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APPLICATION OF EDDY CURRENTS TO THE INSPECTION OF FATIGUE-CORRODED RAILWAY AXLES

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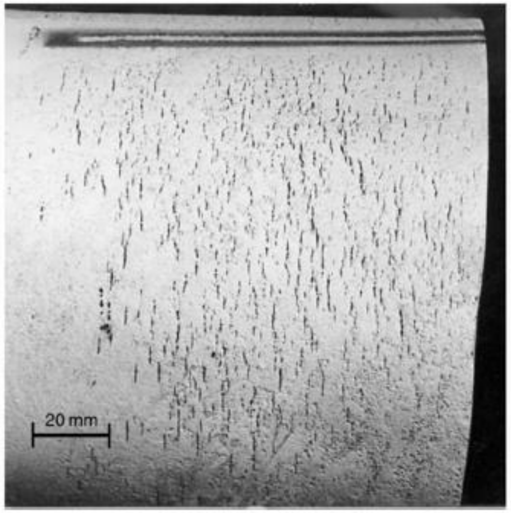
✓ **Corrosion-fatigue**: simultaneous and synergic application of a corrosive environment and cyclic loads

✓ Some documented **failures** of railway axles due to corrosion-fatigue:

- 08/03/1996 Stafford
- 29/01/1998 Scotland
- 21/06/2002 Nottingham
- 1998-2000 reported by the Transportation Safety Board of Canada

✓ Examples of **damage** and **failures** due to corrosion-fatigue



Challenges

- ✓ The physical phenomenon is **not yet** fully understood and known, especially considering the railway industry

- ✓ There's the need to **monitor** surface damage of axles during service! No standardised procedure is available for inspecting corrosion-fatigue

- ✓ **Today:** UT and MPI are usually applied to detect initiation and propagation of fatigue cracks at press-fit seats and transitions

- ✓ **Aims:** to get clues on the phenomenon by means of experiments and numerical simulations. To investigate the possibility to apply eddy currents to the detection of corrosion pits and corrosion-fatigue cracks during the service of railway axles

Challenges

The present investigations were carried out in the frame of:

- The on-going European Project **WOLAXIM** (end expected by October 2012) aiming the development of different NDT techniques for inspecting and individuating corrosion-fatigue phenomena in railway axles

- The recent international scientific collaboration **T728** carried out between 2009 and 2010 by Deltarail, TWI and PoliMi for RSSB aiming the understanding of the corrosion-fatigue phenomenon on UK railway axles

Driving force for ET

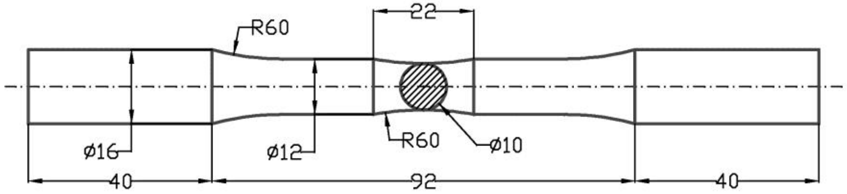
- Highly innovative for the railway field
- Good for inspecting surface damage
- It can be automated

Methodology

- Experiments on small-scale specimens (A1N)
- Numerical simulations

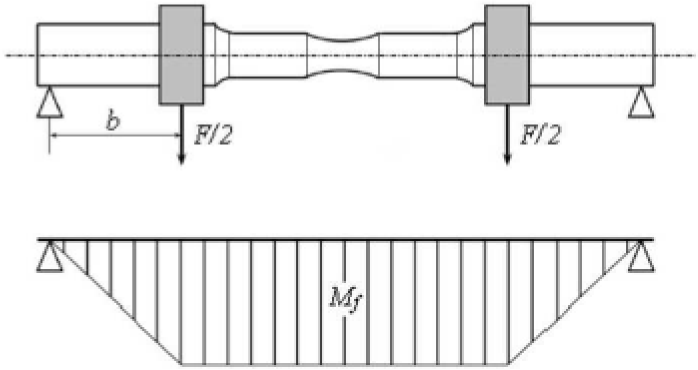
Experiments on A1N small-scale specimens

✓ Specimens geometry

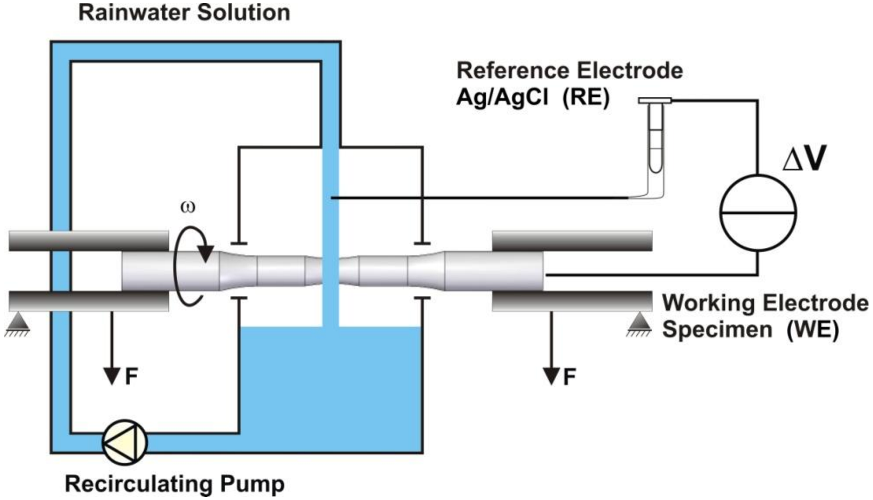


✓ Test facility

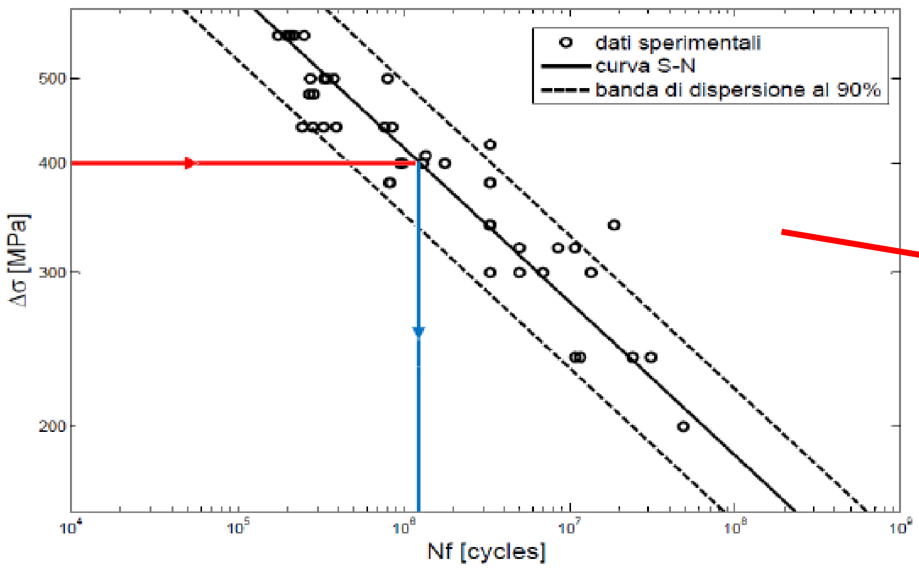
✓ Rotating bending moment (4pb)



✓ Experimental set-up



Test plan



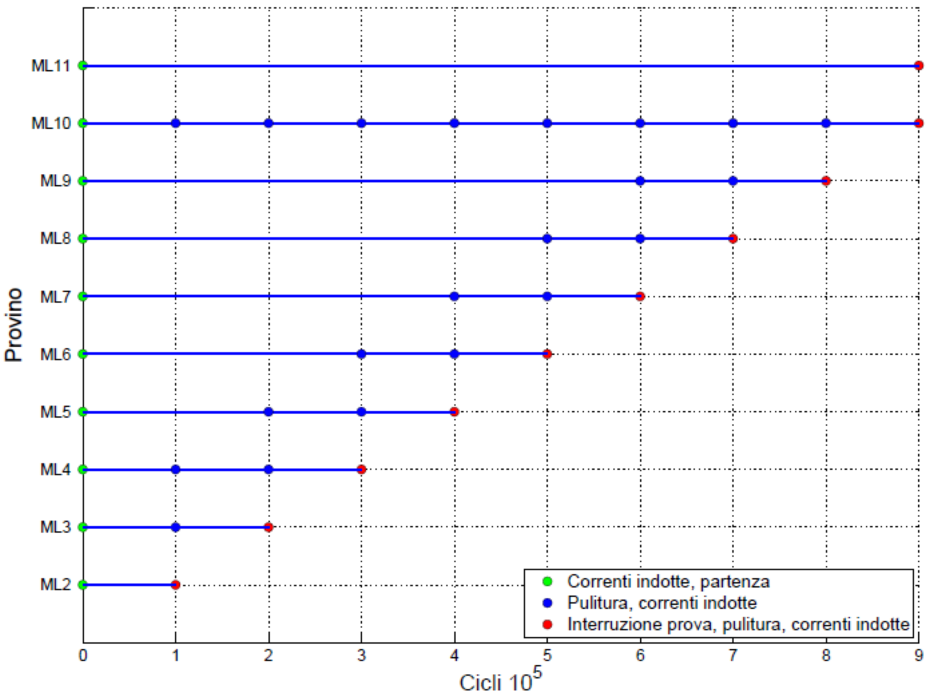
✓ **Test conditions:**

- $\Delta\sigma$ = 400 MPa
- ***Rotating speed*** = 600 rpm

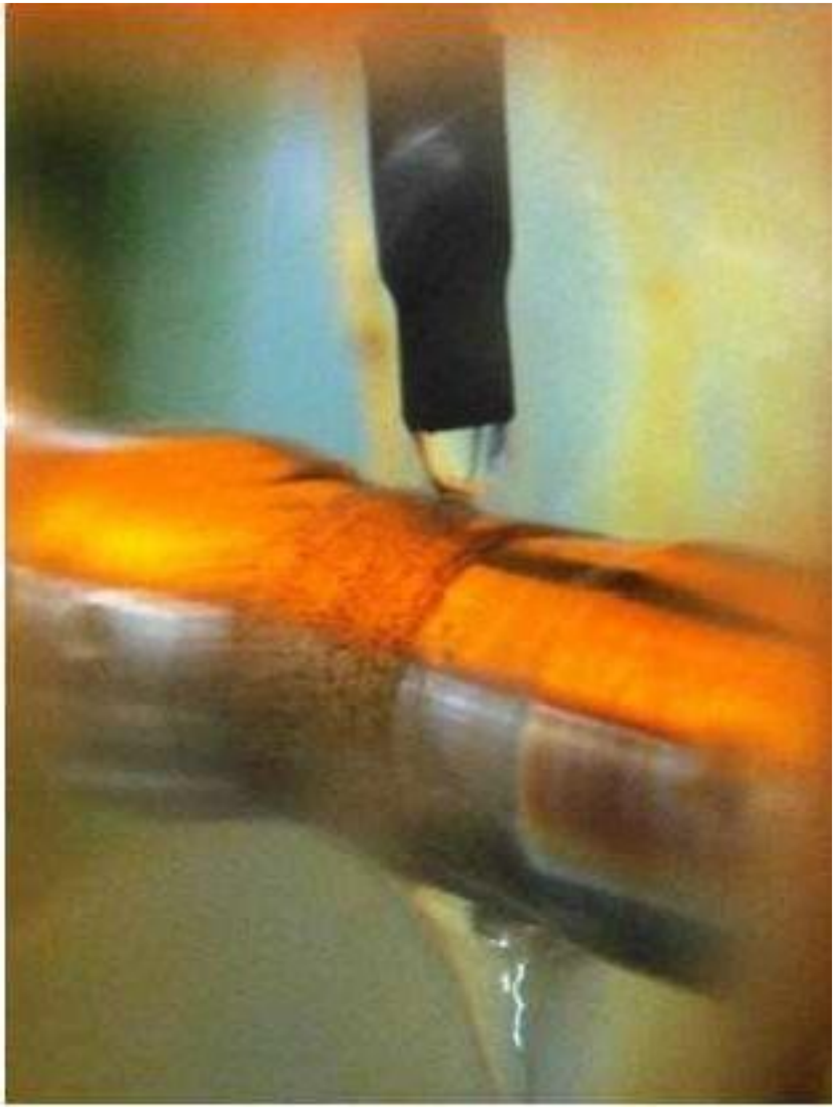
Estimated fatigue life: 1 million cycles

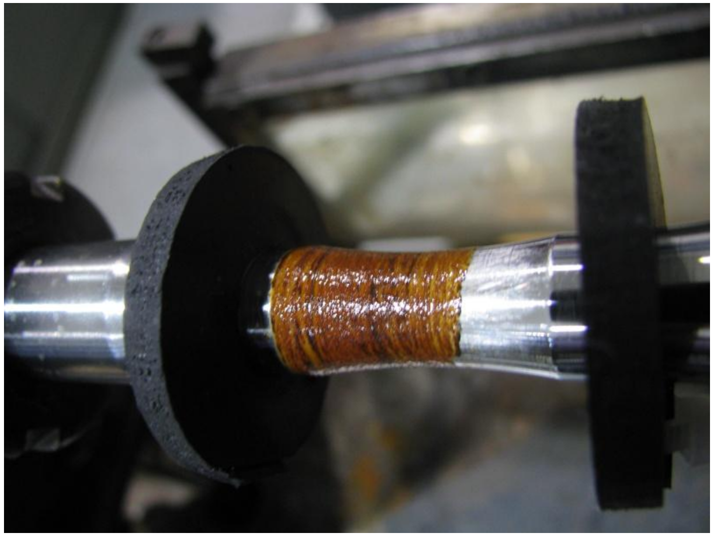
✓ **Aims:**

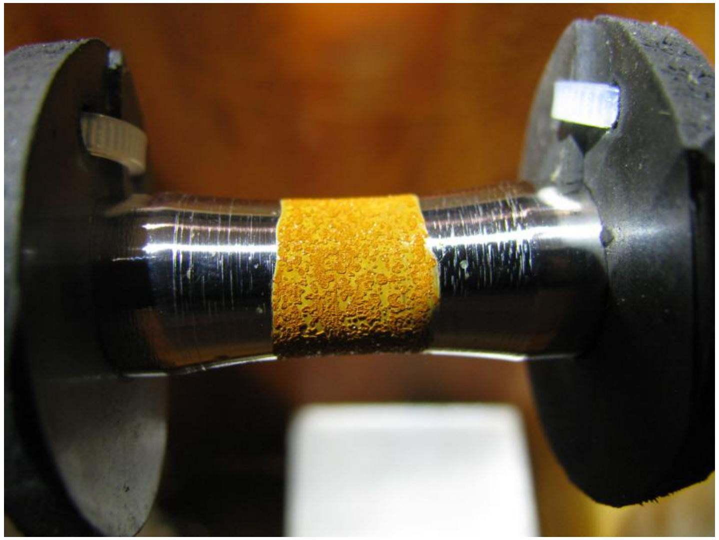
- Investigate the development of surface damage
- To allow for at least four eddy currents measurements for every specimen



Examples of fatigue-corroded specimens

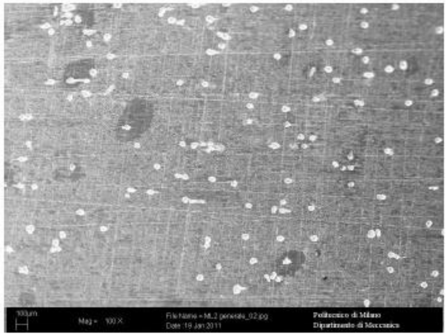


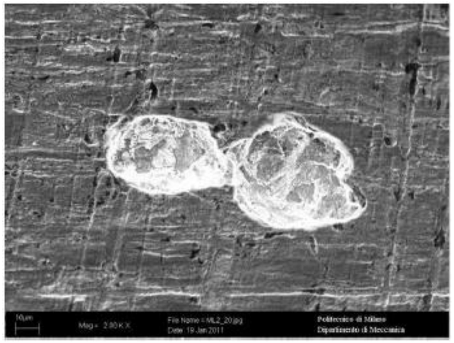




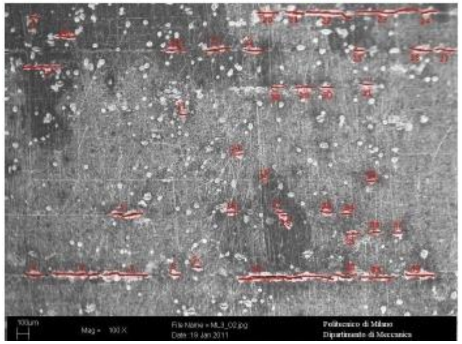
Development of surface damage

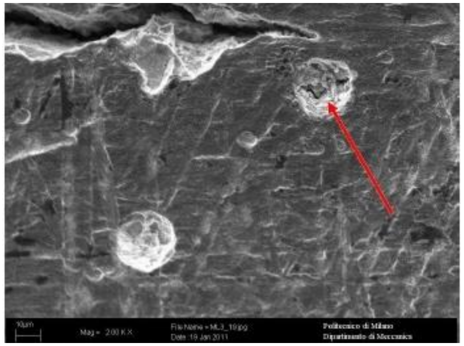
Specimen ***ML2*** (100.000 cycles)



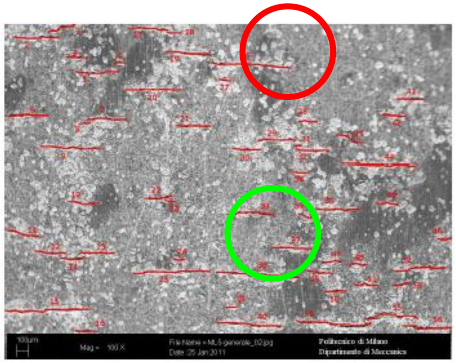


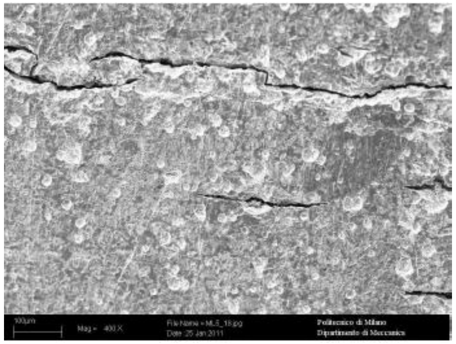
Specimen ***ML3*** (200.000 cycles)





Specimen ***ML5*** (400.000 cycles)





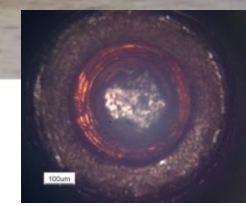
Eddy current testing - Instrumentation

✓ Nortec 1000S+

The calibration of the working frequency was carried out using an artificial known defect located on a specimen made of A1N

✓ Absolute probe

500 - 1000 kHz: 500 kHz

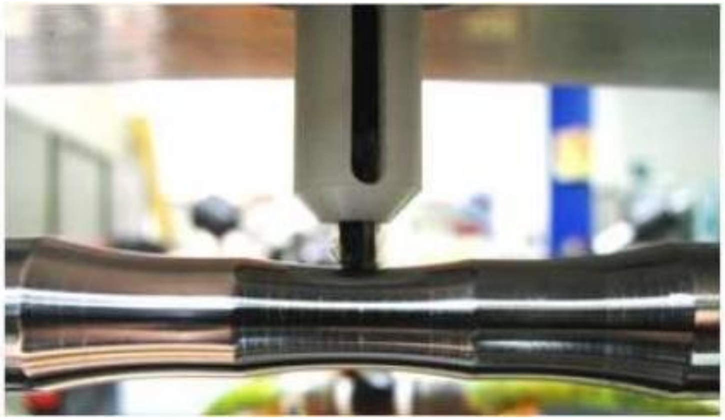


✓ Differential probe

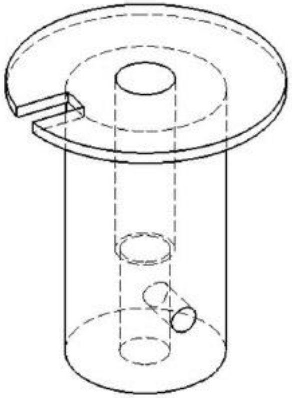
500 - 2000 kHz: 620 kHz

Experimental set-up

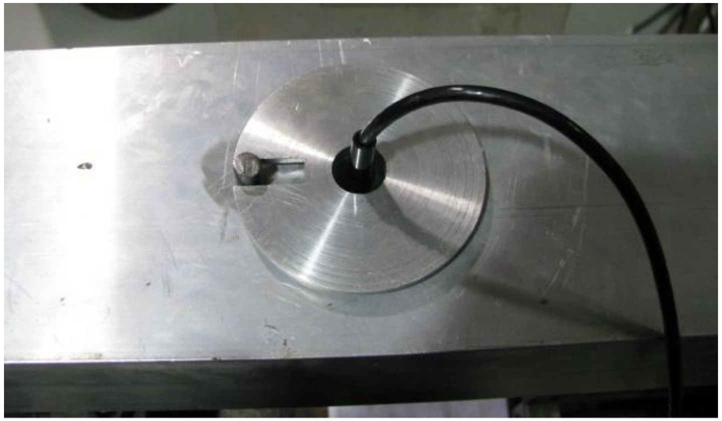
- ✓ Measurements repeatability: suitable frame and contact inspection



- ✓ Probe holder



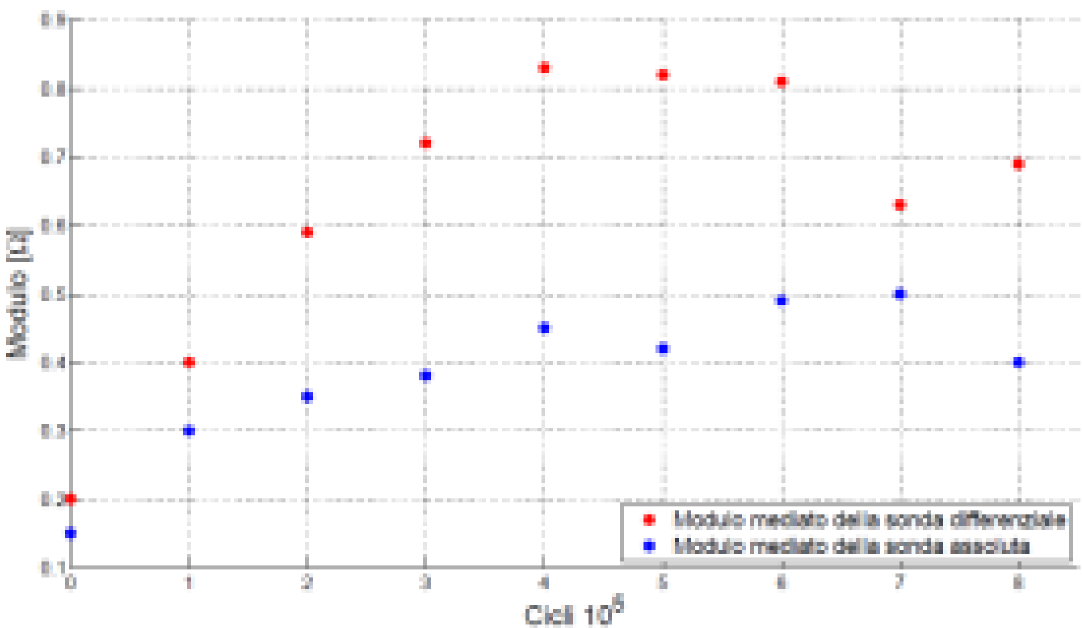
- ✓ Anti-rotation system



Experimental Results

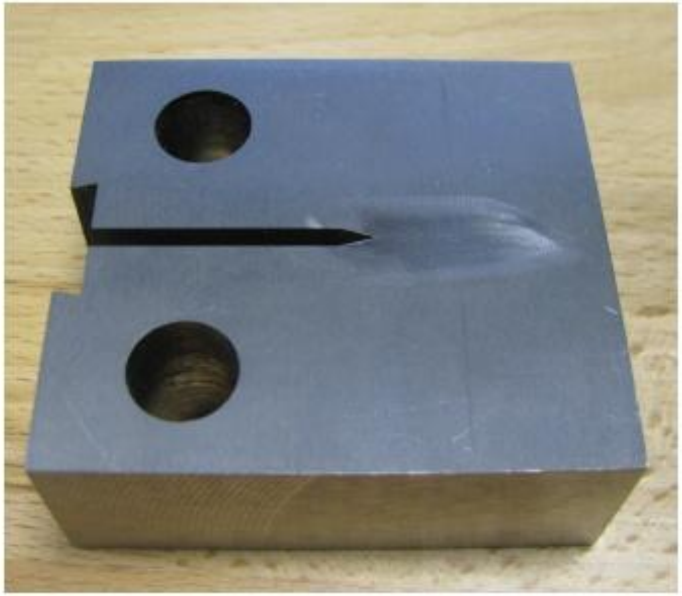
The measurements consisted in the acquisition of the eddy current response:

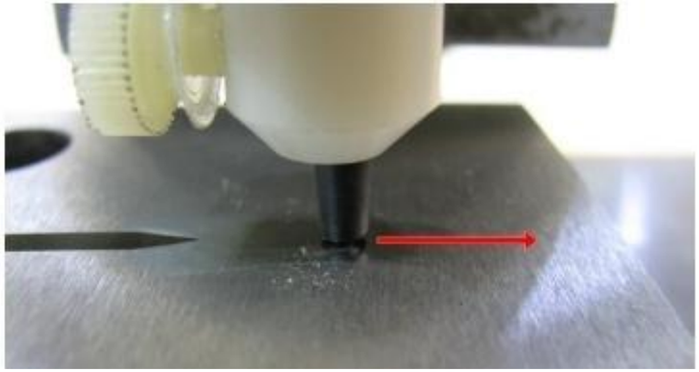
- along a complete **circumferential revolution** (360°) of the specimens: this means that all the prospective cracks were longitudinally inspected.
- at **1** rpm.



- The differential probe seems to be more performing
- At 0 cycles an impedance variation could be observed
- Two regions: linear and saturated

Which could the **interpretation** for the saturated responses be?





R=2.06 mm

Numerical simulations

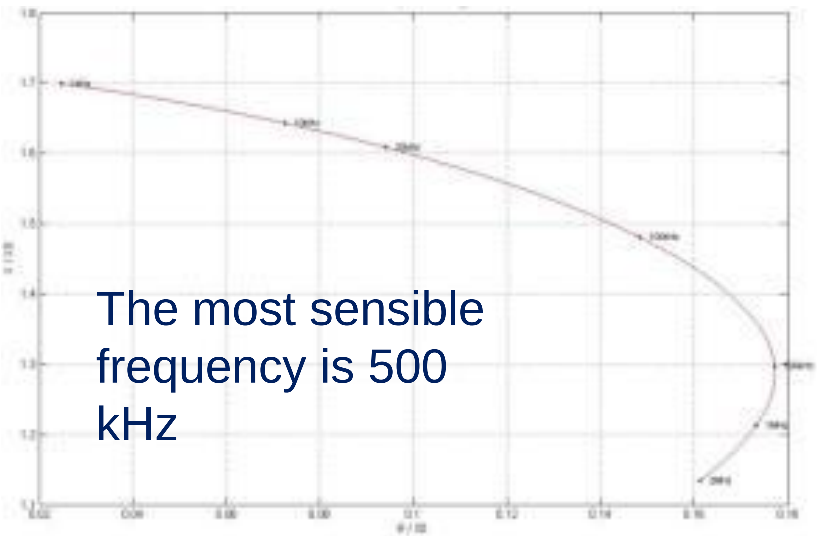
- Numerical simulations were carried out In order to interpret and understand some of the obtained experimental results by means of **CIVA^{nde} v.10.0b**

- Only the **absolute** probe was considered

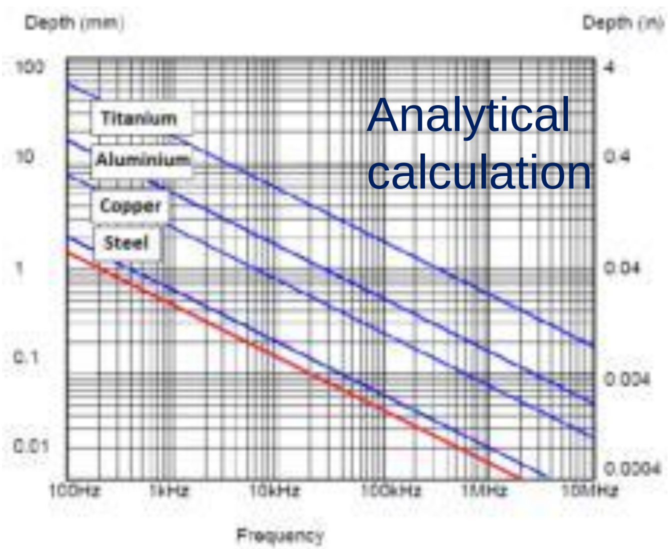
- The general geometry of the absolute probe coil was derived by a **reverse engineering** procedure based on radiography and optical microscopy, the details are **not** provided due to the proprietary nature of the information

- A 50x50x5 mm **panel** made of a general carbon steel similar to A1N grade (electrical conductivity s=6.2 MS/m and magnetic permeability m =200 H/m) was considered instead of the real cylindrical geometry which is not available in CIVA.

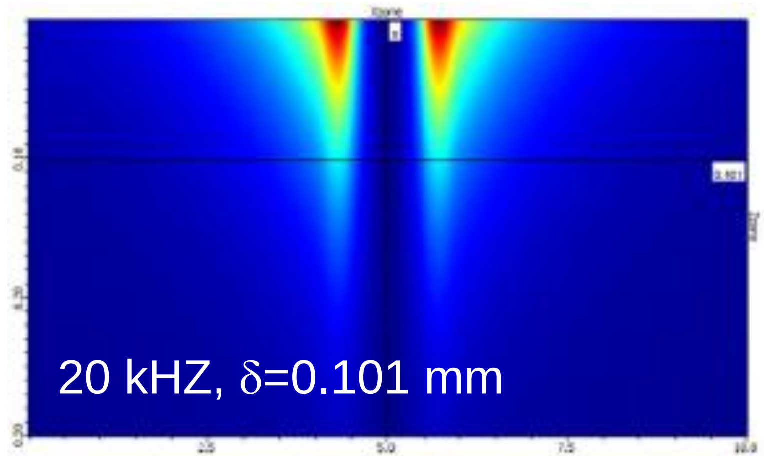
Preliminary numerical simulations



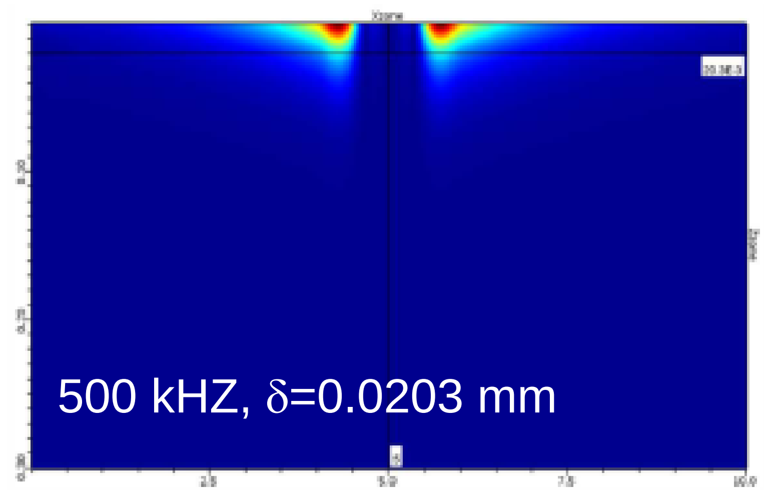
The most sensible frequency is 500 kHz



Analytical calculation



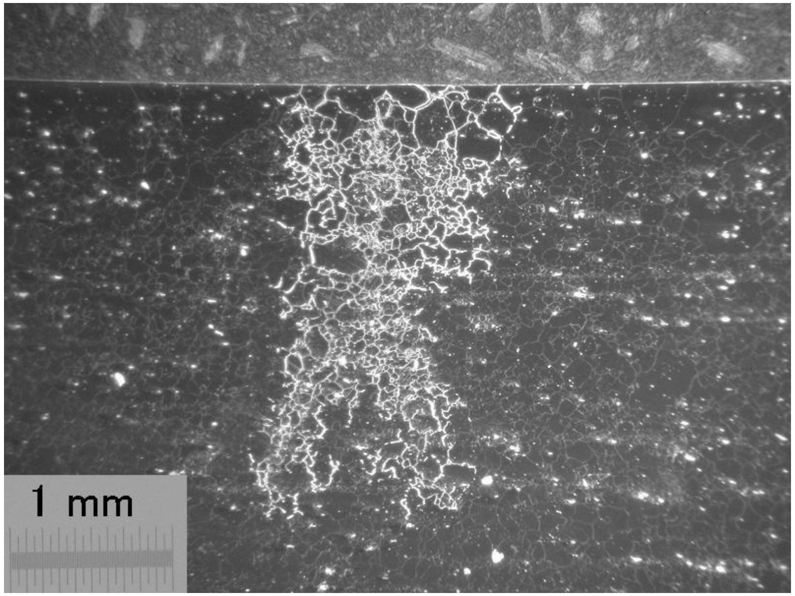
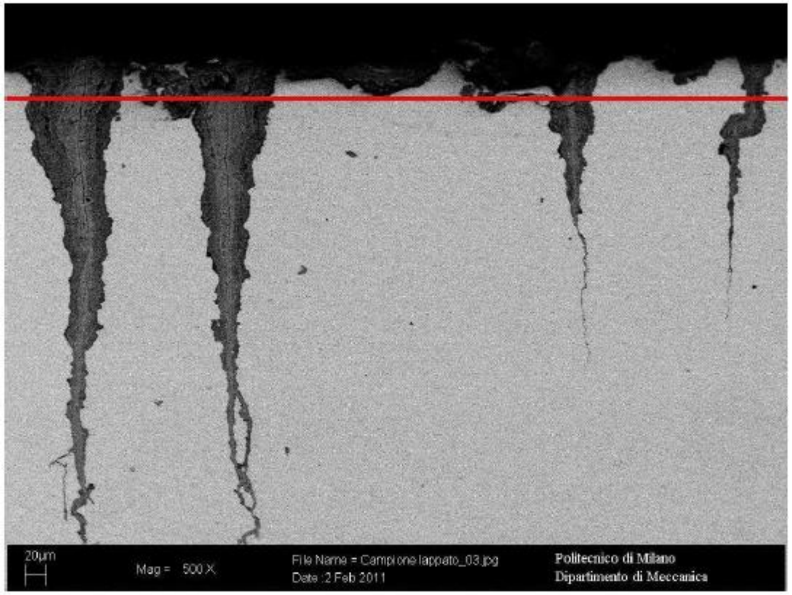
20 kHZ, δ=0.101 mm



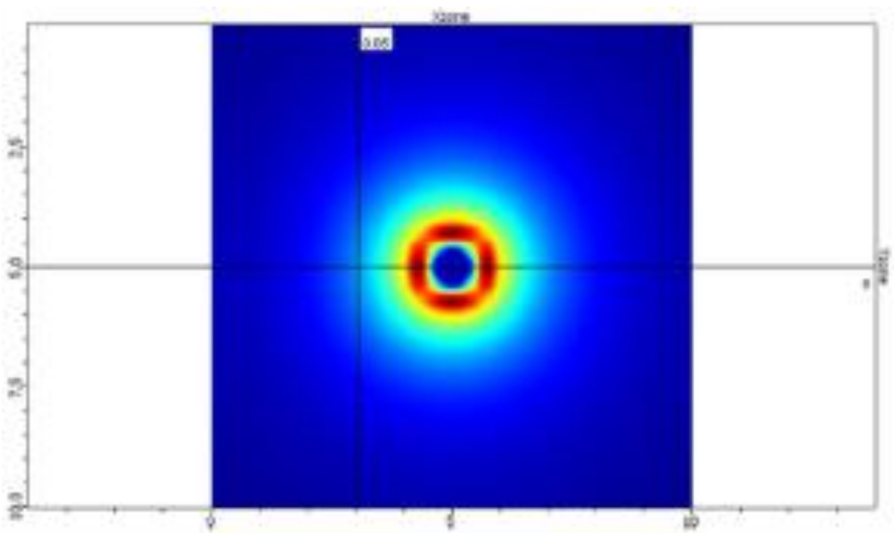
500 kHZ, δ=0.0203 mm

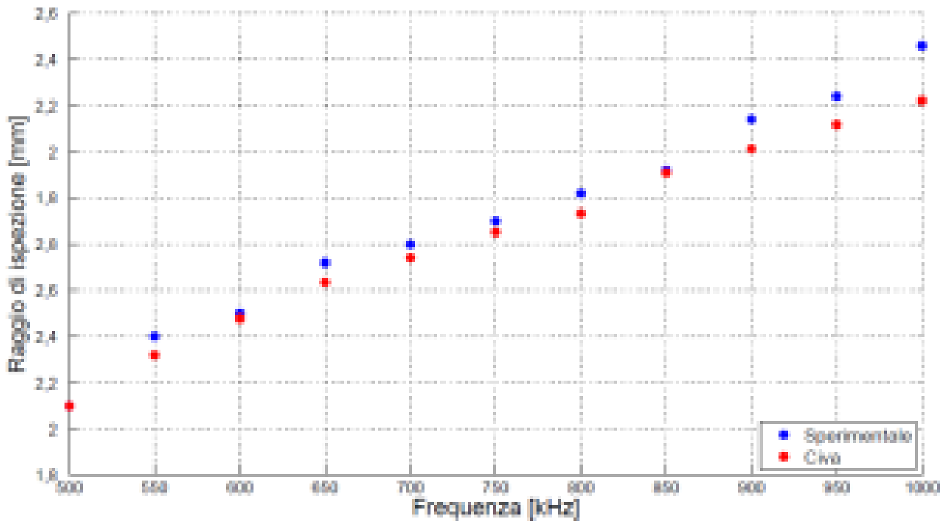
Very similar to analytical values

Preliminary numerical simulations

Stress corrosion	Corrosion-fatigue
	
Are low frequencies better?	Are high frequencies better?

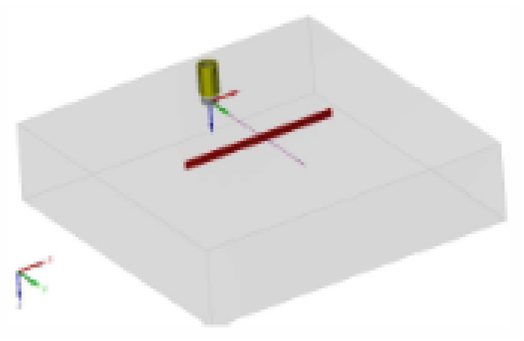
The last preliminary simulation regarded the **inspection radius**

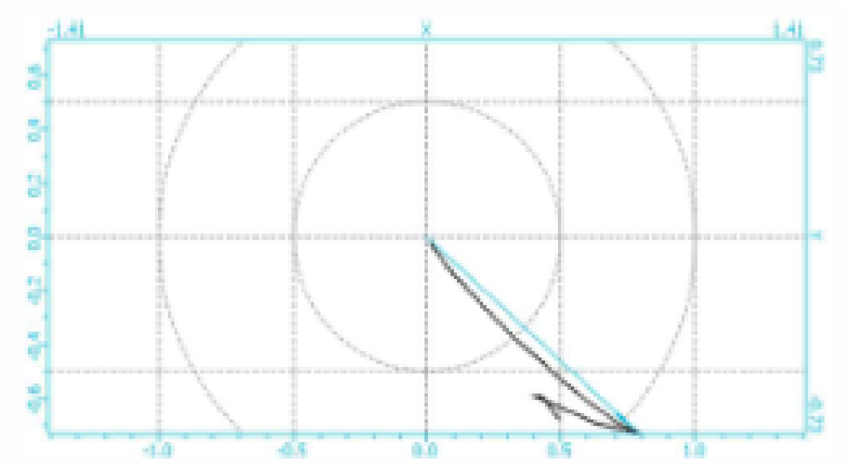




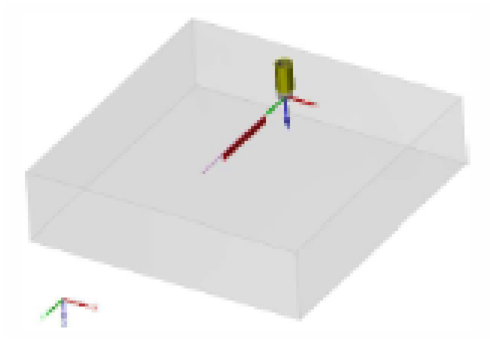
The **inspection radius** trend is very similar between experiments and simulations varying the working frequency

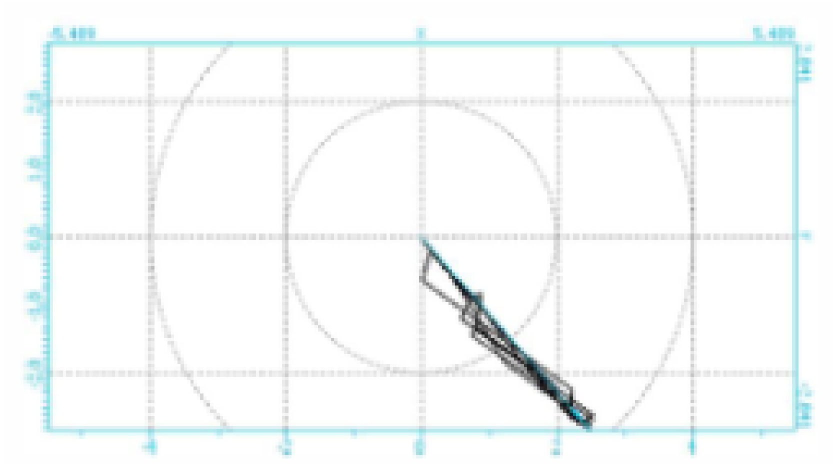
Scanning direction





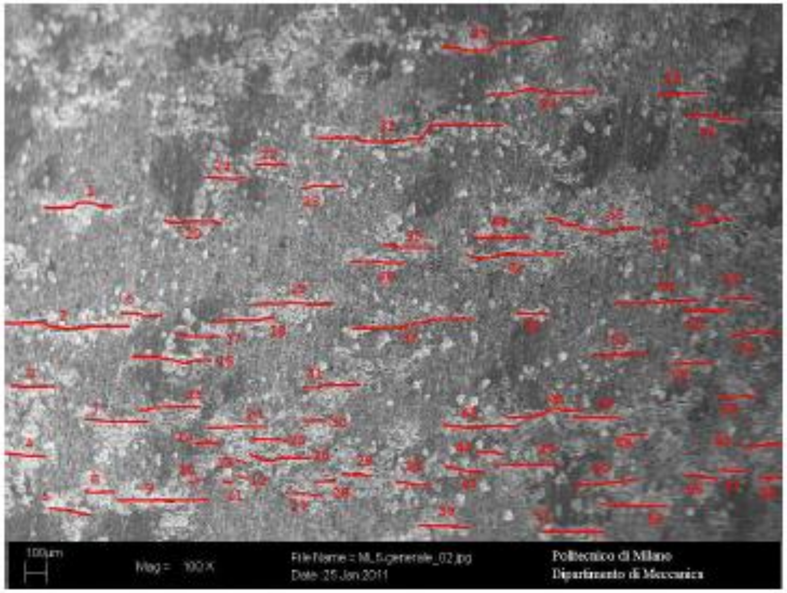
Phase: -43°
Module: 1.072 mV

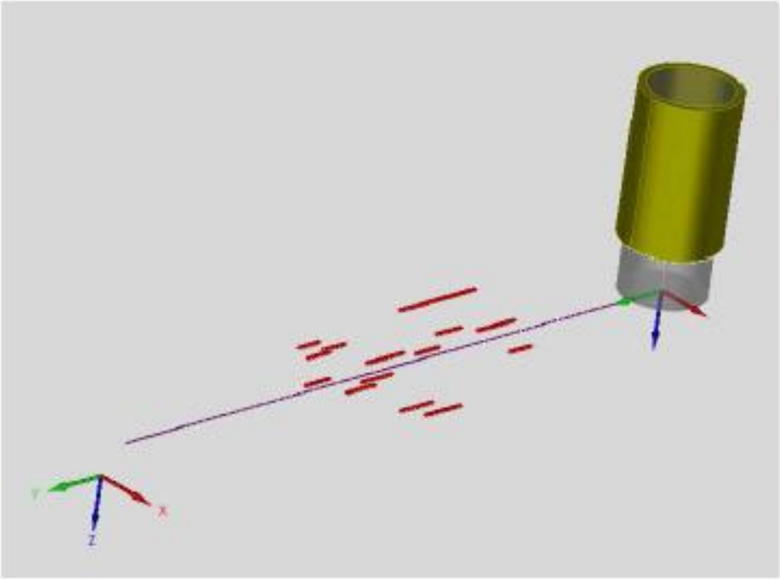




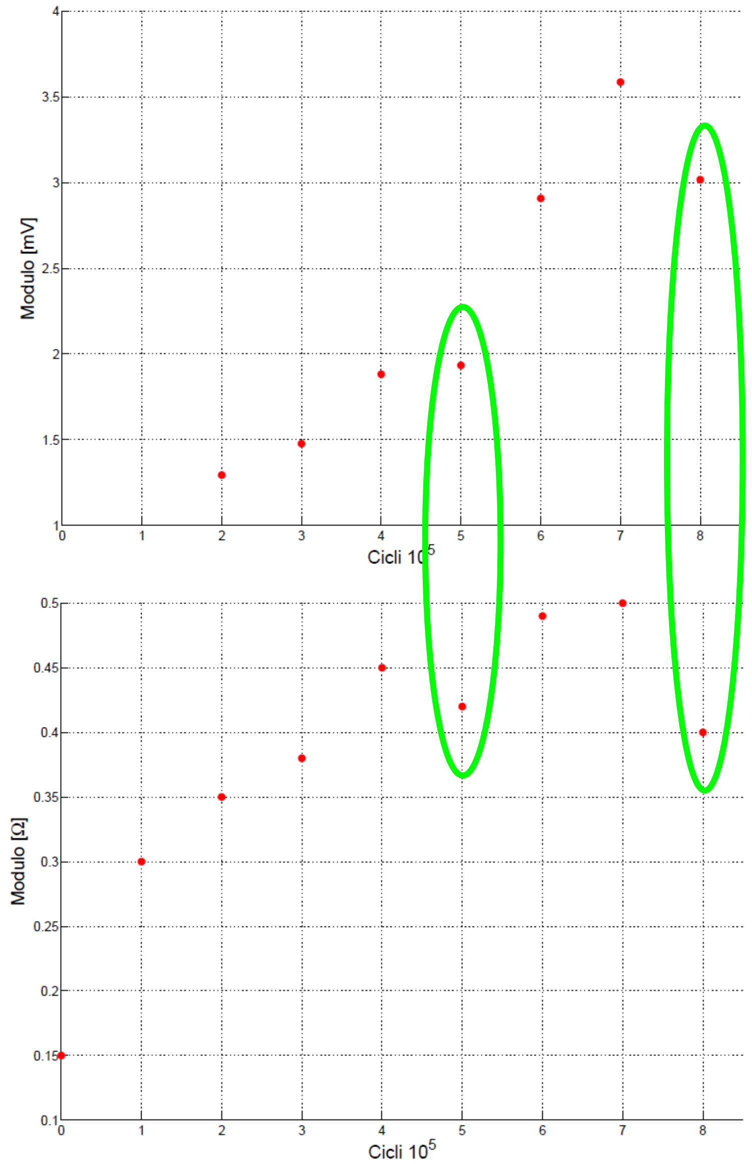
Phase: -49°
Module: 3.77 mV

- ✓ **Multi-crack** simulation starting from defects taken from a micrograph
- ✓ The 15 longest cracks were considered





Simulation of ET inspections on specimens



- ✓ Qualitative comparison
- ✓ Increasing linear trend
- ✓ Two not linear results

Conclusions

✓ **Experiments:**

- Crack initiation at 200.000 cycles at $\Delta\sigma$ = 400 MPa
- Different stages of coalescence
- Eddy currents
  - differential probe better than absolute one
  - increasing response till a stabilised value
  - saturation due to very complex damage pattern

✓ **Numerical simulations:**

- A careful numerical calibration could be obtained
- The best working frequencies for corrosion-fatigue are significantly higher than those useful for stress corrosion
- Inspection radius: multiple cracks are inspected at the same time, it is not useful to consider and to study the response of a single crack
- Scanning longitudinally a crack seems to be better than transversally
- Multi-crack simulations show good qualitative performance with respect to the module response coming from experiments