FRAMATOME Operating Transients Monitoring System Used for Equipment Mechanical Surveillance

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1. *INTRODUCTION*

Plant life extension of Pressurized Water Reactors (PWR) would bring an economical benefit. Considering actual operating of the PWR units, there are good reasons to believe that the life of these PWRs could be longer as designed. But it is of crucial importance to correctly evaluate the equipment ageing and assess plant life. The OPERATING TRANSIENTS MONITORING SYSTEM provides many answers to plant operator about knowledge of plant ageing evolution. They are based on mechanical damage criteria and described below.

The objective of structural analyses during the design of nuclear components is to ensure the structural integrity of the plant for a fixed service life (typically 40 years) with applicable regulations (RCC-M [1], ASME [2]). These studies are based on postulated operating conditions. They consist of a scenario of potentially pessimistic transients including a predeterminated overestimated number of "design transients".

Since the startup of the PWR units, the procedure to recording the transients occurring during plant operation shows that the operating transients are usually less severe and less frequent than the design transients. Furthermore, equipment is subjected to some loadings which do not correspond exactly to any design transient.

The fatigue damage level of nuclear components is estimated from the actual occurrence frequency of each type of transient. The gradual deterioration of some critical materials is often a major cause limiting the lifetime of equipment. The O.T.M.S. is a system designed to maintain real operating conditions and to calculate more realistic structural damage parameters in order to estimate plant ageing and take decisions concerning plant operation, equipment inspections and maintenance.

2. *DESCRIPTION OF THE O.T.M.S.*

The Framatome OPERATING TRANSIENTS MONITORING SYSTEM (O.T.M.S.) is based on a real time computer system. As shown on figure 1, it comprises :

- a rapid and efficient multi-task computer, which receives the set of signal emitted by standard plant instrumentation, performs calculations, provides data storage on disks and tapes, plots results and their interpretations on a monitor screen and on a printer,
- software which have four functions : (1) to drive the acquisition center, (2) to reconstruct and individualize the operating transients experienced by each monitored zone, (3) to perform structural analysis, (4) general software to provide data storage on disks and tapes and to display results on a graphical screen or on a printer,
- a database which contains specific characteristics of the monitored components, such as Green's functions and all the material fatigue curve data, calculation results such as cumulative fatigue usage factors at specific critical locations, the actual state of transient recording and bookkeeping temporarly stored transient raw data (e.g. pressure, temperature, flaw rate or logical status) and stress transient data.

3. *FUNCTIONS OF AN O.T.M.S.*

As shown on figure 1, Framatome has developed the OTMS software for 4 main functions :

3.1. Transients recording and data processing

- Acquisition of the operating parameters required to monitor the critical points. The collected data provide a complete and detailed description of inservice operation of plant systems. Significative transients are obtained through eliminating parameter variations not exceeding given thresholds. This detection phase, in order to eliminate small fluctuations and damage non-significative transients, uses either determined parameter thresholds (10 bar for primary pressure, 5'C for hot leg temperature,...) or stress thresholds with respect to the fatigue damage of the monitored area.
- These signals are processed to eliminate noise and other parasitic signals. Numerical operations are performed to minimize the quantity of parameters information (storage requirements).
- The information given by the operating sensors are converted into temperature, pressure and flowrate at the monitored zones. Local conditions can be inferred from plant instrumentation, or from the results of tests performed by EDF and Framatome on mockups and on French power plants, or from thermohydraulic calculations. Many publications ([4], [5]) have reported about such developments. If the plant instrumentation is not sufficient, a thermal sensor may be added on the external surface of the piping near the monitored zone and the OTMS is able to perform the required structural analysis.

3.2. On-line fatigue monitoring methodology

A methodology was developed for immediately converting plant instrumentation data to stress versus time at monitored points. The key to this technique is the concept of Green's function and convolution product. For example, thermal stress "$\sigma(t)$" at time "t" can be calculated at a given point by convolution of a transfer function (or Green's function) with the variations in fluid temperature which is expressed by :

$$\sigma(t) = \int_{o}^{t} G(t-s)\, \frac{d\theta}{ds}(s)\, ds$$

where "G(t)" is the transfer function and "$d\theta/ds$" is the fluid temperature time derivate. Green's functions are preestablished for the geometrical configuration and the caracteristics of each zone. They essentially concern stress parameters related to fluid temperature variations. Especially they depend on the convection heat exchange coefficient. Further development allows a variable value of this coefficient depending on fluid temperature and flowrate.

The stress time-history data issued in this manner are further reduced by extracting significant maxima and minima, from which stress amplitude for damage monotoring modules are obtained using "rainflow" method.

3.3. Real time monitoring of damage

This application involves real time evaluation of damage to critical equipment following an operating transient :

- usage factor monitoring.
  Peak stresses and linearized stresses are computed as described above. Calculation of the cumulative usage factor with the exact events sequence of applied stress peaks and valleys is performed, taking into account the elastic-plastic correction factor Ke defined in the ASME [2] code (other recent formulations could be integrated). This cumulative usage factor, compared to the value of design analysis, gives an accurate indication of design conservatism and thus of margin toward design. Furthermore, while it is lower than 1 in each critical zone, the plant life could be extended.

- For zones with sharp notches.
  For such zones as socket weldings or diffuser-volute welding on primary pump, the OTMS calculates in real time the stress state arround crack-like discontinuities and assesses crack initiation indicators.

- Crack growth monitoring.
  Defects are either detected during an in-service inspection or postulated in any critical zone (see [6]) or in zones with sharp notches (subsequent to the analysis performed above). Each transient involves crack propagation which is analyzed combining rainflow method and Paris propagation law. The stability of the crack toward brittle fracture and plastic collapse is evaluated using the CEGB R6 failure assessment criterion. All this analysis is based on DIDTP method (Defect Injuriousness Diagnosis and Treatment Package : see [6]). The cracksize progression indicates real margins of equipment integrity.

3.4. Quantitative recording of design transients

The principal aim is to systematically relate each operating transient to one design transient, to count the number of occurrences of each type of design transient in the equipment service life, and to verify that these numbers do not exceed those predeterminated in design calculations. Two methods may be used to establish this correspondance.

- a "functional approach".
  An operating transient is then assumed to be equivalent to a design transient which corresponds to the same operating event. This approach is based on the observation of various actuators and the comparison of operating and design parameters evolution curves. Publication [5] explains this procedure. This approach affords accurate knowledge for experience feedback, maintenance and plant management optimization.

- a "structural damage approach".
  This correspondance between operating and design transients uses "Transient Comparison Coefficients" (TCC's). The TCC of any transient is a mechanical value which is related to the damage induced by this transient to the system. The method for applying this concept involves the following steps : the TCC of each operating transient recorded in a specific system is calculated using relevant parameters and then compared with those of the TCC's list previously established for all design transients. This fully automatic procedure serves to verify that the number of anticipated occurrences is not exceeded and constitutes a simple means of evaluating the severity of transients with respect to fatigue-induced damage and, thus, the ageing of equipment.

4. *O.T.M.S. AND ASSISTANCE TO THE OPERATOR*

The OTMS is a system designed to assist the plant operator in his task of monitoring nuclear power plant operation. It is a tool which enables him to store knowledge of the operation of the plant (recording of measured parameters), assists him in evaluating the evolution of damage during operation (transients accounting) and helps him in reaching decisions concerning equipment maintenance and removal (critical points damage monitoring).

The OTMS provides realistic answers to the following questions :

- how can operating conditions be adapted more efficiently ?

- how can the frequency of inspections be optimized and for which equipments ?

- what are the remaining operating margins ?

5. *O.T.M.S. AND PLANT LIFE EXTENSION*

OTMS provides accurate information concerning stress level, number of occurrences and damage.

The necessary conditions for plant life extension include :

- the numbers of operating transients occurrences are lower than those specified at design studies. The information of the transients accounting module could be interpreted in terms of damage and thus of margin toward design,

- the usage factor in monitored critical points is less than 1. Furthermore the margin with the design usage factor gives an accurate indication for plant lifetime extension,

- monitored (detected or postulated) defects are acceptable.

Otherwise it should be of interest to replace the most sensitive equipment.

6. ***CONCLUSION***

As a computerized expert system, OTMS provides cost-effective knowledge of plant components ageing through a large number of indicators (usage factor in critical zones, cracksize progression, transient severity in terms of structural damage, transient accounting,...).

Framatome has designed the OTMS in cooperation with EDF to meet safety requirements and to improve the safety level. This cooperation will be developed for monitoring a number of French PWR units and evaluating real damage and plant life margins [7]. Further investigations have been undertaken in order to improve the knowledge of true operating conditions and particularly thermal hydraulic phenomena.

OTMS is an important step towards the objective of assisting plant operators in taking decisions concerning inspection, maintenance, removal of equipments, and extension of the power plant life.

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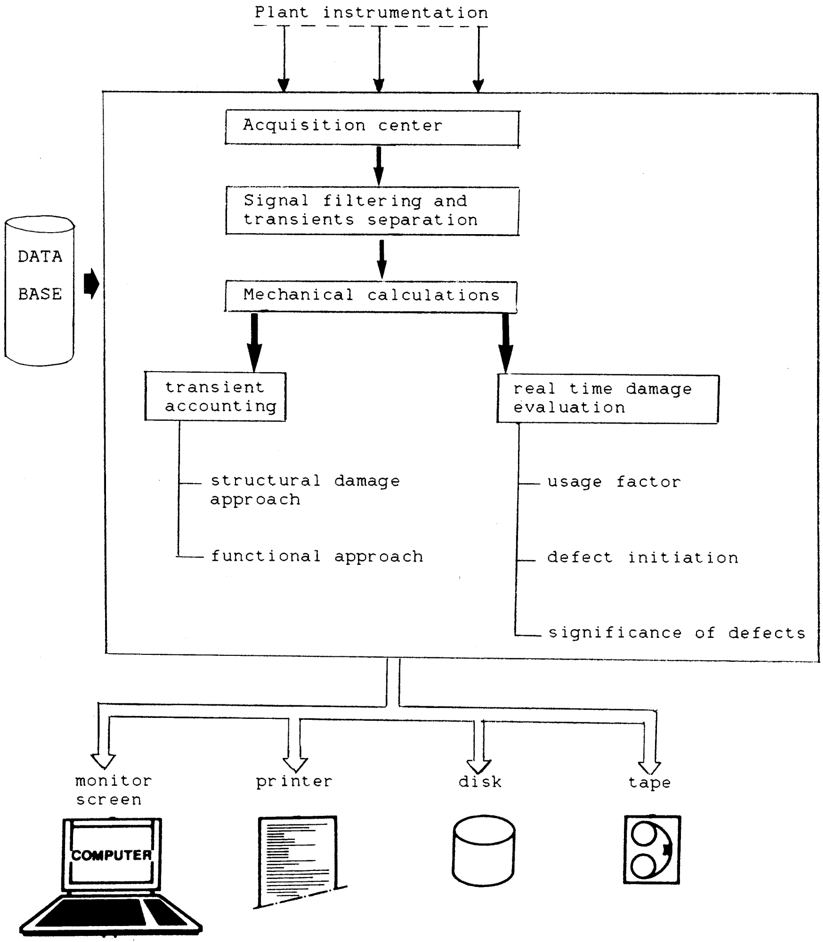

Figure 1 : typical monitoring system configuration