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POLITECNICO DI MILANO

A "Model Assisted Probability of Detection" approach for ultrasonic inspection of railway axles

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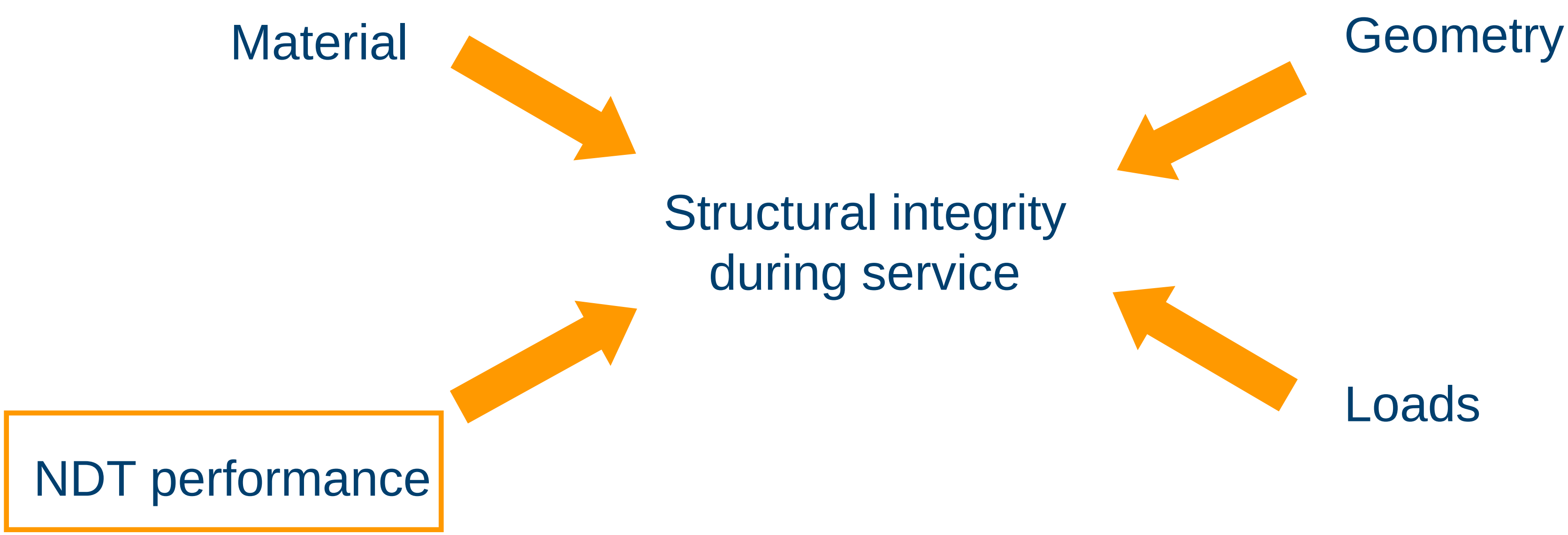
Introduction

Fatigue is the most important source of failure for mechanical components during service

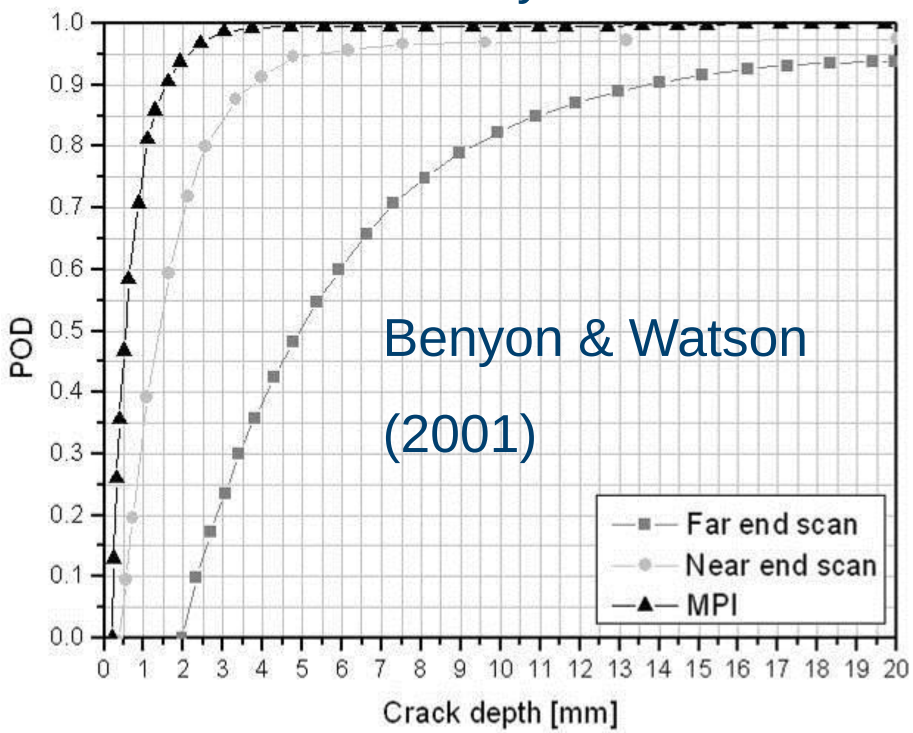
Particularly, initiation sites, in the most critical sections, can be observed in correspondence of production or service defects (also due to the environment)

The most appropriate design approach in this scenario is the Damage Tolerance: to determine the most opportune inspection interval given the POD curve of the adopted NDT method or vice versa



NDT performance is usually quantified and summarised using the POD curve which relates the probability to detect a defect to a characteristic linear dimension (length, depth, diameter, …)

Railway axles



Actually, a POD curve is also a function of many other factors:

- material
- time of flight
- geometry
- equipment
- operator (human factor)
- …

Consequently, it is rarely possible to apply the POD curve obtained for a given configuration to another one, even if similar

Introduction

Another critical aspect of POD curves is the need to statistically characterise the largest defect that can be missed and not the smallest that can be detected

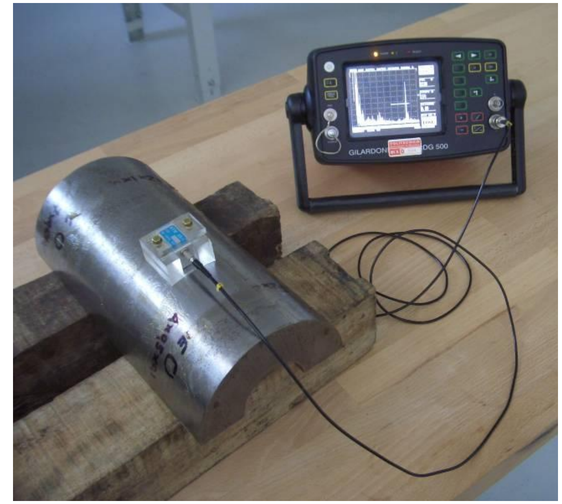
Consequently, POD curves should be always given together with a suitable confidence level (usually 95%) needing a high number of tests to be determined

In the present research, the special case of the UT inspection of hollow railway axles made of A4T steel is considered in order to:

- describe a novel methodology for the interpretation of UT responses with the aim to generalise, at least for some aspects, the POD curve
- investigate the possibility to apply the Model-Assisted Probability of Detection (MAPOD) methodology where, with the aim to diminish the experimental effort, part of it is substituted by proper numerical simulations

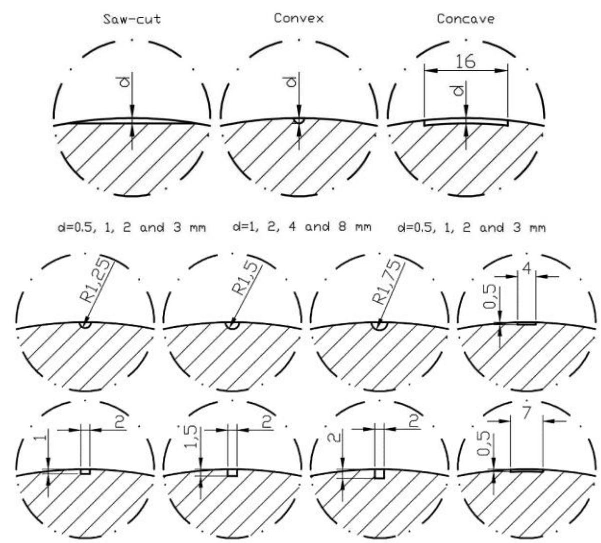
“Reflecting Area” approach

- Gilardoni RDG500
- Probe: ATM 45/4, 8x9 mm
- Plexiglas wedge (V_L=2700 m/s and V_S=1100 m/s)
- Coupling: grease
- Reference: 48 dB

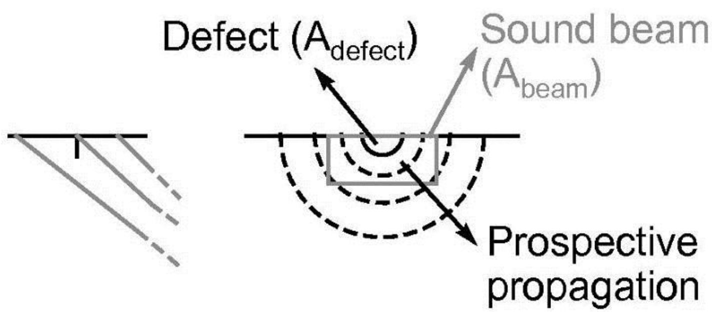


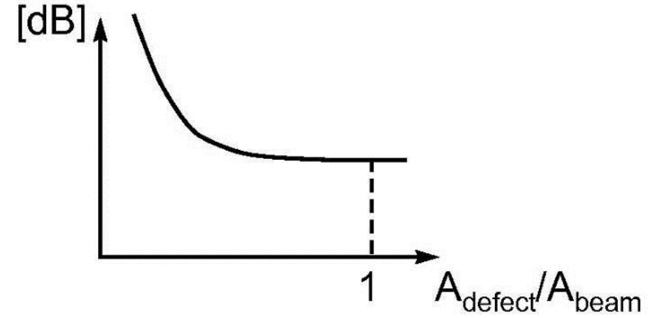
- Hollow axles: D_{ext}=152 mm, D_{int}=65 mm
- A4T: V_L=5920 m/s and V_S=3230 m/s

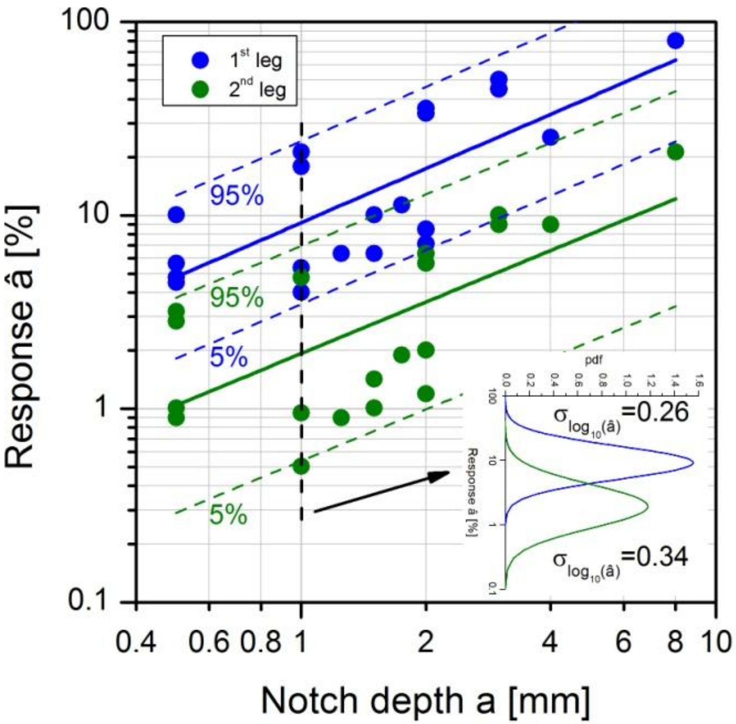
- Twenty artificial defects
- 1st leg and 2nd leg inspections

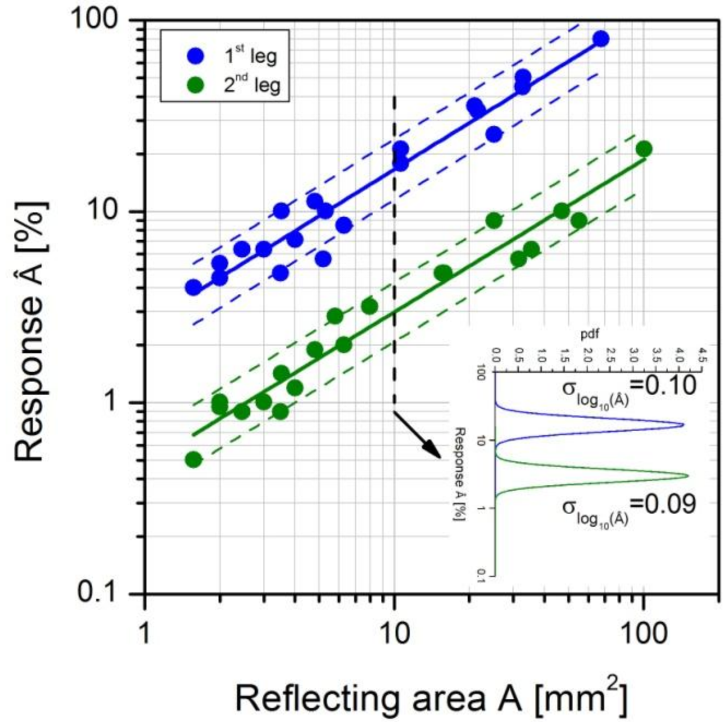


"Reflecting Area" approach

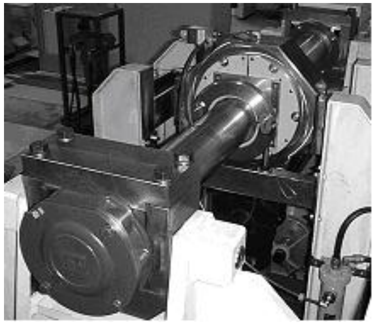


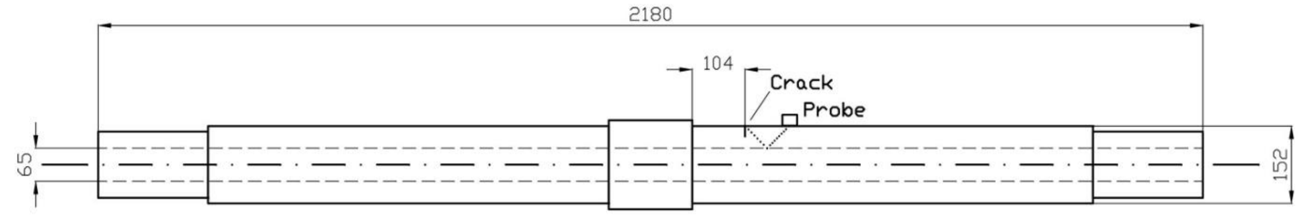


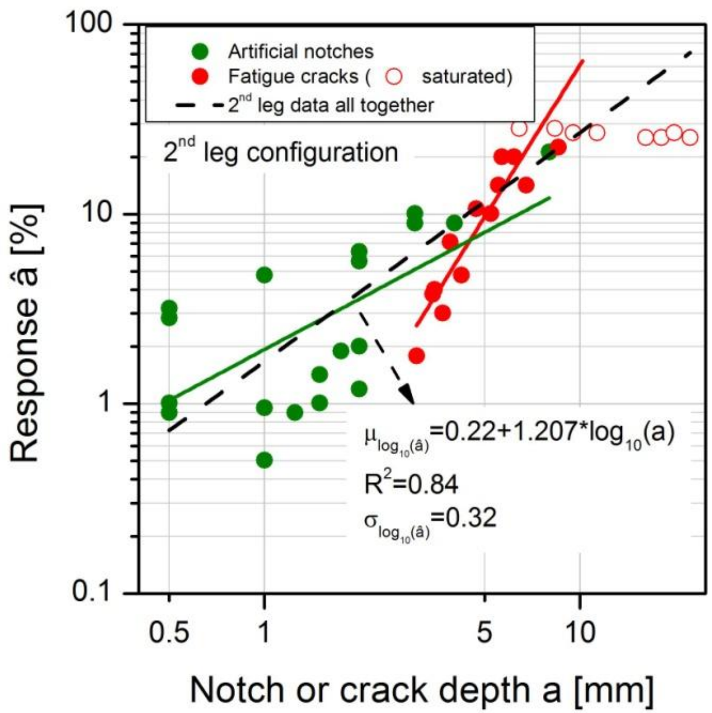


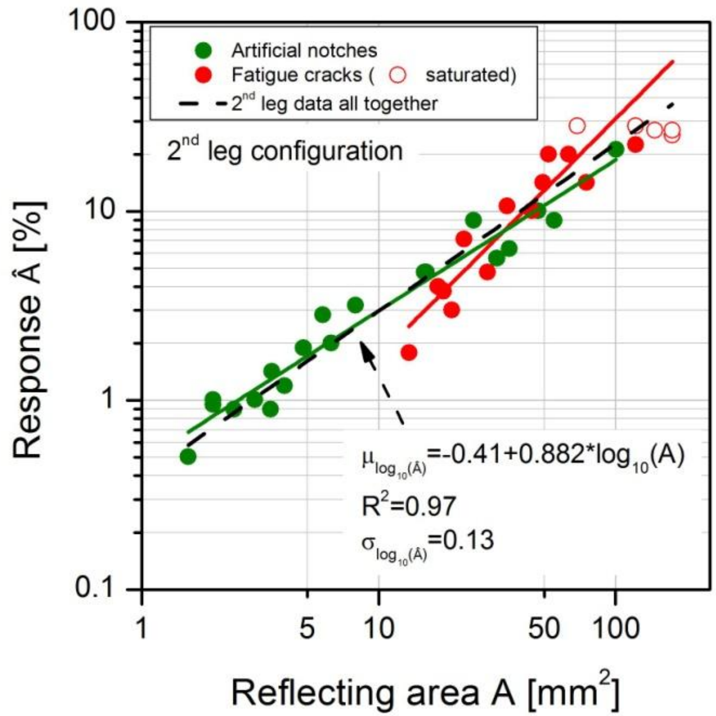


"Reflecting Area" approach









“Reflecting Area” approach

It is possible to conclude that:

- defects characterised by different shapes, but the same depth, can have completely different POD curves
- depth is not the best parameter to characterise UT responses, the area actually invested by the sound beam seems to give more consistent results
- adopting the proposed approach, POD curves assume a more general applicability because independent from the defect shape

Unfortunately, the results shown so far, required an expensive amount of time and costs

So, why do not try a MAPOD approach ?

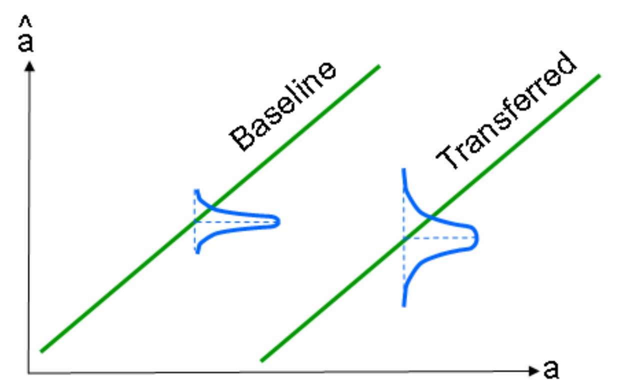
Numerical simulations for POD curves

POD curves are based on the statistical distribution of UT responses which, on the other hand, are controlled by numerous factors related to the adopted NDT procedure

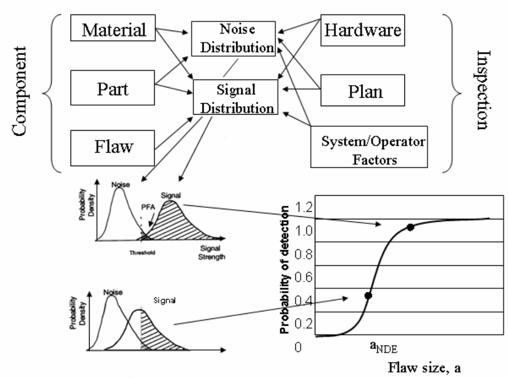
Today, many of such factors can be modelled and simulated by suitable physical and numerical models and MAPOD uses this possibility at its best

Unfortunately, MAPOD **does not** allow to completely avoid experimental tests because not all of such factors can be, at the moment, described by known physical models

Two different versions of MAPOD exist today



Transfer function

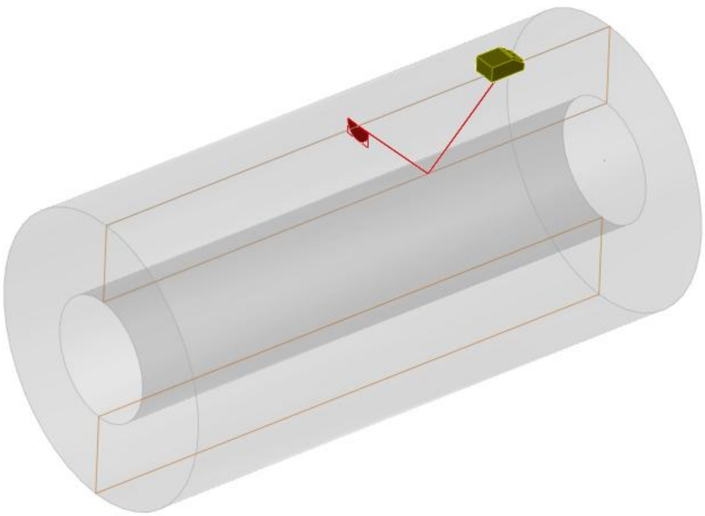


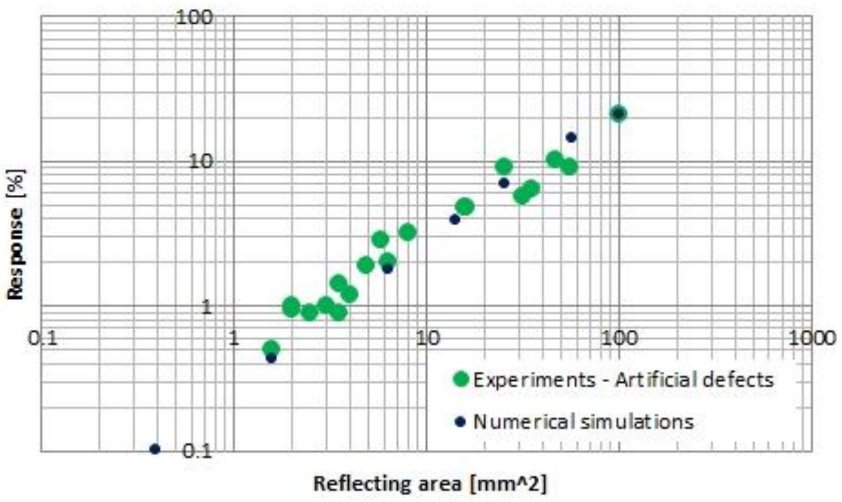
Complete approach

Numerical simulations for POD curves

Both the two versions can be successfully applied to the case of railway axles

In this research, the numerical tools used for simulations is CIVA 10.0b. Its calibration was carried out simulating the 2nd leg UT response of the 8 mm convex artificial defect and imposing to such response to be equal to the experimental one. Eventually, keeping the same gain, other defects with different reflecting areas (radius from 0.5 to 8 mm) were simulated





Transfer function

The calibrated numerical model was then used to predict 1st leg UT response of defects

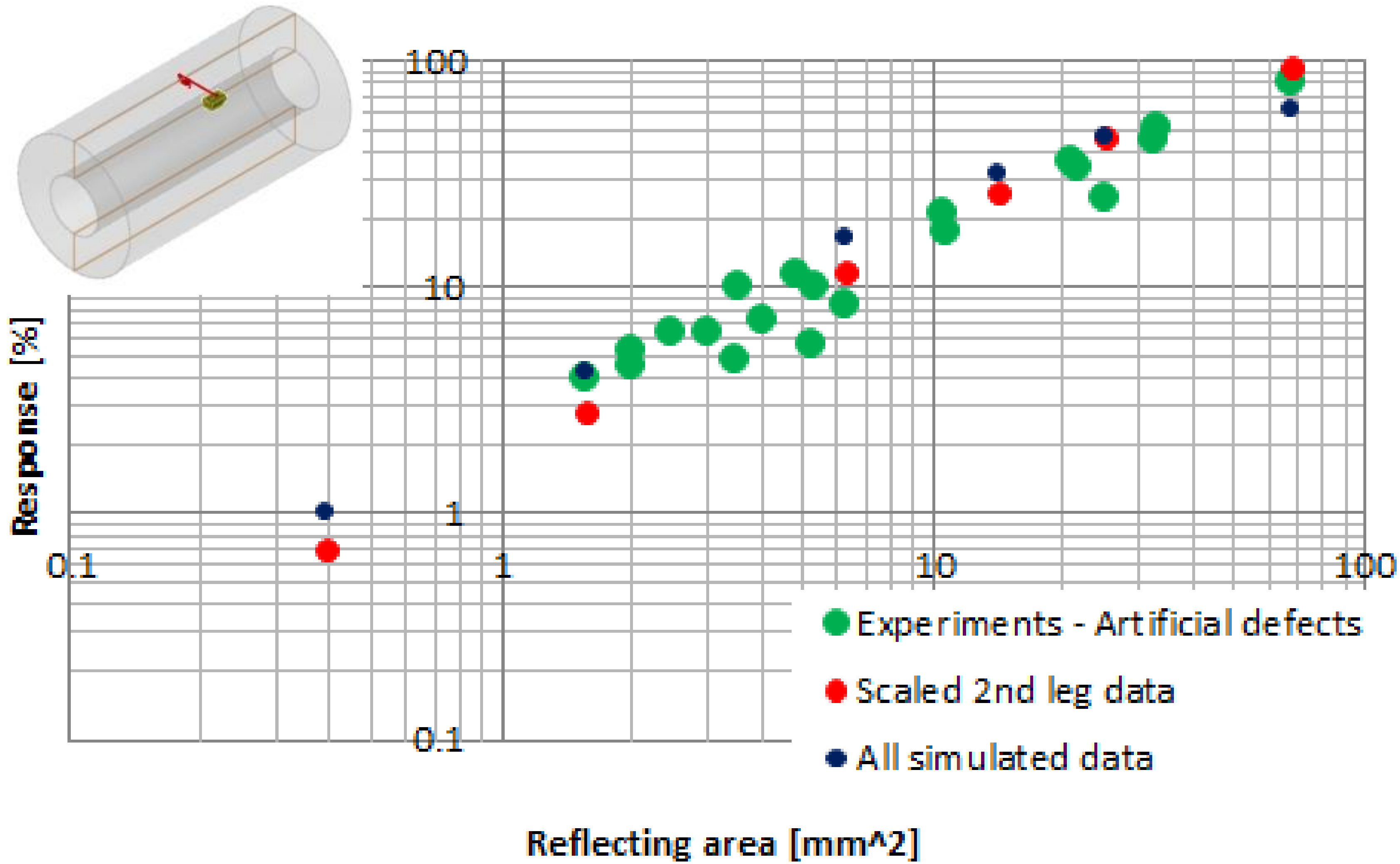
In this way:

- it was possible to consider a situation similar to the calibration, but with a significantly different parameter (time of flight)
- experimental responses in 1st leg configuration are available in order to validate the simulations

Two different sets of numerical results were compared to experimental results:

- “All simulated data”, where each numerical datum in 1st leg configuration was achieved by a dedicated CIVA simulation
- “Scaled 2nd leg data”, where only one UT response was numerically calculated and all the others were achieved by vertically scaling the 2nd leg numerical calibration data

Transfer function



Complete approach

The just presented results are a first simulation level useful for some kinds of analyses, but they are not able to provide useful info about the experimental intrinsic variability

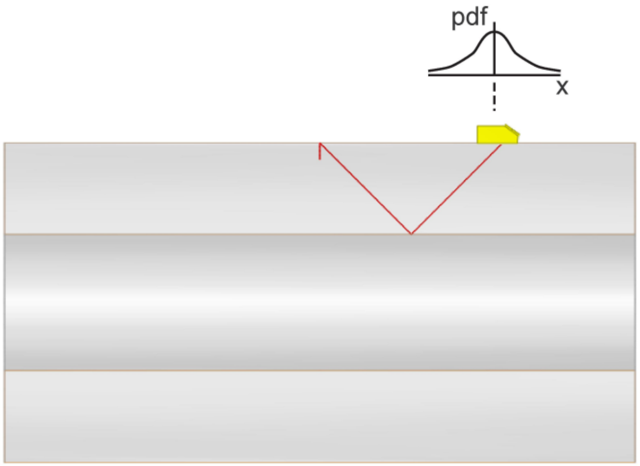
It is then necessary to apply the MAPOD complete approach which requires to adopt, during simulations and for each variability source, a suitable statistical distribution from which to extract values following a Monte Carlo methodology

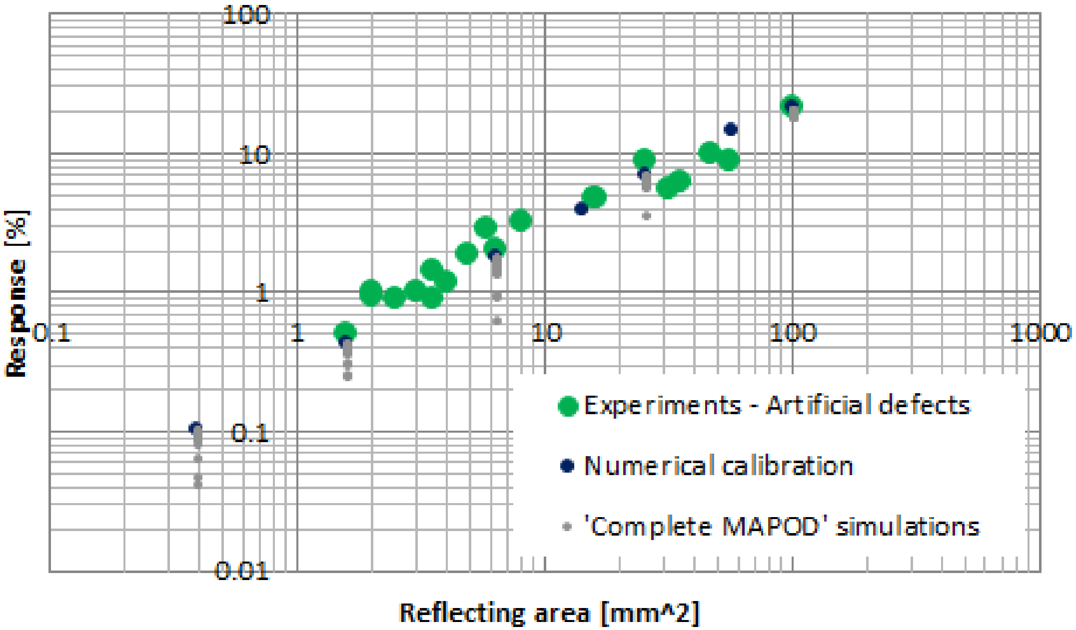
For simplicity, just one variability source was here considered: the longitudinal position of the probe

Manual inspection in 2nd leg configuration (traditional probe: 45°, 4MHz)

A Gaussian was adopted characterised by a mean equal to the position maximising the UT echo and CV=0.05

For each simulated defect (R=0.5, 1, 2, 4 and 8 mm), 30 runs were carried out (total 150)



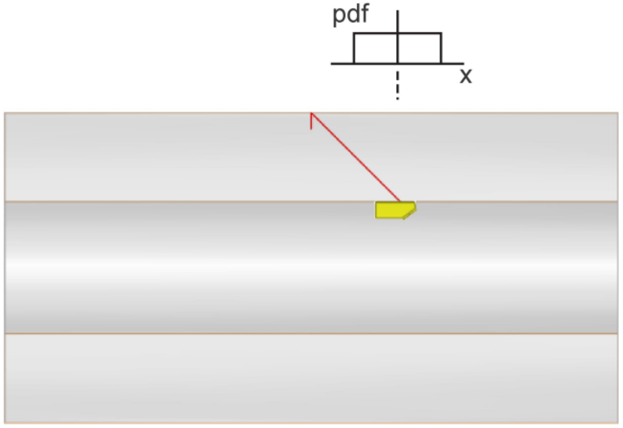


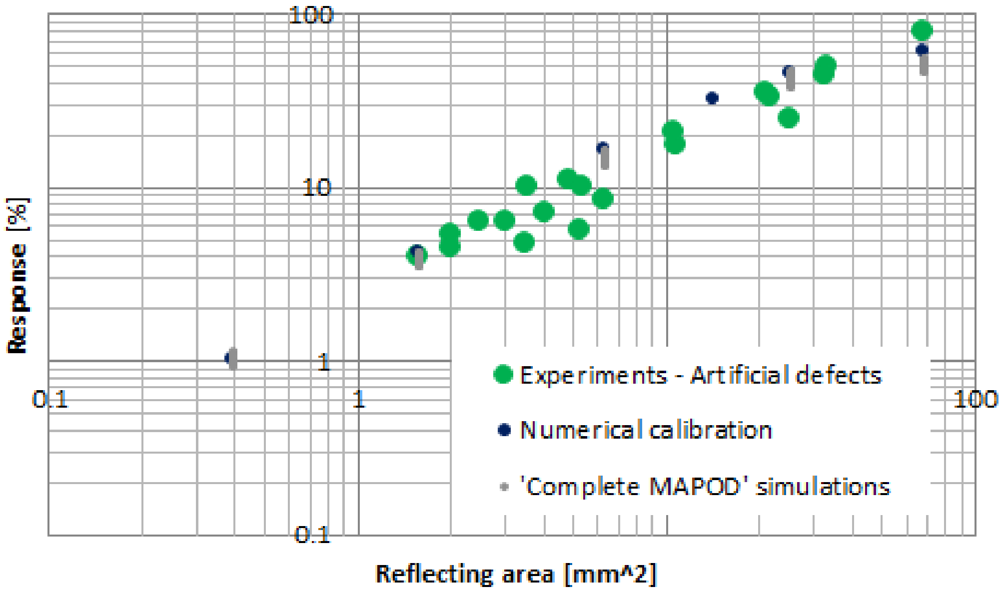
Complete approach

Automatic inspection in 1st leg configuration (boreprobe: 45°, 4MHz)

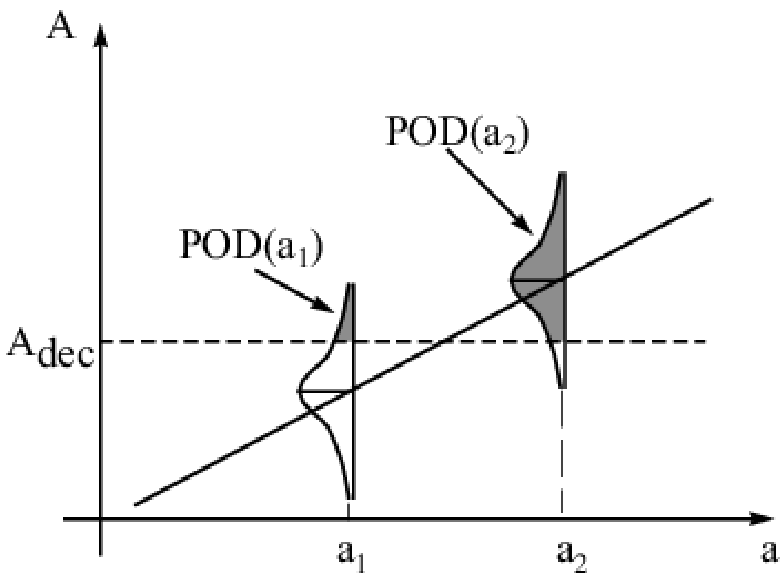
A Uniform distribution was adopted characterised by a range of possible positions, around the UT maximizing one, equal to ±2.5 mm

For each simulated defect (R=0.5, 1, 2, 4 and 8 mm), 30 runs were carried out (total 150)





Derivation of POD curves



$$POD(A) = \Pr\left[\log_{10}\left(\hat{A}\right) > \log_{10}\left(\hat{A}_{th}\right)\right]$$

$$POD(A) = 1 - F\left\{\frac{\log_{10}\left(\hat{A}_{th}\right) - \left[\beta_0 + \beta_1 \cdot \log_{10}(A)\right]}{\beta_2}\right\} =$$

$$= F\left\{\frac{\log_{10}(A) - \left[\dfrac{\log_{10}\left(\hat{A}_{th}\right) - \beta_0}{\beta_1}\right]}{\dfrac{\beta_2}{\beta_1}}\right\}$$

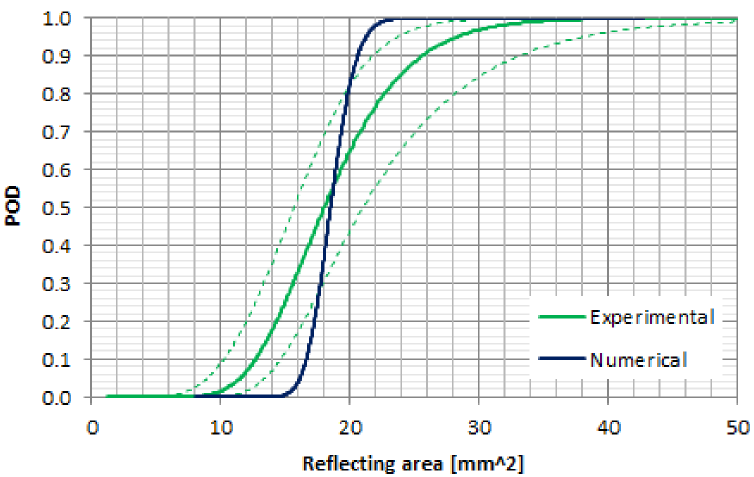
$$\begin{cases} \mu_{\log_{10}\left(\hat{A}\right)} = \beta_0 + \beta_1 \cdot \log_{10}(A) \\ \sigma_{\log_{10}\left(\hat{A}\right)} = \beta_2 \end{cases}$$

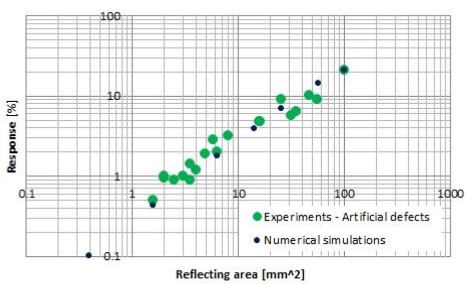
$$\mu = \frac{\log_{10}\left(\hat{a}_{th}\right) - \beta_0}{\beta_1} \qquad \sigma = \frac{\beta_2}{\beta_1}$$

Derivation of POD curves

The decision threshold was here chosen as the saw-cut with depth equal to 1 mm

Calibration





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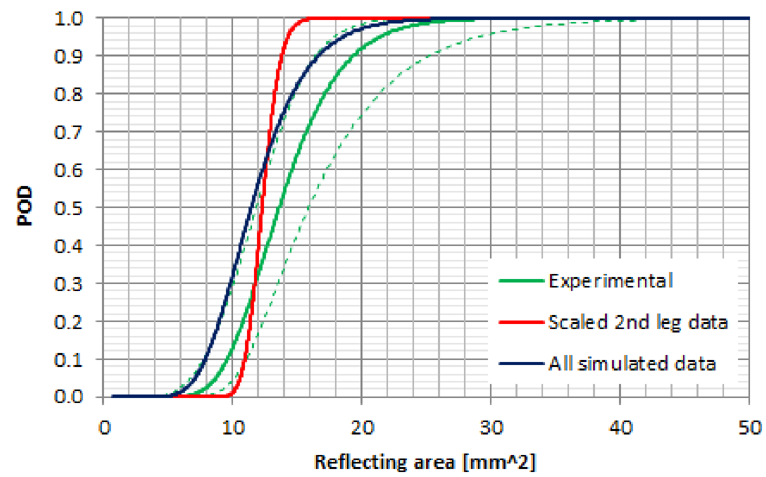
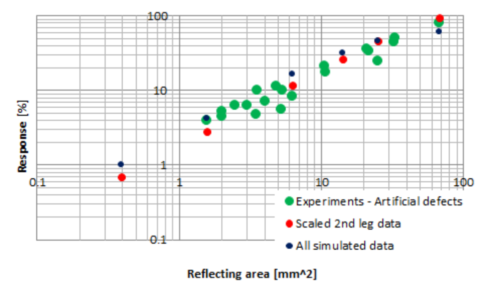
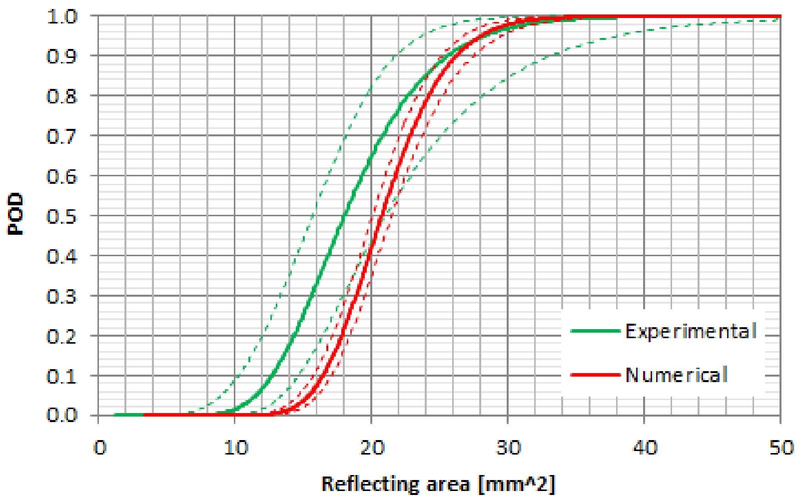
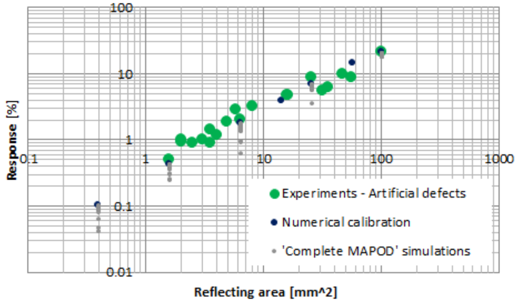




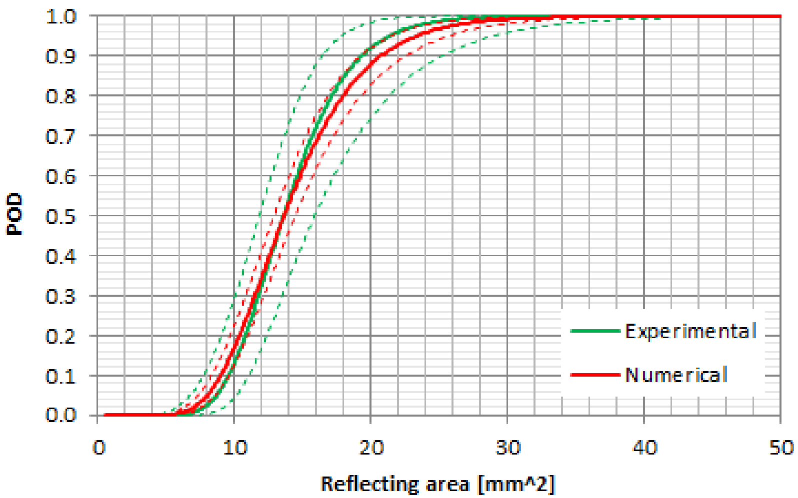
Derivation of POD curves

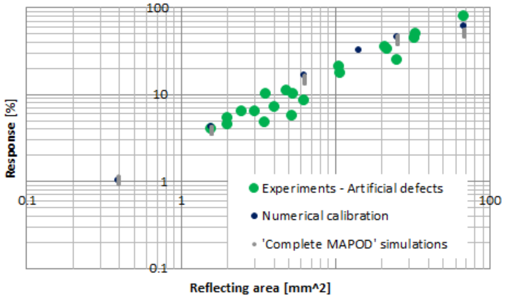
Complete approach: Manual





Complete approach: Automatic





Conclusions

In the present research, considering the special case of hollow railway axles made of A4T steel, some improvements of the procedure for deriving the UT POD curves were analysed. The obtained results can be so summarised:

- the “reflecting area” approach allows to generalise, at least in terms of defect morphology, the application of POD curves
- the results obtained from both the MAPOD versions seem to be encouraging because good predictions of experimental results could be achieved
- there is effectively a possibility to diminish the experimental effort maintaining the same reliability of the inspection
- the MAPOD approach is very recent (2003), so much work must still be done