STEAM GENERATOR TUBE SUPPORT PLATE DEGRADATION IN FRENCH PLANTS : MAINTENANCE STRATEGY

Jean-Paul Gauchet (*) Nicolas Gillet (**) Marc Stindel (***)

ABSTRACT

This paper reports on the degradations of Steam Generator (SG) Tube Support Plates (TSPs) observed in French plants and the maintenance strategy adopted to continue operating the plant without any decrease of the required safety level.

Only drilled carbon steel TSPs of early SGs are affected. Except the particular dammage of the TSP8 of FESSENHEIM 2 caused by chemical cleaning procedures implemented in 1992, two main problems were observed almost exclusively on the upper TSP :

- Ligaments ruptured near the aseismic block located at 215°. This degradation is perfectly detectable by bobbin coil inspection. It occurs very early in the life of the SG as can be seen from the records of previous inspections and no evolution of the signals was observed. This damage can be detected for 51M model SGs on several sites.
- Wastage of the ligaments resulting in enlargement of flow holes with in some cases complete consumption of a ligament. This damage was only observed for SGs of at GRAVELINES. This damage evolved cycle after cycle.

Detailed studies were performed to analyze tubing behavior when a tube is not supported by the upper TSP because of missing ligaments. These studies evaluated the risk of vibratory instability, the behavior of both the TSP and the tubing in case of a seismic event or a LOCA and finally the behavior of the TSP in case of a Steam Line Break.

Concerning vibratory instability it was possible to define zones where stability could not be demonstrated. Damping cables and sentinel plugs were then used when necessary to eliminate the risk of Steam Generator Tube Rupture (SGTR). For accidental conditions, it could be shown that no unacceptable damage occurs and that the core cooling function of the SG is always maintained if some tubes are plugged.

From this analysis, it was possible to define the inspection programs for the different plants taking into account the specific situation of each plant regarding the damages detected. These programs include bobbin coil inspections and special Motorized Rotating Pancake Coil (MRPC) inspections when indication of ruptured ligament is obtained with the bobbin coil. It also includes televisual inspection for GRAVELINES SGs.

Prevention of evolving damage observed in GRAVELINES was also dealt with. Erosion corrosion of carbon steel of the TSP was identified as the root cause. The occurrence of erosion corrosion was analyzed as the result of secondary chemistry and thermalhydraulic conditions at the periphery of the upper TSP. In 1996 it was therefore decided to modify the secondary chemistry by using morpholine instead of ammonia and by increasing the pH. Results of inspections carried out at the end of the cycle in 1997 provided positive conclusions about the efficiency of this modification.

(*) EDF, NPP Operations/Maintenance Department (**) FRAMATOME, Steam Generator Department
(***) EDF, Central Laboratories

Steam generator tube support plate degradation in French plants : Maintenance strategy

Jean-Paul Gauchet (EDF, NPP Operations/Maintenance Department)
Nicolas Gillet (FRAMATOME, Steam Generator Department)
Marc Stindel (EDF, Central Laboratories)

INTRODUCTION

The degradation of steam generator tube support plates (TSP), a phenomenon discovered in April 1995, applies to 51A and 51M type SGs (equipped with carbon steel drilled tube support plates). The phenomenon affects 37 of the 48 SGs of this type.
In 1995, 755 tubes (including 224 at Fessenheim 2 and 274 at Gravelines 2) were plugged due to this type of damage. 281 tubes were plugged due to TSP degradation in 1996 (mainly at Gravelines 3 and 4 : 252 tubes) and only 11 tubes were plugged in 1997, showing that this phenomenon has been brought under control.

1. BACKGROUND

TSP damage was first discovered in 1995, during an outage at Fessenheim 2, since eddy-current inspection procedures previously required to check only the tube integrity and not the tube supports.

- At Fessenheim 2, the damage mainly concerned TSP8 (8th tube support plate) on two of the three SGs, and was caused by chemical cleaning procedures implemented in 1992. In fact, the damage was due to an overly high flowrate of reagent, leading to a local wastage of the plate. Eddy-current inspections with a bobbin coil (BC) on SG3, review of reports made during previous inspections, RPC10 (usual rotating probe coil) and televisual inspections have shown:

  - total wastage of the TSP8 around the 12 tubes where the phenomenon was discovered ;
  - partial wastage of TSP8 in the same zones : anti-seismic support 215° 30 (ASB 215°) for 102 tubes on one steam generator and 82 tubes on another one ;
  - presence of star pieces of tube support plate 8 ("yo-yo" like structures of material around the tubes and flow holes) on the 7th tube support plate, geometrically in line with the damage observed on TSP8 ;
  - presence of all these above observations at inspection performed in 1993, but not before chemical cleaning of 1992.

- From April to August 1995, much more limited damage was observed during eddy-current inspections at Saint-Laurent B2, Dampierre 4, Blayais 1 and Tricastin 2. This damage generally occurred very early in the life of the component and has not evolved since. It consists of partial fragmentation of ligaments between flow holes and tube holes, near ASB

215°, and/or abnormal eddy-current signals, especially from tubes close to welding pins for patch plates.

- In August 1995, during inspection at Gravelines 2, a review of the records showed that a large section of TSP8 was affected by some damage on two steam generators. Televisual inspection and correlations between televisual and eddy-current inspections indicated that this damage was evolving, with a progressive loss of ligaments due to wastage. In 1996, the same degradations were also observed on Gravelines 3 and 4 SGs.
  A review of BC inspections and analyses of previous inspection data on all of the 51A and 51M SGs have provided a list of the SGs affected and determined if damage was evolving or not.
  To evaluate the extent of this damage, anticipate other possible damage and define a maintenance strategy, a Design Review of SG Internals was undertaken by EDF and FRAMATOME. The main results for TSP degradation are reported below.

2. DAMAGE ANALYSES

With regard to nature and origin of tube support plate damage, the SGs 1 and 3 at Fessenheim 2 (chemical cleaning performed) must be distinguished from the other 51A and M steam generators.
For the latter, damage observed can be divided into three categories.

2.1. TSP ligaments ruptured in front of ASB 215° (tubes not showing changes in the BC signal)

Broken ligaments are located around the closure of the tube bundle wrapper and the bundle anti-rotation system ; it concerns only 51M type SGs. These observations can be made very early in the life of the SGs; they are perfectly identifiable from phase-shifted bobbin coil signals during the pre-service inspection, or during the initial inspections, or after two cycles, and do not change over time.
Due to their early apparition, work was undertaken to identify at which stages of fabrication, erection, or start-up, high stresses could be produced. This work included tests of representative mock-ups, specific instrumentation of steam generators during fabrication and refined mechanical analyses. It was also necessary to take into account that for more recent SG models, these ruptures of ligaments do not occur.
Finally it was possible to conclude that the ruptures on SG 51M occurred because of a combination of material properties (drilled carbon steel TSPs), mechanical design of SG internals and stresses introduced at different stages of fabrication.

2.2. Wastage of TSP ligaments (tubes with bobbin coil signals that change over time)

The televisual inspections of SGs at Gravelines 3, in 1996 confirmed the hypotheses developed during televisual inspection of the Gravelines 2 SG, in 1995: the progressive wastage of ligaments results from Flow-Assisted Corrosion (FAC) which results in enlargement of the water flow holes at TSP8.

Analysis of televisual inspections carried out in 1996 on 16 SGs and of chemical and thermalhydraulical studies has confirmed the different mechanisms behind this damage to tube support plates. It was therefore decided to change the water chemical treatment of the Gravelines units (from ammonia to morpholine), starting with Gravelines 3 and 4, and to study the impact of different chemical parameters, in particular the hydrazine concentration influence. This programme is performed using a dedicated loop in EDF Laboratory.
The switch from ammonia + hydrazine to a combined morpholine + hydrazine + ammonia treatment on units 3 and 4 allowed increasing the PH at the TSP level at operating temperature. A new eddy current probe, more specific and avoiding spurious signals (see section 2.3) has also been used ; NDT results confirmed by televisual inspections were satisfactory :

- During the 1997 outage at Gravelines 4, only a few tubes were plugged because of TSP degradation (morpholine treatment implemented in 1996, three months after start of the fuel cycle).
- No tubes plugged because of TSP degradation at Gravelines 3 during 1997 outage (morpholine treatment implemented in 1996 at the beginning of the fuel cycle).

Furthermore, a thermalhydraulical analysis and use of the BRT Cicero Code developed by EDF show that FAC appears in the hot leg, and more specifically at the 8th plate in a zone which corresponds to the damage observed at Gravelines 2, 3 and 4.
A detailed televisual inspection to locate FAC occurrence on the TSPs of the SG removed from Gravelines 2 is continuing. The primary goals are to refine our understanding about the precise location where FAC occurs and to increase the accuracy of the predictions obtained with the codes.

2.3. Tubes with no TSP damage but with abnormal BC signals

For tubes near patch plate welding pins, televisual inspections and use of a new rotating probe (STF) which discriminate between BC artifacts and actual ligament rupture were performed.

Except two or three cases, no rupture was observed.
In some few cases, the televisual inspection did show an overlap of the pin weld for the tubes with BC signals but generally no degradation was noted.
Again, these BC signals have not changed since the pre-service or initial inspections. These abnormal BC signals are caused by the specificity of the pin welds. Similar cases have been observed on foreign units.

3. SAFETY ANALYSIS

The safety analysis for the plants affected by TSP damage was carried out by EDF and FRAMATOME. To evaluate the short and long-term corrective and preventive measures needed for the steam generators involved, studies were performed to determine:

- Impact of actual or potential degradation on internals and consequences on tube vibrational behavior and fatigue resistance.

- Impact of considering an anti-seismic support ineffective and consequences on tube integrity under faulted conditions, such as LOCA or safe shutdown earthquake (SSE).

3.1 Vibrational behavior of tubes when upper TSP is damaged

The CAFCA4 code, developed jointly by EDF and FRAMATOME, was used to characterize flow patterns and associated energy in the secondary side of steam generators.

Results were used for vibrational analyses. The following cases were analyzed :
- upper tube plate without degradation (baseline) ;
- upper tube support plate with observed degradation ;
- upper tube support plate with conservative evolution of the degradation ;
- upper tube support plate with conservative evolution of the degradation and with the tubes in the degraded zone being plugged.

The vibrational analyses were carried out using the GERBOISE computer code (developed by FRAMATOME and CEA) and "GEVIBUS", developed by EDF. This last code is based on an advanced methodology for predictive analysis of the flow-induced vibration of tube bundles subject to cross-flow.
These different analyses enabled identifying the tubes potentially at risk of rupture by fatigue due to vibrations. Based on these analyses, areas where these tubes were located were defined to receive specific attention for maintenance (see section 4).

3.2 Impact of TSP degradation on tube bundle integrity for loss of coolant accident or seismic conditions

Under faulted conditions, the TSPs are subjected to loads that transit between the tube bundle and the SG shell, at the level of the anti-seismic supports. Zones near the supports therefore experience heavy stresses.
Local degradation of a TSP in one of these zones results in a localized loss of plate stiffness and in the redistribution of forces, with increased loads exerted on the other anti-seismic supports.
Specific models and methods were developed to evaluate the behaviour of TSPs and tubes. In particular, an elastoplastic model more precisely determines the effect of horizontal loadings on tube integrity.
TSP yielding occurs and deformation of flow holes causes "pinching" of SG tubes. It is therefore necessary to analyze the risk of tube rupture and the impact of reducing the primary fluid cross-section on SG operation in faulted conditions.

Risk of SG tube rupture

Specific tests were performed to characterize the behavior of tubes internally pressurized when pinched by TSP deformation. Testing involved undamaged or corroded tubes and portions of plate damaged by rupture or wastage of TSP ligaments. Tubes were subjected to increasing pinching until rupture occurred.

Analysis of the results shows that tube rupture can occur in some zones where deformation can be considered as "critical" under Safe Shutdown Earthquake (SSE) but not under LOCA conditions.

Risk of loss of SG core cooling function

The risk of loss of the SG core cooling function is related to a reduction of the primary fluid cross-section of the tube bundle. The extent of this reduction is determined on the basis of the number of pinched tubes.

For SSE, the resulting loss of heat transfer area is compared with the allowable reduction. For LOCA, differential pressure changes are such that secondary side pressure becomes higher than reactor coolant pressure and possible tube collapse must be taken into account. Specific tests were therefore performed to establish a correlation between the extent of pinching and collapse pressure. Analyses were performed taking into account observed or assumed degradation of the TSPs.

For each accident, each type of SG and each kind of degradation, the zones of tube/TSP interaction were determined and the impact on safety evaluated.

It was shown that the number of tubes likely to be pinched as a result of TSP degradation is sufficiently low to maintain SG function during SSE and LOCA. The study also enabled identification for SSE of tubes vulnerable to rupture in case of TSP degradation.

3.3 Harmfulness of loose parts

Analysis shows that all loose parts, whether actual or potential, will not cause a steam generator tube rupture (SGTR), when the frequency of NDT for 51A and M SGs is 100% BC inspection every two cycles and 100% BC of the two most peripheral rows at each cycle.

4. MAINTENANCE STRATEGY AND POLICY

The maintenance strategy concerning damage to tube support plates on 51A and M SGs is based on operating experience and results of studies performed for the Design Review. It takes into account the possible evolution of damage observed on some SGs and results in :

- equipping the tubes in the vibration risk zones (defined in section 3.1) with a damping cable to prevent instability of the tube and fatigue rupture in case of loss of support occurring during the next cycles ;
- preventively plugging the tubes vulnerable to rupture by pinching for degraded TSP experiencing an earthquake (SSE).

The major aspects of the maintenance policy are as follows:

- SGs with damage that may evolve :
During each outage, BC inspection of tubes, in zones where rupture has been identified as possible under faulted conditions in case of TSP degradation, is performed to identify tubes with signals indicating plate fragmentation. Plate/tube intersections that show indications of fragmented plate are subjected to an additional non destructive testing with STF rotating probe on order to confirm the fragmentation.

- SGs without damage that may evolve :
The usual inspections as required by the Basic Preventive Maintenance Program are adequate. No additional BC inspection is required, since the tubes with plate fragmentation are known based on reviewing the last 100% BC inspection. Only additionnal STF inspection is required in tubes where BC indicated fragmentation in order to confirm it.
Cables were installed in 1996 at Fessenheim 2 and Gravelines 3 and 4.
In 1995, as all the studies were not completed, sentinel plugs were used to immediately ascertain any tube damage which may occur. Some of them have been replaced by damping cables during the next outages.

5. CONCLUSION

After first degradations appeared on internals of SGs, EDF and FRAMATOME carried out a Design Review to understand the causes of damage, and to anticipate eventual new damages. This Review led to defining in relation with the French Safety Authority a long term policy for inspection and, when necessary for repair of the Steam Generators. Main work was concentrated on 51 model SGs but other models were also analysed by comparison with 51 SG model. Only the work related with TSPs was reported here.

The final aim of this Review, which was to define a maintenance strategy for continuing operation under good safety conditions in spite of problems encountered, was reached.

DISCUSSION

Authors: J.P. Gauchet, N. Gillet, M. Stindel, EDF and Framatome

Paper: Steam Generator Tube Support Plate Degradation in French Plants: Maintenance Strategy

Questioner: R. Crovetto, Betz-Dearborn

Question/Comment:

(1) Did you consider, as chemical maintenance, to prevent FAC by increasing the O_2 levels in the SG?
(2) Is there any correlation between chemical cleaning and the support plate deterioration?

Response:
(1) French strategy about chemical maintenance is first of all to protect tube bundle against IGA ODSCC. So the secondary conditioning has to be a reducing environment. So we do not favour oxygen addition. About FAC, the problem can be put under control with other means such as pH.
(2) No, except for the special case of Fessenheim 2 where TSP degradation is due to a problem of implementation of chemical cleaning hoses.

Questioner: K. Bagli, OH, SESD

Question/Comment:

(1) You have placed a lot of emphasis on the mechanical maintenance strategy. My feeling is that the change in chemistry from ammonia to morpholine/hydrazine has also played a key role. Your comments please?
(2) Your TSPs are suffering from FAC. Low chromium, copper, molybdenum play a vital role in FAC of carbon steel. What is the material specification of your CS TSPs? What is the chromium content?

Response:

(1) Yes, we agree that the change of chemistry played a significant role in stopping FAC.
(2) Chromium is not specified for the CS of TSP and the content of the TSP of GrA2 (after analysis) is very low (0.02%).

Questioner: M. Wright, AECL, CRL

Question/Comment:

Regarding the ruptured ligaments, I have been looking for examples of SCC of C-steel since we found SCC in a carbon steel feeder pipe at the Point Lepreau Generating Station. Would you like to comment on its possible role in this case?

Response:

The SCC phenomenon is not possible in this case because rereading BC signals during pre-service inspection identifies the broken ligaments signals.

Root cause is not perfectly known but work was undertaken to identify at which stages of fabrication, erection, transport, high stresses, could be produced. Finally, it was possible to conclude that the rupture ligament occurred because of a combination of material properties (drilled CS TSP), mechanical design of SG internals and stresses introduced at different stages of fabrication. For maintenance strategy the important thing is that this kind of degradation is not evolutive and concerns only a few tubes.

Questioner: Gorman, DEI

Question/Comment:

Have you quantified the FAC rate after the chemistry change to morpholine?

Response:

We have not been able to quantify exactly the FAC rate with morpholine, but it is clearly better than with ammonia. In fact, televisual metrology examination of Gravelines 3 and 4 after one full cycle with morpholine show no loss or thickness for ligament, confirmed by an appearance of the surface of TSP (and flow hole) repassivated. FAC kinetics in morpholine are 0 (with high pH) at GRA3 and GRA4. At Fontevraud IV (September 1998) there is a paper about FAC modelling at GRAVELINES before and after the switch from ammonia to morpholine.