CONTINUOUS IN SERVICE VERIFICATION OF DESIGN LIFE ASSESSMENT CONDITIONS IN PWR PLANTS

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This paper presents what is done in french PWR plants to check the validity of the design analysis hypothesis (particularly the fatigue loadings) after starting operation. A procedure is described which allows to monitor and bookkeep the actual loading cycles. Results may be used to validate design demonstration or to work out more realistic analysis. Improvements are proposed to monitor more precisely the real fatigue damage.

1 - INTRODUCTION

It is probably not necessary to emphasize the increasing need for reliable components and structures, particularly in the field of nuclear engineering and industry. That is the reason why this conference intends to address the current status of methods and theories dealing with the life assessment of dynamically loaded materials and structures. Mechanics and mechanisms of failure phenomena, fracture theories and models, material characteristics and properties will probably be discussed in detail. And, the point which is to be developed in the present paper will likely bring nothing new to these theories ; however it is thought to be a very important and too often forgotten point in the application of these theories to a valid and rigourous reliability assessment of actual structures. That is the in-service and eventually continuous verification that the life assessment hypothesis, models and data remains valid throughout the life of the structure. It is a very logical requirement to insure the validity of the design analysis and it will be shown that, in turn, it can be used to improve and get better insights into the reliability assessment itself.

Obviously, this remark applies essentially to data or hypothesis which may be subjected to change with time or which are difficult to ascertain beforehand. A well known example in the nuclear field is the possible material characteristics evolution due to irradiation which must be monitored through an appropriate surveillance program. But the example which will be discussed in greater detail is the list of operating transients which has to be postulated to perform the life assessment analysis of main components.

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Indeed, how many life assessment studies have been performed without anybody checking, after starting operation, whether the actual stress cycles look like the postulated design ones or not ? In fact, such a verification is required by the French nuclear regulation which asks the plant operator to make sure that, during operation, components are never put in a more severe situation than what they were designed for with respect to any type of damage including fatigue (1). After describing how it is done, some examples will be given of the expected costs and benefits and of the possible consequences on "classical" fatigue analysis as well as fatigue crack propagation studies of actual flaws.

2 - LOADING CONDITIONS

When designing the main components of a nuclear steam supply system, the designer is required to demonstrate that their inservice behaviour will be reliable and safe by using various criteria which are proposed or imposed by codes and/or regulations. To perform the corresponding analysis, input data are needed and, particularly, a list of operating transients has to be postulated. This list is established on the basis of previous experience and anticipated operating practice and it may be worth noticing how difficult it is to make reliable assumptions about how a plant will be run within the next forty years ! The list includes a functional description of each transient, the corresponding variations of the main physical parameters (pressure, temperature, flow rate etc...) and the expected number of occurrences during the life time of the plant. These data are used not only to verify the design criteria (particularly the fatigue one) but also to work out the propagation and stability analysis of flaws which may be detected before starting operation or during inservice inspection. They are chosen in a quite pessimistic manner in order to insure the conservatism of the results ; however, the analyses are really meaningful and reliable only if these various assumptions are shown to be true at any time.

3 - FATIGUE THRESHOLD

The plant operator must be able to prove, at any time, that all transients occurring during operation are very much the same as the predicted ones with respect to parameter variations and frequency. In order to do that, he first has to detect these transients. This is done by monitoring main physical parameters, mainly pressure and temperatures, using regular plant instrumentation. Steady state fluctuations are "eliminated" from the procedure by establishing parameter thresholds below which the structure is shown to undergo no fatigue damage. To estimate these thresholds, thirty four regions of the primary circuit were selected on the basis of the stress report results as being the most sensitive to fatigue damage. Using a simplified thermoelastic approach, it was possible for each of these critical points, to derive an expression of the total stress variation $\Delta\sigma$. Keeping this stress variation below the fatigue limite resulted in an inequality :

$$f\ (\Delta P,\ \Delta T) \leqslant S$$

S : stress limit related to material fatique property.

There is one such inequality for each region under study. In order to simplify the bookkeeping procedure, it was decided to separate the pressure and temperature thresholds by postulating a reasonable pressure fluctuation and calculating the highest temperature variation that satisfies the inequality. Results for each region were compared and the lowest values were selected. For some specific components, a slightly more complicated analysis was necessary, particularly when two fluids at different temperatures had to be considered. It must be also reminded that the selected thresholds correspond to <u>the</u> point which is the most sensitive to fatigue. In any other points where specific transients occur, specific thresholds may be estimated (like in the charging line case). These various studies led to the presently adopted threshold values :

Monitored parameter	Threshold
primary pressure	1 MPa
secondary pressure	0,5 MPa
primary loop temperature	5° C
pressurizer temperature	6° C
charging-line temperature	20° C

The threshold calculation methodology was presented by Baylac in (2).

It appeared also reasonable to eliminate very slow thermal transients from the procedure. For that purpose, it was shown that it was possible to neglect any temperature variation as long as its slope was less than one threshold value in three hours.

As it will be discussed later, one of the drawbacks of this procedure is that these classical fatigue thresholds do not necessarily correspond to the fatigue propagation threshold of a given crack.

4 - MONITORING AND BOOKKEEPING PROCEDURE

Each time a threshold is overpassed, the transient must be identified with one of the design list ; actual and predicted parameter variations must be compared with respect to amplitude and slope and all these informations are kept on file. An example of this comparison is shown in figure 1. Bookkeeping of this monitoring procedure allows the operator to know, at a given time, how many transients of each kind have already been encountered and how many are left. The detailed procedure includes other instructions to deal with special cases : rapid sequence of transients, transient within an other one, threshold overpassing in very long time etc... The reasons which led to chose this method have been discussed by Noël and Mercier in (3).

Of course, this way of handling the problem raises many questions. In many cases, actual transients are easy to identify functionally in the design list and the comparison between actual and postulated parameter evolutions is straightforward. However, there is cases where the identification is difficult or where the parameter variations are different from what was expected. Then, special bookkeeping procedures may be applied using appropriate criteria based on the mechanical consequence of the observed situation. Other problems arise if the expected number of transients of a given type is reached before the end of the plant life-time. In this case, results of design fatigue analysis (and possibly fracture mechanics analysis of non-repaired defects) need to be reevaluated. An other difficulty already mentioned is the fact that, with regard to some mechanical damage processes, besides "classical" fatigue, the existence of thresholds is not always sure (for crack initiation and propagation in flaw assessment studies for example).

It may be noticed that, in the case of very unusual transients, a possible significance with regard to the risk of fast fracture may be assessed using a simple screening criteria which has been developped to select significant events in the pressurized thermal shock issue as discussed by Buchalet in (4).

5 - RESULTS, COSTS AND BENEFITS

This bookkeeping procedure is now applied in all E.D.F. PWR units (more than 25 are now in operation, the first of them since 1977). Results accumulated until now support the idea that the design transients match reasonably well with the actual service conditions as far as the main primary circuit is concerned. It may be worth giving a few examples of how these results may yield significant improvement of engineering practice, particularly in the field of structural mechanics.

5.1 - The charging line case

Very soon, the monitoring and bookkeeping procedure brought evidence that the fatigue loadings had not been accurately predicted for the charging line of the chemical and volumetric control system : the number and amplitude of temperature variations were found to be largely in excess to the design list. This led to modifications of the pressurizer level, charge and discharge line control systems and of several operating procedures. But still the actual transients remained sufficiently different from the design one to make unavoidable a revision of the fatigue analysis with a new set of loading conditions.

As a consequence, the modifications reduced the potential fatigue damage and the re-analysis gave a more realistic understanding of the mechanical behavior of this line.

5.2 - The underclad cracking case

After starting operation of several units, underclad cracks were discovered on core vessel nozzles. Because repair was extremely difficult to make, an extensive analysis was performed using very elaborate stress computation models and state-of-the art fracture mechanics approach. The point was to bring evidence that the fatigue propagation would be slow enough for the cracks not to reach instability within the plant lifetime. At some point, it was realized that large load variations as postulated in the design list were among the most severe fatigue cycles by their amplitude and their frequency.

After discussion, operators agreed that the design allowed number of occurence (12000) was larger than necessary : it was then decided to perform the fatigue analysis with 9000 small load variations and only 3000 large ones. This was of a significant help in assessing the underclad flaws. But it must be understood that it was made possible only because, for the remaining lifetime of the plant, the monitoring and bookkeeping procedure will allow to verify continuously that the new set of hypothesis is not overpassed.

5.3 - Inservice inspection and plant lifetime

In all inservice inspection programs, the interval between two visits is given in terms of number of years. But, in fact, there are locations where the main damage to be feared is fatigue due to pressure and thermal transients. So that it would be more logical to express the frequency of inspections in terms of number of cycles. Transient monitoring and bookkeeping allow this kind of approach which has not been adopted definitely but which has been used in several cases. A good example is one of a non-repaired fabrication defect for which, besides a classical fracture mechanics analysis, a yearly inspection was required by safety authorities. After one year of operation, postponing of the inspection was accepted because the number of actual transients was far less than the number postulated in the analysis.

This idea can be extended to the plant lifetime itself. If, after forty years of operation, only a part of the design transients actually occurred or if the real transients were less severe than the design ones, it should be possible to bring evidence that the plant may be kept running, at least with respect to fatigue damage (corrosion or erosion should be looked at with a proper approach). Of course, the contrary may happen !

5.4 - Assessment of flaws detected during inservice inspection

When defects are discovered during inservice inspection, decision is generally hard to take. Indeed, repairs are often very costly and difficult to perform, proper heat treatment are not always possible, irradiation adds particular constraints... In such conditions, repair may be more harmfull than the defect it self. That is why the utility staff, before taking a decision, cannot rely only on a too conservative analysis (as it is generally the case during fabrication) but needs also a more realistic assessment. For that purpose, the transient monitoring and bookkeeping can yield invaluable data either to trace back the actual loading history of the defect or to make, year after year, a more realistic estimate of its possible evolution.

In the same manner, several attempts have not been very successful in looking for consistency between usual flaw acceptance standards (generally stemming from industrial experience) and fracture mechanics flaw assessment results. As indicated by Simonen (6), a better consistency could be found by using more realistic loadings in the analysis.

6 - POSSIBLE IMPROVEMENTS

An attempt to set up a system to process automatically the measured parameters is in progress. But it will probably be quite difficult to have a completely computerized procedure. Indeed, if a transient detection system is easy to imagine once the thresholds are estimated, the functional identification of the transients raises many questions so that it is likely that this part of the procedure remains hand-made. Moreover the problem of actual transients which are different from the design ones may be solved, in many cases, through simple engineering judgment. With respect to that issue (mismatch between actual and design transients), one of the most promising improvements would be to use the transfer function concept. For that purpose, a limited number of points must be selected as representative of the whole circuit and transfer functions have to be established which relate stresses in the chosen points to parameter variations (P, T = f (t)). The conditions for the existence of such functions have been discussed by Bimont (5). This would allow the engineer, when dealing with any transient, to get a simple estimate of the associated stress variations in the most sensitive parts and to compare and classify this transient on the basis of stress amplitude instead of functional aspect, at least when it may be helpful.

Of course, this project can be brought one step further by continuously feeding a computer with inservice measurements of the significant parameters and permanently estimating the fatigue damage (usage factor or anticipated crack growth). Such an automatic system would be useful to get realistic views of the fatigue evolution, at least in regions where design criteria are not easily met even if the design transients do not seem to be overconservative or in parts where non-repaired flaws have been difficult to assess. Figure 2 shows a good agreement between two stress analysis of the same nozzle under the same thermal transient, one using finite element method and the other using transfer functions. Figure 3 shows the stress variations computed with transfer function in the charging nozzle during a discharge isolation transient : one curve is based on the design transient ; the other corresponds to an actual transient. In that specific case, the difference could permit to increase the design life and to reduce the inspection frequency by as much as a factor of 5 !

7 - CONCLUSION

Although it is a point which does not seem to be addressed very often, either in congress or in actual affairs, the inservice verification of design conditions should deserve a lot of attention particularly with respect to anticipated cyclic loading in parts where the fatigue damage is expected to be severe or where unrepaired defects have been left. It has been shown how French nuclear plant operators cope with that problem.

This continuous verification may have important consequences. If what is actually observed is more severe than what was initially postulated, design structural analysis may have to be performed again or/and procedure, system and control may be modified and improved. On the other hand, if what is observed is less severe than what was expected, plant operator may find evidences to justify a reduction of some regulatory requirements (in-service examination program for example) or, even, an extension of the authorized lifetime of the plant. It must be noted that the work associated with this design condition verification is made easier by two facts : (1) the French plant operator is very much aware of design analysis and studies since he reviewed, verified and discussed them as required by regulation (2) operating a large number of identical units gives a larger population sample and, then, increase the reliability of the demonstration. Last but not the least, "surveillance" procedures are a strong incentive to a close and permanent cooperation between mechanical and material engineers, system specialists and operators, in the user's staff as well as with the constructor staff so that safety and reliability are significantly enhanced.

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ACKNOWLEDGEMENTS

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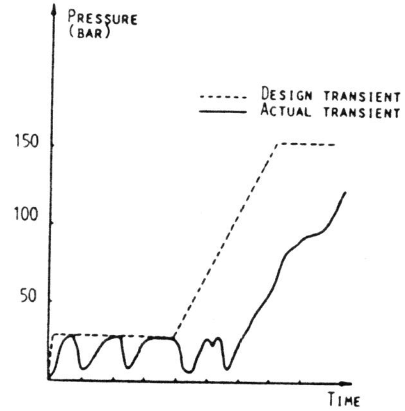

FIGURE 1 : COMPARISON BETWEEN DESIGN AND ACTUAL PRESSURE VARIATION DURING REACTOR HEATING

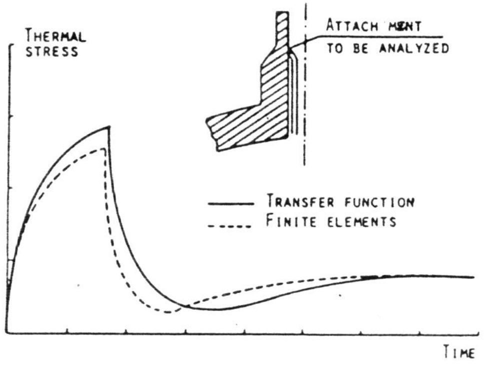

FIGURE 2 : COMPARISON BETWEEN FINITE ELEMENT AND TRANSFER FUNCTION ANALYSIS OF A SLEEVE - TO - NOZZLE ATTACHEMENT

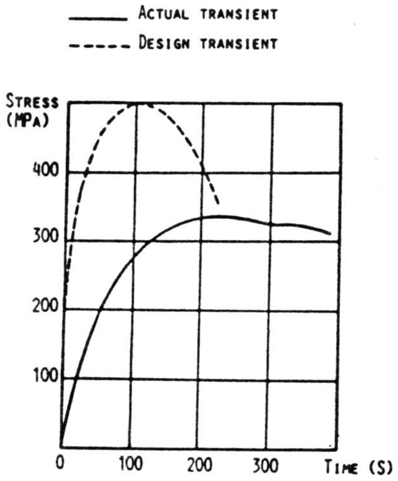

FIGURE 3 : COMPARISON OF STRESS VARIATIONS DURING ACTUAL AND DESIGN TRANSIENT IN THE CHARGING LINE NOZZLE