displacement transducer (5D0) and on external vessel accelerometer (AC1) near the internal n = 1 natural frequency.

Therefore an evolution of the mechanical characteristics of the internals is very well detected by external instrumentation.

II. Measurements results with fixed guides

As we said in the introduction, contacts between the core barrel and the vessel may occur at the level of the radial guides for different reasons (especially dissymetric flow rates of the loop and missalignment problems).

Then the n = 1 internals natural frequency is increased (7.5 Hz to 11 Hz from on site measurements). This point has been verified on SAFRAN mock up.

The contact phenomenon is simulated by the mean of centre-punch screw (see fig. 1).

For each spring the following configurations have been tested :

a) 180° guide fixed

b) 270° guide fixed

c) 180° and 270° guides fixed.

(Tests have been performed without core, at nominal flow rate with three pumps in operation).

Study of the n = 1 mode of the internals

Frequency analysis :

The effect on the natural frequency is more important for damaged springs than for non damaged springs.

Amplitude analysis :

An important decrease of the amplitudes is observed when the guides are tightened. The more the spring is damaged, the more the variation is important.

There is a very dean movement of the upper part of the core barrel when the guides are tightened.

Damping analysis :

No precise law can be deduced from the measured values. Meanwhile we observe that the damping increases with the damage of the spring (already underlined) and also with the tightening of the guides.

Global mode rocking of the mock-up

The values of the frequencies of the global mode of the mock-up are not significantly modified by the tightening of the guides for the different springs tested.

Conclusions

The tests performed in the "free guide" configuration show a clean evolution of the vibratory characteristics for the n = 1 mode of the internals. In the case of in-service inspection of the reactors, vibratory signatures then could be easily interpreted and the diagnosis will be clear.

In the case of "clamped guides" excepted particular cases (1 guide clamped) and if the spring is not too highly damaged the diagnosis is still possible as shows the hereafter summary tables.

a) with free radial guides

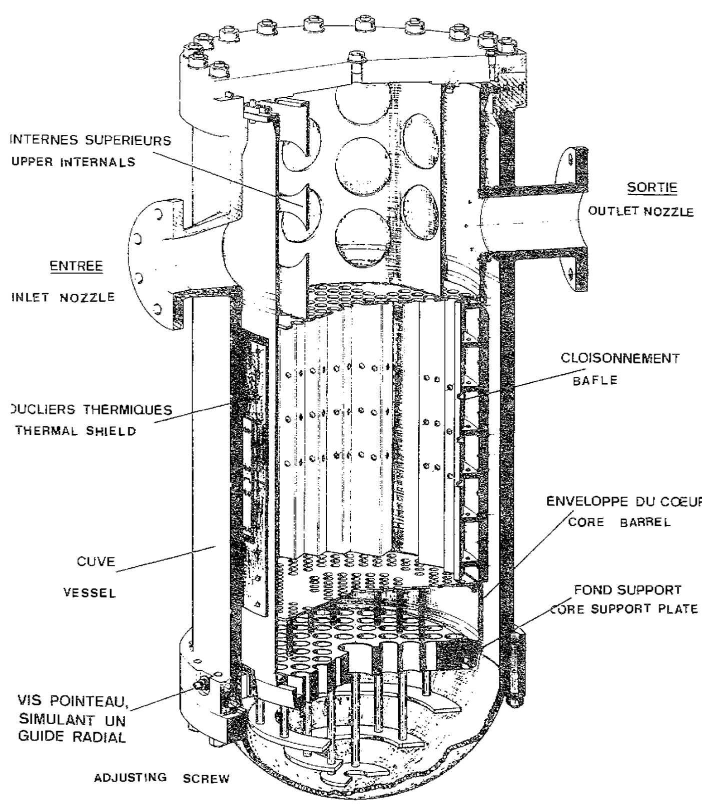
(mode n = 1 internals)

Spring	+ 300	+ 150	0	- 150
Frequencies	64 Hz	54 Hz 60 Hz	40 Hz 46 Hz	25 Hz 35 Hz
Amplitudes	6,5 μm	6,5 μm	10-12 μm	20-22 μm
Damping	3,75 %	8 % 5 %	13% 10%	20-25 % 15-20 %

b) with fixed guides (guides 180° and 270° fixed)

Spring	+ 300	+ 150	0	- 150
Frequencies	72 Hz 76 Hz	86 Hz 86 Hz	68 Hz 78 Hz	40 Hz 60 Hz
Amplitudes	3,1	1,8	2,6	4,6
Damping	5 à 11 %	11,5-5,25%	13,5-8%	25%

Fig 1 Safran II model



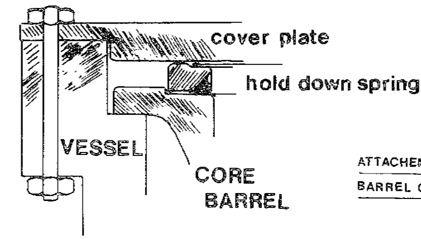


Fig 2

ATTACHEMENT CONDITIONS OF TOP CORE BARREL ON THE VESSEL OF SAFRAN MOCK UP

RADIAL KEYS BETWEEN CORE BARREL AND VESSEL

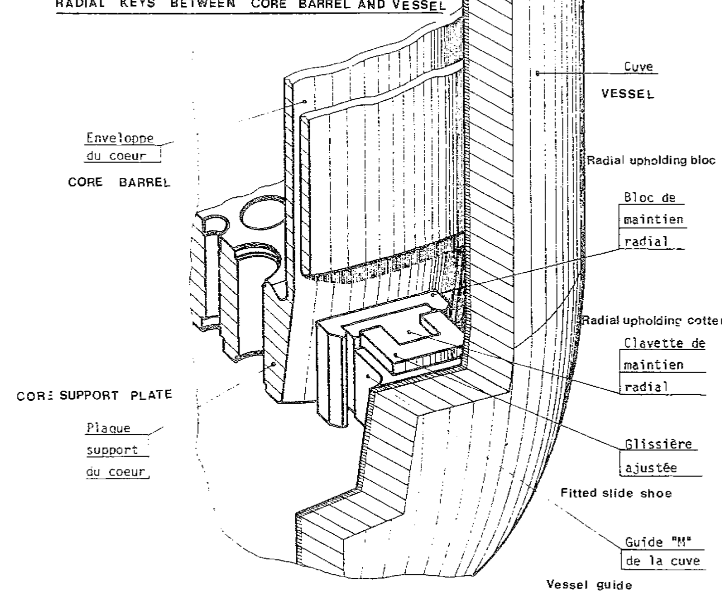


Fig 3

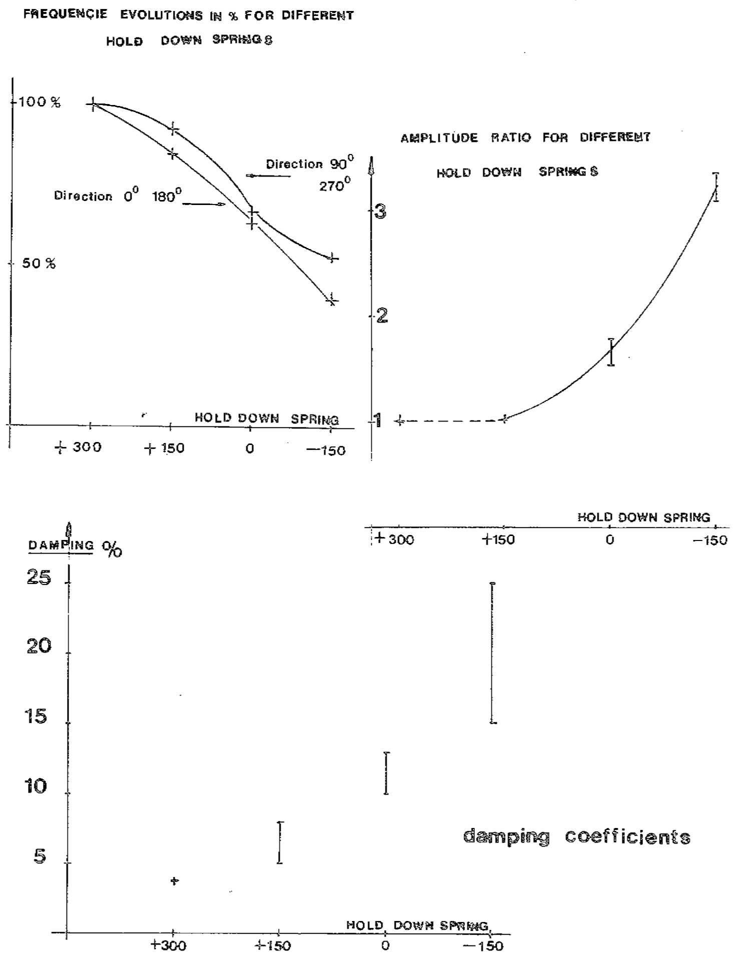


FIG 4 PSD EVOLUTIONS FOR DIFFERENTS HOLD DOWN SPING

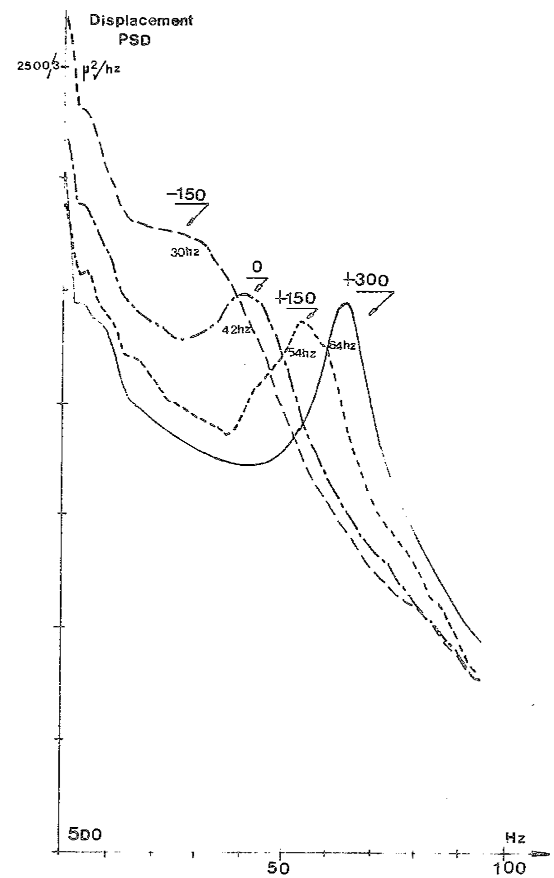
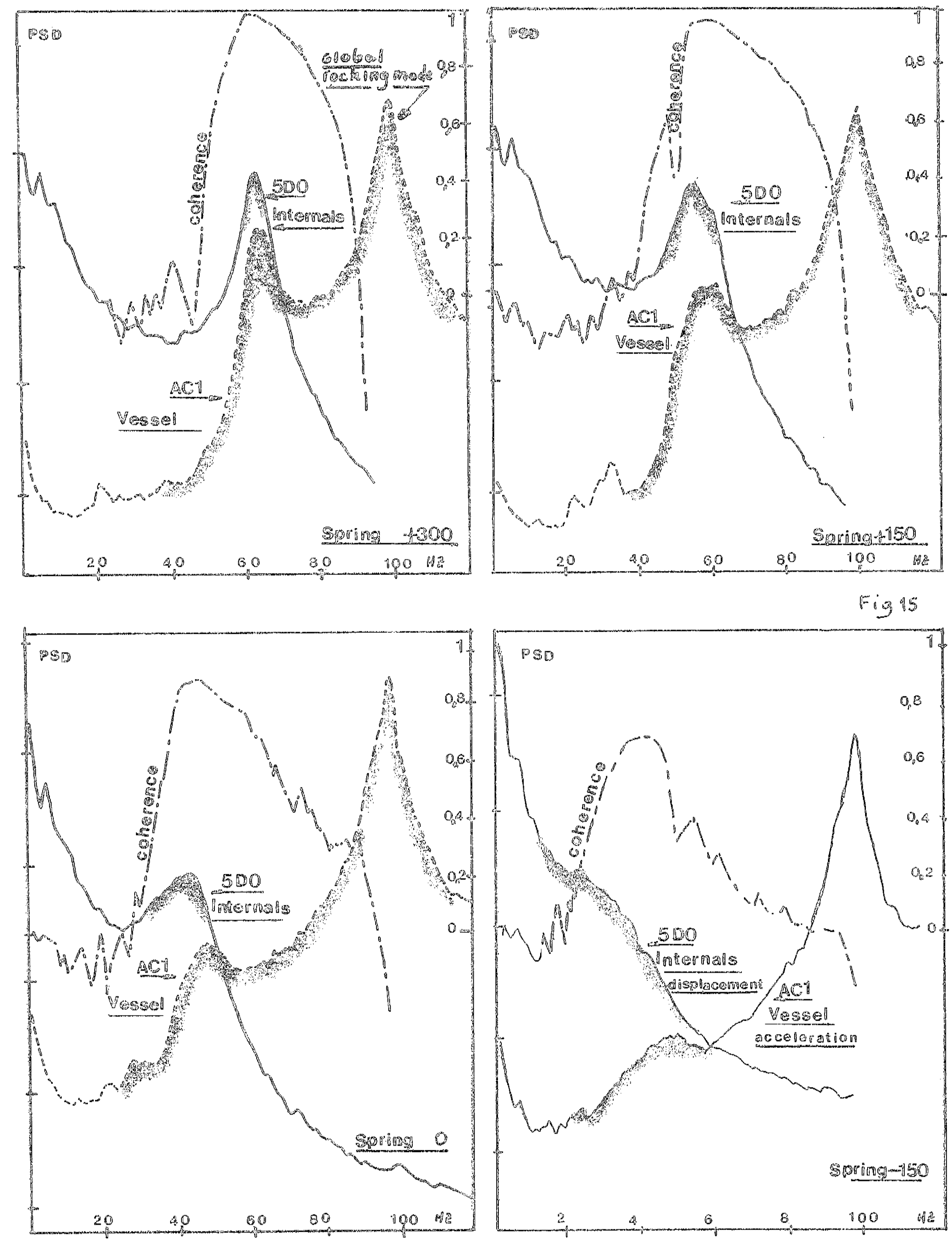


Fig 5 CORRELATION BETWEEN INTERNAL AND EXTERNAL MEASUREMENTS



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