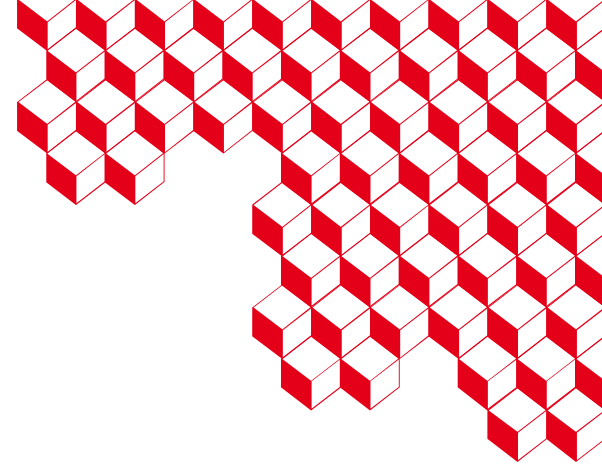




IRSN
INSTITUT DE RADIOPROTECTION
ET DE SÛRETÉ NUCLÉAIRE



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

Audrey Vigneron¹, Edouard Demaldent¹, Thierry Sollier², Jean-Marc Decitre²

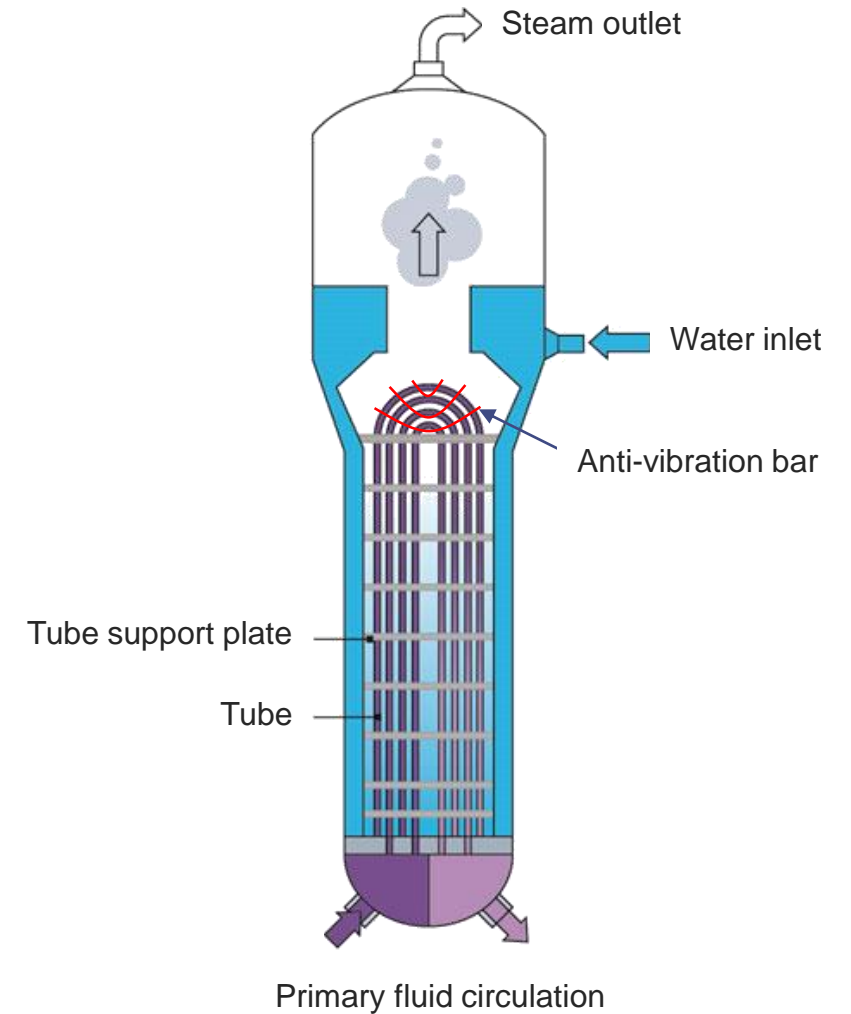
¹ Université Paris-Saclay, CEA LIST

² IRSN

NDE in Nuclear 2023, Sheffield

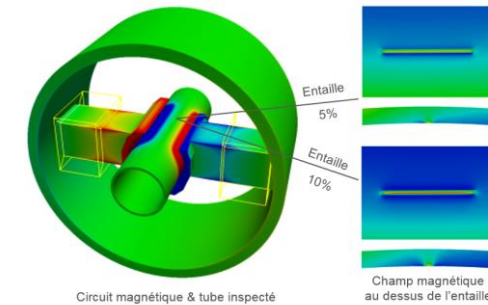
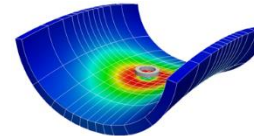
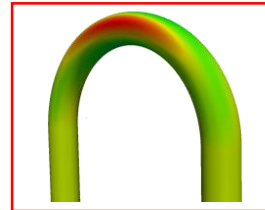
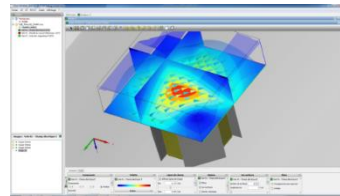
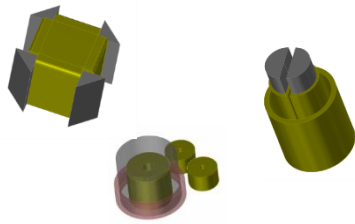
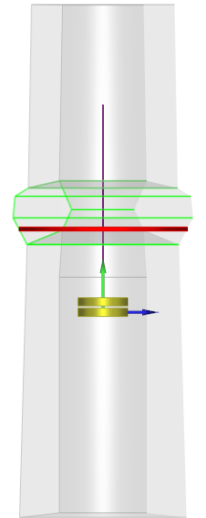
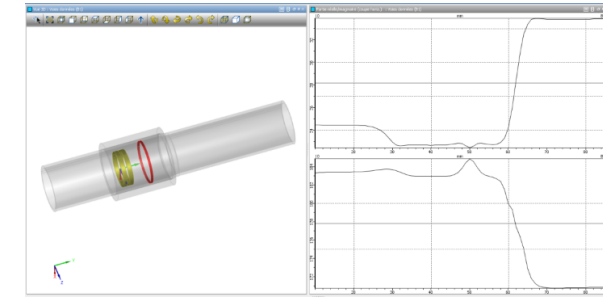
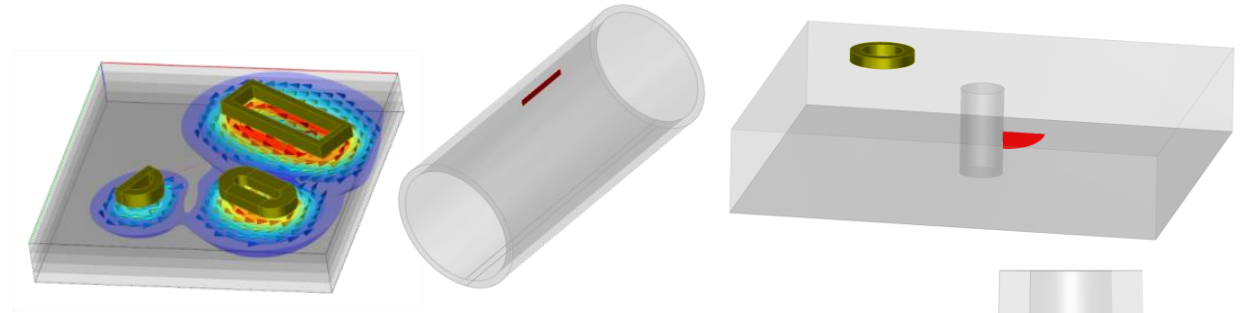
Context and motivation

- ❑ Tube support plates (TSP) are positioned at regular intervals to secured the tubes in place
- ❑ Anti Vibration Bars (AVBs) limit vibratory phenomena in the top of tubular bundle (U-Bend)
- ❑ Steam generator (SG) tubes are regularly inspected as part of eddy current non destructive inspection
 - To assess the tube integrity and prevent tube rupture
- ❑ The aim of the study between CEA LIST and IRSN is to validate simulation tools for the eddy current inspection of SG tubes, enabling the implementation of parametric studies




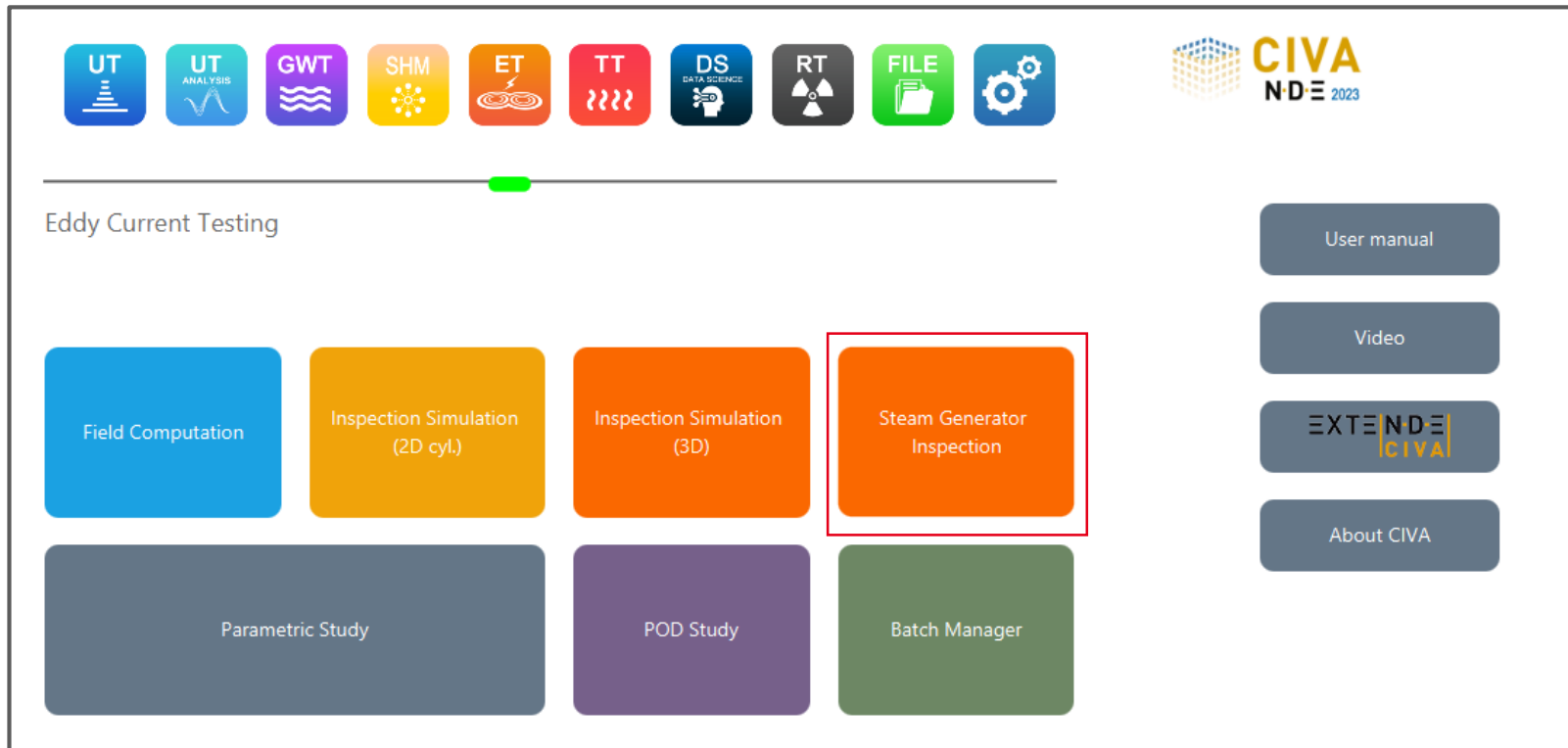
Context and motivation

- ❑ Semi-analytical approaches (modal methods)
 - Very fast and accurate
 - Limited to canonical geometries
- ❑ 2D solver based on Finite Integration Technique (FIT)
 - 2D numerical approach
- ❑ **3D solver based on Boundary elements**
 - Pieces and sensors with complex geometries



CIVA ET module « Steam Generator Inspection »

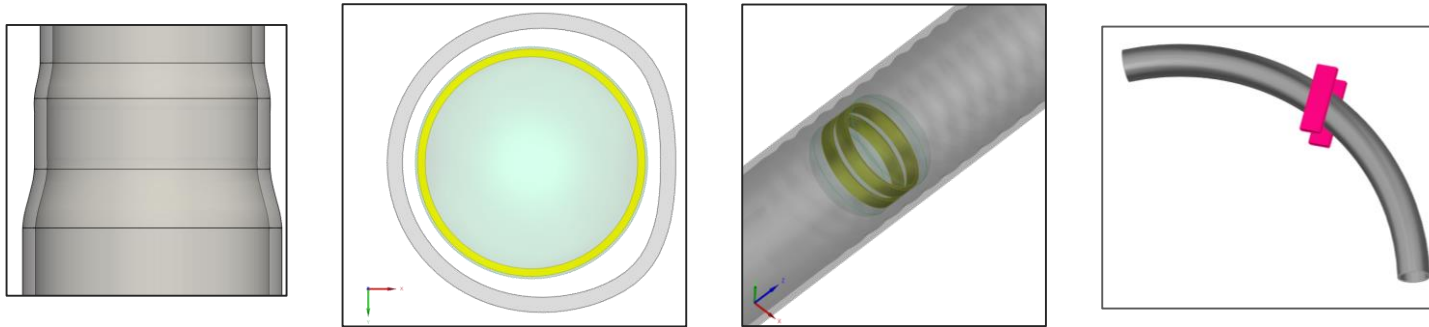
- Development and validation of a  module dedicated to the complete eddy current inspection of steam generator tube



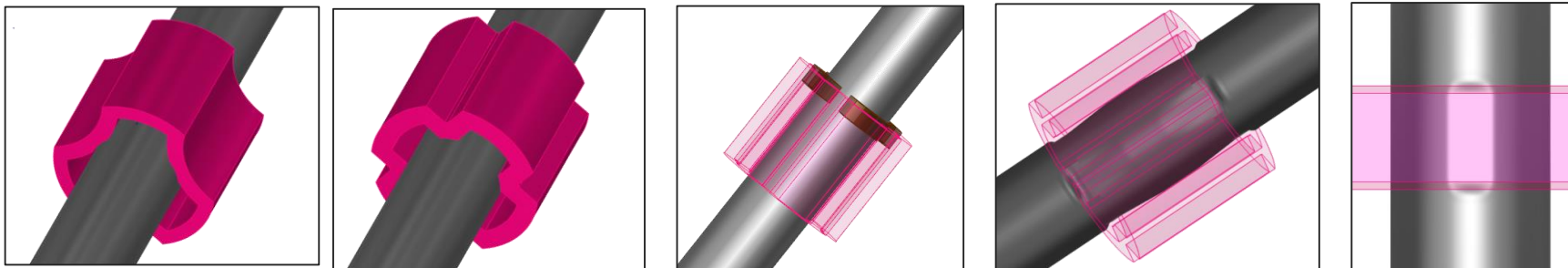
CIVA ET module « Steam Generator Inspection »



- ❑ Tube geometry: U-bend, expanded tube, section distorsion, pilgering distorsion, deposit



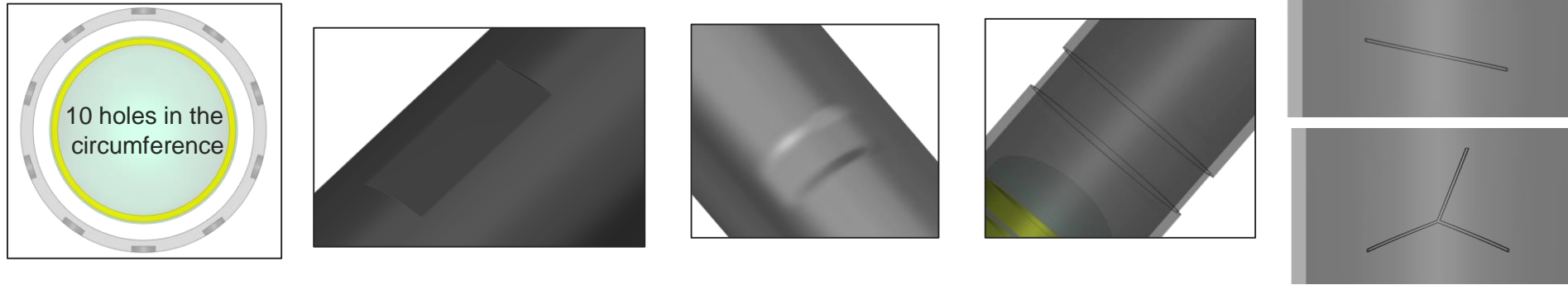
- ❑ External objects: antivibration bars, trifoiled support plate, quadrifoiled support plate, cylindrical plate,
 - Clogging
 - Wear defect due to the external objects



CIVA ET module « Steam Generator Inspection »

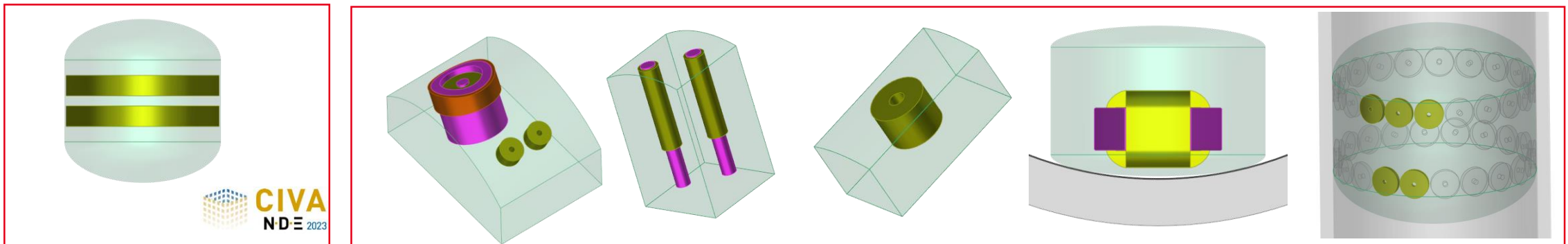


- Defect: Calibration defects, hole, straight wear, bump, groove, progressive groove, notch



- Probes: bobbin coils, rotating probes, +point, multi-element

Version under development



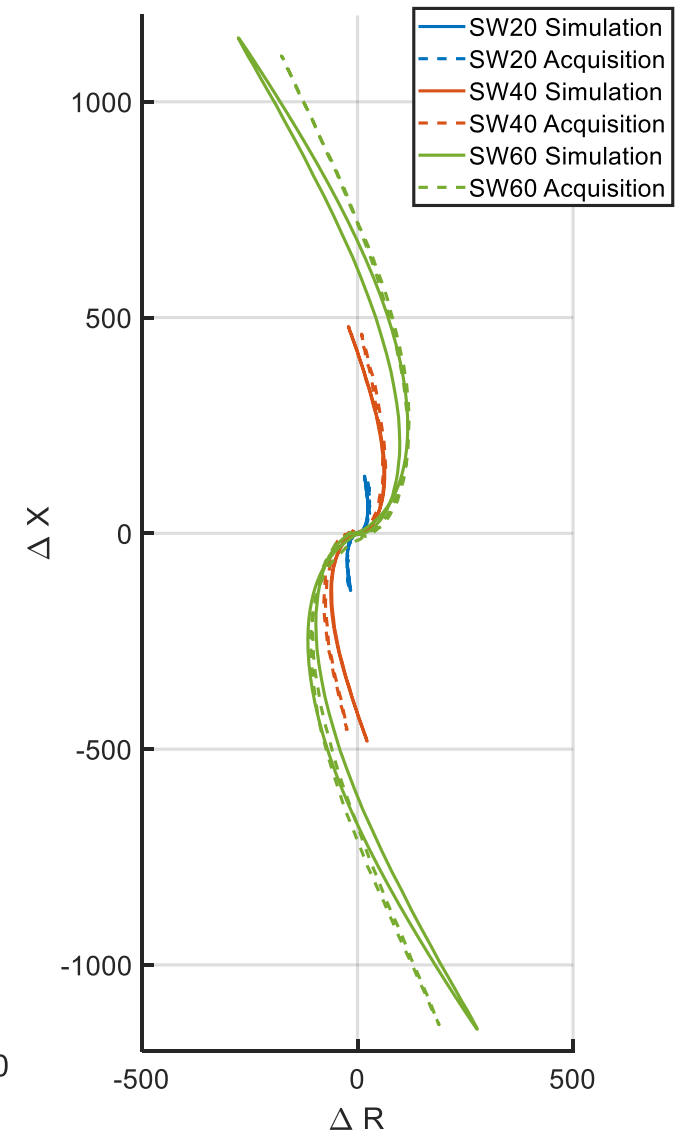
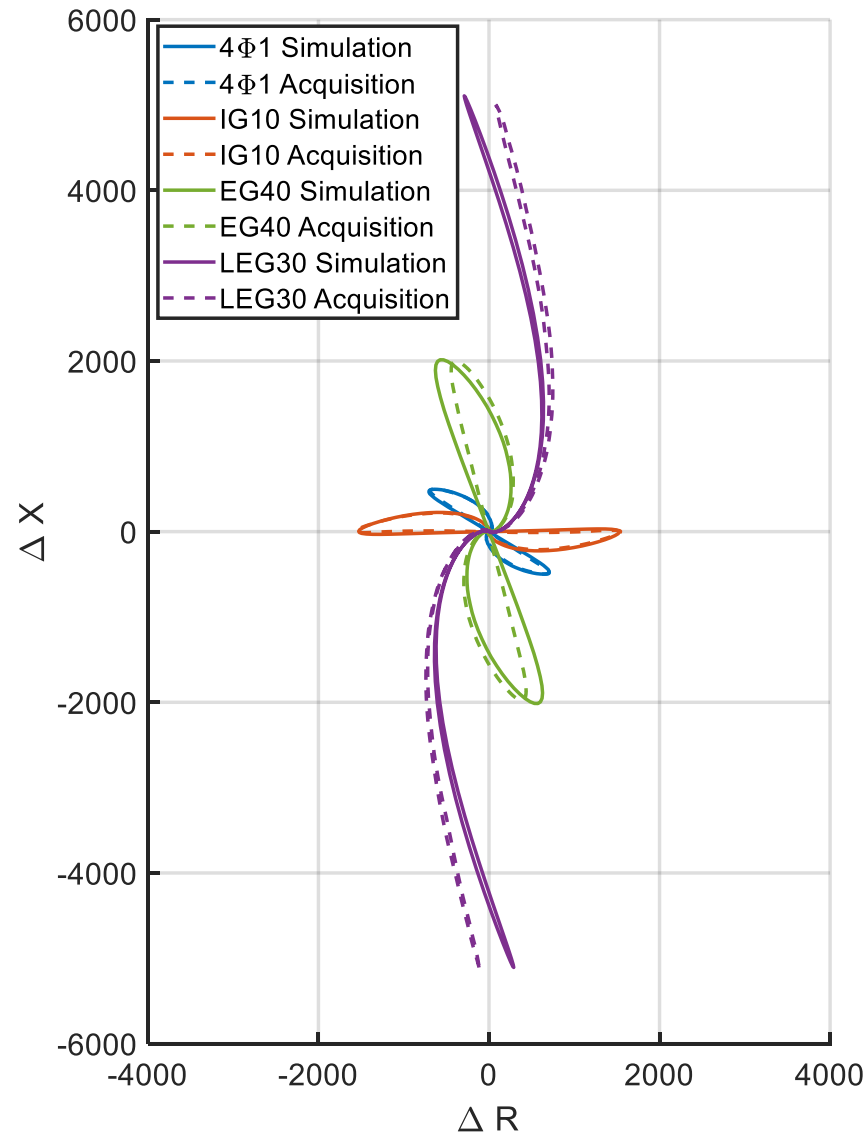
Experimental validations: configuration

- ❑ Probe: bobbin coils
- ❑ Device: Impedance analyzer
- ❑ Frequency: 280 kHz (Differential mode)
- ❑ Calibration defect: 4 through wall $\Phi 1$ holes (Amplitude = 1700 mV, Phase = -35°)
- ❑ Samples of $\frac{3}{4}$ " OD SG tube made in alloy 690 with calibration defects and straight wears with rectangular bottom flat
- ❑ AVB in alloy 600

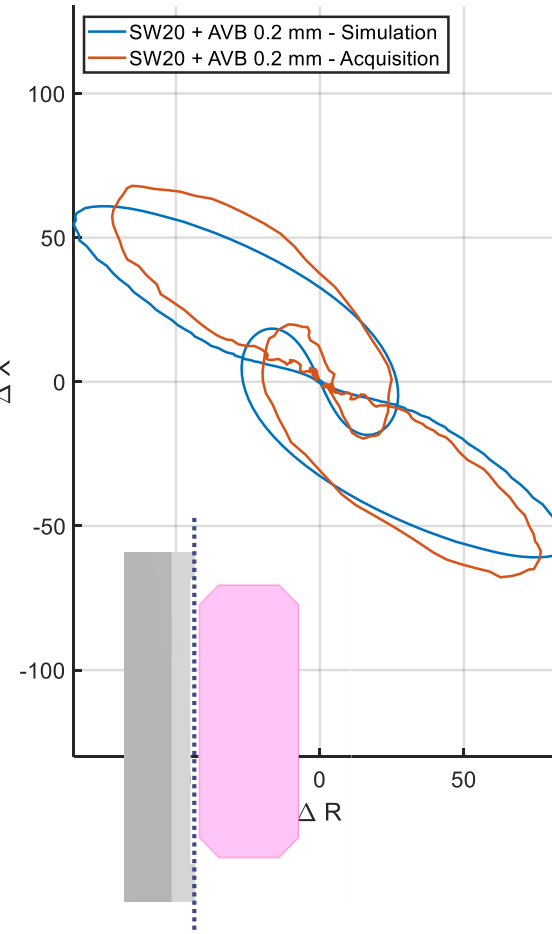
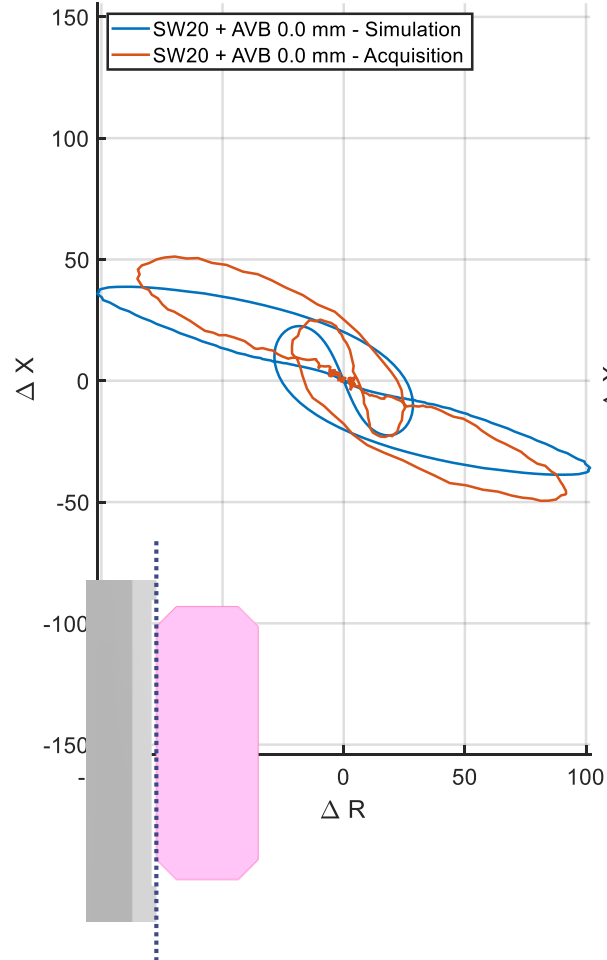
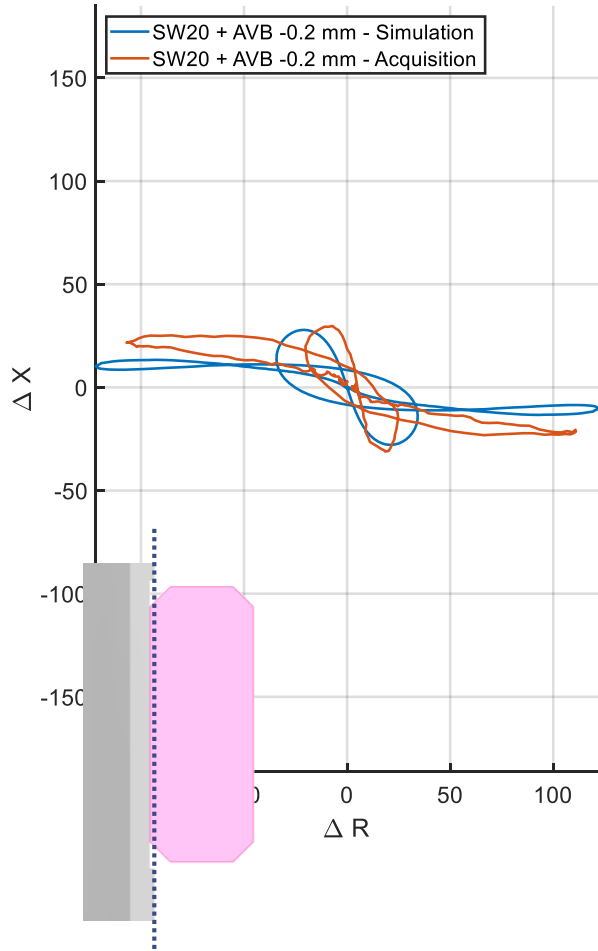


Experimental validation: Calibration defect and straight wear

	Amplitude Difference (%)	Phase Difference (°)
Internal Groove 10%	1,31	0,07
External Groove 40%	3,45	4,57
Large External Groove 30%	0,74	4,33
4Φ1	0	0
Straight Wear 20%	4,80	3,91
Straight Wear 40%	4,54	4,77
Straight Wear 60%	3,69	4,33

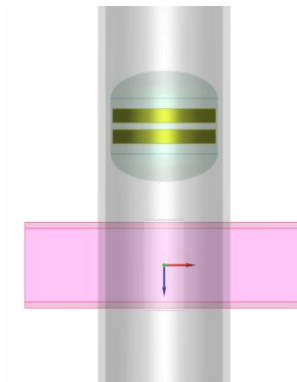


Experimental validation: 20 % straight wear with AVB



	-0.2 mm	0.0 mm	0.2 mm
Amplitude (mV)	245	216	205
Phase (°)	-5	-19	-35

AVB at 90°



Experimental validations: work in progress

- ❑ The 3D solver has been experimentally validated for
 - Calibration defects (holes and grooves), straight wears
 - Bobbin coils
 - Anti-vibration bars

- ➔ Configurations available in commercial version are experimentally validated, the calculation kernels are the same for the different external objects (AVB, TSP)

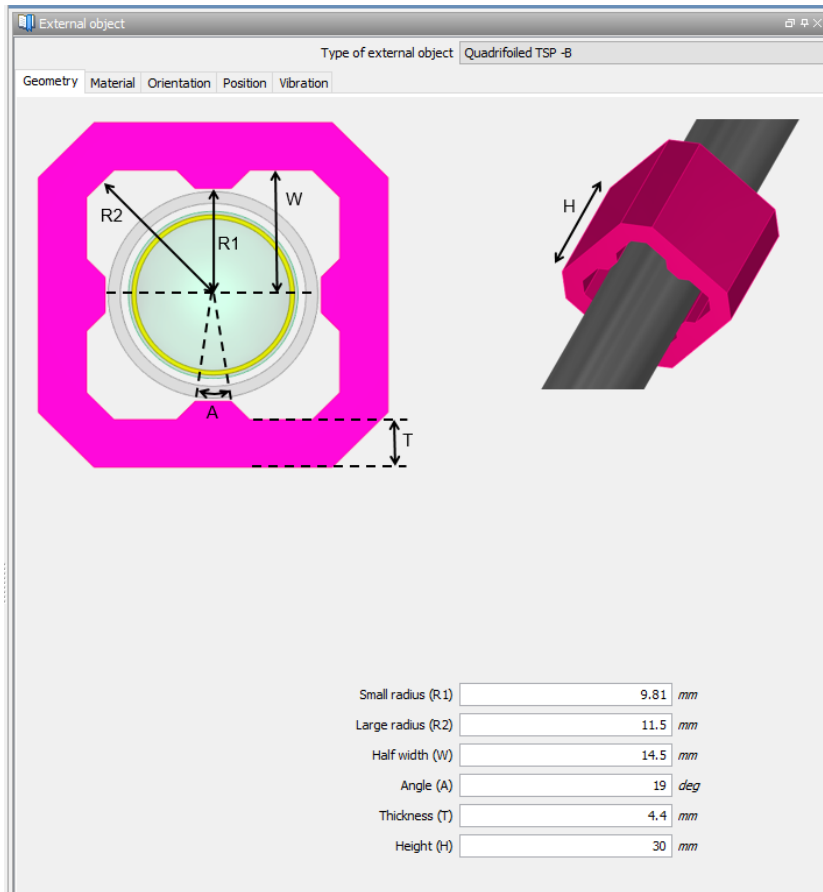
- ❑ In progress
 - Tube support plate (cylindrical and quadrifoiled)
 - Clogging
 - Rotating probes



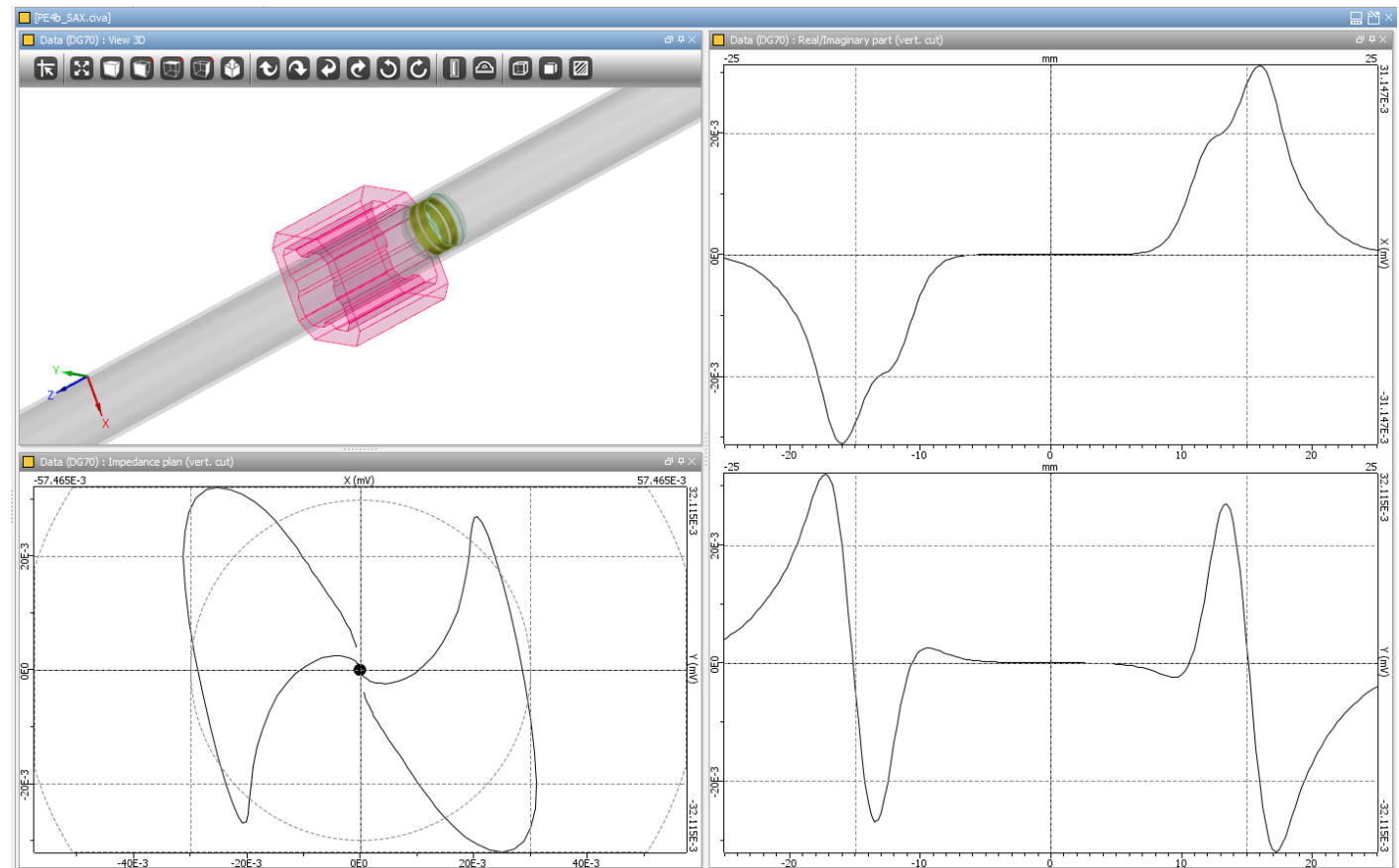
All the simulations presented after are not calibrated and balanced

Simulation of quadrifoiled tube support plate

- EC signal at 280 kHz in differential mode for bobbin coils and quadrifoiled plate ($\sigma=1.75 \text{ MS/m}$, $\mu_r = 50$)

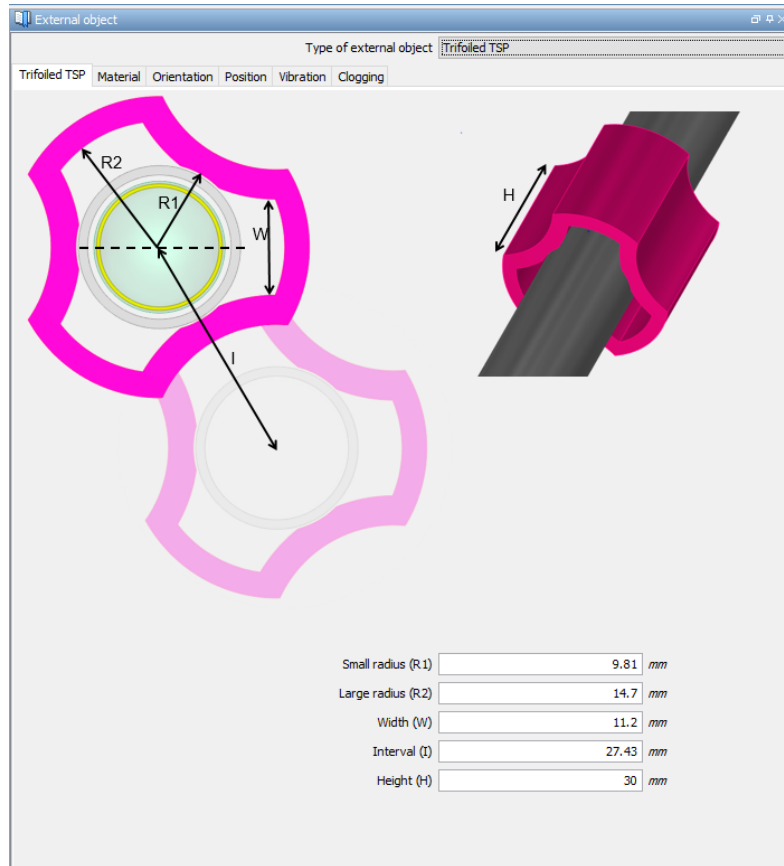


CIVA panel

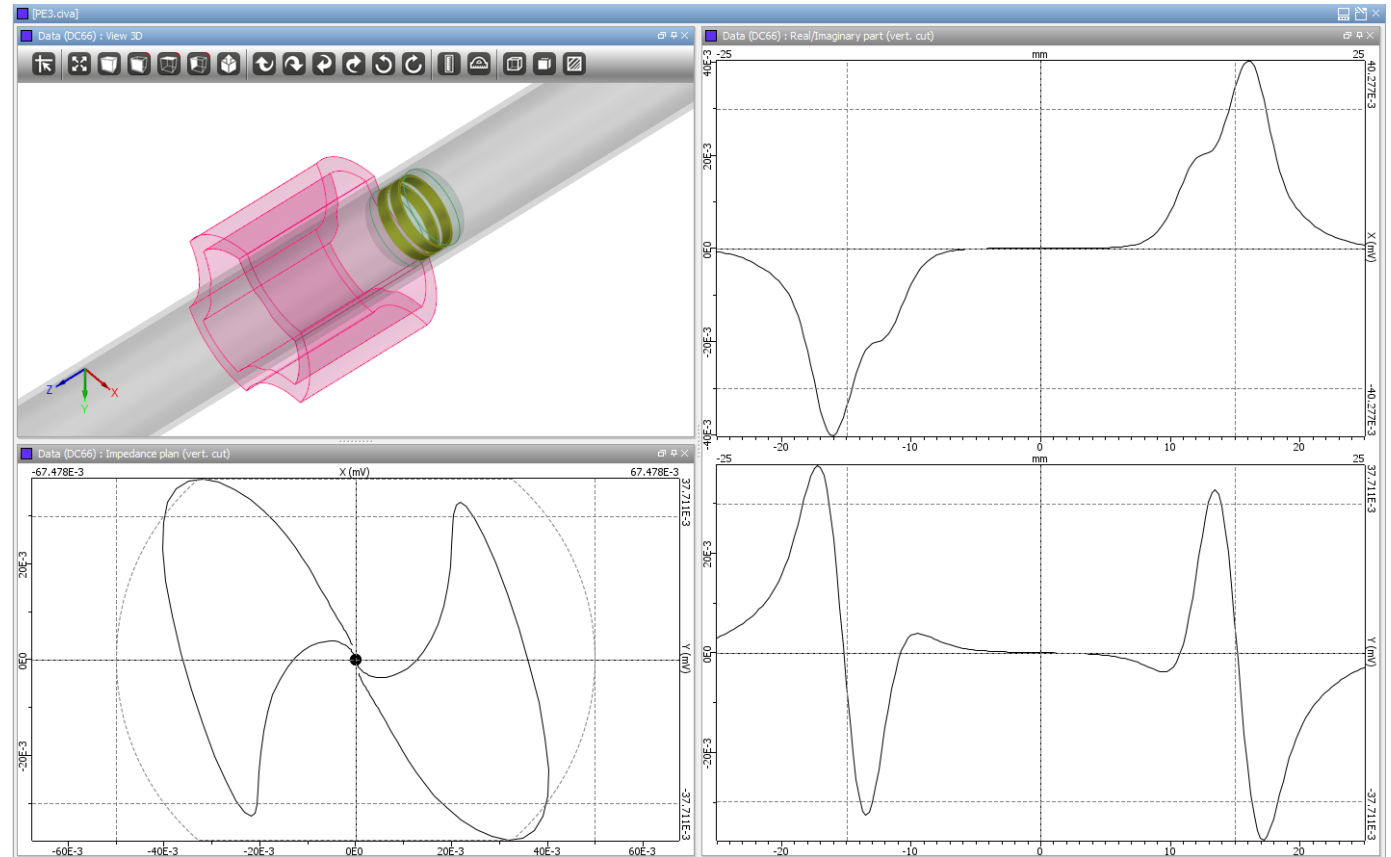


Simulation of trifoiled tube support plate

- EC signal at 280 kHz in differential mode for bobbin coils and trifoiled plate ($\sigma=1.75 \text{ MS/m}$, $\mu_r = 50$)

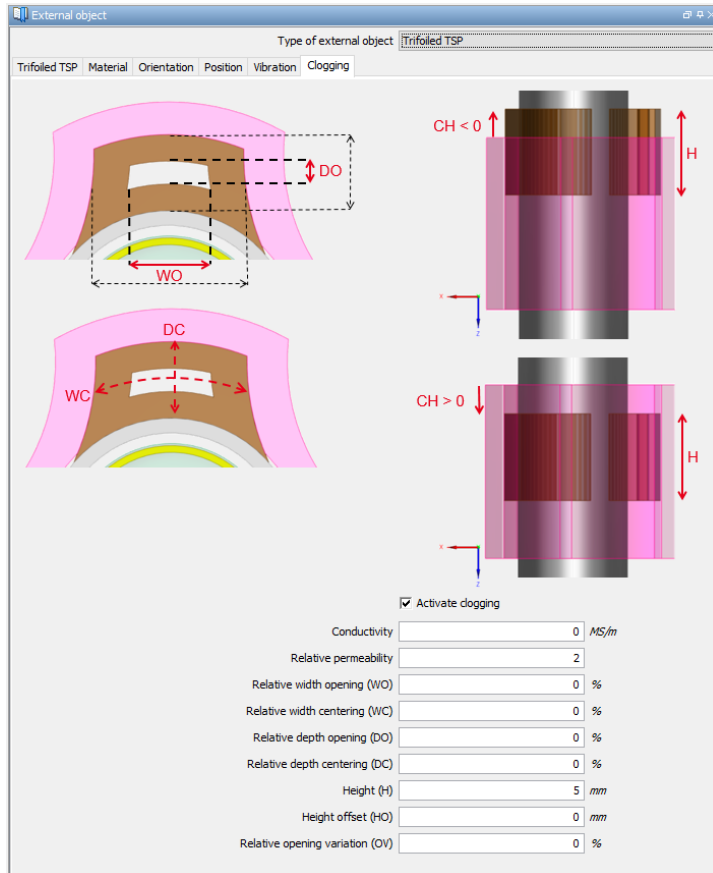


CIVA panel

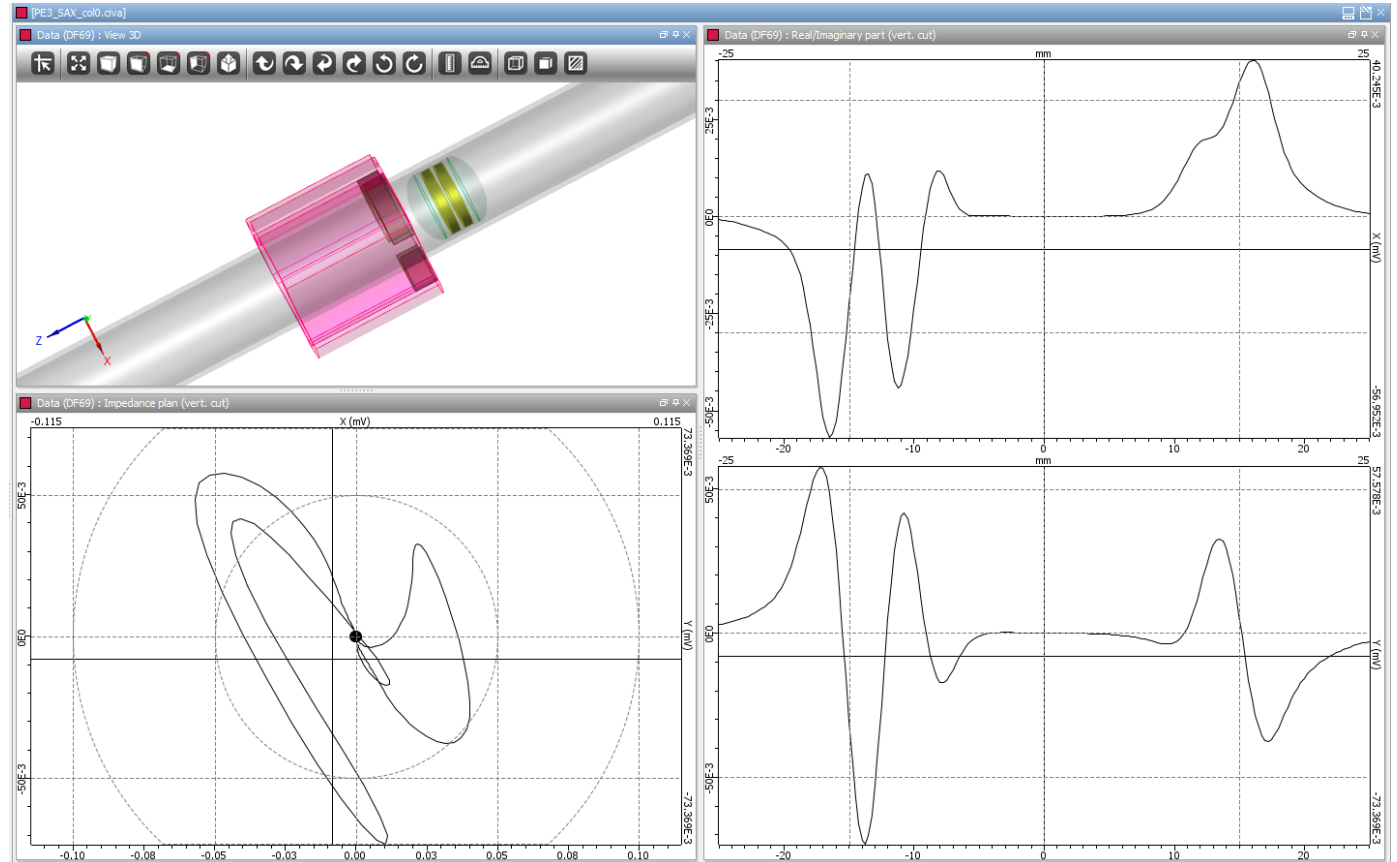


Simulation of trifoiled TSP with clogging

- EC signal at 280 kHz in differential mode for bobbin coils and trifoiled plate ($\sigma=1.75 \text{ MS/m}$, $\mu_r = 50$) with clogging ($\mu_r = 2$)

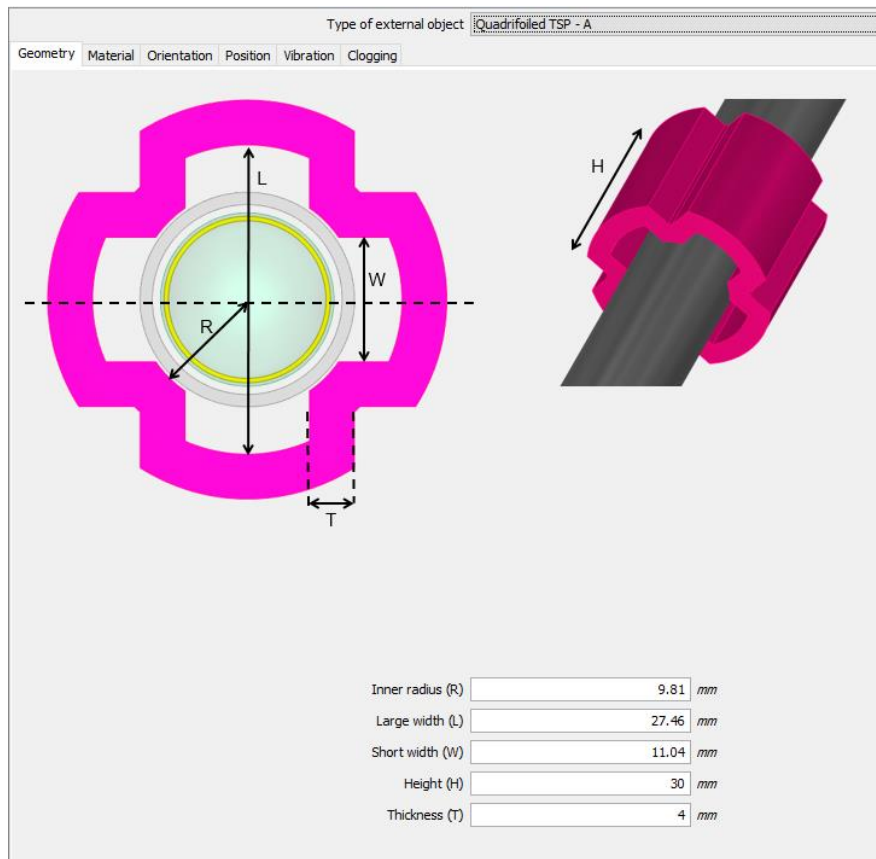


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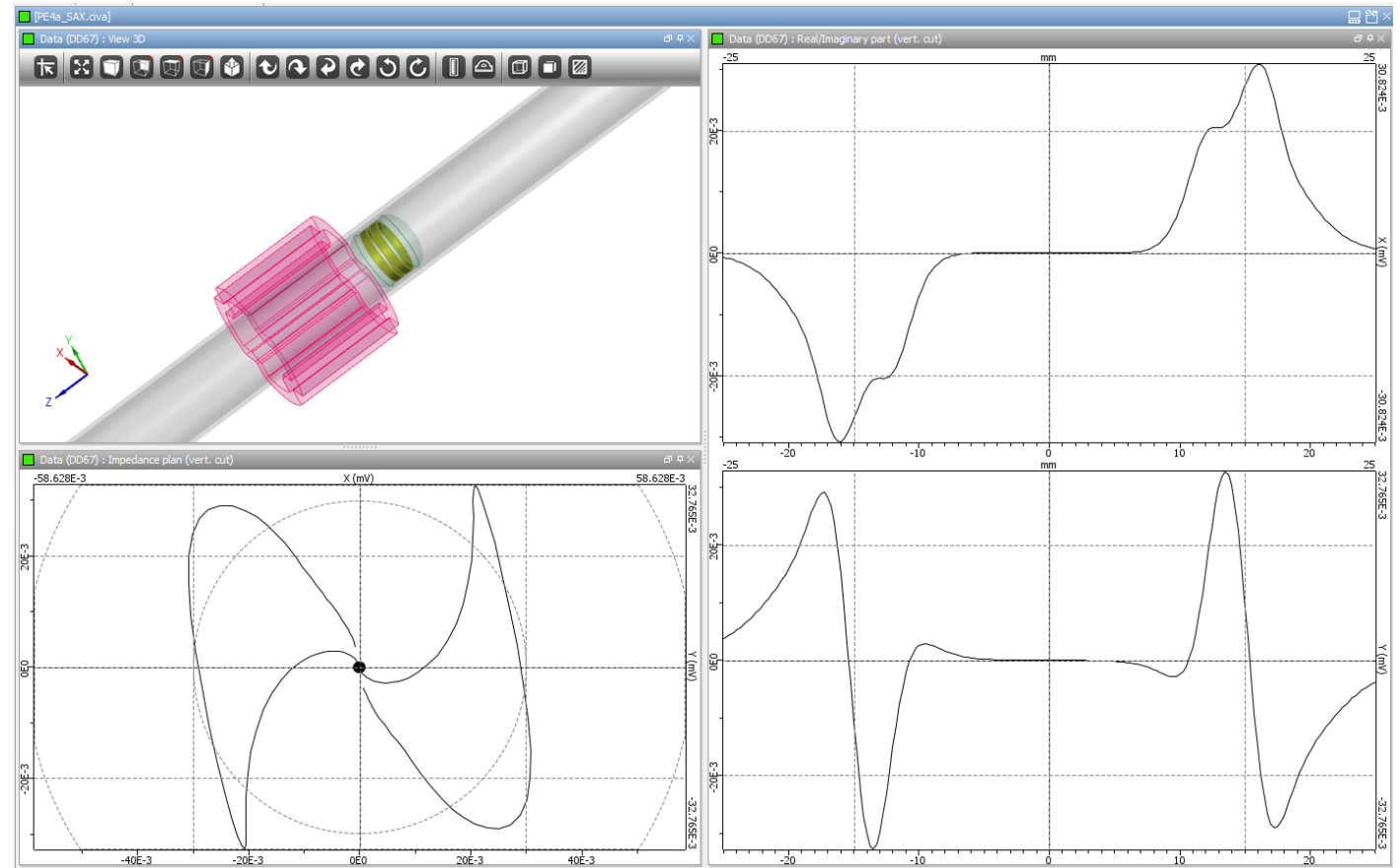


Simulation of quadrifoiled tube support plate

- EC signal at 280 kHz in differential mode for bobbin coils and quadrifoiled plate ($\sigma=1.75 \text{ MS/m}$, $\mu_r = 50$)

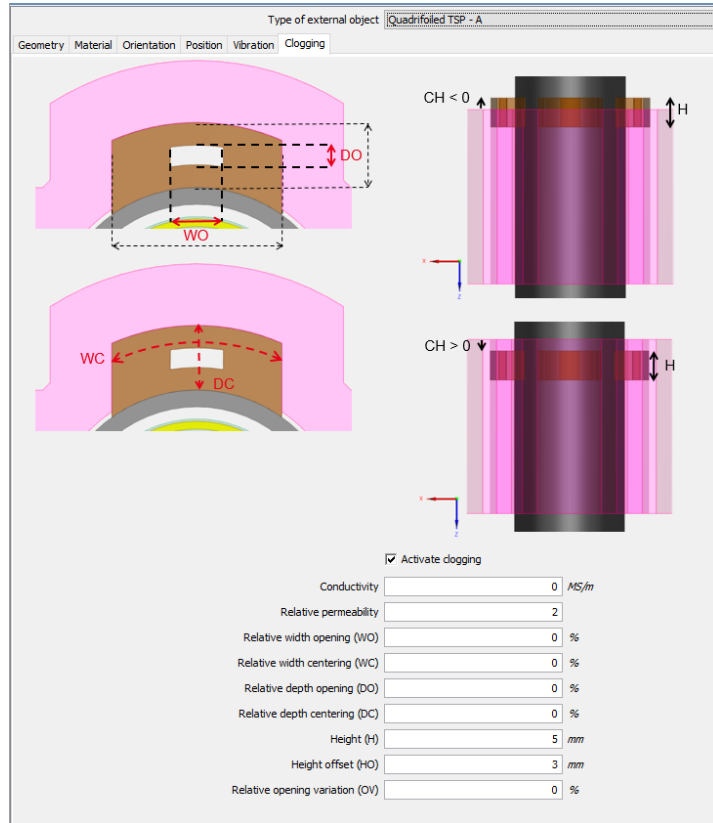


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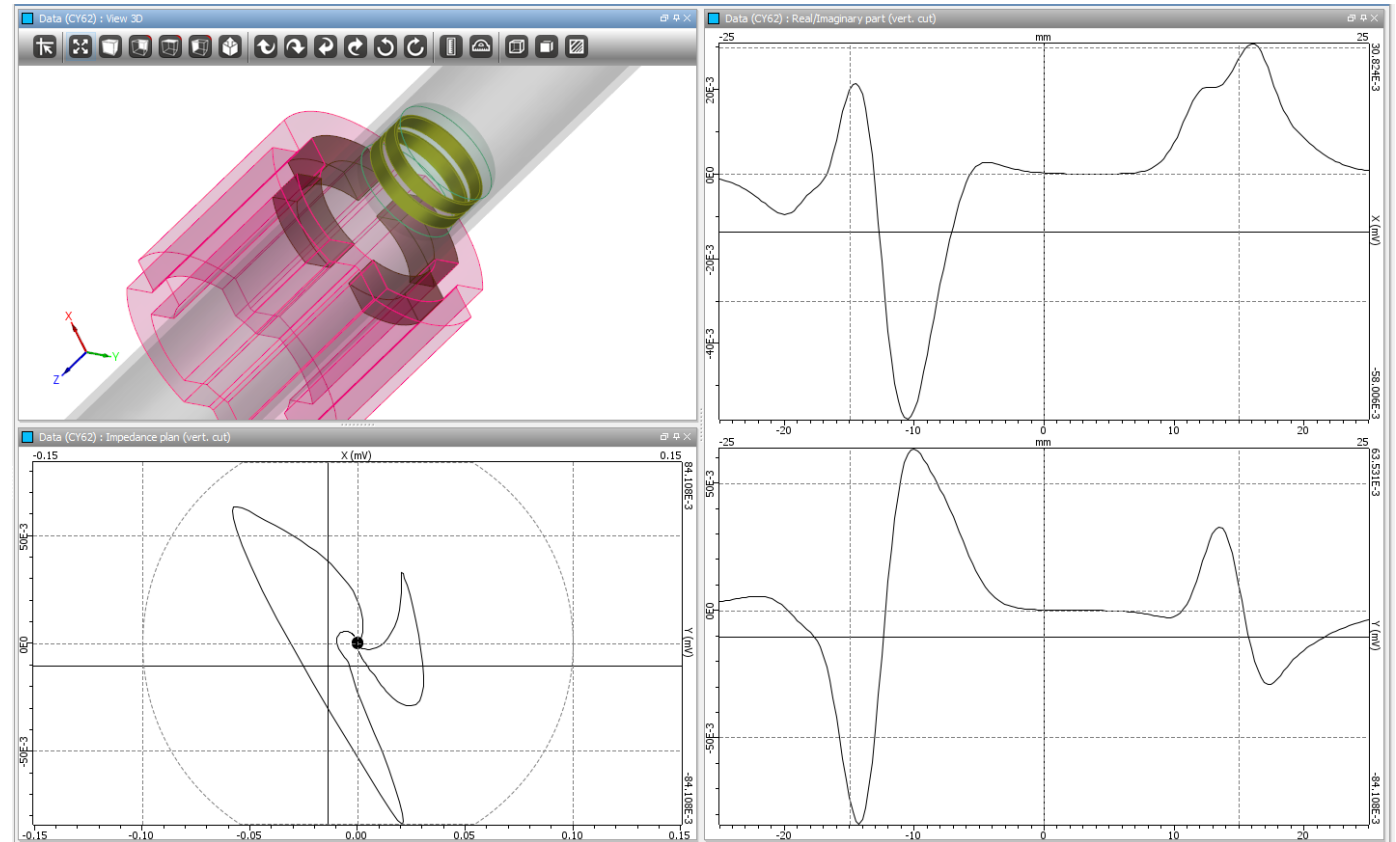


Simulation of quadrifoiled TSP with clogging

- EC signal at 280 kHz in differential mode for bobbin coils and quadrifoiled plate ($\sigma=1.75 \text{ MS/m}$, $\mu_r = 50$) with clogging ($\mu_r = 2$)

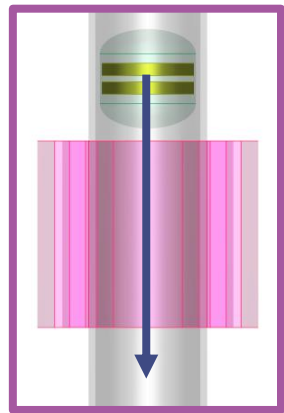


CIVA panel

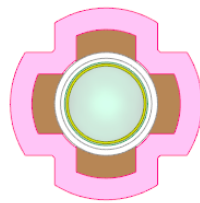


Quadrifoiled TSP with clogging: position effect

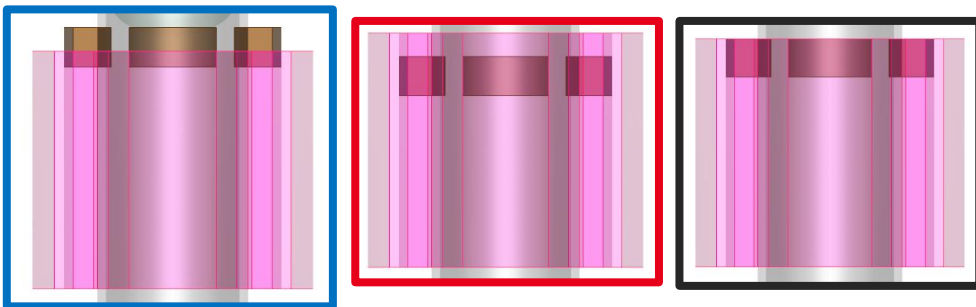
- EC signal at 280 kHz in differential mode for bobbin coils and quadrifoiled plate ($\sigma=1.75$ MS/m, $\mu_r = 50$) with clogging ($\mu_r = 2$) at different positions



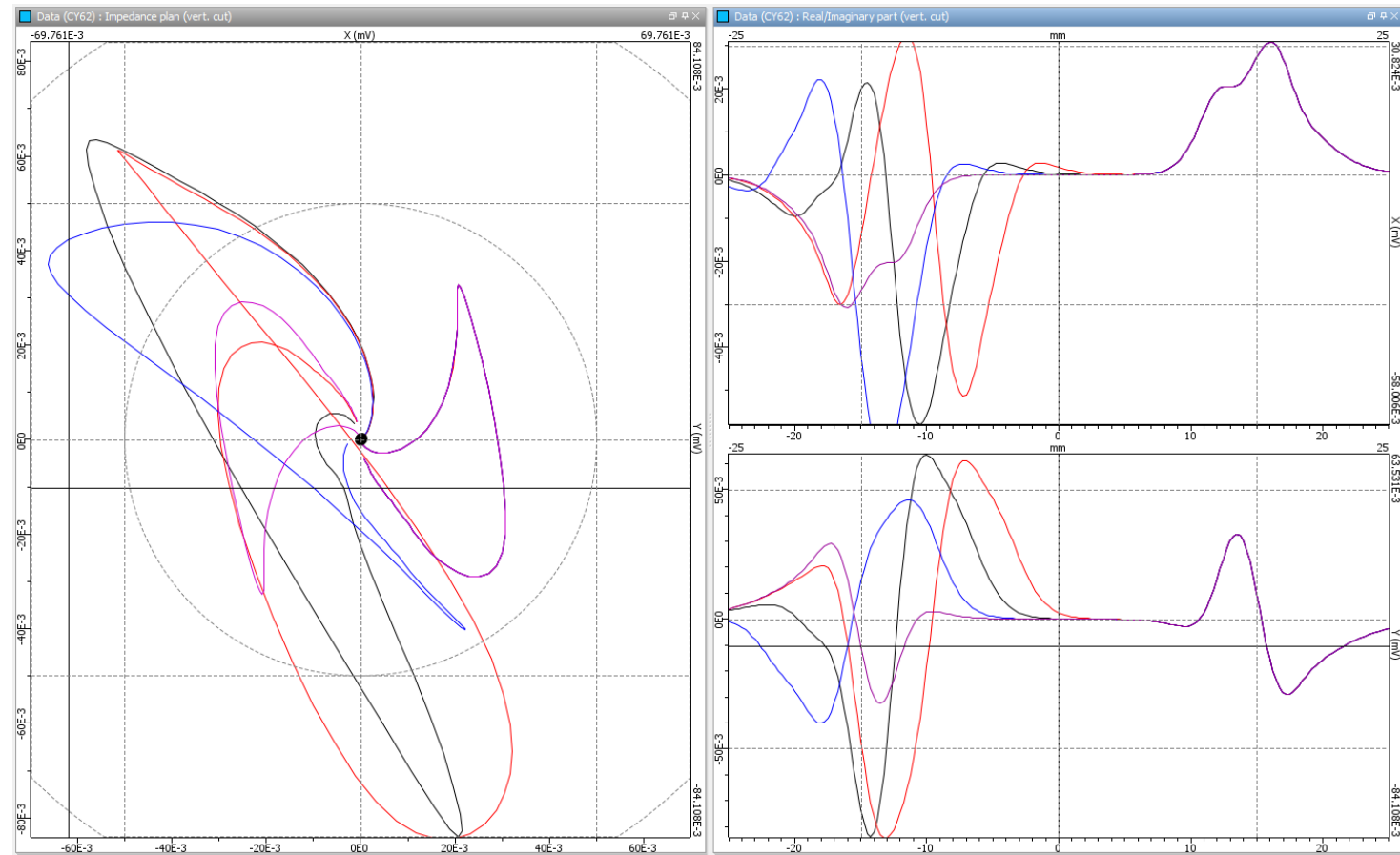
Probe displacement



Clogging geometry

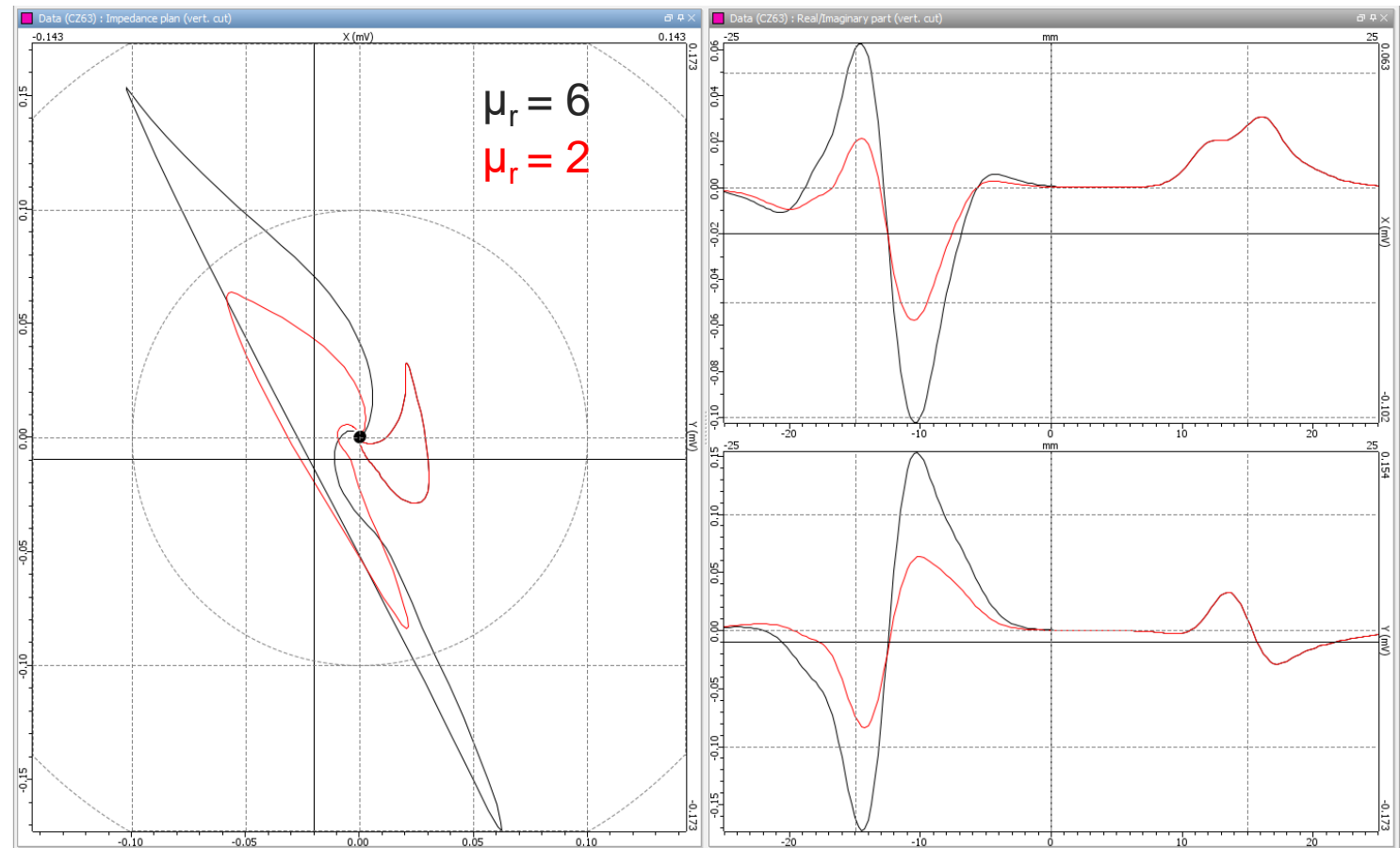
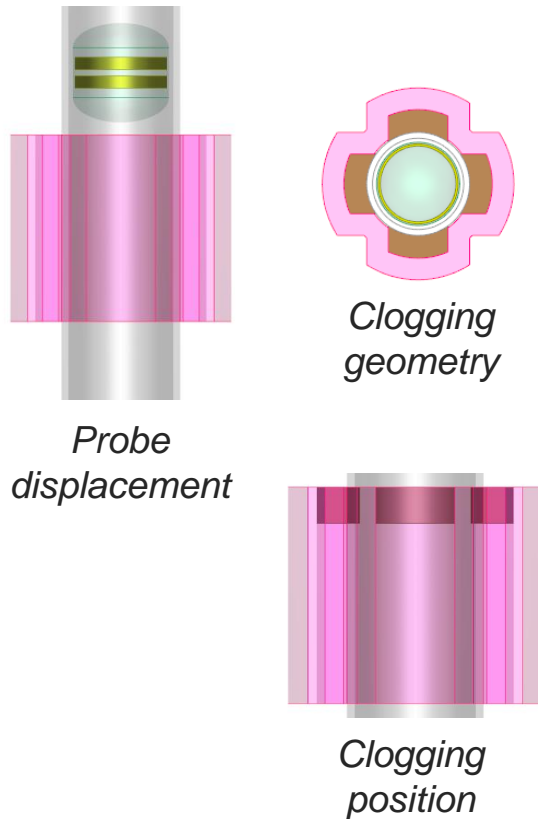


Variation of the clogging position



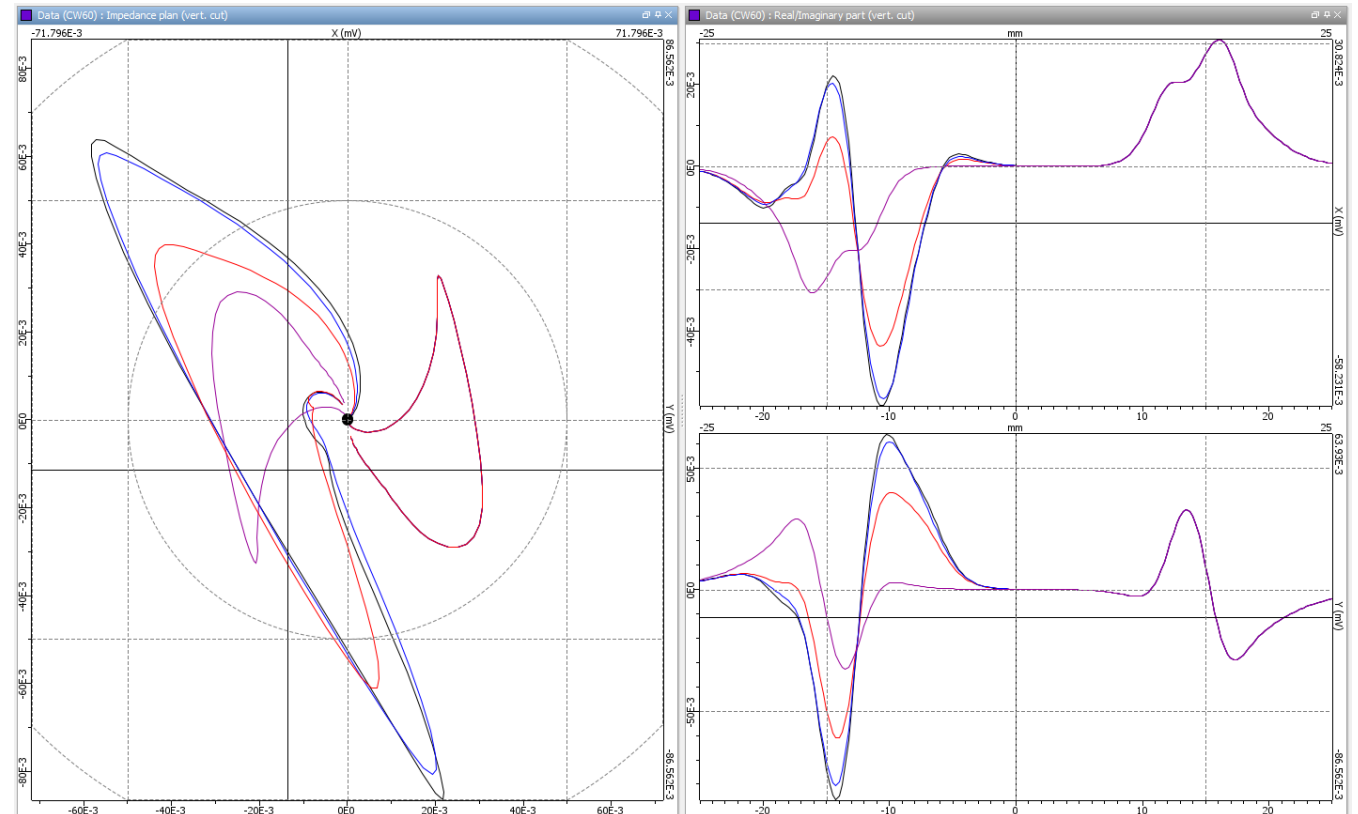
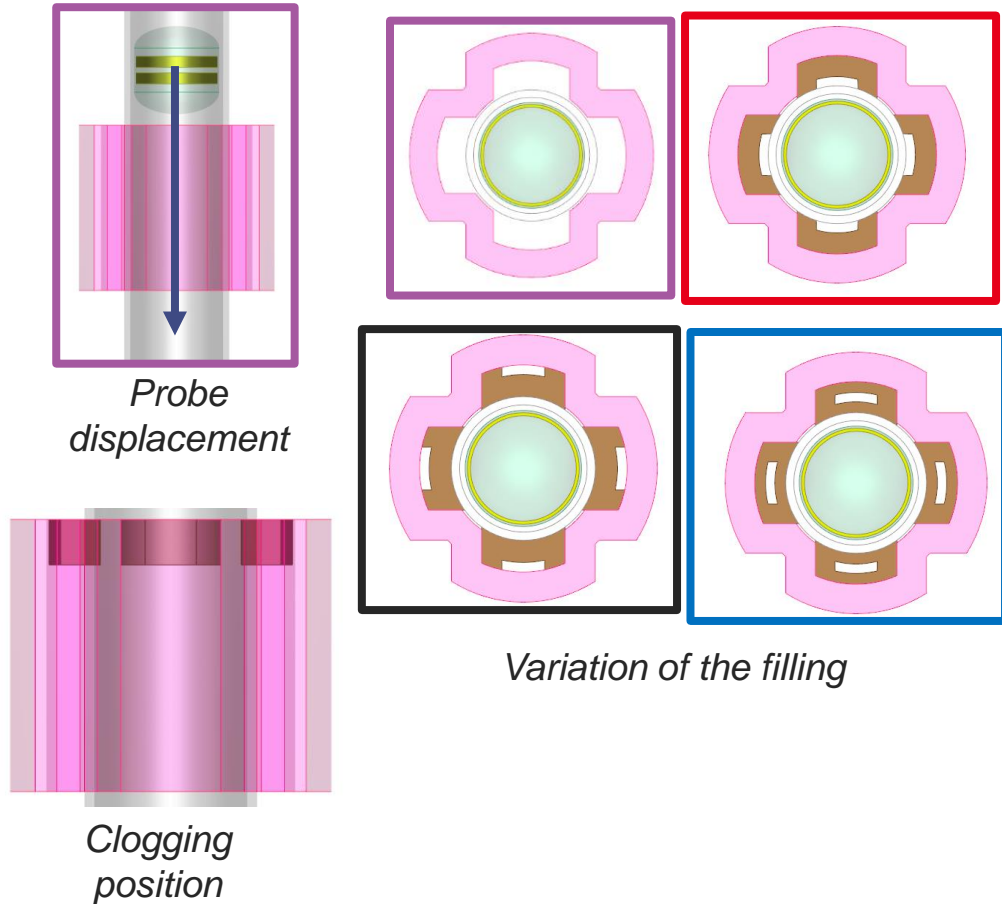
Quadrifoiled TSP with clogging: position effect

- EC signal at 280 kHz in differential mode for bobbin coils and quadrifoiled plate ($\sigma=1.75$ MS/m, $\mu_r = 50$) with clogging with different magnetic permeability



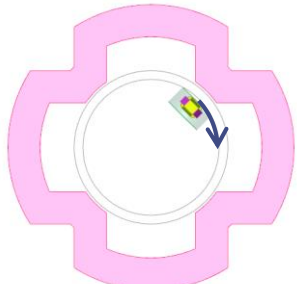
Quadrifoiled TSP with clogging: filling effect

- EC signal at 280 kHz in differential mode for bobbin coils and quadrifoiled plate ($\sigma=1.75$ MS/m, $\mu_r = 50$) with clogging ($\mu_r = 2$) with different filling

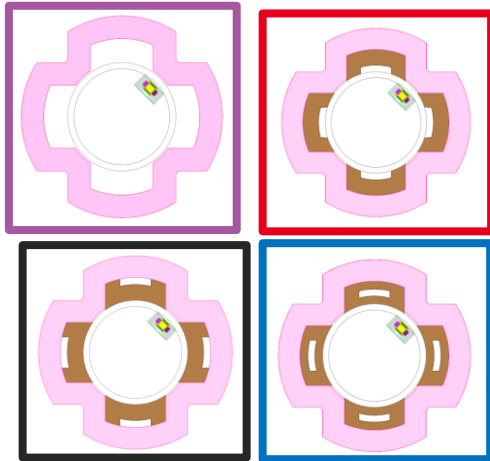


Quadrifoiled TSP with clogging: filling effect

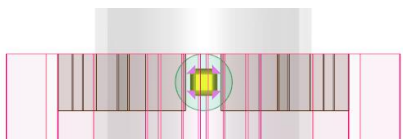
- EC signal at 280 kHz in differential mode for +point and quadrifoiled plate ($\sigma=1.75$ MS/m, $\mu_r = 50$) with clogging ($\mu_r = 2$) with different filling



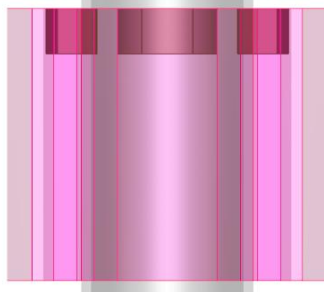
Probe displacement (45°)



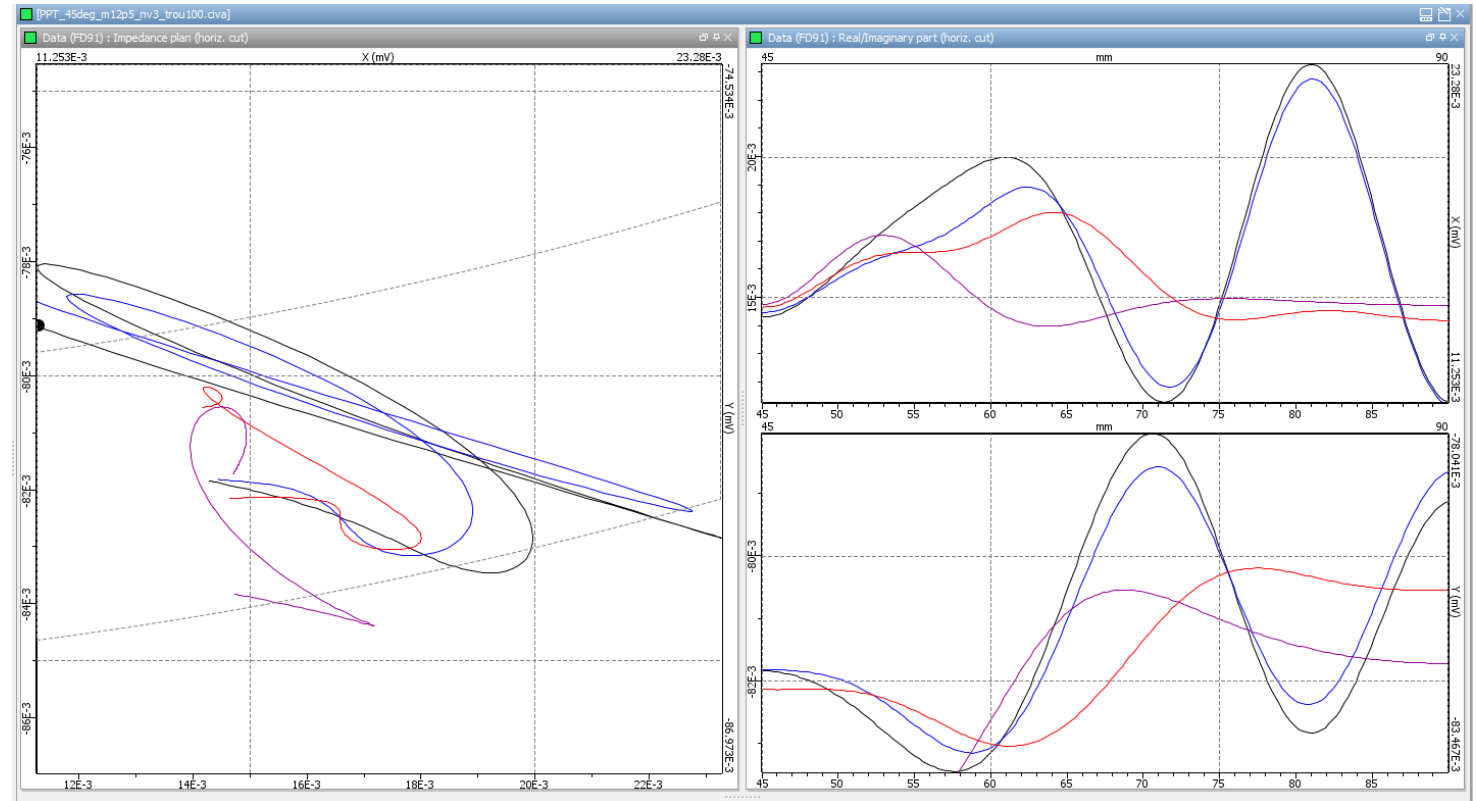
Variation of the filling



Probe position



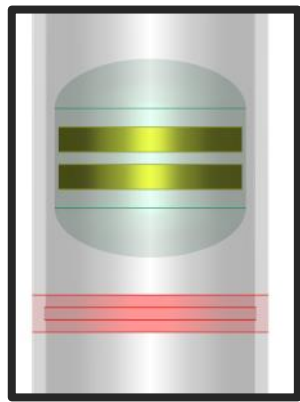
Clogging position



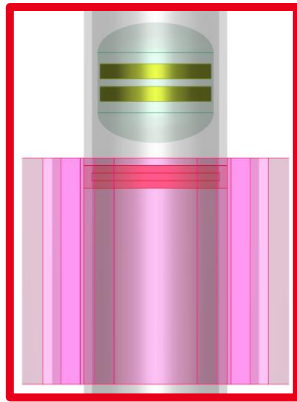
Version under development

Quadrifoiled TSP with clogging: filling effect

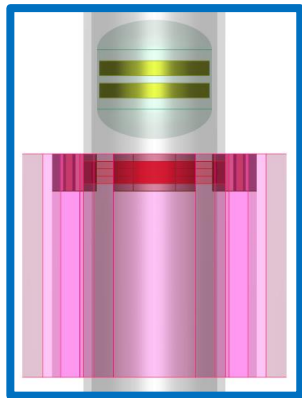
- EC signal at 280 kHz in differential mode for +point and quadrifoiled plate ($\sigma=1.75$ MS/m, $\mu_r = 50$) with clogging ($\mu_r = 2$) and internal groove (opening 1mm, depth 10%)



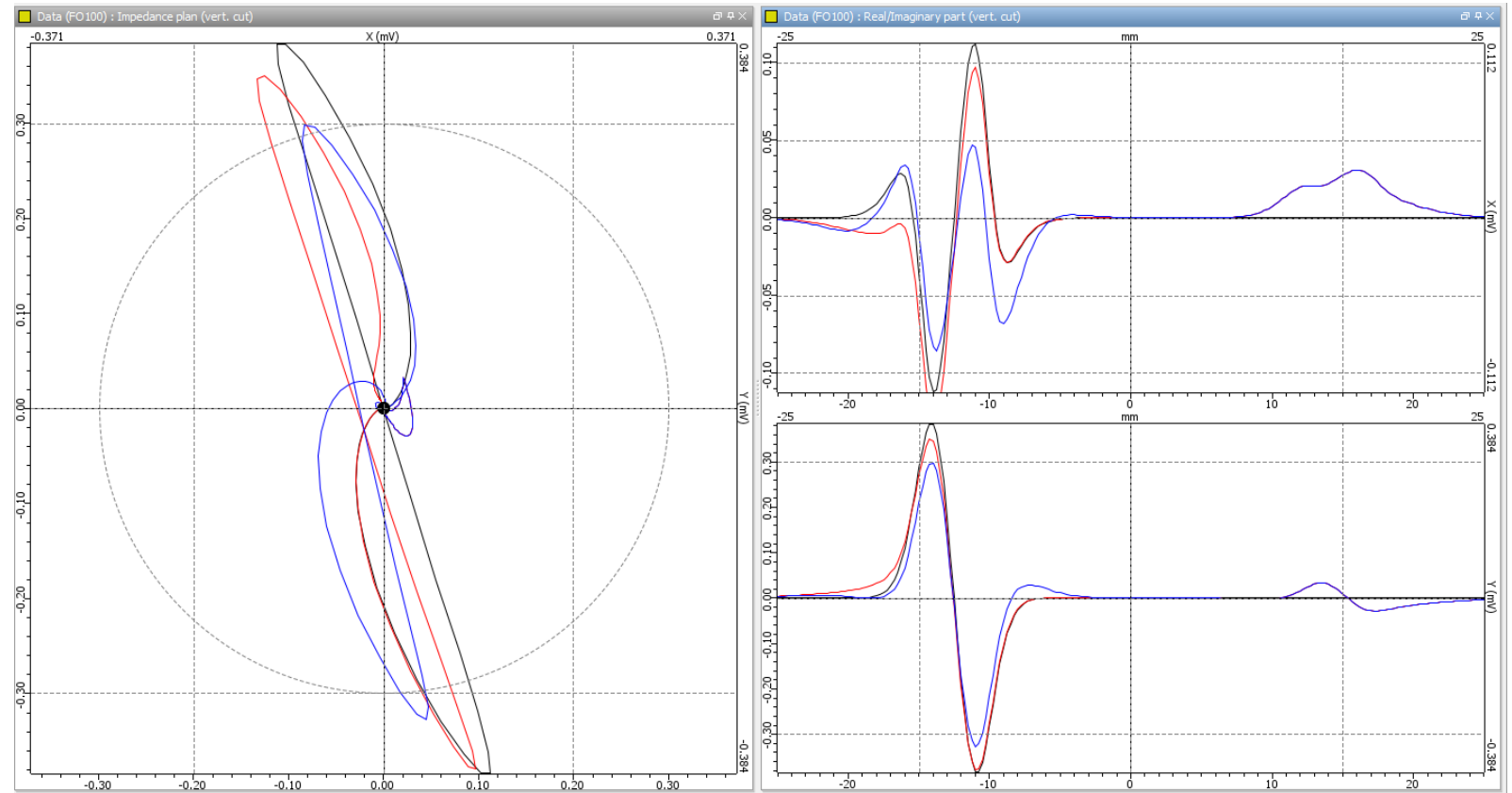
Internal groove



Internal groove+TSP



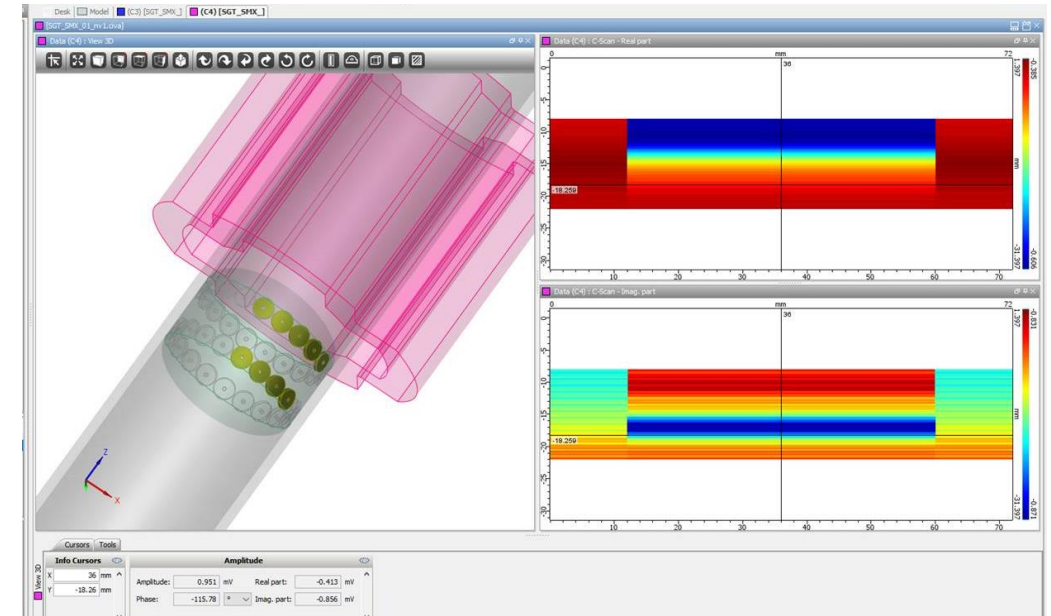
Internal groove+TSP+clogging



Conclusions

- ❑ Collaborative study between CEA LIST and IRSN for the simulation of eddy current inspection of steam generator tubes
 - ❑ Module dedicated to the inspection of SG tubes in **CIVA NDE I**
 - ❑ Experimental validation for bobbin coils
 - ❑ Modelling of TSP with different geometries and clogging
 - ❑ Study in progress on the experimental validation of clogging of tube support plates for various probes
 - ❑ Numerical tools for sensitivity study of the parameters influencing the EC signal
 - ❑ Clogging geometry and position
 - ❑ Presence of clogging
- Civa users can quickly assess the sensitivity of their inspection setup settings

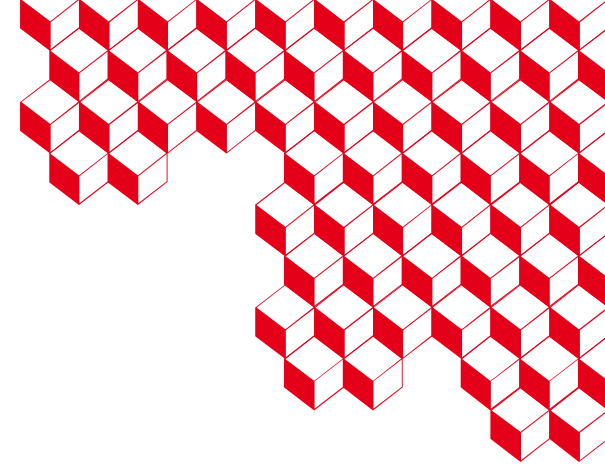
CIVA
NDE I



Multi-element probe numerical settings in development



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Thank you for your attention.

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