A New Approach for NSSS Fatigue Life Assessment

G. Bimont
Electricité de France, Research and Development
Saint-Denis, France

G. Cordier
Electricité de France, Nuclear and Fossil Generation
Paris, France

1. OBJECTIVES

When its first 900 MWe PWR started operating, Electricité de France, the French national utility, in order to comply with safety regulations, set up a Transient Monitoring and Logging Procedure (TMLP). This procedure checks the validity of the design hypotheses.

It also provides an operating load database which is particularly useful for experience feedback.

However, this manual monitoring rapidly showed its limitations, due partly to its simplicity, as will be discussed later. Therefore, a new system based on real-time fatigue monitoring has now been in development for several years. This prototype system called "Fatiguemeter" has been implemented and set up on two PWR plant units, Bugey 2 since 1985 and Dampierre 1 since the beginning of 1988. The final goal is to gradually equip the PWR plant units with monitoring networks, which will integrate EDF experience both for transient logging and fatigue monitoring system (Fatiguemeter).

2. TRANSIENT MONITORING IN FRENCH PWR PLANTS TO DATE

2.1 TMLP description

EDF has implemented a procedure to verify that the actual transients to which the main primary system is subjected are less severe and less frequent than those allowed for in the design hypotheses. This verification is based on the comparison of the actual temperature and pressure changes with those anticipated during the design phase for various operating conditions. The consequences, in terms of stresses or damage are not directly assessed.

The procedure has already been described in several publications [Noël, 1981; Hutin, 1983; Cordier, 1986]. It mainly consists in executing the following tasks.

Detection

We detect any variations in the parameters capable of creating significant stress variations and hence increase the usage factor (i.e. the fatigue "damage"). Small fluctuations where eliminated from the procedure by determining parameter thresholds below which the structure is shown to undergo no fatigue damage.

Identification

Identification consists in locating, if possible, the functional origin of the transient whenever a significant fluctuation in temperature or pressure is observed on the recorders. This step is essential for several reasons, and mainly because:

- there are cases where physical measurements, due to the position of the instrumentation, does not enable, by itself, accurate assessment of the actual severity of the transient (in the case of isolation of a system, for example),
- functional identification of the transient makes it possible to analyse the causes of malfunctioning (transients too severe or too numerous) and provide solutions.

Assignment

Once the transient has been identified, the last step consists in checking the validity of the design hypothesis, that is to say verify that the actual changes in temperature and pressure are less severe than those given by the design curves for this transient.

If this is not the case, the transients are the subject of special analysis. If such transients have no general characteristics, simple thermomechanical analysis are used to find representative (conservative) design transients. On the contrary, it may be due to an oversight in the design transient list or unexpected parameter changes. The possible solutions are then as follows:

- either the operator modifies the operating conditions so as to prevent such severe transients,
- or he may work with the manufacturer to modify the design transient list and correct the design analyses. Of course, the integrity of the Reactor Coolant Pressure Boundary (RCPB) must be checked with these new design hypotheses.

2.2 Experience feedback

2.2.1 Agreement between real transients and design

Experience feedback shows:

- good concordance between the operating transients and the design transients with respect to parameter variations,
- in general, less severe transients than expected in design studies,
- fewer transients than estimated.

To illustrate the fact that changes in the design transients are more severe than what is found to actually be the case, Figure 1 shows the change in primary-loop temperature recorded in a loss of offsite power which occurred in Blayais 4. It can be seen that both in terms of slope and amplitude, it is below what was taken into account at design level.

Although actual transients are far less numerous than predicted at design level in the great majority of cases, there have been occasions, in the auxiliary circuits, where it was not the case.

Thus, in the chemical and volume control system, we have found evidence for an abnormally high consumption rate in the "isolation of the letdown line" transient. In Figure 2, we show the number of transients recorded for extreme behaviour in two units. It is found that:

- there is a high annual consumption rate (even in the last few years) which is close to that predicted,
- a higher total number than was predicted, resulting, once again, from consumption rate that was initially very high.

Thus, at Fessenheim 2, 60% of the quota initially planned for 40 years has been consumed in 11 years.

There are two causes for this:

- the presence of transients of which the severity closely corresponds to that of the "isolation of the letdown line", but having other functional causes,
- frequent isolation due to low pressurizer levels after over-cooling during scrams.

2.2.2 Aging indicators

From what has just been said, it may be seen that transient logging provides precious results concerning plant unit operation which may be used as aging indicators.

These indicators may be used for the following:

- on-condition maintenance,
- optimization of plant population management to obtain homogeneous aging of all the plants,
- justification of a request to obtain plant life extension made to the Safety Authorities [Noël, 1987].

As part of the life extension project which has begun by EDF, a work programme has been drawn up with the following objectives:

- assessment of the state of fatigue aging in the units,
- analysis the effect on aging of the changes in operating conditions and fuel management which are currently planned, particularly to assess their impact on life duration.

To attain the first objective, the idea is to use records of the numbers of occurrences per transient and per unit to assess the usage factor in the most sensitive areas. In Figure 3, we see the result of a usage factor thus recalculated at a charging line and a comparison is made with the predictions. The margins are found to be large, although, as mentioned earlier, excessive consumption of one transient was observed in this line. This means that in others, of which the theoretical contribution to fatigue is less great, there is under consumption of the number of occurrences, hence the need to calculate the usage factor to weight the influence of each type of transient.

All other sensitive areas in the NSSS are the subject of identical evaluations.

2.3 Limitations of the present TMLP approach

Even though TMLP has met the regulatory objectives initially set and is, in addition, found to be a precious information feedback tool, it has limitations which are mainly that:

- Some areas of the reactor coolant pressure boundary (RCPB) are not monitored by transient logging. These are heavily loaded zones where the thermohydraulic phenomena are complex and operating instrumentation is poorly adapted.
- Transient logging fulfils correctly the monitoring required under French regulations. However, it does not accurately take in account the severity of the actual transients (in comparison with design values) that would be useful for plant life extension.
- The regulatory requirement leads us to systematically identify design transients with actual transients, even if there is no functional link. This results in difficulties in subsequently interpreting the functional causes of the transients recorded. However, the possibility must be retained so as to make it possible to understand the origins of any malfunctioning or simply to understand the cause of the aging.

These three essential reasons led EDF, at a very early stage, to develop other monitoring methods which are more accurate as we shall now see.

3. EDF EXPERIENCE WITH FATIGUEMETER

Once TMLP was in place, EDF began investigating the development of more sophisticated facilities for monitoring the severeness of transients affecting the most highly loaded parts of the primary system. The objectives of this were threefold:

- to provide more realistic evaluation of the life durations of the critical zones, making it possible to envisage extending the operating periods of our power plants,
- to enable automation of surveillance, removing the need for an irksome task in which errors are liable to occur,
- faster experience feedback by immediately associating increases in damage (usage factor) with the consumption of transients.

We therefore developed a surveillance system making it possible to evaluate, in real time, local loading and the resulting damage on the basis of existing operating measurements alone.

3.1 Principle

Using a minicomputer, this system (Figure 4):

- determines the local thermohydraulic conditions,
- automatically calculates in real time the loading at the most highly stressed points in each critical area,
- automatically gives the logging status of the transients and the change in consumption relative to the design hypotheses. This is carried out using two separate channels: functional accounting on the basis of the logic signals of the plant and regulatory accounting on the basis of the actual harmfulness of the transients.
- calculates periodically the usage factor,

– displays variations in loading the resulting stresses and the usage factor.

The development of this prototype system, called Fatiguemeter, is based on two concepts [Bimont, 1987]:

- One is the use of data obtained during testing on the site and on scale models to correlate in a simplified manner the local hydraulic conditions and the available operating parameters. In most cases, this obviates the need for permanent local instrumentation in all the units.
- The other is the development of methods of calculating stress which are suitable for the real time environment. This could only be done by using transfer functions making possible, on the basis of a single prior finite element calculation, to locally determine the elastic thermal stresses during the transient.

Once the stresses are obtained, damage is calculated by more conventional means, counting of cycles and sub-cycles by a Rain Flow method and determination of the usage factor from a conventional fatigue curve in the typical sections or by the application of crack initiation and propagation rules in the notch effect zones.

3.2 Implementation

As early as the beginning of 1985, an experimental Fatiguemeter was set un in an operating 900 MW PWR unit at Bugey 2. This first installation only provided surveillance of a single zone: the charging line on the cold loop of the primary system [Bimont, 1985].

This zone was selected because of the numerous loads to which it is subjected. Furthermore, it offered the benefit of the numerous experimental results acquired by Electricité de France during on-site testing sessions, facilitating modelling of the local boundary conditions.

Early in 1988, another Fatiguemeter was installed at Dampierre 1 (900 MW PWR) on a minicomputer with a multi-task operating system making it possible to work on several critical locations in parallel.

Initially, this system detected and classified transients on the surge line and calculated the usage factor in two zones: the pressurizer surge line nozzle and the hot loop/surge line nozzle. These two zones are highly loaded, particularly during primary temperature fluctuations resulting from frequency adjustment.

This system is in the process of being extended. Since the beginning of the year, modules for surveillance of the cold loop feed line nozzle and the steam generator feedwater nozzle have been put into service. A module for surveillance of the RHR injection nozzle at the cold loop is in progress.

Each zone is the subject of special processing, from acquisition of the operating parameters necessary for all the zones under surveillance.

3.3 Results

Bugey 2 Fatiguemeter

This is the system for which there is the most experience, as this Fatiguemeter has been operational since the beginning of 1985. This experience, which is limited to surveillance of the charging line nozzle, nevertheless constitutes a precious set of full-scale data which can be used to show what benefits can be expected from extending of the system to all the units.

Apart from being reliable (better than 95%), the Bugey 2 Fatiguemeter has provided proof of the highly conservative nature of the present design hypotheses.

The comparison of actual transients and design transients on the basis of their actual severeness, evaluated by the stress variations and not directly from variations in temperature and pressure which are more difficult to assess, shows the extremely conservative nature of the present transient logging.

A systematic trend towards identification with the less severe transients is found (Figure 5).

For that reason, the usage factor may be expected to be considerably lower than that estimated in the design studies, and even lower than that obtained by conventional logging. This reduction is extremely significant, as can be seen in the Figure 6 which plots change relative to the design usage factor and that evaluated by the analysis of actual transients (Fatiguemeter).

It can therefore be hoped that the life duration may be considerably greater than the contractual life duration, despite the heavy consumption of certain situations.

Dampierre 1 Fatiguemeter

This was installed to provide surveillance initially of the pressurizer surge line, particularly at its two ends (the nozzles at the hot loop and at the pressurizer). Due to the low flow rate and the fact that the line is virtually horizontal, permanent stratification is present which considerably changes the conditions at the local boundaries in the nozzle. Previous tests carried out on site at Cruas 2 Nuclear Plant had made it possible to develop and validate correlations between the principle operating parameters and the temperatures in the critical zones constituted by the nozzles (Figure 7).

The first results obtained clearly show the beneficial consequences of modification of the procedures resulting from Cruas 2 test experience feedback.

This modification consists in imposing a high average spray rate due to the action of the pressure control system with additional heater sets.

The effect of this spray flow circulating through the pressurizer and surge line is to create better thermal conditions in the pressurizer nozzle and to avoid thermal shock due to power variations (remote control and load following).

To facilitate analysis, classification by local transient amplitude is effected periodically for each characteristic event of the unit (NSSS heating, hot shutdown, load variation etc.).

This type of information can enable more accurate predictive analysis of the consumption of transients by analyzing separately the distribution of the main NSSS events (associated with future operating modes of the facilities) and the local consequences for the pressurizer and hot loop nozzles.

Overall comparison of the distribution of the transients detected by the Fatiguemeter with those allowed for in the design hypotheses clearly illustrates the conservativeness of the current hypotheses.

Evaluation of aging

Aging is evaluated by analyzing the initiation factor for the pressurizer nozzle thermal sleeve weld, and by a conventional usage factor calculation in the hot loop nozzle.

In both cases, the stresses are calculated in real time and the damage is evaluated periodically using the Rain-Flow method for determination of the cycles and the sub-cycles.

Figures 8 and 9 show the changes in usage factors during the five months in which records were made.

It is found that change is extremely slight, which closely corresponds to the actual transient consumption level.

The principal NSSS events liable to cause a significant increase in aging are NSSS heating and cooling, which are periods where the potential amplitude of the thermal shocks is at a maximum (between 60 and 110°C).

4. SYSFAC, THE FUTURE TRANSIENT LOGGING AND FATIGUE MONITORING NETWORK

After more than ten years of experience with TMLP and four years of successfully experimenting with Fatiguemeter, Electricité de France believes that it is time to create a modern fatigue monitoring system which integrates experience feedback.

The specifications of this entirely new automatic system which could be operational in all the 900 MW PWR units within the few years have been drawn up in consultation with Framatome, the NSSS manufacturer.

The monitoring system proposed would have a certain number of options, resulting from fatigue monitoring feedback:

1. The system is supplied with operating data, no additional instrumentation is required. This choice, which means simplicity and reduced cost, is made possible by the standardized plant effect.

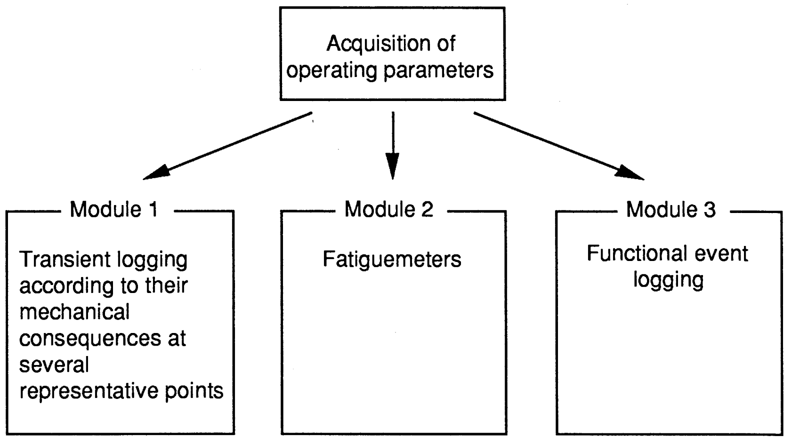
2. The sophistication of the methods to be used to monitor various points of the RCPB must be adapted to the extent of risk and methods are to be reserved for a few very stresses areas such as surge line, charging line and the System RHR injection line which are subject to complex phenomena that are not accurately be monitored by a transient logging method.

3. Transient logging according to the mechanical consequences of the transients with respect to the NSSS must be associated with the logging of the operating incidents that occur.

   This is indispensable in order to be able to interpret, a poste*riori*, any drift observed with respect to either the computed usage factors or the number of transients recorded, and, then, propose solutions.

4. The system must be on-line and fully automatic.

From these choices the system chart is the following:



The purpose of the first module is to monitor roughly the fatigue in the overall NSSS. This will be obtained by previously selecting few zones representative of NSSS behaviour. Then the transient logging will be carried out, contrary to current procedure, no longer according to changes in T and P, but using a very simplified computation of the stress response of these zones to an operating transient.

This response will be compared to the pre-computed values, associated with the various design transients. The actual transient will be assigned in the design transient whose severity is just greater than its own.

We therefore see that the general methodology of the transient logging procedure will maintained.

For the most critical location (high design) usage factor, transient logging feedback, manufacturing and in-service inspection results, a more precise computational method via transfer function will be used and real usage factor computation will be effected (module 2). This will offer the advantage of a better determination of the fatigue due to the transient, taking account of its actual shape, and no longer by equating it with a design transient which may be very enveloping. The methods used will be those described in paragraph 3.

The objective of module 3 will be to record the actual operating events (reactor trip, load rejection, load changes etc.) which occur along with their dates. This will be done using simple operating criteria (logic signals). The events will be identified in a list of operating transients which could be much more complete than the list of design transients used in module 1.

In practice, these systems will be installed in a minicomputer and connected to the on-site computer system, so as to ensure management of monitoring data and results at local and national level.

5. CONCLUSION

NSSS fatigue monitoring is a key aspect of PWR operation and maintenance optimization.

It is also indispensable if it is to be demonstrated that the NSSS can operate for longer than initially planned. Fully aware of what is at stake, EDF has an ambitious programme in hand for the development of an automatic monitoring system using the wealth of experience it has acquired over the last ten years in situation logging and experiments with prototype Fatiguemeters.

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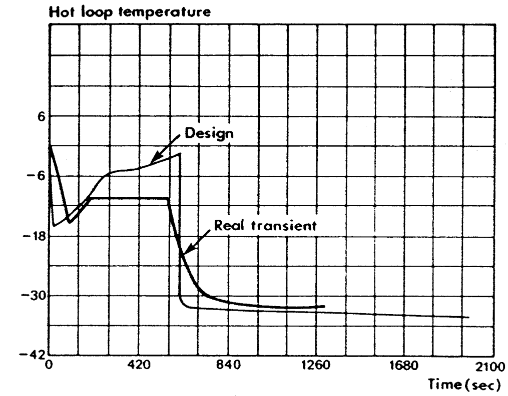

Figure 1 : EVOLUTION OF PRIMARY SYSTEM TEMPERATURE DURING A "LOSS OF OFF-SITE POWER" AT BLAYAIS 4 - COMPARISON WITH DESIGN HYPOTHESES

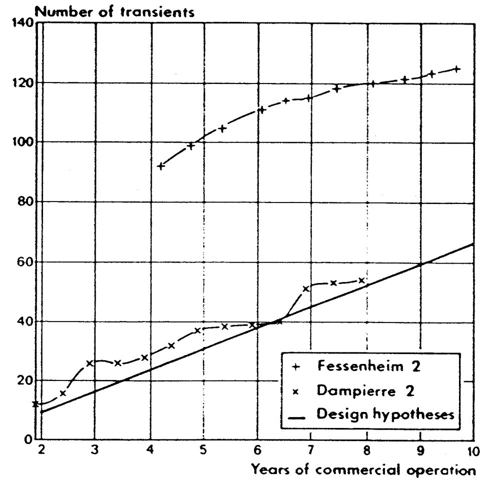

Figure 2 : NUMBER OF LETDOWN LINE SHUT OFF AT FESSENHEIM 2 AND DAMPIERRE 2

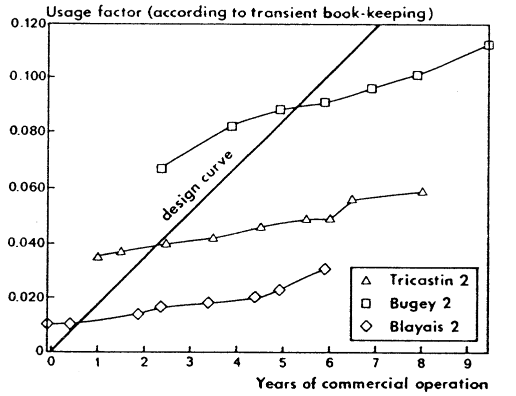

Figure 3 : USAGE FACTOR DUE TO MOST SIGNIFICANT TRANSIENTS AT CVCS CHARGING LINE NOZZLE (thermal sleeve weld)

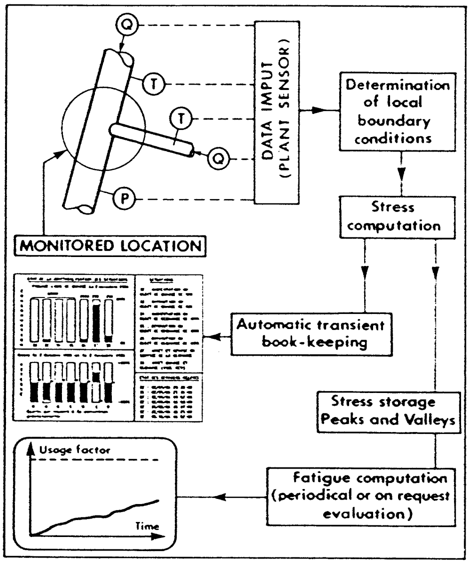

Figure 4 : FATIGUEMETER PRINCIPLE

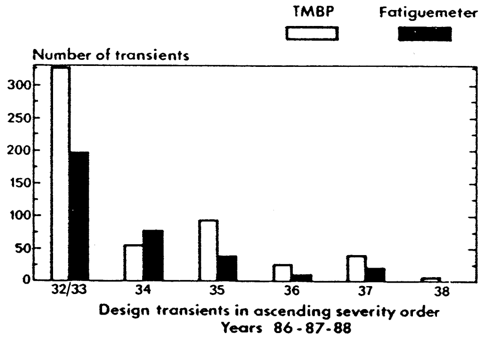

Figure 5 : CHARGING LINE NOZZLE BUGEY 2 - (transient book-keeping)

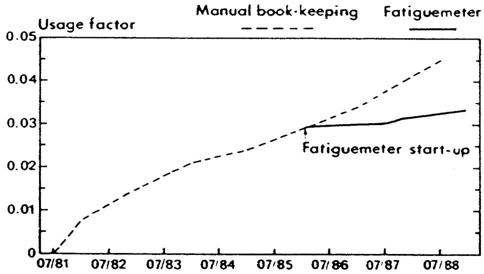

Figure 6 : CHARGING LINE NOZZLE BUGEY 2 - (usage factor)

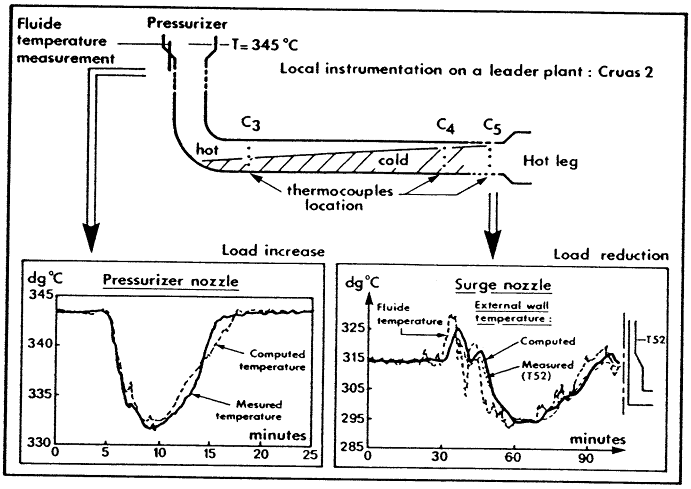

Figure 7 : DAMPIERRE 1 FATIGUEMETER :
Validation of thermohydraulic module

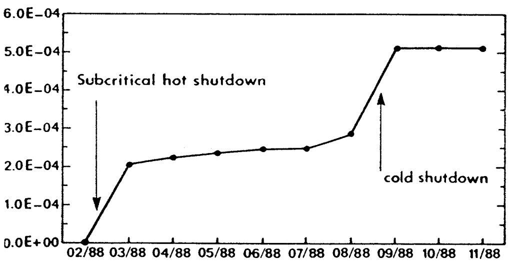

Figure 8 : DAMPIERRE 1 - PRESSURIZER NOZZLE - Usage factor variation from 02/13/88 to 10/27/88

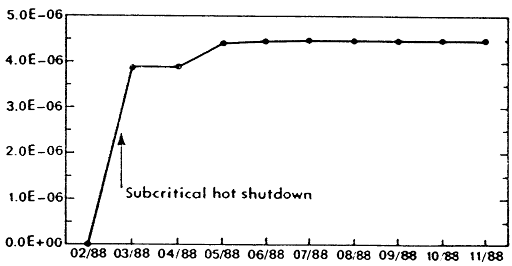

Figure 9 : DAMPIERRE 1 - SURGE LINE NOZZLE - Usage factor variation from 02/13/88 to 10/27/88