Transactions of the **13th International Conference on Structural Mechanics in Reactor Technology** (SMiRT 13), Escola de Engenharia - Universidade Federal do Rio Grande do Sul, Porto Alegre, Brazil, August 13-18, 1995

Internal structure vibratory monitoring of 54 French PWRs

Trenty, A.
Electricité de France, Research and Development Division, Chatou, France

ABSTRACT: EDF has been monitoring the vibratory behavior of vessel internals on its 54 pressurized water reactors since the time of their startup. A monitoring system detects variations in the spectral signatures acquired from ex-core neutron detectors and from accelerometers mounted on the reactor vessel. Interpretation is based on the results of preliminary calculations as well as on tests on mockups and on the reactor itself prior to startup. The EDF Research and Development Division (Monitoring, Diagnosis and Maintenance Branch) has acquired extensive feedback on internal vibrations through the analysis of some 400 fuel cycles. This has enabled the detection of slight effects of aging (considered as normal) on the hold-down spring, the fuel rod assemblies and the radial keys. It is envisaged to integrate automated diagnosis in "PSAD" (the Monitoring and Aid to Diagnosis workstation) which groups all functions for monitoring main plant components (reactor, main coolant pump, turbine, generator, etc.).

1 OBJECTIVES OF VIBRATORY MONITORING OF INTERNALS

A number of incidents throughout the world have affected PWR internal structures, sometimes leading to costly repairs. Others could well result in removal of certain structures, which can affect the lifetime of the reactor vessel (e.g. the thermal shield described in § 1.2). It is therefore indispensable, by means of inservice monitoring, to detect anomalies in the behavior of internals at a sufficiently early stage. The inservice surveillance procedures at EDF aim most particularly at monitoring degradations in the following structures (Figure 1):

1.1 *Hold-down spring*

The hold-down spring is a steel ring compressed between the upper and lower internals. It is therefore subject to static stress. Furthermore, it is the fixed point around which the lower internals (and, to a lesser degree, the upper internals) swing as a result of hydraulic excitation: it is thus also subject to periodic stress. The compounded effects of these two stresses can lead to degradation of the spring, which can translate as loss of stiffness or even deformation or loss of function.

1.2 *Cylindrical thermal shield*

On the Bugey and Fessenheim reactors (900-MW PWRs), a cylindrical thermal shield has been placed around the lower internals (core barrel). Its purpose is to limit radiation-induced embrittlement of the steel of the vessel. It is attached to the core barrel by means of blocks screwed into the upper part and flexures at the bottom. While the lower internals (core barrel and shield) swing together, the thermal shield also moves in relation to the core barrel due to the fact that it is vibrating in shell modes. The attachments holding the shield to the core barrel are therefore subject to stresses (essentially traction-compression) which cause oligocyclical fatigue. As a result, they can suffer damage, and may even break (Sweeney 1986).

1.3. *Fuel rod assemblies*

The fuel rod assemblies vibrate on their bending modes, causing stresses and possible deformation of the alignment pins on the lower and upper core plates. Furthermore, the pre-load spring maintaining the fuel rod assemblies between the upper and lower internals may relax, as may the spacer grid springs (Sweeney 1983).

2 STUDIES PRELIMINARY TO MONITORING

2.1 *Defect simulation codes and mockup*

A Safran mockup (Carré 1987) reproducing the internals on a 1/8 scale as well as the hydraulic conditions in the reactor has enabled simulation of two types of defect:
- *degradation of the hold-down spring*. Figure 2 shows the effect on the vibratory signature characteristic of core barrel swinging of a decrease in thickness of the spring: a drop of over 15% in the frequency, increased damping.
- *degradation of the flexures*. Safran has demonstrated that rupture of a flexure decreases the shield's mode 2 frequency from 11.2 to 10 Hz. This confirms the results found with modal analysis codes (Carré 1977), which predicted a shift from 11.2 to 9.8 Hz.

2.2 *Pre-startup tests*

During hot tests on each first-off plant in a given series, specific internal instrumentation (accelerometers and deformation gauges mounted on the internals under water - Figure 3) has enabled:
- verifying that the behavior of internals corresponds to the results of theoretical calculations,
- providing a vibratory reference,
- correlating the internal and external vessel signals (Figure 4) and thereby validating the inservice monitoring procedure.

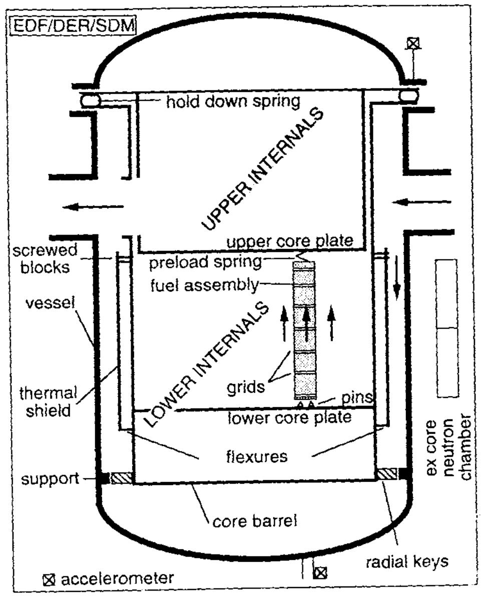

Figure 1. Schematic diagram of internal structures and instrumentation.

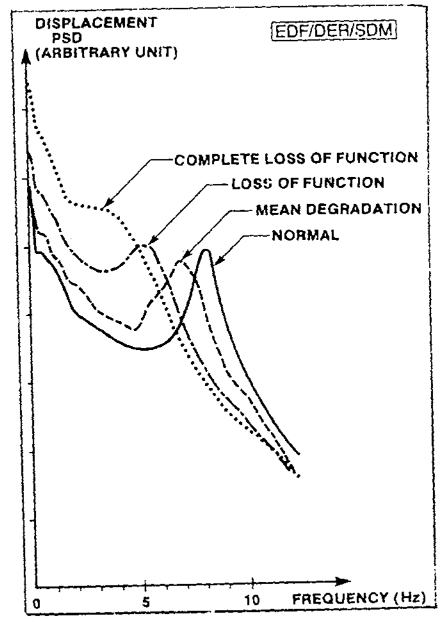

Figure 2. Decreased thickness of the hold-down spring inducing a modification in the spectral signature for core barrel swinging.

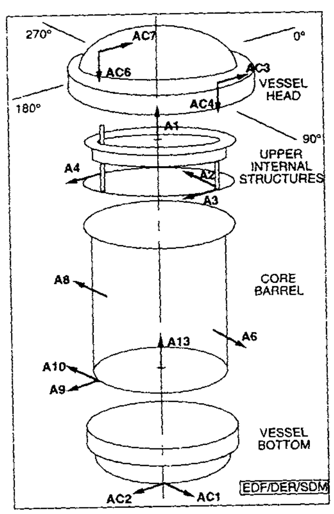

Figure 3. Accelerometer instrumentation for internals during hot tests at Paluel 1 (1300-MW).

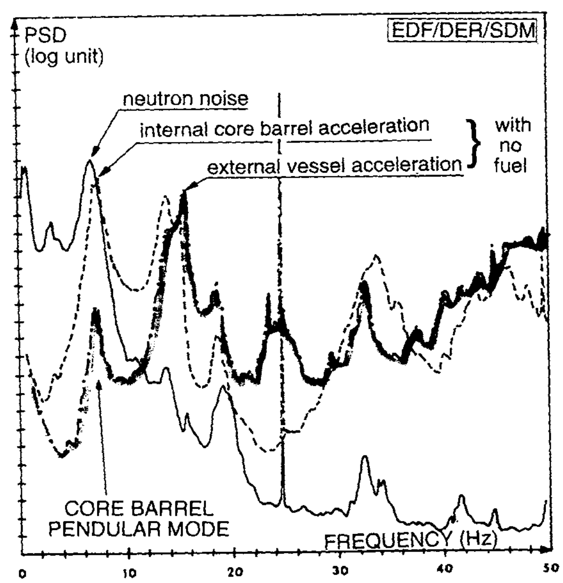

Figure 4. Correlation of internal and external vessel signals.

3 INSERVICE MONITORING

This type of surveillance consists in identifying, characterizing and monitoring the evolution over time of vibratory peaks (obtained through spectrum analysis) corresponding to different structure modes. Because of the large size of the structures monitored, all vibratory modes essential to surveillance are below 40 Hz. Moreover, changes in the phenomena (and any degradations) are extremely slow and, in the absence of an anomaly, periodic analysis around once a week is amply sufficient.

3.1 *Principle of measurement*

The monitoring signals have two origins:
- *variation in the ex-core neutron flux*: Let us take the example of swinging of the core barrel. This induces a variation in thickness of the water layer dx between the core barrel and the reactor vessel. The result is a greater or lesser damping of the flux ϕ of neutrons reaching the ex-core detectors, at the swinging frequency of the structures. Thie (1979) has shown that:

(1) $$d\phi/\phi = di/i = -h\,dx$$ in which:

di is the elementary fluctuation in current (delivered by the detector) centered on the swinging frequency and due to fluctuation in the neutron flux $d\phi$,

i is the global current delivered by the detector due to the global neutron flux ϕ reaching the detector,

h is a coefficient for neutron transport obtained with a neutron calculation code (Bernard 1984).

The above relationship (1) applies to other vibration modes of internals, with the h coefficient dependent on the mode in question. It enables determining the displacement of internals in their different modes on the basis of what is called *neutron noise* (di/i).

- *vessel vibrations*: the internal structures induce a forced vibration of the vessel via the water layer between the core barrel and the vessel. Accelerometers mounted on the vessel (Figure 1) therefore detect any vibration of internals, providing it is of sufficient amplitude to be transmitted by the water layer between internals and vessel.

3.2 *Description of the monitoring system*

All EDF PWRs are fitted with an internal structure monitoring system, consisting in a computer driving a spectrum analyser, a switching unit and a printer. Three software programs are periodically triggered by plant operators following standard procedures for all units. The programs develop spectral functions, detect peaks, quantify structural movement (frequency and displacement) and verify the absence of any significant change in spectral signatures. The operator analyses the results and sends data to the EDF Monitoring, Diagnosis and Maintenance Branch for verification and validation of his diagnosis.

4 OPERATION FEEDBACK

4.1 *Building up of the SINBAD data base*

Data from the plants is loaded in an ORACLE data base (UNIX system) and more elaborate calculations from spectral signatures are launched automatically. The data base, dubbed SINBAD, contains several thousand signatures acquired during the course of some 400 fuel cycles.

4.2 *Effects of aging detected on internal structures*

No incidents have occurred involving EDF PWR internals, but SINBAD data processing has pinpointed certain trends in behavior that can be attributed to the effects of aging:

- *relaxation in the fuel rod assemblies*: the mode 1 frequency of the assemblies decreases in around 50% of the fuel cycles (Figure 5), by a value which may amount to 30% of the initial frequency. This is due to relaxation of the assembly, either in the upper fuel spring set or, more probably, in the spacer grid springs.
- *relaxation in the hold-down spring*: slight shifts in the free-swinging frequency of internals (representing less than 5% of the frequency at the beginning of the cycle) are detected during the fuel cycle (Figure 6), particularly on the oldest reactors. These are

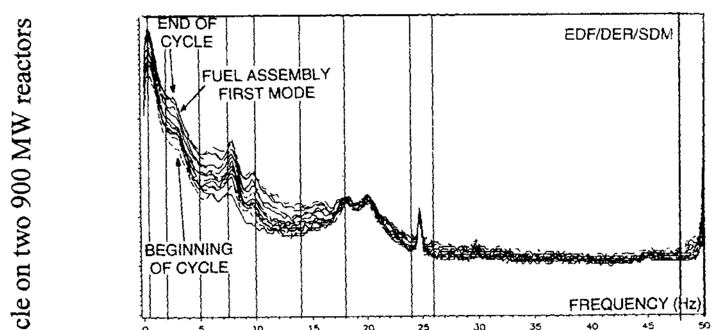

Figure 5. Relaxation of fuel rod assemblies in 50% of fuel cycles.

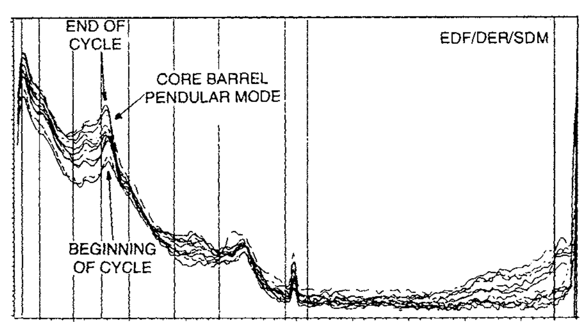

Figure 6. Slight relaxation of the hold-down spring during the fuel cycle in some older reactors.

due to a minute relaxation of the hold-down spring. To date, this phenomenon has always proved reversible, as the frequency always returns to its normal value upon restart following shutdown: any deformation is therefore of an elastic nature.
- *wear on lower internals*: it may happen that contact occurs between internal structures and reactor vessel, particularly around the radial keys. Inservice monitoring enables detection of such contact, and has shown a two-thirds decrease in the rate of occurrence of contact on 900-MW reactors between the first three years of operation and subsequent years. This can be explained by the increase in space between internals and reactor vessel over time, due to some hammering in of contact surfaces (wear on radial keys and corresponding supports on the reactor vessel). This interpretation has been confirmed during inspection of internals at the time of unit shutdown.

5 PROSPECTS FOR AUTOMATION IN PSAD

The operation feedback accumulated thanks to SINBAD has enabled the drawing up of specifications for an automated "internal structure monitoring" function. It will consist in systematic diagnosis of the condition of internals once every week, and triggering of analysis followed by a diagnosis in the event a set threshold is exceeded. It is hoped that this function will soon be integrated in PSAD, the on-line Monitoring and Aid to Diagnosis workstation (Joussellin 1994). PSAD will provide the plant operator with diagnosis support (via a single interface) for the following monitoring functions: main coolant pumps, turbine, generator, inlet valves, loose parts in the primary cooling system, and internal structures.

REFERENCES

Bernard, Messainguiral, Cloué 1984. Relation between mechanical vibrations and neutron noise in PWRs. *SMORN IV. Dijon.*

Carré, Gibert, Jeanpierre, Assedo, Epstein 1977. PWR internals vibrational mode shape calculations and test. *Progress in Nuclear Energy* I 353.

Carré, Epstein, Puyal, Castello, Dumortier 1987. Malfunction test and vibration analysis of PWR internal structures. *SMORN V. Munich.*

Joussellin, Chevalier 1994. Diagnosis of faults in EDF power plants: from monitoring to diagnosis. *ASME conference. Minneapolis.*

Sweeney, Renier 1983. Sensitivity of ex core neutron detectors to vibrations of PWR fuel assemblies. *SMIRT 7. Chicago.*

Sweeney, Fry, Chen, Simonis, Shiu 1986. Thermal shield support degradation in pressurized water reactors. *ASME PV&PC.*

Thie 1979. Core motion monitoring. *Nuclear Technnology* Vol 45.