SG Internal Design Review Part III: Corrective and Preventive Maintenance and in Service Surveillance of Steam Generator Bundle Wrappers

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SUMMARY
The experience feedback and its perspectives, the associated studies and the justifications established in terms of safety and availability (see sections 1 and 2 above), consequently led to the development and implementation by EDF and FRAMATOME, of a certain number of means of investigation and repair of a preventive and corrective nature. Within the scope of the application of a basic preventive maintenance programme, these resources, which are described in this document, serve:
- to improve understanding and enhance control of the phenomena and the potential deterioration,
- to guarantee the normal operation and the safety of the installations and to limit the impact of any deterioration on the installations.

0. INTRODUCTION

As stated earlier, during the 1994 refuelling shutdown of Blayais 3, the bundle wrapper on steam generators 1 and 2 sustained a downward movement following rupture of the support blocks. As soon as this problem was identified, actions were initiated to determine the cause of the observed damage (at the welds between the support blocks and the wrapper), and to assess whether this phenomenon was potentially generic or not. These studies have also shown that there is no safety risk if the wrapper were to fall (see section 2 above).

The advances in TV inspection led to the detection in 1995 of cracks on the bundle wrapper in the upper corners of the Blayais 3 SG1 and SG2 support blocks; these cracks were propagating along the span of the wrapper.

Among the damage mode studies (both observed and potential damage) adopted for the SG internals design review, the following modes applied to the bundle wrapper and its support:
- the constrained differential expansion due to certain SG cooling transients during the return to cold conditions.
- a fatigue phenomenon due to the vibration behaviour of the bundle wrapper.

Based mainly on the on-site readings taken with strip-type instrumentation installed on the Blayais 3 SG1 and SG2, these studies have provided an explanation for the fatigue cracks found on the support blocks.

The information presented in this document refers to the resources developed by EDF and FRAMATOME for corrective and preventive maintenance on the affected equipment items.
and for in-service surveillance of certain of them in order to gain a better understanding of them and the changes in their kinetics (instrumentation).

I. MEANS OF SURVEILLANCE

The general approach adopted (and incorporated in the Basic Preventive Maintenance Programme – BPMP – see section I) consists of checking regularly the position of the bundle wrapper and the physical state, of its supporting elements. This approach, applied both to the 900 MW and to the 1300 MW standardised plant series, calls for simple resources, described below, and, according to the observed results and appropriate analyses, serves to determine whether there is justification for keeping the equipment as it stands or implementing repair, the resources for which are described in the next chapter.

I.1. Elevation monitoring

Elevation monitoring consists of measuring the variations in the axial position of the bundle wrapper. This form of monitoring constitutes a basic element in the BPMP. Nevertheless, it is not sufficient, on its own, to determine whether the supporting structure is in an acceptable condition.

It takes the form of the measurement of position of the wrapper, by taking a reading of the differential elevation between the crown of the eyehole on the pressure vessel and the bottom of the bundle wrapper. The location and the block diagram are provided below.

![Location](image)

![Block diagram](image)

I.2. Television monitoring and characterisation

Several means have been developed by EDF for the periodic measurement and monitoring of the condition of the supporting elements of the bundle wrapper, both from a qualitative (detection and evaluation of disorders) and a quantitative (measurement of deformation angles, play and directional shift, characterisation of cracks) point of view.

I.2.1. TV Local Characterisation inspection (TVLC) and TV Metrology inspection (TVM).
These two means of inspection enable the visual examination (TVLC) and/or the measurement of notable angles and play on the supporting elements of the bundle wrapper.

**TVLC:**

This tooling is used to perform TV inspection of the bundle wrapper support blocks for the steam generators in 900 MW and 1300 MW plants, and consists of carrying out a qualitative observation of the assembly comprising the Support Block (SB) – Stud – Anti-Popout Block (APB) – Bundle wrapper (BW).

It allows a strictly lateral sighting of the entire supporting system and a tangential sighting of the bundle wrapper. The direction of the sighting may be oriented about a horizontal plane.

The tooling makes it possible overall and qualitatively:
- to assess the overall configuration of the supporting elements and their environment,
- to assess the condition, wholly or partially, of the lateral, upper and lower weld seams,
- to detect, by high magnitude examination, the start of cracking in the bundle wrapper, or to note linear indications and to characterise them,
- to detect the start of tearing of the weld lines,
- to take a decision regarding a marking phenomenon on the support blocks.

**TVM:**

This tooling offers practically the same possibilities for overall observations as TVLC and, in addition, the quantification of certain parameters, namely:
- the measurement of angle "i" between the inner face of the SB and the upper face of the stud,
- the measurement of play "j" between the inner face of the stud and the upper face of the APB,
- the assessment of directional shift of the BW as well as the space between the stud and the BW.

This TV inspection is performed at least once in order to establish the reference state and to classify the SG in the appropriate BPMP family (see section I).

I.2.2. Characterisation and control of cracking on bundle wrappers

Stresses due to vibration of the bundle wrapper (observed on 900 MWe 51 Bi/B SG models) could lead, for some SGs which have experienced severe transients, to initiation and propagation cracking around the support blocks.

EDF and FRAMATOME have therefore developed and implemented (particularly on the Blayais 3 unit) tooling for the characterisation and control of cracking (CCCT). This tooling also incorporates a "repair" function, the additional features of which are described in the next chapter.

The functions of the Crack Characterisation and Control Tooling (CCCT) are:
- TV inspection and associated brushing to confirm the presence of the detected crack: form and location relative to the support block and/or the anti-popout block.
- ultrasound inspection of the defective zone using the TOFD (Time Of Flight Diffraction) sweeping method to characterise the crack: precise position of the crack and its extremity relative to the support block and/or the anti-popout block, depth in the bundle wrapper.
In-service surveillance of the fault:
On completion of the appraisal, the position of the extremity of the crack may be marked so as to allow subsequent monitoring of its evolution (by TV and US inspection) and thereby provide the plant operator with a decision-making aid as regards the repair.

Repair:
The available repair solution comprises the boring of a hole emerging at the extremity of the crack.
The hole is bored by electro-erosion, a technique fully mastered and used elsewhere in numerous applications.

Multi-purpose carrier

II. MEANS OF REPAIR

In accordance with the provisions of the BPMP for the bundle wrapper, on completion of the inspections using the means described above, a certain number of means of repair, developed by EDF and FRAMATOME, may be implemented. Depending on the state of the SG, the scheduling of such repairs may be either immediate (during the outage), or postponed to a later outage, after analyses and justification of the state and the kinetics of the evolution of damage on the lower supporting elements.

II.1. Immobilisation of the support blocks
The technical and logistical resources developed within the scope of operations to immobilise the support blocks of the SG tube bundle wrapper are currently applicable to 900 MW SG, types 51 B and 51 Bi, and 1300 MW SG, type 68/19.

Principle of repair:
The operation consists of installing a device referred to as a "stirrup" on each damaged support block of a steam generator. This stirrup, in the shape of an upturned "U", encircles the assembly comprising the stud, the support block and the anti-popout block and prevents the generation of loose parts between the bundle wrapper and the pressure vessel as a result of a damaged support block breaking free.

II.1.1. Classic stirrup
The "classic" stirrup avoids any risk of loose parts arising from a support block falling in the peripheral tube lane (between the bundle wrapper and the pressure vessel).

Schematic representation of a classic stirrup
II.1.2. Keyed stirrup

The keyed stirrup is used to avoid any risk of a pulled-off SB tipping over loose parts on the tube bundle side, which would damage the tubes and cause the SB to jam between the bundle wrapper and the tubes.

In order to fit a keyed stirrup, it is first necessary to mill a slot in the support block by electro-erosion, into which a radial immobilisation key is then inserted.

![Schematic representation of a keyed stirrup](image)

II.2. Repair by the addition of supporting elements to the bundle wrapper

In order to make up for the shortcomings of the bundle wrapper's original supporting elements, whether under normal or accidental operating conditions (steam line break), technical and logistical resources have been developed and are applicable to 900 MW SG, types 51 B and 51 Bi, and 1300 MW SG, type 68/19.

**Principle of repair**

The addition of supporting elements consists of ensuring the vertical immobilisation of the skirt by means of a metal structure. Beams (cross members, suspenders, base plates, cleats, ...) are welded to the roof of the bundle wrapper and bear down on cleats attached to the SG pressure vessel.

**Particularity:**

The cleats attached to the pressure vessel were initially bolted in place and strengthened by a shearing pin. A new fastening system using a keyed cleat has been developed in order to dispense with US inspection of the nut-bolt system. This new solution only requires the slot for the cleat to be bored into the pressure vessel.

II.2.2. Active/Inactive supporting structure

The supporting structure is said to be active when the original assembly (SB/STUD/APB) is no longer sufficient to hold up the bundle wrapper. Insofar as the studs and the associated support blocks are sufficient to hold up the bundle wrapper, the so-called "inactive" supporting structure is assembled with a clearance and only becomes operative in the event that the bundle wrapper continues to descend.

Figure 1 indicates the min. and max. clearances that define the active/inactive criterion.

![Schematic representation of the supporting structure (active/inactive)](image)

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II.3. Maintenance of SG after repair

The BPMP makes provision for inspections suitable for the surveillance of the repaired SG. These inspections consist:
- for support block immobilisation, of periodic removal for expert appraisal,
- for additional supporting elements, of checking the condition of the supporting structure and, in particular, of inspecting the welds linking it to the bundle wrapper as well as possible changes in the various assembly clearances.

III. MEANS OF INVESTIGATION

Initially, the necessities of in-service elevation monitoring of the bundle wrappers (particularly those of Blayais 3) and, subsequently, the experience feedback (marking and cracking of the support blocks, traces of wear detected on certain in-service surveillance devices) and the theoretical studies of bundle wrapper behaviour highlighted the existence and the occurrence of vibratory stresses at the bottom of the bundle wrapper on a certain number of units.

In view of this, EDF and FRAMATOME designed and developed instrumentation in order to measure and characterise these stresses.

Essentially, the aim of this instrumentation was to improve the understanding of the phenomena involved and to demonstrate and enhance the pertinence of the BPMP. The actions undertaken continue today with the same aim but, more specifically, to confirm the effectiveness of the options selected (see section I: D4-A1-FR).

III.1. Elevation monitoring and adaptation

III.1.1. Gauge instrumentation

![Schematic diagram of gauge instrumentation](image)

**Operating principle:**

This is a tool for monitoring the vertical position of the bundle wrapper, which is installed through the SG eyecle.

Any displacement of the skirt results in the deformation of a pre-stressed strip fitted with a gauge type extensometer. The variation in the signal from the gauges is processed by an electronic data processing centre, located in the computer room near the control room, which indicates the position of the bottom of the skirt.

This solution has proven to be reliable, as instrumentation of this type has been in
service, since 1994.

It provides measurements accurate to ± 0.5 mm.

**Application:**

This device is currently installed on Blaysis 3 SG1.

On account of the application of BPMP BW and the associated justifications, no other use of this type is planned.

Nevertheless, an adaptation of this instrumentation has been carried out in order to detect traces of wear on the contact between bundle wrapper/pointer – strip (with an appropriate pointer) and thereby assess the amplitude of the vibrations (radial) generated within the SG (removal of the elevation monitoring function/gauges/electrical signal).

This adaptation is to be applied to SG 47/22 and 68/19 (Tricastin 2 and Paluel 3) in 1999.

III.1.2. Mechanical instrumentation

- Schematic representation of mechanical instrumentation

**Operating principle:**

This is also a tool for monitoring the vertical position of the bundle wrapper.

It is a "crank" type system fitted to a special handhole cover, which serves as its mounting plate. The crankshaft passes through the pressure vessel and is mechanically connected to the skirt. It transmits the vertical displacements of the latter (instrumentation channel).

The rotation of the crankshaft is recorded outside the SG. Leaktightness is ensured by a stuffing box at the point the shaft passes through the handhole cover. The measurement converts a vertical translation of the SG skirt into a rotation of the transmission shaft, thereby providing a direct angular reading.

This method minimises the sources of error: minimal play, insensitivity to temperature variations (the main dilation of the mechanism does not occur along the axis of measurement), insensitivity to the horizontal position of the skirt.

The mechanical device for the transmission of movement is followed by an electromagnetic movement sensor associated with electronic signal processing equipment. The signals are transmitted to a chart-paper recorder and saved on diskettes.

The accuracy of the mechanical and electrical assembly is ± 0.5 mm.

The inspection function, installed in parallel to the measurement function, retransmits the signals to the control room. The signals are then processed by the signalling system of the power unit.

The thresholds are set in the following manner: threshold S1 operator alert: + 1 mm / origin, threshold S2 operator alarm: + 2 mm / origin.
Scope:
This device is currently fitted on Blayais 2 SG1.

As for the previous device, no other uses of this type (elevation monitoring) are planned on account of the application of BPMP and the associated justifications.

Nevertheless, this instrumentation has been adapted in order to detect traces of wear on the contact between the bundle wrapper/instrumentation strip (by means of an appropriate link) with the same aim as that stated earlier.

This adaptation of the application is currently in service on Blayais 3 SG2, Dampierre 1 SG3 and Blayais 4 SG3.

III.2. Dynamic instrumentation
Operating principle:
Apart from monitoring the displacement of bundle wrappers, the information provided by gauge type instrumentation highlighted a vibration phenomenon without, however, allowing the characterisation of its amplitude or its direction.

It therefore became necessary to replace the gauge type instrumentation with instrumentation mounted on covers, the design of which, while maintaining the "bundle wrapper displacement monitoring" function (abandoned in 1999), allows the vibration behaviour of the bundle wrapper to be determined. (This type of instrumentation made it possible to quantify not only the amplitude but also the frequency of the vibrations and to establish that the shedding of vortices downstream of the blocks in the bottom of the water return is very probably the source of the vibratory motion at the bottom of the BW).

The device is identical to the previous case except for the addition of variable angle pointers (5° and 30°) ensuring contact with the skirt. These pointers allow the radial and axial components of the movement to be distinguished.

The measurement is accurate to ± 0.5 mm.

Scope:
This device has been installed on the 4 eyeholes on Blayais 3 SG2 (SG Bi) since 1998 and is to be installed during 1999 on Blayais 4 SG3 (SG model B).

IV. CONCLUSION

EDF has developed and implemented an extensive range of surveillance and repair equipment in order to be in a position to control, at all levels, in terms of both prevention and correction, within the scope of a BPMP, the observed and potential deterioration that may affect the lower supporting elements of SG bundle wrappers on the 900 and 1300 standardised plant series.

In order to improve the understanding of the phenomena involved and characterise them more accurately, additional means of investigation ("on-board", static and dynamic instrumentation) have been developed and installed on a number of units that are representative of the most pertinent SG models and of the nuclear park as a whole.

Overall, the actions undertaken allow EDF:
- to guarantee the safety and the availability of the installations,
- to control the phenomena involved through a better understanding of their fundamental causes and their consequences, and by the implementation of suitable preventive means,
- to eliminate the risk of maintenance at a prohibitive cost (the cost of a single steam generator replacement is twice that of all the design work and maintenance tooling development undertaken on the 900 and 1300 MW standardised plant series), and therefore, to define a low cost maintenance strategy.