Modelling of the ET inspection of bended parts in Steam Generators Tubes with the FEM software « FLUX® »

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DCNS

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EXTENDE activity

- **Distribution** CIVA
  - Sales
  - Technical support
  - Training courses

- **Consulting:**
  - Computation - Studies : CIVA *(UT/ET/RT)* – Flux*(ET/MT)*
  - Development methodology
  - Link to **innovation**

CONTEXT: QUALIFICATION

- DCNS: one of the world leader in the naval defence:
  - Builds and supports submarines and surface warship.
- Embedded nuclear vessels in submarines:
  - Change in the regulation
  - Required qualification of NDE processes used for in service inspections
  - Steam Generators tubes type « K15 »
  - Eddy Current inspection with a bobbin probe
- Implies a sensitivity study to the influential parameters:
  - Workpiece parameters, sensor parameters, flaw parameters, etc.
  - In order to qualify the limit of the inspection process

CONTEXT: QUALIFICATION

- In this study:
  - Parameter: Influence of the flaw position in the elbow of the SG tubes
  - Mock-ups used for this qualification include only external notches (on the OD side)
  - Supposed to be the worst case for the detection (lower amplitude signal) with the inspection procedure
- Purpose of the simulation study:
  - To confirm the above hypothesis
  - Comparison of flaw response in the OD and the ID
- DCNS asked EXTENDE to work on this modelling study

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DESCRIPTION OF THE STUDIED CASE

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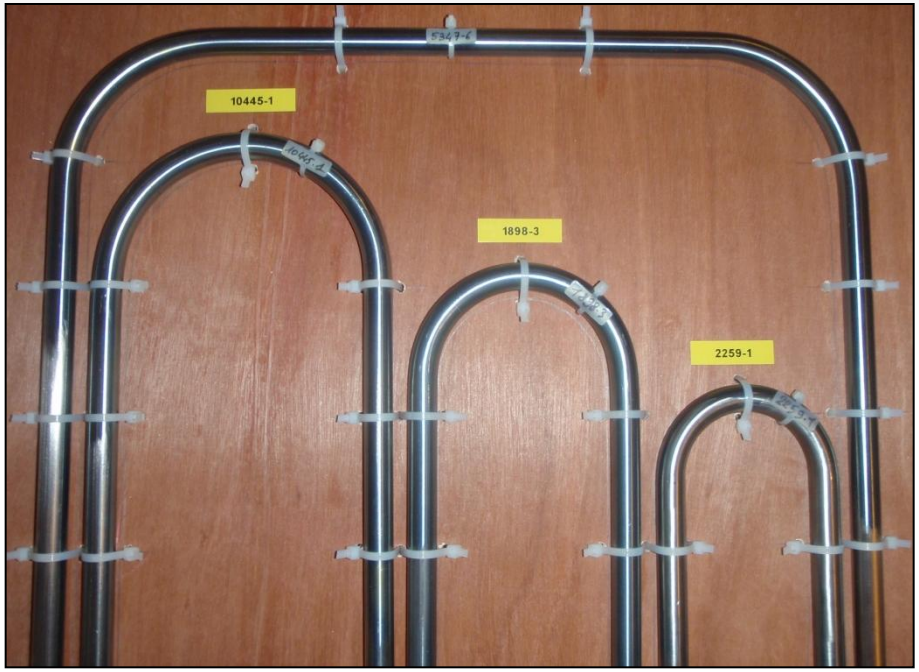
SG TUBES « K15 »

- GV K15 : Bended parts

- **Geometrical data:**
  - External diameter : 14 mm
  - Thickness : 1.35 mm
  - Bending radius: 38 mm

- **Material : INCOLOY 800**
  - Conductivity: 1 MS/m
  - Non ferromagnetic



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FLAWS UNDER STUDY

- Two type of notches :
  - Longitudinal notches :
    - Length 10mm - Width 0,2mm – Depth 50%
  - Circumferential notches:
    - Width 0.2mm – Angular extension 180° – Depth 50%

- Position:
  - Center of the elbow: Angular Position 45°
  - Internal (ID) & External (OD)
    - To compare these 2 positions is the main goal of this study
  - On the upper and inner surface

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PROBE « SAX »

- BOBBIN PROBE Type A138098B ZETEC

- 2 windings working both as transmitter and receiver
- Reception in differential mode
- Properties :
  - External diameter: 9.8mm
  - Frequencies : 170kHz and 35kHz

INSPECTION PROCEDURE

- 2 Frequencies : F1= 170kHz & F3=35kHz
- Calibration of channels F1 and F3:
  - 3 Through-wall holes of 0.8mm diameter separated by 120° in the straight part of an incoloy tube having the same section as the SG tubes
- Channel C2 used for the detection
    - C2 is obtained after operating a frequency mixing on F1 and F3
    - Aims at removing the geometrical signal at the transition straight part/Elbow
    - Mathematical expression: Combination matrix [M] with 4 coefficients: **C2= F1+[M]*F3**
    - [M] : coefficients calculated by the analysis software JADE
- Calibration of C2 :
  - Same process as F1 and F3

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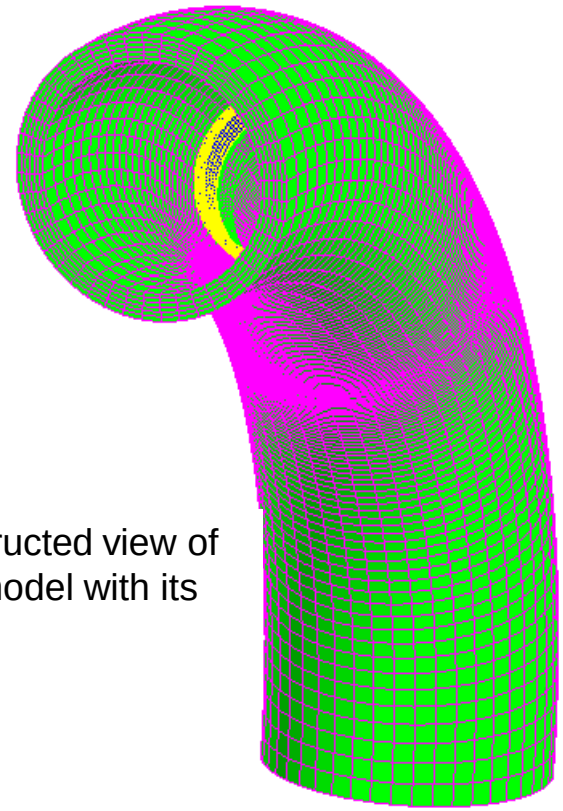
DESCRIPTION OF THE MODEL

FLUX software

- FEM commercial software for electromagnetics & thermal simulation
- Developped by Cedrat company
- Applications : Electrical Machines, Magnetic actuators, Heat treatment, etc.
- Applications in NDT :
  - Eddy Current Testing
  - Other electromagnetics methods (MPI, etc.)
- Release: 10.3 (current commerciale release during the study)

FLUX model

- A lot of experience on Steam Generators tubes modelling



Reconstructed view of the full model with its mesh

y known at the beginning of the study:
:ation of numerical noise), etc.

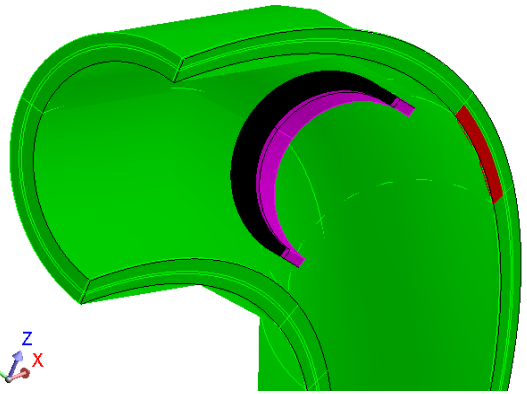
ed part of SGs

Flaws in the medium part (45°)

:ries:

resented + Appropriate Boundary

odel



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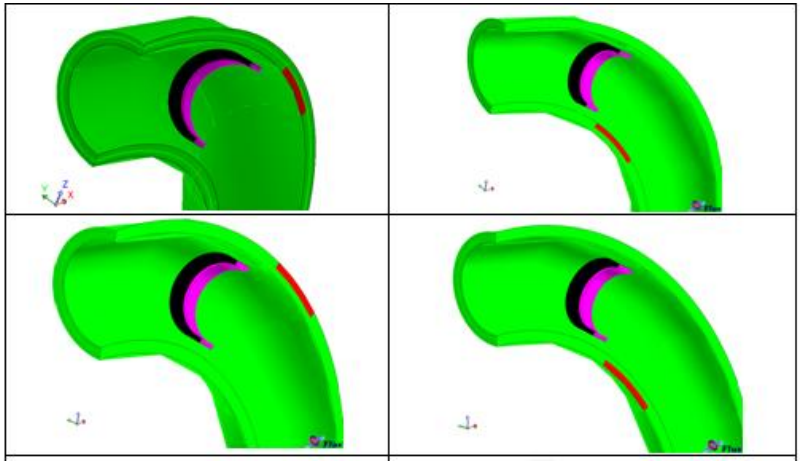
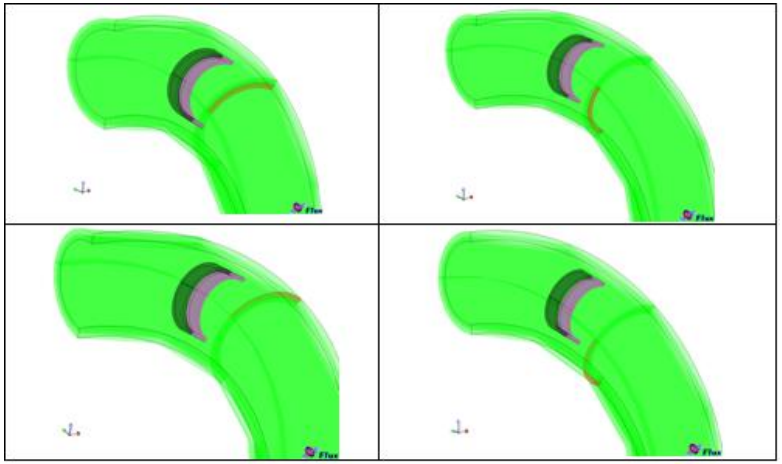
SIMULATIONS PERFORMED

- 8 configurations with flaws habe been simulated :
  - Longitudinal notches / Circumferential notches
  - ID,OD, Upper surface, Inner surface





- The whole inspection procedure has been simulated:
  - 2 Frequencies 35kHz & 170 kHz
  - Calibration
  - Frequency mixing

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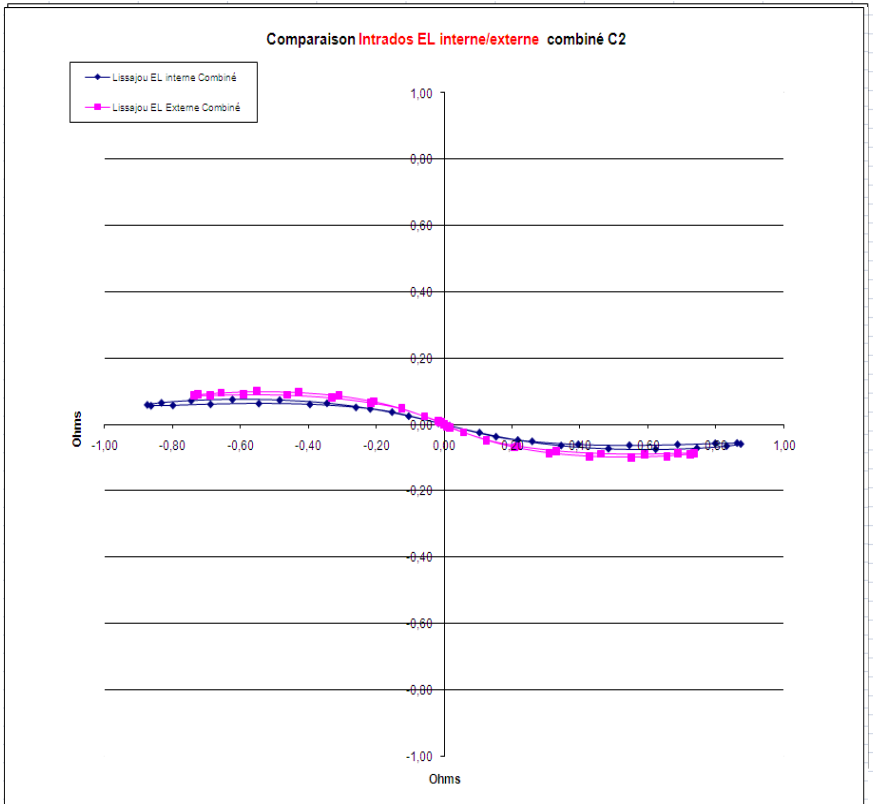
RESULTS

RESULTS OBTAINED

INNER SURFACE

- The channel C2, obtained after frequency mixing, has been analysed :
  - Longitudinal Notches: ID / OD
  - Circumferential Notches: ID / OD



Flaw	Channel	Amplitude (mV)	Phase (degree)*
LIN - Longitudinal Internal Notch	C2	1749.7	3.9
LEN – Longitudinal External Notch	C2	1483.2	6.8

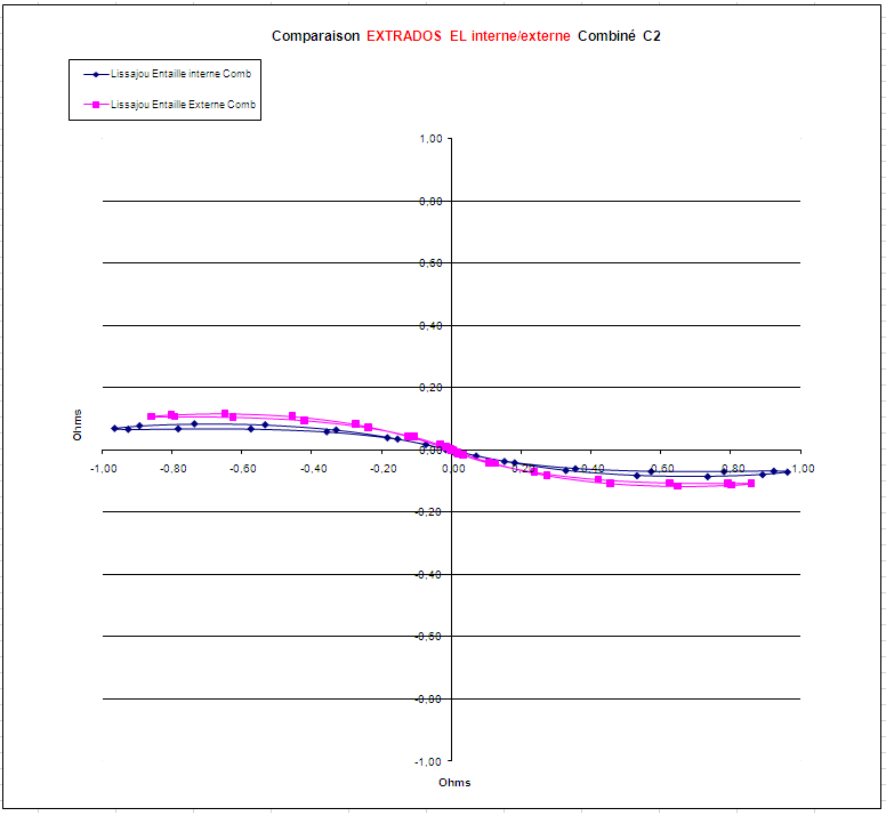
Flaw	Channel	Amplitude (mV)	Phase (degree)*
CIN - Circumferential Internal Notch	C2	1349.5	-1.4
CEN – Circumferential External Notch	C2	1334.3	2.7

* Convention: Positive in the clockwise direction

RESULTS OBTAINED

UPPER SURFACE

- The channel C2, obtained after frequency mixing, has been analysed :
  - Longitudinal Notches: ID / OD
  - Circumferential Notches: ID / OD



Flaw	Channel	Amplitude (mV)	Phase (degree)*
LIN - Longitudinal Internal Notch	C2	1931.7	4.1
LEN – Longitudinal External Notch	C2	1732.0	7.1

Flaw	Channel	Amplitude (mV)	Phase (degree)*
CIN - Circumferential Internal Notch	C2	1264.2	-0.7
CEN – Circumferential External Notch	C2	1178.0	3.3

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*** Convention: Positive in the clockwise direction**

SYNTHESIS ON RESULTS

- For the 4 sets of notches, the ID Notch response gives always a higher signal amplitude than the OD notch:
  - Longitudinal notches
    - Inner Surface: + 18%
    - Upper Surface: +11%
  - Circumferential Notches
    - Inner Surface: +1%
    - Upper surface: + 7%

- Results confirm the hypothesis of DCNS

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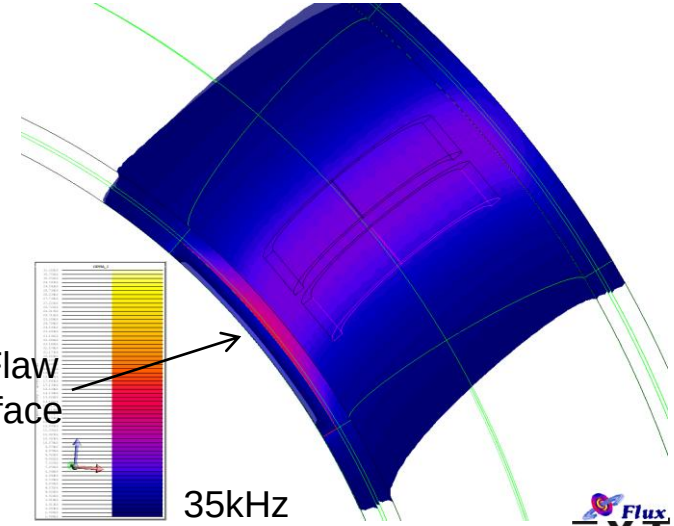
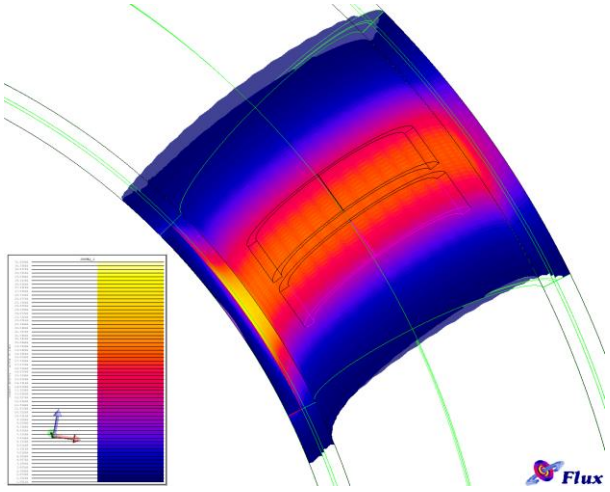
FIELD VISUALIZATION

- Simulation also provides the visualization of induced fields:
  - Check the zone coverage with the ET sensor
  - Check the impact of parameters (frequency, materials) on induced currents
  - Check the impact of flaws on eddy currents flowing



Longitudinal Flaw
OD/.Inner surface

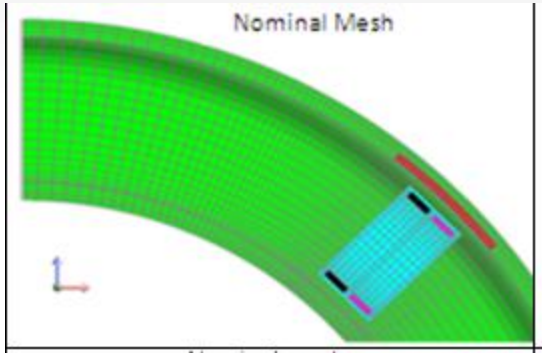
35kHz



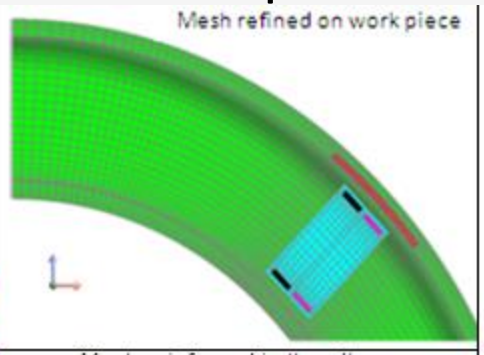
170kHz: Higher amplitude/ More concentrated field distribution

SENSITIVITY TO THE MESH

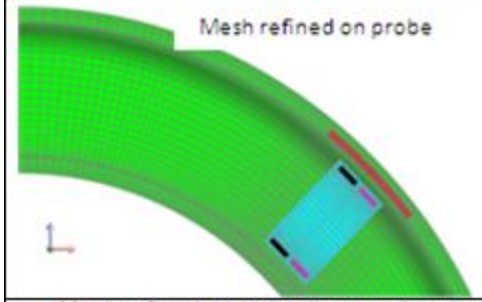
- To validate the model, a study of the sentivity of the model to the FEM mesh has been performed:



Nominal mesh :
338 440 second order elements



Mesh reinforced in the elbow:
564 870 second order elements



Mesh refined on both elbow and probe:
699 790 second order elements

Mesh	Variation amplitude	Phase value
Nominal	Reference	92.5°
Refined in the elbow	-2.99 %	92.5°
Refined in both elbow & probe	-2.99 %	92.5°

Comparison of the different results

- Nominal mesh validated

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EXPERIMENTAL VALIDATION

- Comparison with experimental acquisition : Channel C2
  - Case: Longitudinal Notches on the upper surface

Défaut	Simulation	Experiment	Difference
ID - Amplitude	1931.7mV	1912mV	**1%**
ID- Phase	4.1	5	**0.9**
OD - Amplitude	1732mV	1656mV	**4%**
OD - Phase	7.1	7	**0.1**

- Very good agreement

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CONCLUSION

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CONCLUSION

- Context: Qualification of ET inspection of SGs in embedded nuclear vessels
- Simulation study aims at evaluating the impact of the position of notches in the OD or in the ID in the bended part of the tube
- Modelling with the FEM code FLUX, accounting for the whole inspection procedure
- Very good agreement Experiment/Simulation
- Results confirm the hypothesis that the response of internal notches (ID) gives a stronger signal
- Allows to reduce the number of mock-up required for the qualification by only considering the worst case: Notches on the OD

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