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Impact of certain PWR internal degradations on their vibratory modes

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ABSTRACT :

National and international feedback has enabled EDF to identify four potential degradations in the internal structures of PWR reactors not currently monitored during reactor operations. EDF has begun a study to establish, by digital computations, the impact of these degradations on the vibratory modes of the structures, in order then to deduce the feasibility of detection with the current methods of monitoring. The primary results of the study (at present only 3 degradations have been studied) show that the degradations are not detectable during reactor operation.

1. INTRODUCTION :

In order to improve the maintenance of its nuclear power plants, EDF monitors the appearance in an early stage of certain degradations in the internal structures of its reactors during operation. The two principal degradations monitored at present are (figure 1) :
- the loss of stiffness in the hold down spring ;
- cracking or fracture of one or more of the thermal shield flexures, for reactors with cylindrical thermal shields.

By analyzing national and international feedback, EDF has identified other potential degradations in the internal structures, not specifically at present monitored during reactor operations. So a study was made to establish through numerical calculations the impact of these degradations on the vibratory modes of the structures, in order to deduce the feasibility of detection with current methods.

Four potential degradations have been identified :
- degradation #1: wear and deformation of the upper and lower core plate centering pins of the fuel assembly (figure 2),
- degradation #2: breaking of screws holding the core baffle to its formers (figure 3),
- degradation #3: breaking of screws holding the core baffle former to the core barrel (figure 3),
- degradation #4: core barrel cracking at circumferential welding levels under stress corrosion combined with irradiation (figure 1).

2. EXISTING MONITORING DURING PLANT OPERATION

Monitoring internal structures during reactor operation is based on identification, characterization and monitoring over time (monthly), the peaks corresponding to the vibratory modes of the structures (figure 4). In fact, degradations in the structure can bring about changes in the stiffness, and thus in the vibratory behavior of the structures (frequencies, displacement amplitudes, damping ratios).

A reduced-scale reactor mock-up (on a 1/8 scale), known as SAFRAN and designed by the CEA in the 70s, made it possible to simulate the vibratory behavior of the internal structures as well as the consequences of degradation on the vibratory modes [1]. It has been established that, because of the large size of the monitored structures, all of the vibratory modes essential to the monitoring process are below 50 Hz. Furthermore, the degradations evolve relatively slowly (kinetic evolution on the order of one month).

Every EDF PWR reactor is equipped with an in-service system, known as KIR, which monitors internal vibration in operating reactors [2]. This system uses ex-core neutron detectors to measure internal vibrations. In effect, core barrel vibration results in variations in thickness in the water layer between the core barrel and the neutron detectors. The result is a fluctuation of the neutron flux reaching the ex-core neutron detectors at the vibration frequency of the core barrel. Signal amplitude is thus proportional to the vibration amplitude of the structure. The proportionality coefficients have been calculated in collaboration with the CEA [3]. Accelerometers, mounted outside the vessel, are also used, their signals correlated with the neutron detector signals.

For degradation to be detectable by the existing in-service monitoring method, the following conditions must be met :

- The degradation must result in a change in the vibratory behavior of the internal structure.
- The modification in vibratory behavior must be located in the frequential range detectable by the neutron sensors, which is to say between 0 and 50 Hz.
- The vibratory modes to be monitored must result in a fluctuation of the neutron flux reaching at least one ex-core neutron detector; or else the vibrations must have a sufficient impact on the vessel vibrations (by internals-water layer-vessel coupling) to be detectable by the accelerometers mounted outside the vessel.
- And the vibratory behavior modifications have to be significant enough that they can be distinguished from normal vibration mode variations.

3. RESULTS OF DEGRADATION SIMULATIONS

A finite element model of the vessel and the internals, which takes into account the added water mass effect, has been designed using the EDF simulation code, *Code ASTER*, and certain results of the MASSIC project (Sismic Analyzing Methods for Internal Structures and Core of a PWR reactor) [4].

In each and every case, the hypotheses used in the simulations are severe situations. Hypothetical wear is maximized and connection ruptures are total and without friction. The net knots on the two structures are completely freed of each other. If the degradation simulated with these extremely severe hypothetical situations is not visible, the real degradation will not be visible, either.

Three of the four degradations have already been digitally simulated.

The study of degradation #4, the cracking of the core barrel at circumferential welding levels under stress corrosion combined with irradiation, will not be completed before 1997. Some cases of cracking at circumferential welding levels have appeared generically on BWR reactors since 1991. For this very hypothetical situation of degradation on the PWR, it will be necessary to compare the vibratory behavior of the healthy core barrel to that of the core barrel cracked horizontally along part of its circumference.

3.1 Degradation #1 : Wear and deformation of the upper and lower plate centering pins of the fuel assembly.

Feedback indicates the difficulties in handling the fuel assemblies or the upper internal structures due to prior shocks. Furthermore, EDF's monitoring feedback shows that the fuel assembly first beam mode decreases, on average, every second fuel cycle, and that the decreases can reach 1 Hz. Those decreases are not caused by potential pin degradations but by relaxation, the origin of which this study has identified.

This degradation has been modelled as following :
- pin deformation : by replacing the "vertical sliding" by a locally clamped limit condition ;
- pin wear : by possible lateral movement and rotation of the fuel assembly.

This is rather complicated to model, because of the non linear behavior which arises (contacts between structures).

The simulations show that the centering pin wear and deformation of the fuel assembly do not modify their vibratory behavior enough to be detectable by the monitoring tools.

- A centering pin deformation may result in a clamping of the fuel assembly, but the resulting frequency increase is lower than 0.1 Hz. To be detectable, frequency changes should be at least of 0.5 Hz.
- Centering pin wear results in a partial horizontal releasing in the fuel assembly. This can be detectable if the resulting strength in water flow is stronger than the friction of the fuel assembly against the lower core plate. Actually, this is not the case.

However, the study has shown that frequency decreases in the fuel assembly first beam mode, observed during the cycles, are not the result of spring but of grid relaxations.

3.2 Degradation #2 : breaking of screws holding the core baffle to its formers.

Because of the nearness of the reactor core, baffle plates undergo a significant neutron flux that results in a weakening of the screws holding the core baffle to its formers. Feedback from France showed that screws first crack in areas simultaneously accumulating high temperatures, stress, and irradiation. In this extreme case, it is possible to imagine that a separated plate enables certain vibratory behavior under hydraulic flow, preceding and resulting in screws breaking from fatigue in the upper formers.

If a separation exists, the baffle vibrations could possibly be detected by ex-core neutron sensors. The neutron capture cross-section depends on the angle of the entering flux. At present, the baffle vibration effects on neutron flux are not known. It is only possible to refer to the fluctuations induced by the shell mode of the thermal shield, and experience has shown that this mode is not easy to monitor. On one hand, the baffle is not nearly as thick as the thermal shield, which would seem to promote a decrease of the neutron fluctuation induced by the baffle vibrations. On the other hand, the baffle is located in an area where neutron flux has far greater energy, and if there is degradation, the vibrations of the baffle should have far greater amplitude.

This study has dealt with possible plate vibratory modes in the case of clean breaks in the screws (which is not the case for reactors, where cracks do not occur throughout), as well as possible instabilities induced by the primary flow. Numerous degradation configurations (all very penalizing because truly encompassing) and hypotheses concerning the modelling of the cracked connections (free vibrations, with contacts . . .) have been studied (figure 5).

In realistic situations, the connection conditions are non linear (because of the contacts). The vibratory behavior is then "complex". The vibration comprises all the frequencies between free vibration frequency and the frequency involving contacts with the former. Thus, the spectrum obtained is dense and as wide as several Hertzes and is located in the monitoring frequency range. Furthermore, the spectrum risks being unsettled (amplitudes and frequencies). As concerns displacement amplitudes, today it is only possible to evaluate the order of magnitude of the amplitude ratio between several degradation configurations. In particular when former #1 is entirely separated, the vibratory amplitudes are more than 100 times higher than the amplitude of the other degradation configurations. So it is very unlikely to be able to detect degradations when former 1 is not separated.

Flow-induced plate instabilities are very unlikely, as then the degradations must be extreme (at least 3 formers separated). Furthermore, only one screw remaining on each former is sufficient to make all instabilities disappear.

3.3 Degradation #3 : breaks in screws holding the core baffle former to the core barrel.

The core barrel and the core baffle are strengthened by formers (8 on 900 MW reactors, figure 3). These formers are numbered from #1 to #8 starting from the lowest. The core barrel is held to the formers by 3/4" screws on 900 MW reactors (544 screws per reactor) and by 5/8" screws on 1300 MW reactors (800 screws per reactor).

Considering the hypothesis that a screw holding a former to a barrel breaks, these screws are near the core, so they undergo a significant neutron flux that may weaken them. This degradation, although hypothetical, would most probably first strike where the irradiation is highest, or, in this order: row #2, #3, #4, #5 and #6.

A separation of the baffle (encompassing situation) could have as a consequence a decrease in stiffness of the core barrel, resulting in a modification of its shell mode (frequency decrease).

This mode appears on the ex-core neutron signals, at a frequency of around 20 Hz. This frequency tends sometimes (in about 30% of cases) to decrease during the fuel cycle (up to 1 Hz on 900 MW reactors but only 0.2 Hz on 1300 MW reactors). This could actually be due to light relaxations in the structure (no degradation has been observed). Furthermore, the peak corresponding to this vibratory mode, appearing on ex-core neutron detectors, slightly emerges in the spectrum (near the background noise). The frequency of this mode is thus difficult to know with precision. To be detectable, the barrel shell mode has to shift more than 1.5 Hz.

Four hypothetical situations of degradation have been considered for the computations. The degradation simulation method used (connection net splitting, clean and complete former separation), enables an easy use of the computation, but it is not necessarily realistic. Indeed, considering the hypotheses used, the barrel and the former are no longer in contact, which would not be exact in the case of a screw actually breaking. Friction between both parts may occur. The frequency value obtained by simulation in the case of degradation is then a minimum limit.

The results of the 4 hypotheses studied are given in the following table 1 :

#	*Modelling hypothesis*	*Probability, risk, consequence*	*Shell mode frequency shift*
1	Former 2 totaly separated	-At first glance, the most probable hypothesis studied (the most irradiated former). -Releases the greatest height between two formers.	ΔF< 0,2 Hz <<detection threshold
2	Former 8 totaly separated	-At first glance, lower probability than hypothesis 1 (lower irradiation, but more stress). -Hypothesis very severe in regard to the modifications in vibratory behavior. -Decreases the stiffness and releases the upper part of the barrel.	ΔF < 0,4 Hz < detection threshold
3	Former 1 totaly separated	-Same probability for order of magnitude as for hypothesis 2. -Hypothesis more severe. -Releases the lower part of the barrel at a greater height, results in a more significant stiffness decrease.	ΔF < 0,8 Hz detection threshold, but a significant frequency modification
4	Former 1 and 2 totaly separated	-Extreme hypothesis : very unlikely.	ΔF ≈ 1,5 Hz ≈ detection threshold

Table 1: Degradation #3, computation results with different hypotheses

The computations made confirm that only the shell mode of the barrel is changed by the degradation, and this appears very clearly on the mode shape (figure 6). But the results show also that with realistic degradation hypotheses, the changes are too low to be detectable. The breaking of screws leading to the separation between the former and the core barrel is not detectable by the monitoring method used during reactor operation.

4. CONCLUSION :

Taking into account the different degradation hypotheses, the digital simulations on the 3 degradations give the following results :

- an estimate, in realistic situations, of the order of magnitude of the impact of degradation on the vibratory modes ;
- a verification of the detectability of the degradation in an early stage and in realistic situations, with the existing monitoring method ; and
- an estimate of the severity of the degradation at which it can be detected.

Though the study is not complete, the results show that with realistic degradation hypotheses, the degradations are not detectable through the current monitoring method used during reactor operation.

Nevertheless, through non-destructive testing, EDF controls the condition of the core baffle bolting. Furthermore, through an advance approach, EDF is also leading studies to establish probable forth coming behavior in lower internals and the degradation limits that are acceptable from a safety standpoint.

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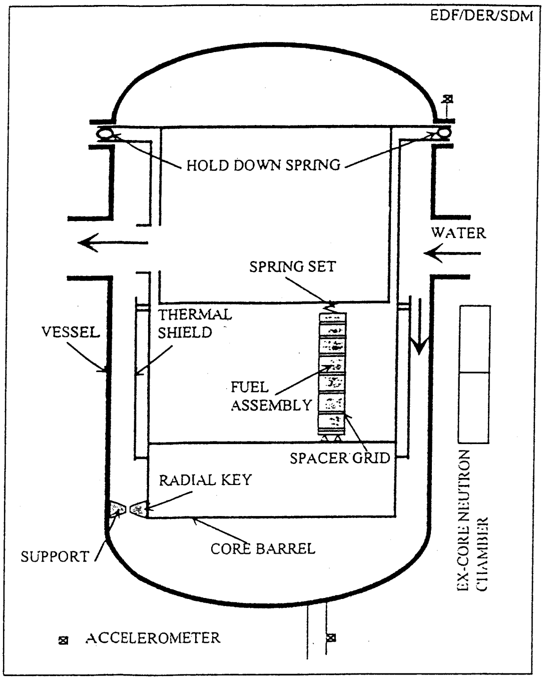

Figure 1 : Diagram of a vessel and internals

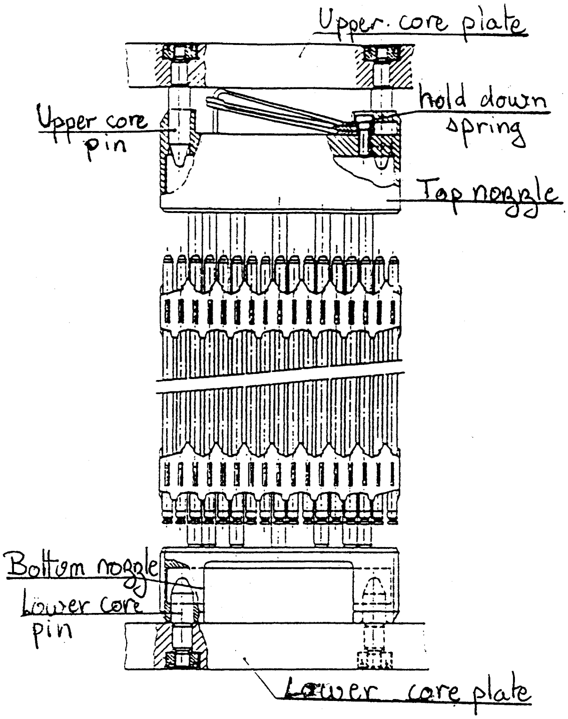

Figure 2 : Fuel assembly

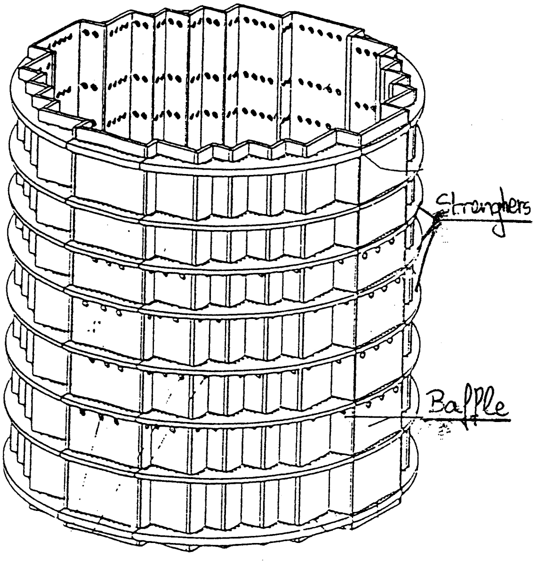

Figure 3 : Core baffle assembly and formers

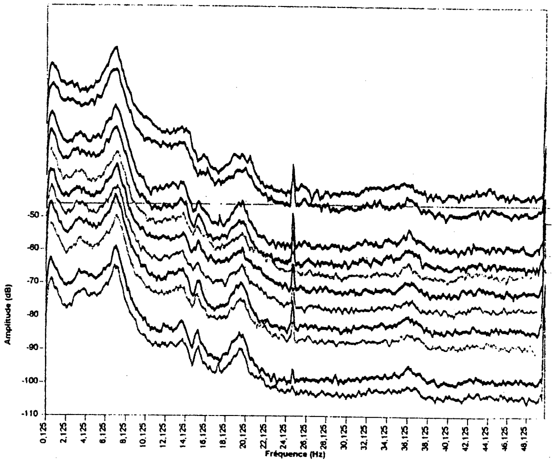

Figure 4 : Over time internals vibratory modes monitoring

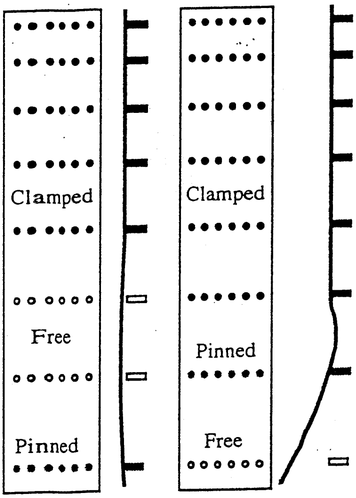

Figure 5 : Baffle plate separation simulations

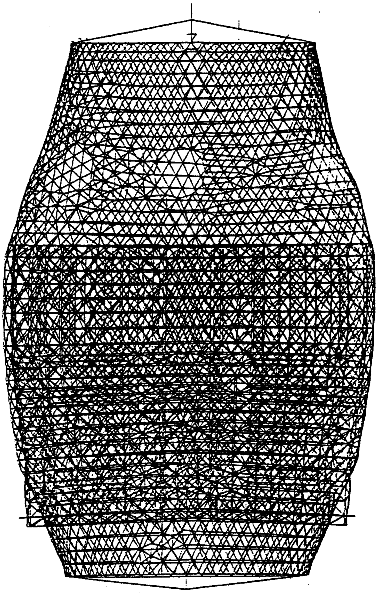

Figure 6 : Former 1 separation simulation