Steam Generator Tube Inspection II

Steam Generator Secondary Side Deposit – NDE Method for Support Plate Clogging
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ABSTRACT

Steam generator tube eddy current bobbin inspections are periodically performed for utilities to detect tube degradation associated with deposits on the secondary side. Using the low frequency absolute data, analysts can measure the thickness of the deposition on the outer diameter tube surface. Furthermore, the bulk amount of deposit material may be estimated with the help of AREVA’s Deposit Mapping Software to supplement the chemical cleaning process. After chemical cleaning, the ET standard method can be used to verify the cleaning effectiveness. In some cases, the cleaning may be ineffective at the Tube Support Plate leaving significant deposit material in the bottom areas of the TSP foils at a significant stand-off distance from the tube. Although these deposits are detected by the standard bobbin coil, the accuracy of characterization is limited.

A flux-leakage approach has been developed by AREVA’s Non destructive Examination Technical Center, NETEC, to detect and measure this remaining deposit in the support plates. The Flux Leakage Inspection Probe (FLIP) can be coupled with a conventional bobbin probe so the special measurements may be made during the same tube insertion as is required for a standard code inspection. This paper presents the development, performance evaluation, and proposed application of the FLIP to detect and measure these deposits and particularly the clogging at the bottom edge of Tube Support Plates (TSP).

INTRODUCTION

Accumulation of corrosion products coming from the secondary circuit has some consequences concerning the efficiency of the steam generators. In extreme cases, deposit build-up can result in altered steam flow, flow induced vibration, denting and/or tube cracking that can compromise the safety of the nuclear power plant. These corrosion deposits form a more or less uniform layer on the outer wall of the tubes but the nature of the deposit build-up is more difficult to predict at the support plate where there can be little additional deposits or significant additional deposits particularly at the bottom of tube support plates. Variations of oxide build-up and associated clogging are shown below (see fig. 1).

- Clogging results from significant deposit material in the TSP foils. It generates a reduction and re-distribution of water and steam circulation inside the SG and can cause flow-induced vibration instability risks. Clogging also compromises the thermal exchange efficiency between the primary and secondary circuits.
- The deposit on the outer wall tubes is normally uniform and of various thicknesses however it may be somewhat splotchy depending on the nature of the secondary side chemistry, the heat-up and cool-down practice, and other variables. Oxide deposits decrease the thermal exchange between the primary and secondary circuits.
STATE OF THE ART

The detection and measurement of the deposit thickness is routinely made with a conventional ET bobbin probe, using a low frequency excitation in the absolute mode. Furthermore, the bulk amount of deposit material may be estimated using AREVA’s Deposit Mapping Software coupled with special calibration standards to match the known SG deposit characteristics, or using reference calibrations from previous inspection campaigns. This information is very helpful to supplement the chemical cleaning process. After chemical cleaning, the ET standard method can be used to verify the cleaning effectiveness.

The Deposit Mapping software allows a 3-D view of the tube deposits in the SG volume and this has been used for several years to characterize the bulk oxide build-up within the SG (see fig. 2). The software has been extended to characterize clogging within the TSPs. In many respects, this is a more critical and important issue for overall SG performance and can influence the plan for secondary side activities as chemical cleaning, lancing, upper bundle flush, … (see fig. 3).
In some cases, the cleaning may be ineffective at the Tube Support Plate leaving significant deposit material in the bottom areas of the TSP foils at a significant stand-off distance from the tube. Although these deposits are detected by the standard bobbin coil, the accuracy of characterization is limited. The flux leakage method is sensitive to permeability material and the detection sensitivity extends further out from the tube so this was a natural approach to the challenge of detecting and characterizing the oxide build-up composed predominately of magnetite material.

**FLUX LEAKAGE MODELLING**

For modelling, an axisymmetric representation of the tube, the TSP, a uniform deposit and a clogging deposit was made. As transmitter, a magnet moves axially along the tube wall in this model (see fig. 4).
These results show it should be possible to detect oxide build-up with the flux leakage method. These results were used to develop a flux leakage inspection probe (FLIP). The probe was built (see fig. 5) and its performance was compared to conventional bobbin ET probes.

REALISTIC DEPOSIT MANUFACTURING

From analysis made on real deposit samples, we know their approximate composition. Oxide deposits are mainly composed of relatively high permeability magnetite (Fe₃O₄) with trace amounts of other neutral permeability oxides and sometimes with copper if the plant has copper condenser tubes. The deposit simulations were made by mixing iron oxide powder (96% by weight – mix of Fe₃O₄ and Fe₂O₃) with a glue fixative (4% by weight) yielding a final product of 90% magnetite by weight (see fig. 6a & 6b). The ring was machined and cut to fit into the TSP foils and to represent different
degrees of clogging. These different degrees of clogging were also able to vary with deposits substantially building from the TSP foil surface away from the tube, or from the tube surface. These moulded pieces were placed at several locations along the TSP but the primary test data was taken with the moulds at the lower edge of the support plate representing the most commonly observed location for deposit build-up to occur from visual secondary side inspections and from other eddy current data.

Figure 6a - Top – simulated oxide moulds, Middle – moulds placed inside TSP foils, Bottom – Inconel tube with oxide build-up initiating on the tube.

Figure 6b - This curve shows good agreement between eddy current tests (blue) and modelling (green) if we consider a value of 3.3 for the relative magnetic permeability of a deposit with 90% by weight of magnetite (deposit volumetric weight of 3.5 g/cm³).

**TESTS AND RESULTS**

The different mock-ups were placed on an Inconel tube, and a pusher-puller was used to move probes (see fig. 7). ET and FLIP data were processed (see fig. 8 & 10), after a calibration, each TSP edge signal is automatically measured. After normalizing the results from the clogging response at the bottom TSP edge are assessed. Note that the axial bobbin response shows a lower accuracy for clogging from TSP for a rate less than 60%.
Figure 7 - Calibration and test tube arranged to pull either FLIP or ET bobbin probes at a controlled speed with an automated pusher-puller

**ET bobbin probe results**

**Calibration**

**Measurement**

**Detail**

Figure 8 - Calibration & measurement with the Deposit Mapping software and ET bobbin axial probe response to TSP oxide build-up in support plates
FLIP probe results

The differential flux leakage signal amplitude is the best way for the clogging rate detection and measurement as shown in figure 9.

The flux leakage method is sensitive to the speed (e = - dØ/dt), so the higher the probe speed, the higher the sensitivity. At a pull-speed of 1 m/s, the FLIP response can be up to 40 times higher than the axial ET bobbin response when used in a standard way (see fig. 10), note this ratio can be reduced in boosting the input voltage, but in all cases the FLIP sensitivity is largely higher than ET sensitivity.

Figure 9 - FLIP absolute and differential mode responses. Note the largest results come from the differential response.

Figure 10 - Axial ET Bobbin and FLIP response vs. TSP % clogging
Uniform deposit on the outer wall tubes

As he Flux leakage method is only sensitive to the magnetic flux variation, it cannot be efficient for the detection and the measurement of a uniform deposit on the outer tube wall. Similarly, the FLIP is insensitive to tube flaws or copper deposits that can complicate the analysis of a conventional ET probe. As shown in figure 11, the FLIP is only sensitive to the beginnings and ends of the different thicknesses of deposit material. So for complete detection and measurement of uniform deposits and localized clogging at the bottom of the TSPs, a probe combining ET and FLIP sensors is required. Such a probe is completely feasible as the two measurements do not interact (see fig. 12). A combined probe also offers the capability of performing both standard tube degradation examinations and deposit measurements in the same insertion and these two measurements can be supported by conventional ET instruments.

Mock-up with different thicknesses of deposit

Figure 11 - FLIP probe demonstrates the same response with and without a uniform oxide layer.

Figure 12 - The combined FLIP and Bobbin probe allows both oxide measurements and conventional tube degradation measurements during the same insertion.
CONCLUSION

To detect and measure clogging at the TSP edges, the flux leakage method has higher sensitivity than conventional ET. The FLIP probe however does not offer a complete solution as it cannot measure uniform deposit on the outer wall tubes. A combined ET and FLIP probe offers advantages of both technologies for oxide measurement. In addition, the combined probe can perform both types of measurements during the same probe insertion thereby having little or no impact on the overall inspection time.

AREVA’s deposit mapping and TSP clogging mapping software allows the complete generator to be characterized and understood. This understanding of the complete deposit map allows appropriate decisions to be made for lancing, upper bundle flush, chemical cleaning, chemical cleaning performance assessments, and secondary side chemistry management.