THIRTY FIVE YEARS OF TRANSIENT CYCLE COUNTING AND BOOKKEEPING IN EDF PWR UNITS

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ABSTRACT

Transient cycle counting process

For more than thirty five years, EDF operates PWR (58 units at present). As a response to a regulatory requirement, EDF has defined and implemented a genuine process to perform cycle counting of the transients of the reactor coolant system and main secondary system. Using operation instrumentation of the main reactor coolant system (RCS), main secondary system and the auxiliary systems, more than 40 parameters (pressures, temperatures, flows, valve actuations) are recorded. Each operating transient is analyzed and counted as a transient of the list of the design transients. EDF is permanently checking that the actual operating transients are neither more severe nor more numerous than the design basis transients.

Experience feedback

In general, the occurrence rates of transients are lower than the design ones. In few cases, they are higher, such as the occurrence rates of the transients related to RCS piping connected to auxiliary systems, often due to operating procedures or particular periodic testing. Transient counting makes it possible to detect actual operating transients not accounted for during the design phase. It is a useful experience feedback tool for operating procedure survey. After analyzing the actual operating transients and their occurrences, the operating procedures can be modified, should they penalize the equipment. Transient cycle counting enables design basis transients to be adapted as closely as possible to operating transients. Thus it enables operating mode changes to be taken into account (fuel cycle with stretch-out, change of the hot leg and cold leg temperatures for the PWR 1300 MWe …). In this way, for example, the consequences due to the load follow-up operation of EDF PWR units were shown to be low on the RCS fatigue damage. Every period of 10 years, the list of the design transients of a PWR series is checked and often updated to be consistent in particular with the forecasts of transient cycle counting.

Advances

After significant studies (Hydraulics and Mechanics) of some local fatigue phenomena, the complementary counting of the cumulative durations of some sensitive operating conditions was defined and implemented to improve the surveillance of some thermo-hydraulics phenomena affecting some locations affected by mixing of fluids with high difference of temperatures or by thermal stratification.

To analyze unusual transients, EDF has developed stress based counting in a software computer program. EDF is taking advantage of advanced systems experience like fatigue-meters that could improve the overall quality of the existing process and the knowledge and the understanding of fatigue in the sensitive locations with specific loads or not well monitored by operating sensors. They could help in evaluating margins in the fatigue damage evaluation.

It is above within the framework of the plant life management that transient cycle counting becomes the most worthwhile. Transient cycle counting is a precious tool to anticipate sooner fatigue damage and to optimize operating procedures or in-service inspection programs if necessary. The forecasts show that, after 40 years, only part of the potential lifetime fatigue will be consumed and it will be possible to operate the reactor over a longer period. It is worth noting that the transient records are very valuable and could be used to perform less conservative, detailed fatigue analysis.

Conclusion

With the activity of Transient Cycle Counting, EDF owns a database corresponding to more than 1500 reactor-years for the PWR units. Transient Cycle Counting is complementary with other surveillance activities like in-service inspection programs.

References

[1] “Twenty years of transient counting experience in French PWR units” B. Barthelet, D. Savoldelli, R. Fritz, ICONE 9 conference, Nice, 2001.

INTRODUCTION

Electricité de France (EDF) has implemented a procedure of Transient Cycle Counting, ever since the startup of his 58 PWR units. This procedure answers to a regulatory requirement laid down by the Order of February 26, 1974, renewed by the Order of November 10, 1999, which determines the aims of regulatory steps during operation for the Reactor Colant System (RCS) and the main secondary circuits of the PWR reactors. The aim of « transient cycle counting » is to verify that the actual operating transients are neither more severe nor more numerous than the design basis transients.

After a rapid description of the procedure of transient cycle counting, the main results experience feedback results of this activity.

TRANSIENT CYCLE COUNTING

At the design phase, to establish the service life of the reactor coolant system (main primary circuit and main secondary circuits of the PWR reactors) as required by the regulation, the operating conditions are defined and classified in categories (design, normal and upset, emergency, and faulted conditions). Under these conditions, plant series behaviour are analysed in relation to the various damage which might be initiated by the assumed loads.

Transient Cycle Counting (TCC) ensures that, under operating conditions, the RCS (and the main secondary circuits) is not subjected to either more severe or more numerous transients than that provided for during the design phase. As mentioned in the introduction, TCC has been implemented by EDF to meet a regulatory requirement, but it also leads to a better knowledge of the actual thermal transients and loadings withstood by the RCS pressure boundary, as far as severity and frequency are concerned.

Principles and procedures

It might be useful to briefly recall some elements which will enable to appreciate the transient cycle counting contribution better as well as its limits.

Transient Cycle Counting relies on the information collected by the unit operating sensors : RCS hot leg and cold leg temperatures, RCS and secondary pressures, auxiliary line temperatures, and in addition some logical (on-off) signals (valve position, pump ...); approximately 40 parameters are regularly monitored with specific recorders. No particular instrumentation was installed to check on an area nor particular local phenomena.

From the above mentioned signals, only the transients likely to increase the fatigue usage factor of some points are detected. Therefore, thresholds of insensitivity to fatigue were calculated. These threshold values are as following :

- rate of RCS main loop temperature changes 5° C/3 h
- RCS pressure changes 1 MPa
- secondary pressure changes 0.5 MPa
- rate of auxiliary circuit temperature changes between 20 °C/h and 40 °C/h.

It is worth noting these thresholds have been calculated very conservatively. More detailed calculations show that for transients equivalent to the detection threshold, the calculated stress ranges are far below the material endurance limit for the most heavily loaded RCS areas.

When a transient is detected, the first task is to find, in the design basis transient file, an “envelope design transient", i.e. a design transient at least as severe in terms of temperature and pressure changes. It is recommended to first for an “envelope design transient” with the same initiating event and then checks the "envelope" feature by comparing the range and the rate of the various parameters changes. Would this approach fail, it will be possible sometimes to classify the transient in a category with a weaker functional connection, provided that the design transient evolved more severely. Consequently, for example, at the end of the unit startup tests, power variations are sometimes already accounted for transients without power variations, or safety injection type transients are accounted for transients without safety injection.

Currently, the transients are counted according to their characteristics (pressure, temperature variations) and initiating event, but not according to their consequences on the equipment (stress, fatigue damage).

In the design transient file, each transient is affected to a number of allocated cycles (estimated over 40 years of operation) as used for the design studies. It is verified that these allocated figures have not been reached by adding all the transients which have occurred.

Implementation of the procedure

The doctrine and procedure of transient cycle counting are defined by EDF Nuclear Generation Division corporate engineering, and implemented by the nuclear power plants. At present, transient cycle counting is carried out on the sites generally by the testing teams. The staff assigned to this activity varies depending on the sites. It varies from 1 person to 2 persons for a nuclear plant with 2 units. The job is carried out, in rotation, on all plant units. Twice a year, a balance sheet of the transient consumption is sent to the nuclear safety authority.

Training sessions for transient cycle counting have been organized since 1990. More than 300 people have been trained for transient counting (in EDF Nuclear Power Plants, transient counting represents work for 40 people).

Evolution of practices in the plants

During the first 10 years of plant unit operation, the people in charge of this activity were mainly working on counting transients. Transient analysis (cause of the initiating event) was rarely carried out. The procedure is now easier to apply and better mastered than at the beginning of plant unit operation, thus making it possible to spend more time analysing the transients and, in some cases, it has been possible to reduce transient consumptions, thanks to operating procedure modifications. For several years, the staff have been growing more aware of the transient cycle counting concern and the benefits appeared in the consumption reduction of so-called "sensitive" transients.

EXPERIENCE FEEDBACK, DESIGN BASIS TRANSIENT FILE UPDATING

Transient Cycle Counting makes it possible to check whether the design assumptions cover operating transient characteristics. If it is not the case, the design transient file can be updated and the design stress analysis shall then be revised, as required by the regulation.

PWR 900 MWe series

With a first commercial operation of Fesssenheim 1 in 1978 for 900 MWe CP0 series and Tricastin 1 in 1980 for the 900 MWe CPY series, the design transient file of PWR 900 MWe series was modified in 1986 and modified again in 2001 and for the third 10 years outage of Fessenheim 1 and Tricastin 1 in 2009.

For some transients the following difficulties have been noted :

- station heat-up and cool-down
- RCS temperature changes in intermediate state
- pressure excursion in intermediate state
- auxiliary spraying
- charging line temperature changes.

The difficulties encountered are described below.

a) For RCS heat-up and cool-down, the current design transient file only contained complete heat-ups and cool-downs (from cold shutdown to hot shutdown or reciprocally, $\Delta t = 270°C$). For various operating reasons, these heat-ups and cool-downs can be partial, e.g. the reactor can go from hot shutdown to intermediate shutdown state and then back to hot shutdown. These partial heat-ups and cool-downs were accounted for as complete ones. This was a very conservative approach. It resulted in a "unreal" over-consumption of the complete heat-up-cool-down transients. Through this example, it was obvious that it was worth having a detailed design transient file. It should be noted that in many RCS areas, the complete heat-ups and cool-downs are the most significant for cumulative usage factor values.

b) In intermediate RCS states, the transients with high temperature variation rates (> 100°C/h) were detected. Taking into account our method of transient counting and the past design transient file, these transients could not be classified. They constituted the great majority of unclassified transients detected at this time. They were mainly due to RCS pump startings and stops. Therefore, small thermal shock transients were created in the design transient file. In cooperation with the operating personnel, actions were also launched to limit the number of these transients.

c) Transient cycle counting had made it possible to detect severe auxiliary spraying transients not provided for at the design phase and which the pressurizer spray line is subjected to. In fact, periodic tests were set up to a check valve operability at hot shutdown. When this valve opened, an amount of cold water was pushed towards the spray line whose temperature was around 340° C. The frequency of this type of tests was 1 every 1 to 3 years, depending on the plant unit. At the design phase, this type of transient was considered to occur very rarely and was "limited" to upset condition transients. The above-mentioned test was therefore modified, and the analysis of the spray piping behaviour was updated. In order to obtain margins, the design transients which are much more severe

than the real transients were optimized. The design studies assumed that the spraying pipe was subjected to the passage of the cold water at 20° C. On-site measurements showed that the temperature of this « cold water » was about 100°C.

d) At the beginning of the PWR 900 series operation, more transients than forecast were detected on the charging line. Various measures were taken in order to reduce this phenomenon (modification of the pressurizer water level regulation) ; the operators were sensitized to this issue and a decrease in such transients has been observed quite quickly.

e) Difficulties in counting some transients have been encountered, due to discharge isolation. Design discharge isolation duration was given as less than 5 mn. In fact the quicker the line can pass from zero flow rate to flow rate, the fewer transients will be generated : cooling will be compensated for by quick reheating.

This problem is encountered (due to current transient counting methods) for the design transients which comprise a series which is very limited in time (see Figure 3).

PWR 1300 MWe series

With a first commercial operation of Paluel 1 in 1985, the design transient file of PWR 1300 MWe series (20 EDF units) was updated in 1991. At that date, for a total of 70 reactor-years, nearly 1000 transients detected on the sites did not correspond to the descriptions in the transient file. This was essentially due to changes in operating conditions:

- decrease in the average operating temperature
- design not having taken into account stretch-out operating cycles.

The analysis of the various unclassified transients enabled us to define the design transients to be modified and those to be created. These modifications were defined with the aim of reaching a relatively fine breakdown of design transients, so as to follow up fatigue damage as closely as possible.

EXAMPLE :Transients of the charging line (without discharge or charge isolation)

Scenario A	Scenario B
12000 occurrences with $\Delta t = 70°$ C	12000 occurrences with $\Delta t = 70°$ C
1000 occurrences with $\Delta t = 100°$ C	1100 occurrences with $\Delta t = 140°$ C
100 occurrences with $\Delta t = 140°$ C	

Scenario A is preferred to scenario B as it allows for more precise counting. The initial list of transients used in transient counting included 50 transients ; the revised list includes about 100 transients (normal and upset conditions only). As a result of this complete overhaul of the design transient file, the classifications previously carried out had to be considered and this had represented a significant volume of work (between 300 and 400 transients are accounted for every year on each plant unit). After this complete revision of transient cycle counting of the PWR 1300 MWe, a reliable and homogenous data base was available.

Contrary to what might had been feared, the modifications and creations of new transients did not result in too significant an increase in the fatigue usage factor values for the areas most frequently subjected to the cyclic application of pressure loadings and thermal transients. The difficulty in defining these modifications was to find a compromise to cover transient consumption without increasing equipment usage factors too much. When the transient file of PWR 1300 series was revised, it was possible to take advantage of the improved calculation methods, which attenuated usage factor increases; in some cases.

The updating of the PWR 1300 series transient file has been incorporated into the PWR 1400 MWe file.

TRANSIENT COUNTING ANALYSIS AND FORECAST

PWR 900 MWe series

At present, the numbers of observed occurrences of the transients are generally lower than the allocated numbers. The forecasts show that the allocated numbers of occurrences of the design transients, adapted in 2009 for the third 10 years outage, present still margins beyond 40 ans. Most of the transients will not pose problem within 60 years. (see figures 1 and 2).

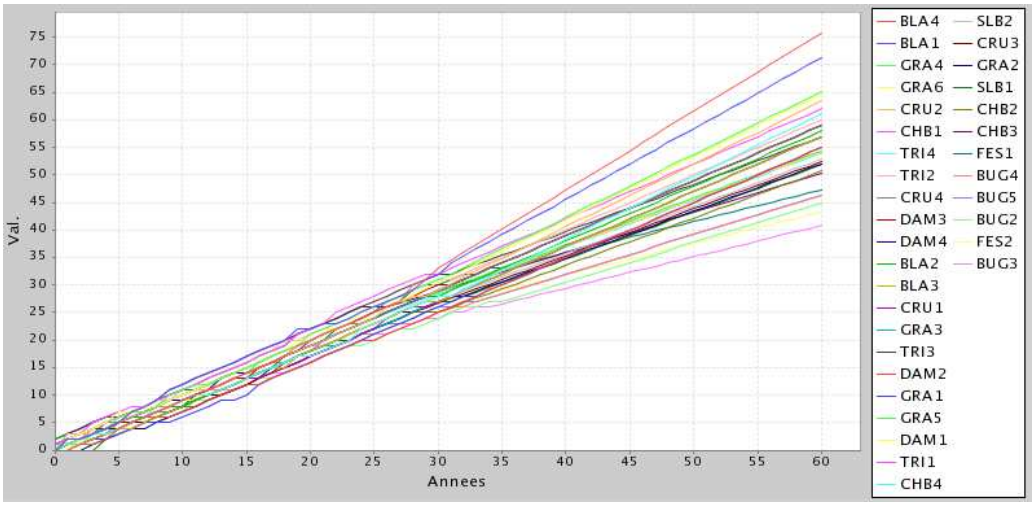

Fig. 1: PWR 900 MWe series – Observed and forecast occurrences as a function of the age (years) of the units
Transient 1A : heat-up from cold shutdown for intervention to hot shutdown (allocated occurrences : 70)

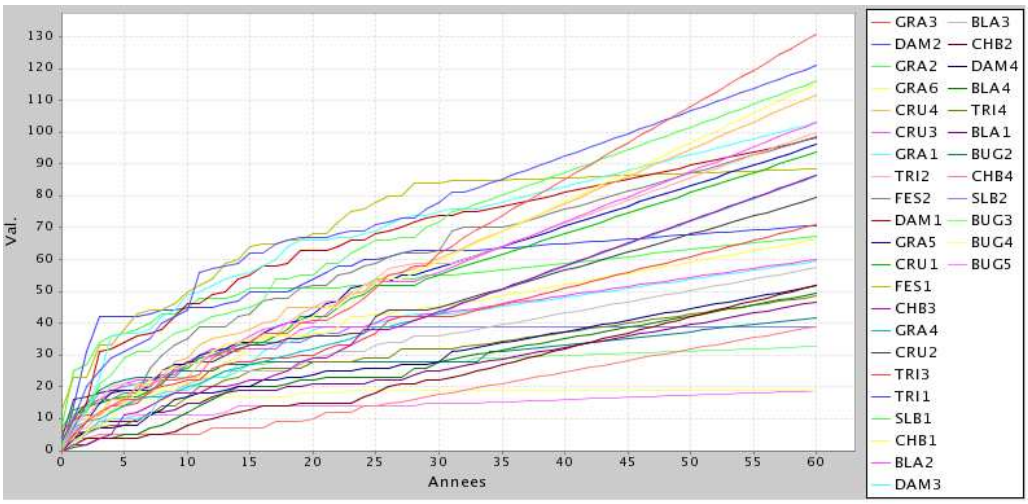

Fig. 2: PWR 900 MWe series – Observed and forecast occurrences as a function of the age (years) of the units
Transient 28D2 : Cold thermal shock of 30°C of the RCS (when RCS is under 180°C) (allocated occurrences : 150)

PWR 1300 MWe series

The revision of the design transient file of the PWR1300 MWe series performed in 1991 is still a good envelope of the forecast consumption of transients. This file is consistent with the forecast. Most of the transients will not pose problem within 60 years.

The consumption is higher than the forecasts for the small thermal transients with high rates of RCS temperature changes (RCS temperature under 180°C). The forecasts predict also the necessity of a small increase of the numbers of occurrences of the transients linked to the simultaneous isolation of the charging and discharge lines.

For PWR 1300 plant units, in case of automatic boration system actuation, a volume of water with a high Boron content is injected into the RCS. The transient file includes this transient with the reactor at nominal power as the initial state. When this injection of cold water takes place at low power or during hot shutdown, the amount of available heat in the RCS is much lower than that available when the reactor is at full power, thus resulting in greater cooling than that taken into account by the design.

The updating of the design transient file for the third 10 years outage is in progess.

COMPLEMENTARY COUNTING

After significant studies (Hydraulics and Mechanics) of some local fatigue phenomena, the complementary counting of the cumulative durations of some sensitive operating conditions was defined and implemented to improve the surveillance of some thermo-hydraulics phenomena affecting some local zones :

- locations affected by mixing of fluids with high difference of temperatures,
- locations affected by thermal stratification.

For the PWR 900 MWe series, the locations affected by mixing of fluids with high difference of temperatures are :

- a piping tee of the reactor heat removal system,
- the nozzle of the charging line on a cold leg (reactor chemical and volume control system),
- the nozzles of the safety injection system on the cold legs,
- the tee of the auxiliary spray piping on the main spray piping,
- the nozzles of auxiliary feed-water system on feed-water piping (near the steam-generator).

For the PWR 900 MWe series, the locations affected by thermal stratification are mainly the feed-water piping near the steam generators (SG).

As the transient cycle counting, the complementary counting relies on the information collected by the unit operating sensors ; more than 10 parameters are monitored without specific recorders. There was no need of complementary instrumentation to check local phenomena. Using the records of the unit operating sensors, a software computer program was developed to compute the duration of the monitored local fatigue phenomena.The cumulative durations of the more sensitive operating conditions are regularly checked and in-service inspections are planned when these durations over-passed the design values.

STRESS BASED CYCLE COUNTING AND FATIGUE-MONITORING SYSTEMS

Stress-based classification computer program

The software computer program called TNC has been developed by EDF for unclassified transients of the PWR 900 MWe series, 1300 MWe series and 1400 MWe series. Component stresses are computed using detailed Laplace-Green transfer functions. A stress-based classification algorithm attempts to classify the analyzed transients according to the stress-based design envelope. This software computer program is currently used by EDF Nuclear Generation Division corporate engineering to analyse the unclassified transients of the plants and to propose a classification.

Fatigue monitoring

Transient Cycle Counting as currently carried out by EDF makes it possible to count the RCS transients. This method which meets the regulatory requirements is generally conservative. For locations with high design cumulative fatigue usage factor, a more realistic method could be useful. Because of the limited information collected by the unit operating sensors, some RCS locations subjected to particular transients due partly to local thermo-hydraulic phenomena are not well monitored (pressurizer surge line, feed-water piping near the SG).

To solve these issues, EDF R&D Division has developed fatigue monitoring devices which enables the stresses undergone in some locations of the RCS to be calculated. The principal steps are:

- direct acquisition of the required operating parameters,
- determination of the local temperature and pressure variations based on thermo-hydraulics modeling,
- periodical stress calculation and calculation of usage factor.

The first fatigue monitoring prototype was installed on the charging line nozzle at Bugey 2 in 1985. A second fatigue monitoring prototype was installed in 1988 on Dampierre 1.

EDF is taking advantage of advanced systems experience like fatigue meters that could improve the overall quality of the existing process and the knowledge and the understanding of fatigue in the sensitive locations with specific loads or not well monitored by operating sensors. They could help in evaluating margins in the fatigue damage evaluation. At present, fatigue meters are installed on two units. The monitored locations are the charging line nozzle, the surge line (stratification) and the feed-water piping near the SG. The experience feedback will be available next year.

CONCLUSION

Transient Cycle Counting was originally considered as a compulsory constraint. Today, it increasingly appears to be a precious tool in understanding the plant units operation and in monitoring RCS fatigue. In fact, Transient Cycle Counting and fatigue monitoring are complementary with other surveillance actions like in-service inspection programs.

Transient Cycle Counting enables design basis transients to be adapted as closely as possible to operating transients. Thus it enables operating mode changes to be taken into account. In this way, for example, the consequences due to the load follow-up operation of EDF PWR units were shown to be low on the RCS fatigue damage.

Transient Cycle Counting makes it possible to detect actual operating transients not accounted for during design. It is a useful experience feedback tool for operating procedure survey. After analysing the actual operating transients and their occurrences, the operating procedures can be modified, should they penalize the equipment.

After long studies (Hydraulics and Mechanics) of some local fatigue phenomena, the complementary counting of the cumulative durations of some sensitive operating conditions was defined and implemented to improve the surveillance of some thermo-hydraulics phenomena affecting some local zones :

- locations affected by mixing of fluids with high difference of temperatures,
- locations affected by thermal stratification.

However, it is above all within the framework of the plant life management that transient cycle counting becomes the most worthwhile. Transient cycle counting is a precious tool to anticipate sooner fatigue damage and to optimize operating procedures if necessary. At the present time, it is expected that only part of the potential lifetime fatigue will be consumed after 40 years in operation and that it will be possible to operate the reactor over a longer period. It is worth noting that the transient records are very valuable and could be used to perform less conservative, detailed fatigue analysis.

The procedure set up by EDF from the unit start-up gives a good but conservative estimation of the RCS fatigue damage. The installation of advanced systems like fatigue-meters could improve the knowledge and the understanding of fatigue in the sensitive locations with specific loads or not well monitored by operating sensors. They could help in evaluating margins in the fatigue damage evaluation.

REFERENCES

[1] Barthelet, B, Savoldelli, D., Fritz, R., “Twenty-five years of transient counting experience in French PWR units”, *International Conference on Nuclear Engineering*, Nice, Franc, ICONE9, 2001.