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# Modelling the Influence of the Tube Support Plate on the Eddy Current Testing of the Steam Generator: Numerical Tools

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## Abstract

Eddy current testing (ECT) of Steam Generator (SG) tubes is part of the maintenance program of Nuclear Power Plants. Tube Support Plates (TSP) are usually only considered as extraneous signals for tube inspection. However, for long-term operation of SGs, there is a safety concern related to the build-up of deposits in the TSPs flow holes. The clogging-up of the TSPs flow holes affect the safe thermal-hydraulic operation of SGs. The deposits come from the feedwater train and are mostly iron oxides (magnetite) with a weak electrical conductivity and magnetic permeability.

The ability of ECT probes to detect and characterize TSPs deposits is therefore of great interest. The most common and industrial ECT technique, the bobbin coil, averages the surrounding electromagnetic field over 360°, whereas the geometry of tri-foiled and quadri-foiled TSPs, and thus of clogging, is rather complex and non-axisymmetric, hence motivating the evaluation of the performance of conventional ECT rotating probes used for SGs tubes inspection. Although simulation is a powerful tool to support such a study, it requires dedicated models to be made available to NDT experts, and CEA develops ECT physical models in CIVA for this purpose. In addition to standard fast CIVA modules based on 3D semi-analytical or 2D numerical calculations restricted to canonical or axisymmetric parts, respectively, CEA develops a module dedicated to the simulation of SG tube inspection based on a 3D numerical simulation. This module allows tube deformation such as ovalization, bending or tube expansion. It also allows the addition of external objects such as anti-vibration bars, different geometries of tube support plates and now their clogging by deposits. This model is used to study various influent parameters and to perform benchmarks in the framework of a scientific collaboration between the CEA and the IRSN, related for example to the inspection of the U-bend tubes or of a friction wear under the anti-vibration bars. Here, the specificity of the TSPs and their clogging justifies further investigations between CEA and IRSN to qualify the simulation model before evaluating the influence of material and geometry properties of the deposit as well as the performance of the inspection techniques. We present the main characteristics of the simulation module in CIVA.

**Keywords:** Eddy current testing, modelling, steam generator tubes, nuclear, clogging, tube support plate

## 1. Introduction

Steam generators (SGs) play a crucial role in French PWR (Pressurised Water Reactor) nuclear power plants. These plants typically have three or four SGs housed within the reactor building, consisting of several thousand tubes shaped like an inverted 'U' and measuring around twenty meters in length. The combined surface area of these steam generator tubes is equivalent to the size of a soccer field and carries out the exchange of heat between the primary circuit (inside the tubes) and the secondary circuit (outside the tubes). Due to their key role in ensuring nuclear safety, the SG tubes undergo periodic non-destructive examinations to detect any indications or defects.

Eddy current testing (ECT) techniques are employed for the in-service inspection of SG tubes. New indications produced by active degradation mechanisms can be detected and the evolution of previously identified flaws can be monitored. If the indications identified during an inspection are characterized as flaws having critical dimensions with respect to structural integrity analysis, the affected tube is plugged to maintain the integrity of the barrier between the primary and secondary circuits. If the tubes plugging ratio is too high for a safe operation, steam generators can be replaced.



The ongoing research conducted by CEA and IRSN aims to enhance the detection and characterization of defects through ECT. In this context, simulation tools are being utilized to assess the effectiveness of existing and upcoming ECNDT techniques.

Tube support plates (TSP) are designed to hold the tubes along their height and to maintain a sufficient distance between the tubes in order to avoid tube-to-tube fretting. TSP provide also support for different mechanical loading during normal and accidental conditions such as seismic loading. TSPs are broached to allow fluids to flow outside the tubes. The foliage (or flow hole) may be subject to a build-up of corrosion products or residues of elements present in the feedwater train. This clogging phenomenon reduces the flow section of water inside the SGs with a detrimental effect on the safe operation of this equipment [1]-[5]. A chemical cleaning of SGs might be required to restore sufficient safety margins for operation.

## 2. Modelling tools

A specific module within the CIVA software has been developed to simulate the ECT inspection of SG tubes. This module relies on a 3D solver based on the boundary element method, as detailed in [6] and [7]. Designed to accommodate non-standard geometries, the SG tube inspection module is capable of handling various external objects such as the AVB and support plates, as depicted in Figure 1.

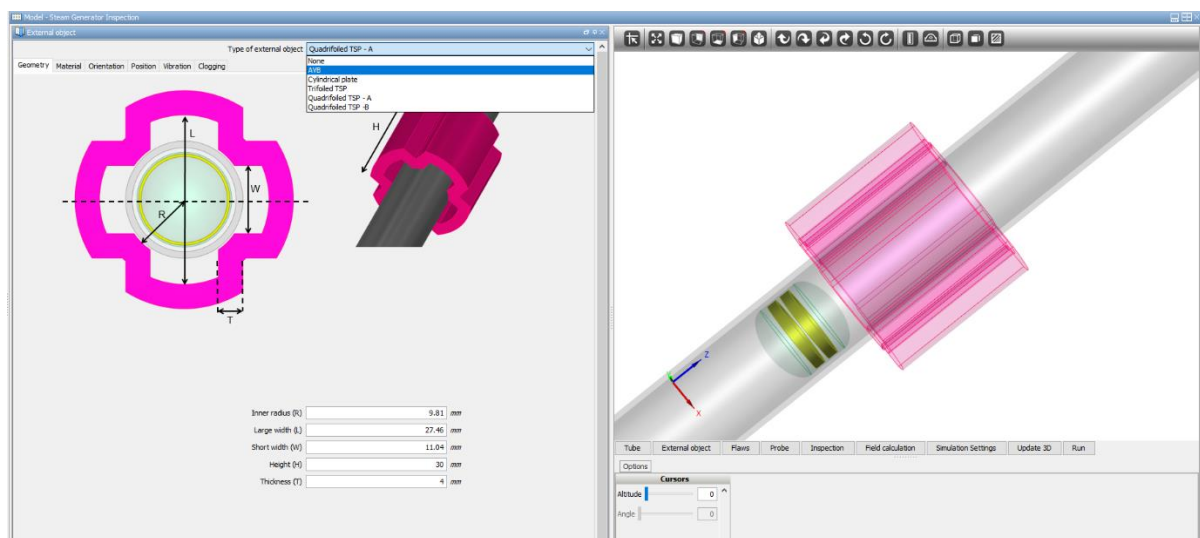


Figure 1: Steam Generator Tube Inspection module in CIVA software.

The SG tubes inspection module is specifically designed for the inspection of steam generator tubes and includes a list of industrial probes (CIVA2023 restricted to the axial probe). These probes have predefined and simplified parameters, encompassing the various components of the probe and optimized trajectory control through the definition of a probe body. Additionally, small variations between elements have been incorporated to account for manufacturing irregularities that may occur.

In the module, four types of tube support plates can be defined: two types of quadrifoiled plates, one type of trifoiled plates, and cylindrical plates, as shown in Figure 2. The module takes input data for the different dimensions and material parameters (electrical conductivity and magnetic permeability). For trifoiled plates and type B quadrifoiled plates, it is possible to incorporate

clogging with various geometries and defined value of magnetic permeability and electrical conductivity.

This module has undergone experimental validation in [8], using experimental configurations that include an axial probe, a tube with straight wear with flat bottom, and anti-vibration bars. The calculation kernels remain the same for all external objects, whether they are anti-vibration bars or tube support plates.



Figure 2. Defining dimensional parameters for tube support plates in the steam generator tube inspection module.

## 2. Simulation results

In this section, we present the simulation results obtained using the tools developed in CIVA. All results are presented without calibration for a frequency of 280 kHz. The probe is composed of two identical bobbin coils spaced 1 mm apart. The coils have an internal radius of 14 mm,

an external radius of 14.8 mm, a height of 2 mm, and consist of 40 turns. The specimen is a 3/4" outer diameter tube with a thickness of 1.09 mm and an electrical conductivity of 0.87 MS/m. The tube support plate is the type A of quadrifoiled plate with the dimensions mentioned in Figure 2 and an electrical conductivity of permeability of 1.75 MS/m and a relative magnetic permeability of 50.

The developed modeling tools allow for conducting parametric studies to assess the influence of various parameters. One such application is the investigation of the impact of tube support plate clogging on the eddy current (EC) signal. In Figure 3, the initial simulated configuration is presented, aiming to observe the effect of the axial position of the clogging on the EC signal. The clogging fills the holes of the plate with a height of 5 mm and a relative magnetic permeability of 2, placed at different axial positions. Figure 4 displays the EC signal corresponding to the different axial positions of the clogging. As anticipated, the signal associated with the plate alone is anti-symmetrical, while the signal related to the presence of the clogging demonstrates similar amplitudes across the three positions.

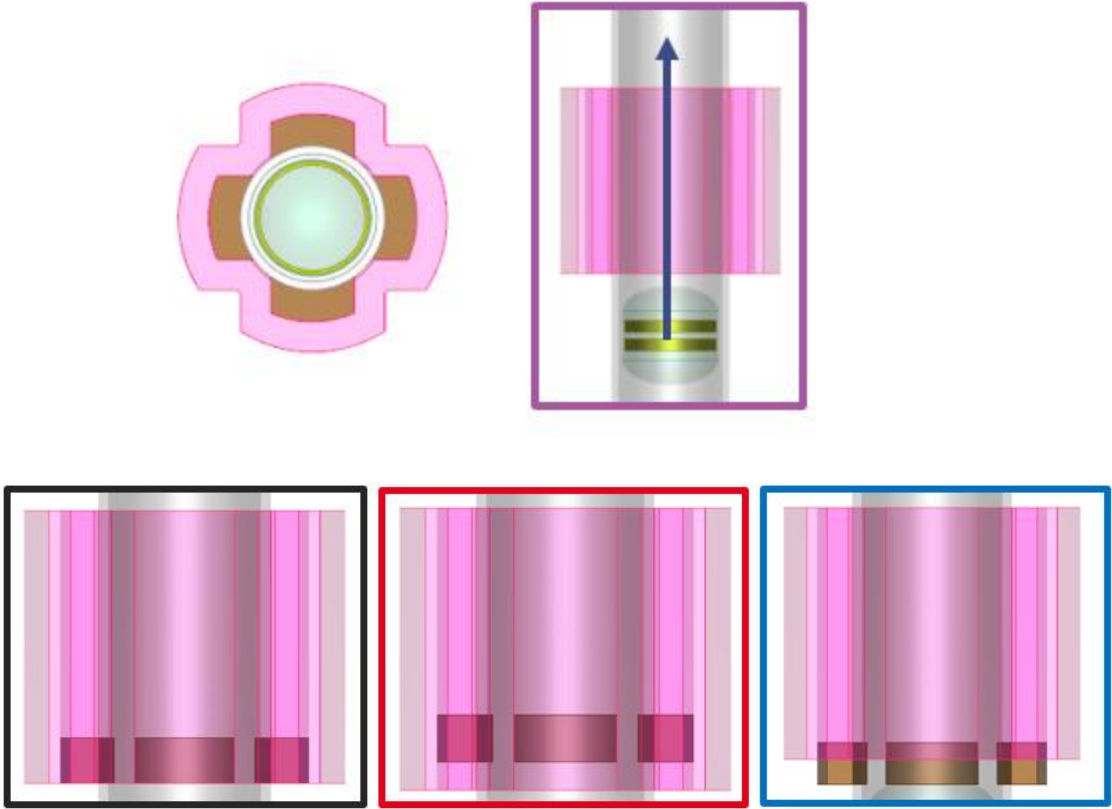


Figure 3. Horizontal section of the configuration, top left, axial displacement of the probe, top right. The different axial positions of the clogging are represented at the bottom.

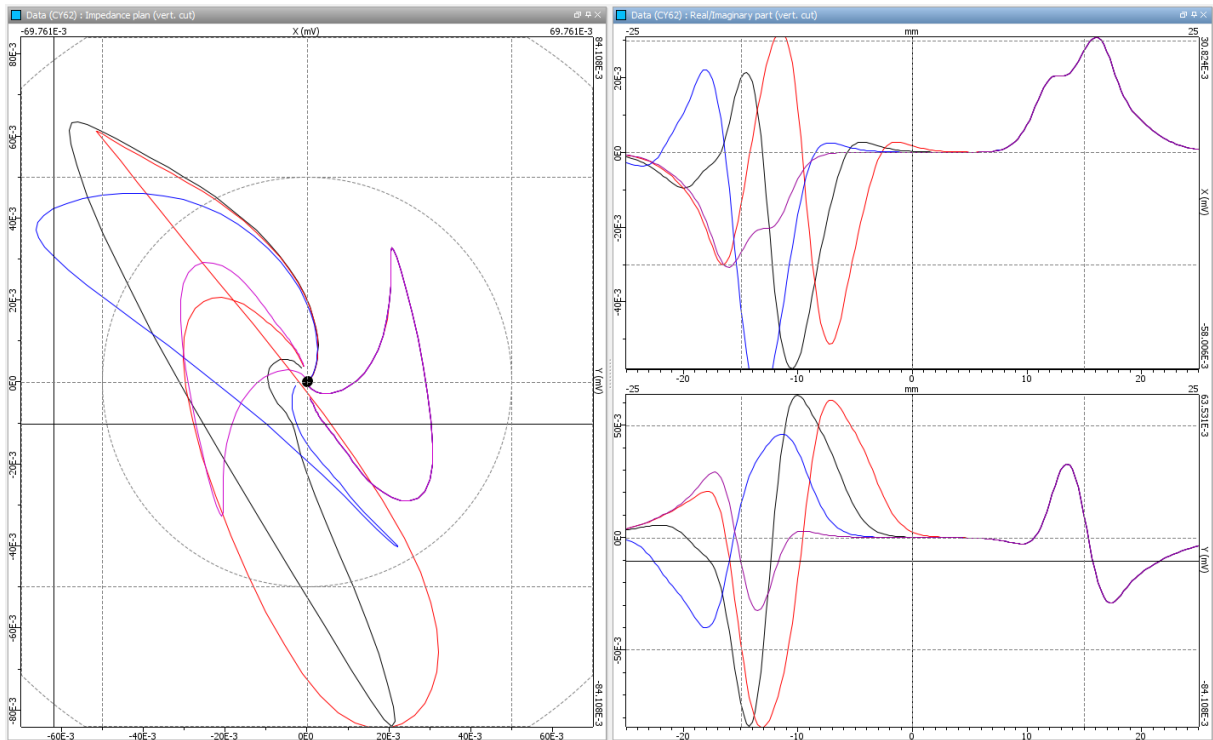


Figure 4. EC signal for the different axial positions of the clogging.

Figure 5 shows the configuration used to observe the effect of the magnetic permeability value of the clogging for a full clogging with a height of 5 mm. Figure 6 shows the EC signal for a relative magnetic permeability value of 2 (red) and 6 (black), observing that the amplitude of the EC signal increases with permeability.

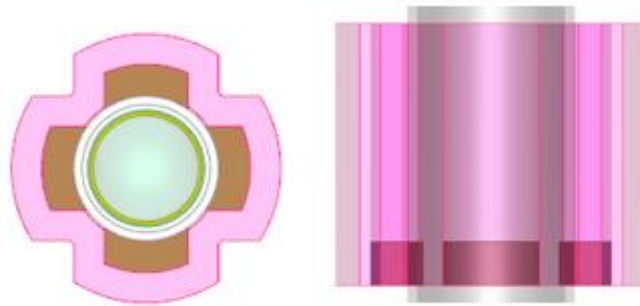


Figure 5. Horizontal and axial sections of the configuration used to assess the effect of magnetic permeability.

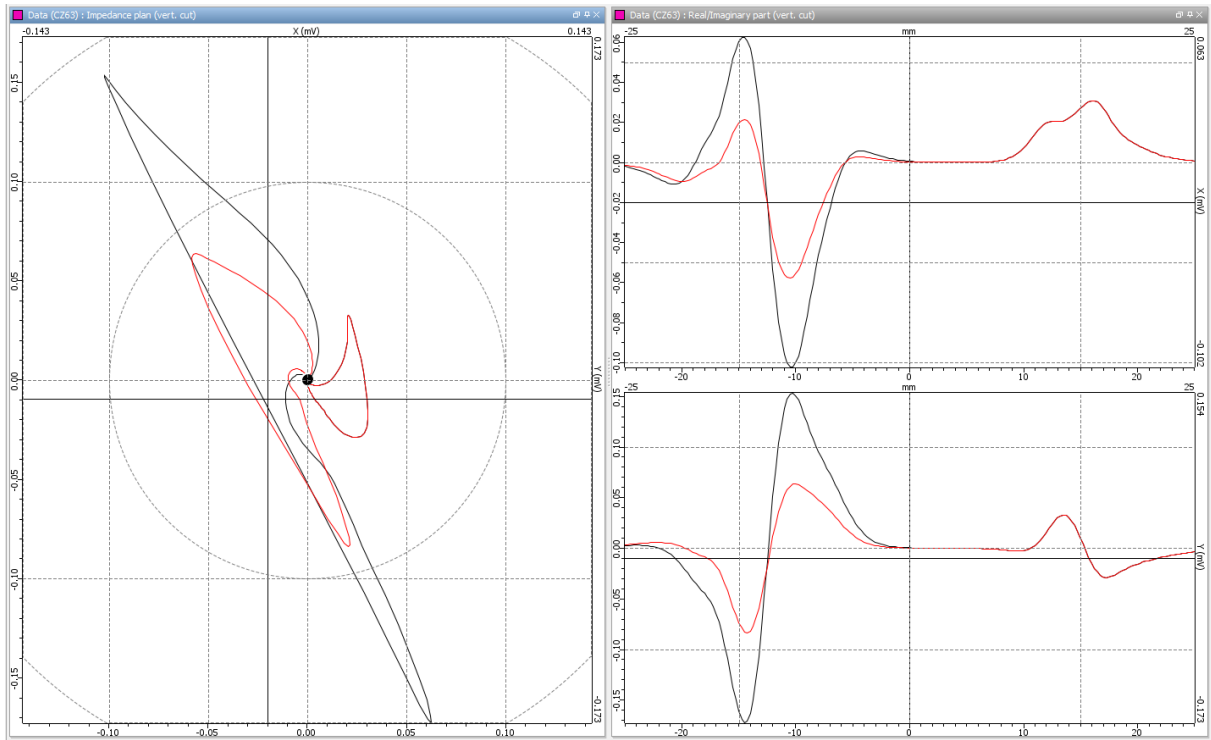


Figure 6. EC signal for different magnetic permeability values,  $\mu_r = 2$  in red and  $\mu_r = 6$  in black.

Figure 7 shows the configuration simulated to observe the effect of the clogging shape on the EC signal. The clogging is placed at the edge of the plate with a height of 5 mm and a relative magnetic permeability of 2. A hole in the clogging is placed at different positions. Figure 8 shows the EC signal for the different positions of the hole in the clogging. It can be seen that the signal obtained for the hole placed in the center and against the edge of the plate is very similar, which is due to the fact that it is too far from the probe to be taken into account.

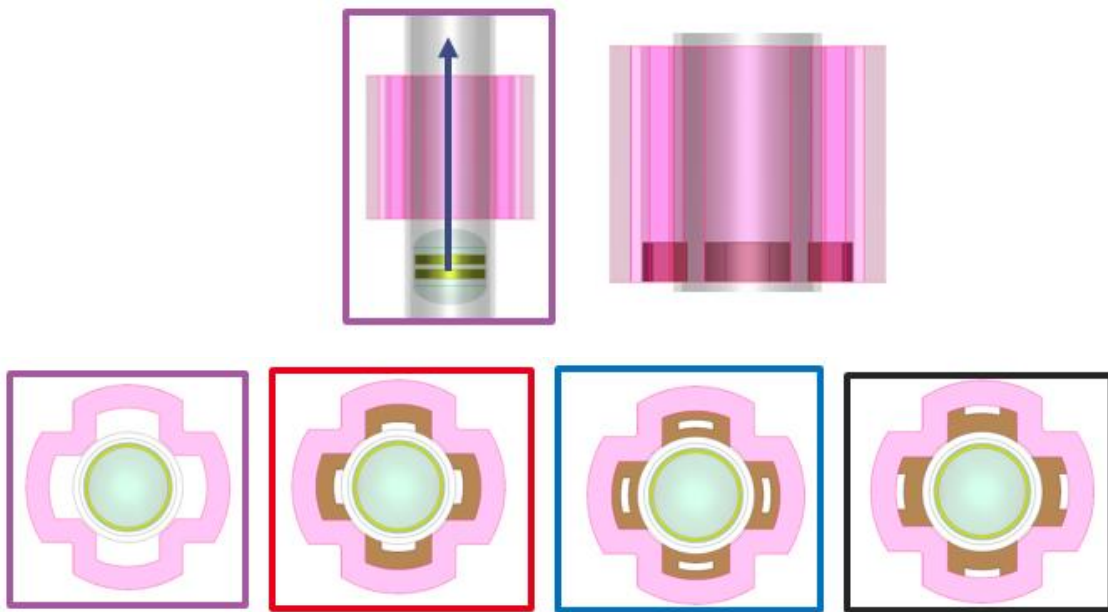


Figure 7. Axial displacement of the probe, top left, axial position of the clogging, top right. Different clogging geometries are shown below.

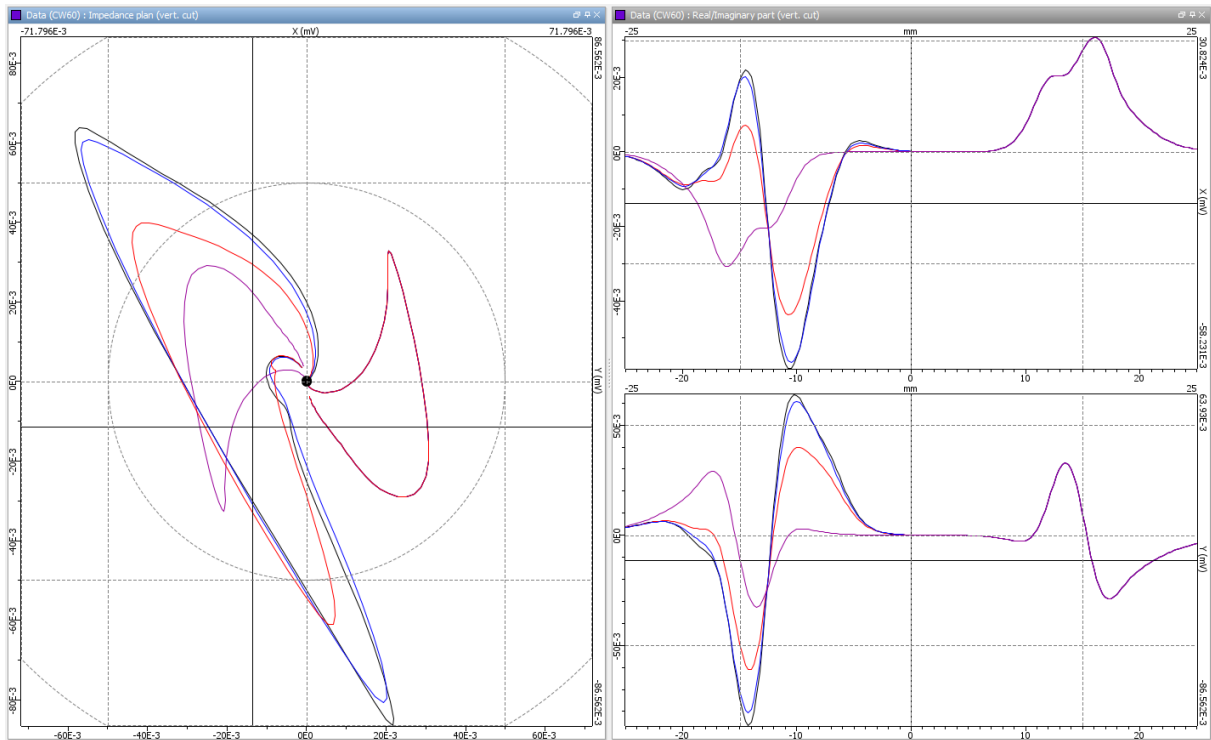


Figure 8. EC signal for different clogging shapes.

Finally, it may be important to estimate the effect of the presence of a plate with and without clogging on the EC signal of a defect, in order to assess the detectability of defects in this zone. The configuration presented in Figure 9 shows in black an internal groove 10% deep and 1 mm opening, in red the presence of a quadrifoiled plate and in blue a full clogging placed at the edge of the plate. Figure 10 presents the EC signal obtained for these three configurations, showing that the fault signal is minimized in the presence of the plate and even more so in the presence of the clogging. It is therefore important to take into account elements external to the tube when assessing fault detectability.

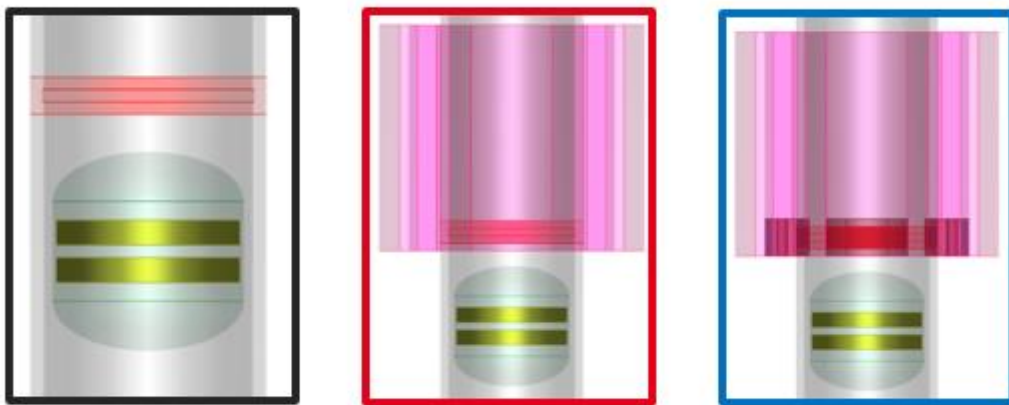


Figure 9. Internal groove, on left, internal groove and tube support plate, on center, internal groove with tube support plate and clogging, on right.



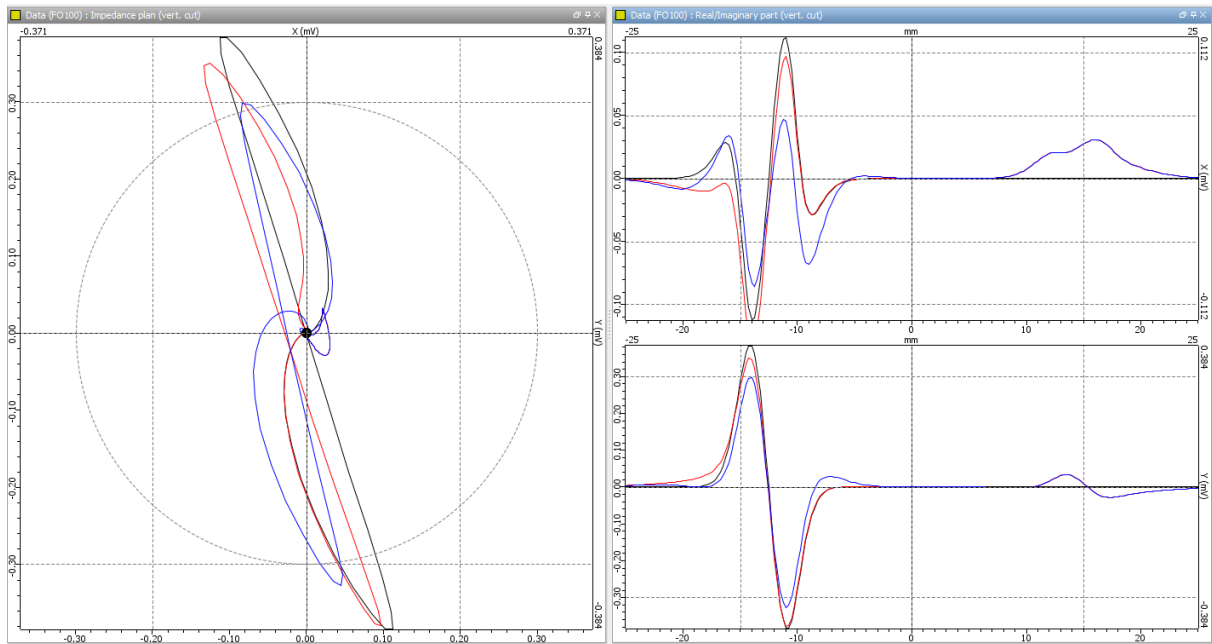


Figure 10. EC signal for on internal groove with and without tube support plate and clogging.

## 4. Conclusion

The development of modelling tools for eddy current testing of steam generator tubes in the presence of tube support plate with clogging has been presented in this document. It is possible to perform parametric studies in order to evaluate the performances of probes in various situations: with or without magnetite deposit at TSPs, with or without flaws and to mix these situations in order to evaluate the ability to detect flaws or magnetite or a combination of both. These tools are available in the commercial software CIVA and have been experimentally validated.

The modelling tools provided by CEA enable IRSN to conduct parametric studies for evaluating the detection and characterization performance of defects in steam generator tubes.

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