ESIS TC 24 MEETING : AXLES DURABILITY Analysis and maintenance

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ADVANCED POD FOR IN SERVICE INSPECTION INTERVALS DESIGN

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Outline

- Foreword : Common POD limits
- Advanced POD
- Inspection Intervals Advanced Model
- Applicative Example : Inspection intervals of a HS train
- Concluding Remarks

Foreword

Railway axles are designed to have an infinite lifetime.

The fact remains that occasional failures have been and are observed in service.

Crack nucleation and propagation are expected in the most stressed points and where defects are introduced due to technological processes (i.e. wrong maintenance practice) or aggressive environmental conditions (i.e. presence of wide-spread corrosion or the possible damage due to the ballast impacts)

Structural integrity of safety components during service is strictly related to different factors such as:

1) **Performance of the adopted NDT method;**
2) **Fatigue crack growth behavior of the material;**
3) **Load history during service.**

Foreword

To guarantee adequate reliability and safety during service NDT on railways axles are performed both in production, in order to detect internal and surface manufacturing defects, and in maintenance, in order to detect surface service damages.

The “**Damage Tolerant**” approach requests to **inspect periodically**, by means of NDT, the outer volume of the axle during service so to detect such cracks and defects before they become dangerous.

-Fatigue cracks *- Deep Corrosion Pit* *- Paint detachment* *- Ballast impacts*

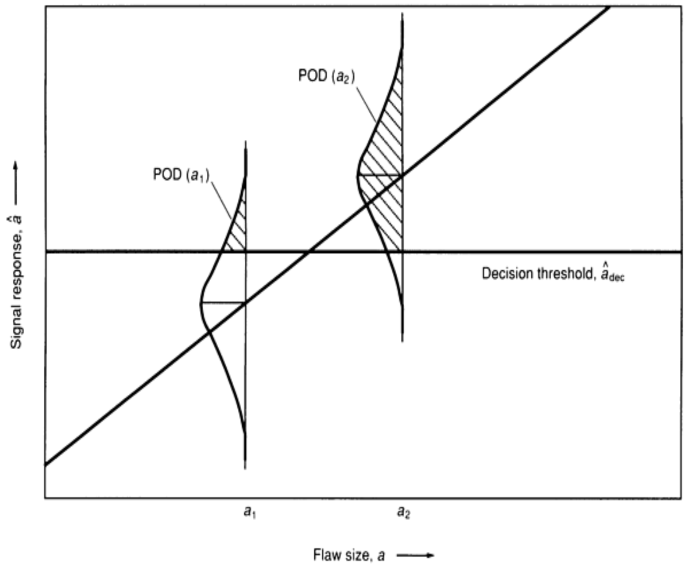


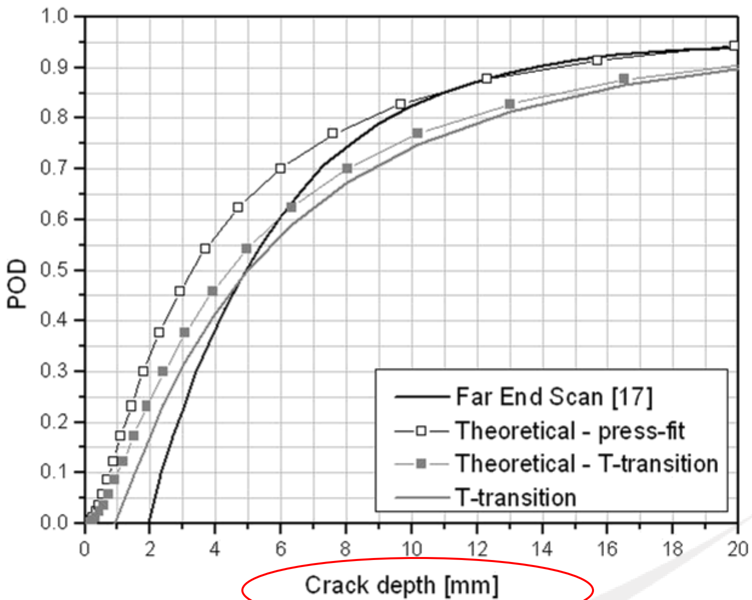




The performance of NDT is quantified by the Probability of Detection ("**POD**") curves, derived by experimental tests on components with artificial or natural defects and eventually integrated by model simulations.

«Signal – Response» POD Approach





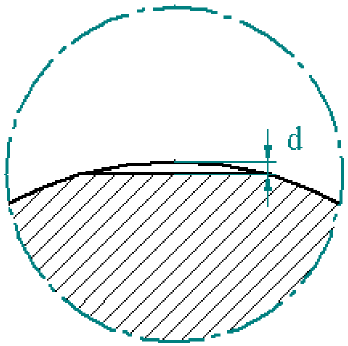
Usually **POD** curves are defined in terms of a characteristic linear dimension of defects (depth, diameter, etc.).

This is potentially inconsistent when dealing with different kind of defects (different causes, different morphology, different reflecting areas).

Foreword

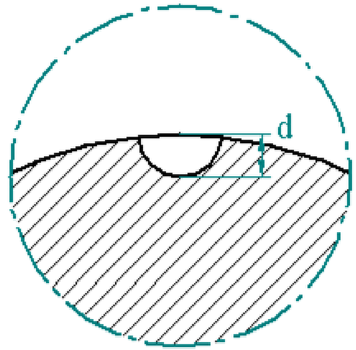
Previous experimental measurements of UT reflections from different artificial defects on axle external surface

saw-cuts notches:



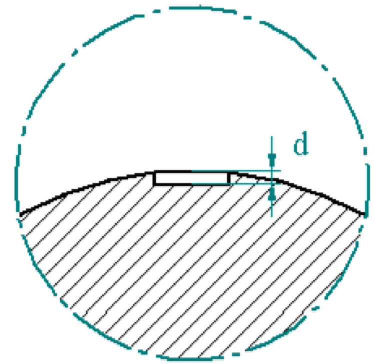
one of the most traditional calibration defect for sample blocks of railway axles

convex EDM notches:

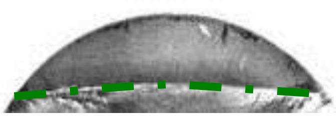


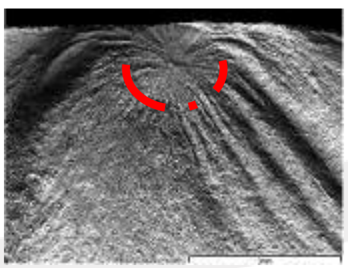
representing fatigue cracks typically observed at the body or at the transitions

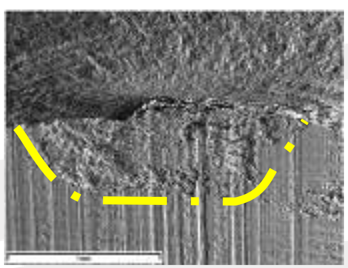
concave EDM notches:

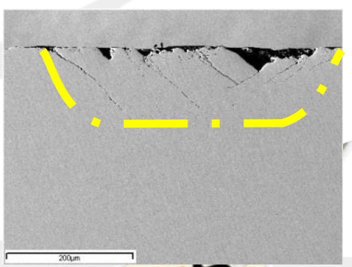


representing fretting-fatigue cracks typically observed at the press-fits or surface damages due to impacts, etc.

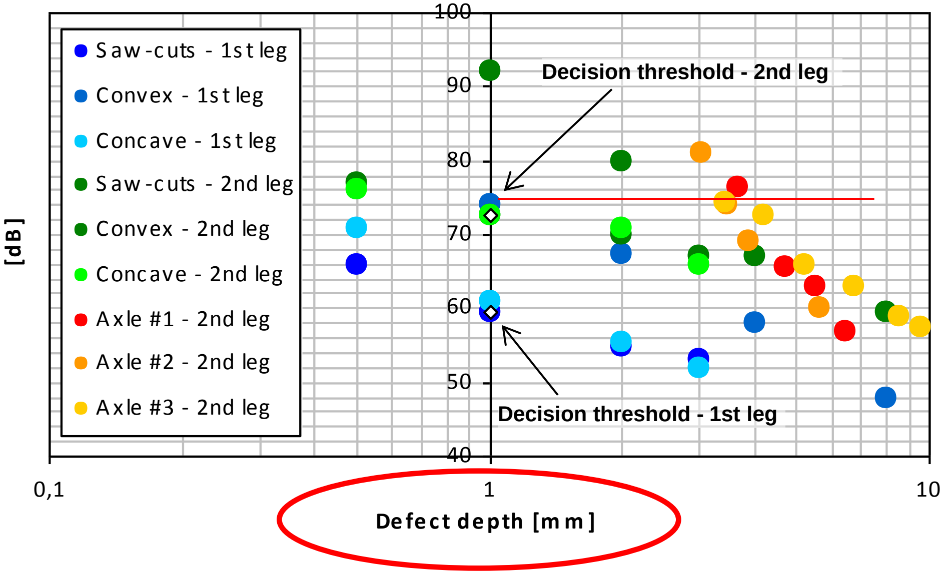


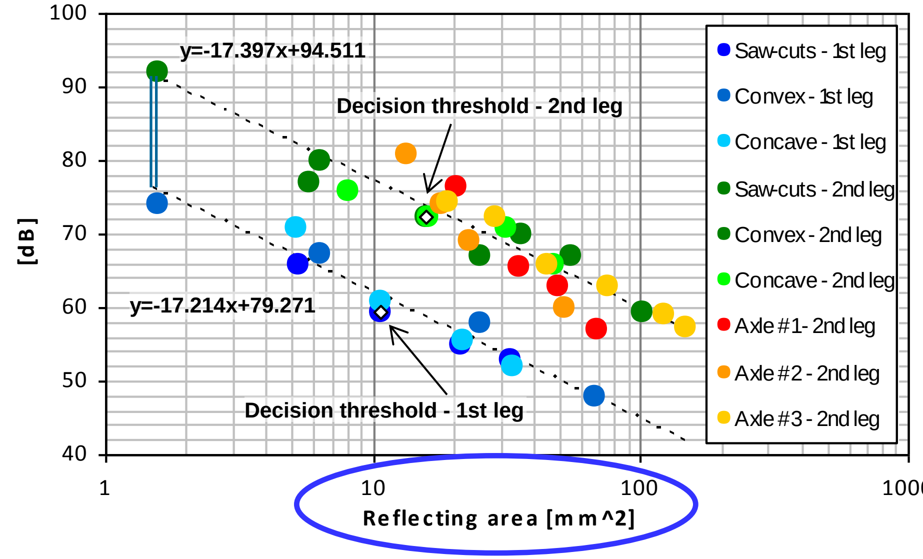






Foreword



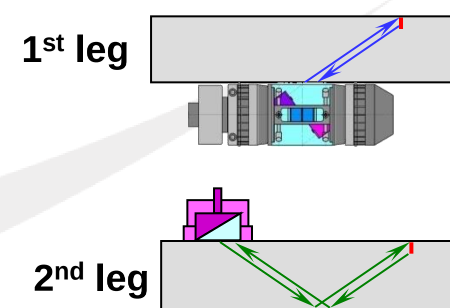


→ Strong dependence of UT echoes on the shape of defects

→ Real fatigue cracks give, as expected, a response similar to convex EDM notches

→ The **depth** of the defect **is not the best parameter** in order **to** entirely **characterize** its **UT response**,

→ It can be more suitable, instead, to consider **the area of the defect** actually invested by the sound beam.

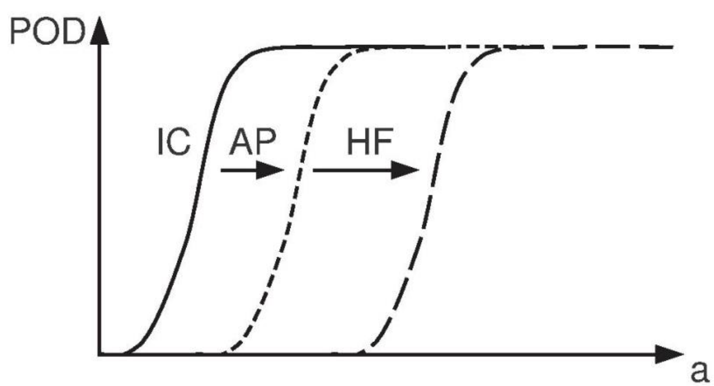


Moreover, when dealing with real-life POD it is important to ditinguish the intrinsic performance of the equipment from its application to different inspecting procedures and from all human factors affecting calibration and inspection operations.

Intrinsic Capability of NDT device (max sensitivity)

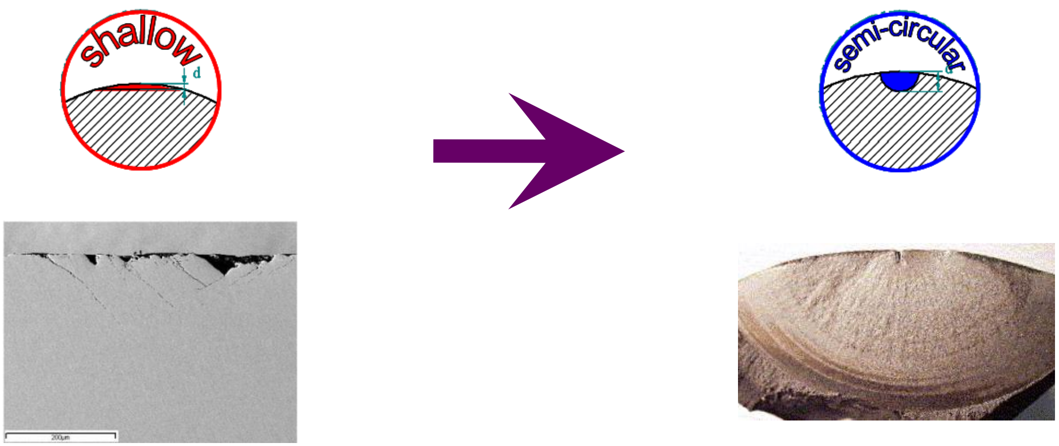
Application Parameters (operating sensitivity)

Human Factors



Foreword

Fatigue cracks during service possibly nucleates from surface damages such as impacts, scratches or corrosion pits and then evolve into semi elliptical shape.

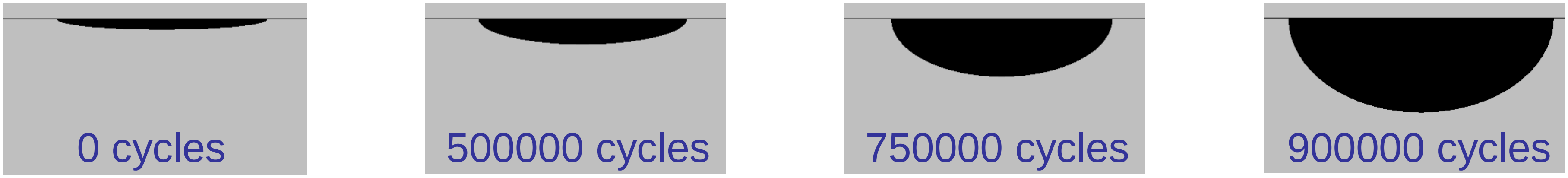


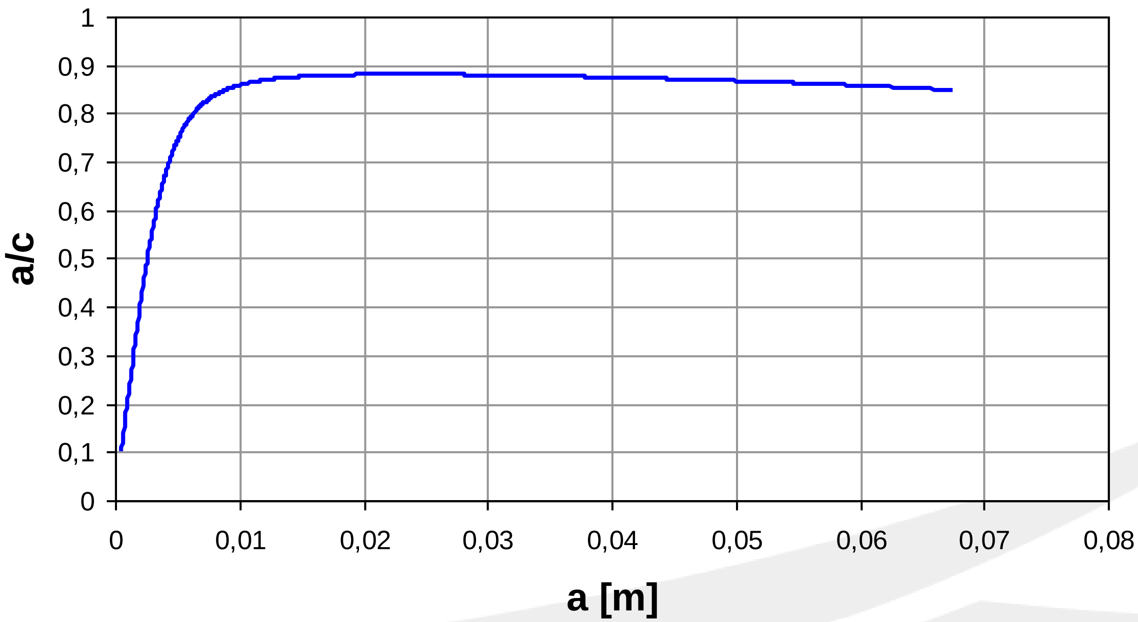
A more reliable approach to «defect tolerant» inpection intervals design shall then take into account of:

- Advanced POD:
  - -Reflecting area related
  - -Human error related
- Advanced Crack propagation model:
  - -Defect shape related

Shallow to semielliptic crack evolution under a given load spectra

Initial Shallow crack: 10x0.5 (a/c=0.1) [a = depth, c = half surface extension)





Advanced POD - 1

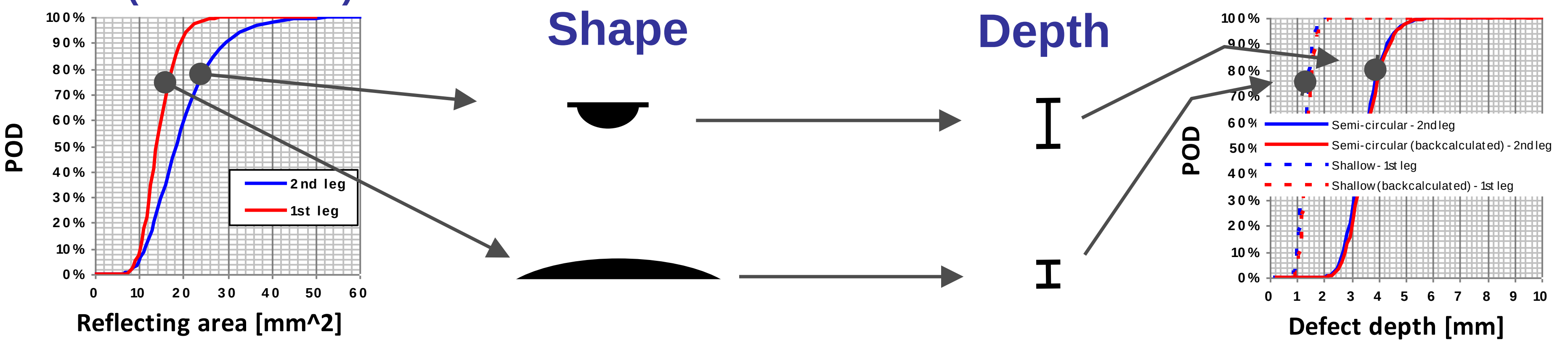
From POD curves in terms of reflecting area to POD curves in terms of depth

Reflecting Area POD

(Master POD)

Depth POD

Traditional POD



→ Transformation simply assuming proper shapes and values for the area.

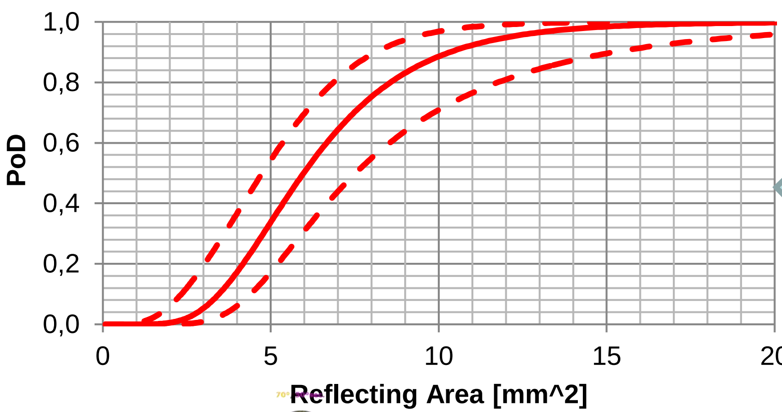
→ Starting from the POD values in terms of reflecting area, **a shape can be continuously associated to the area itself** and, consequently, depth values can be derived and used to back-calculate POD curves in terms of depth for a give defect shape.

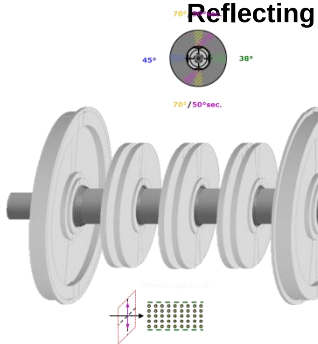
Advanced POD - 2

From POD curves in terms of reflecting area to POD curves in terms of depth

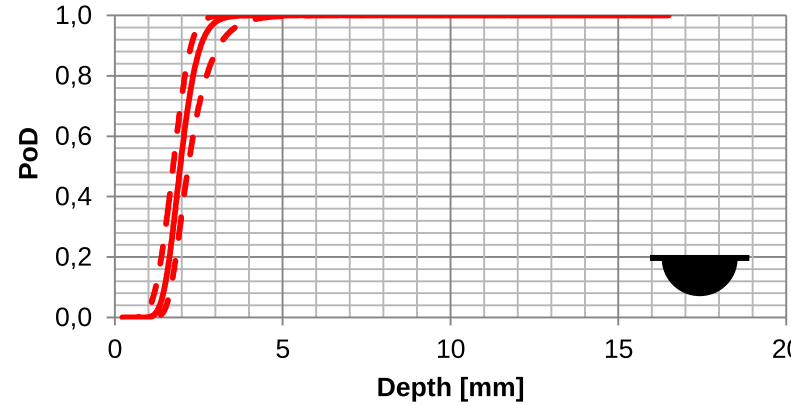
Reflecting Area POD

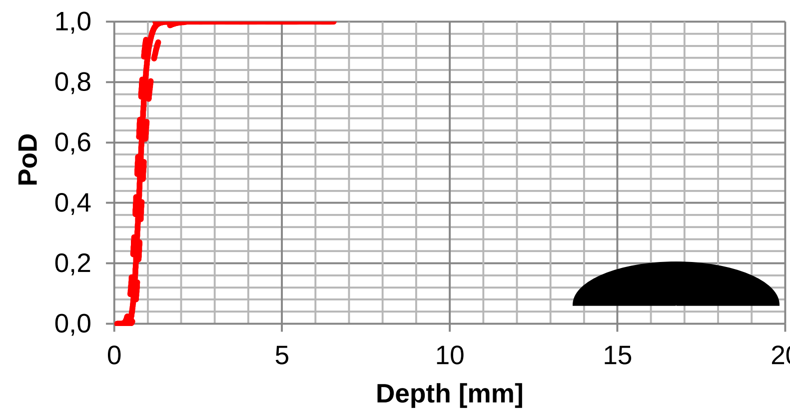
(Master POD)



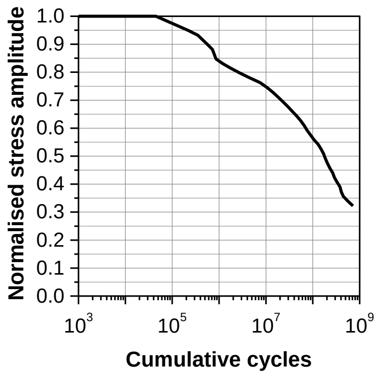


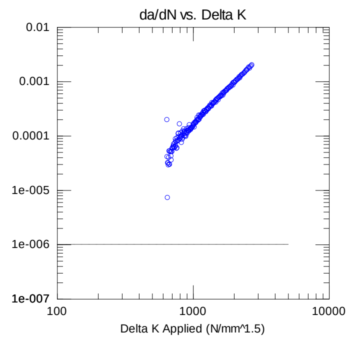
Depth POD (Traditional POD)

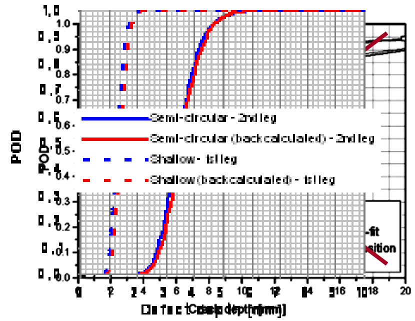




Inspection intervals advanced model - 1





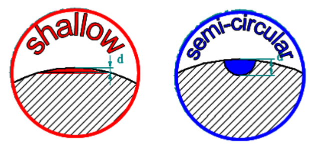


Load spectrum

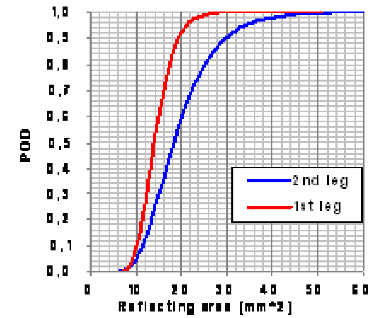
Material behaviour

Traditional POD

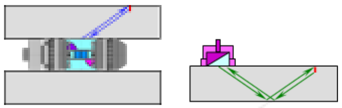
Defect shape



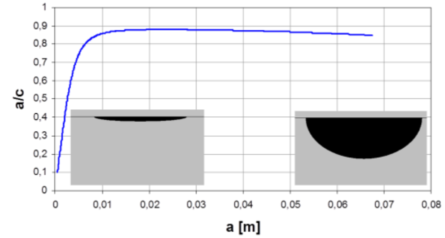
Master POD



Considered path

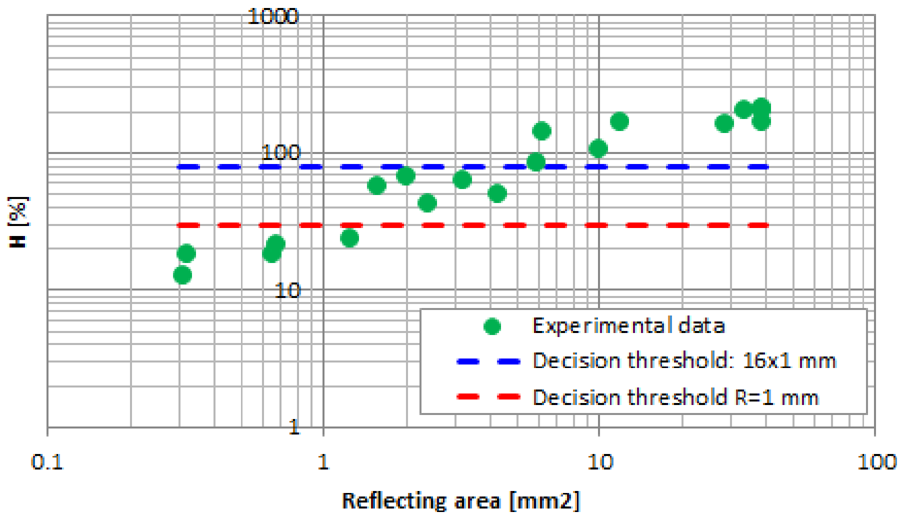


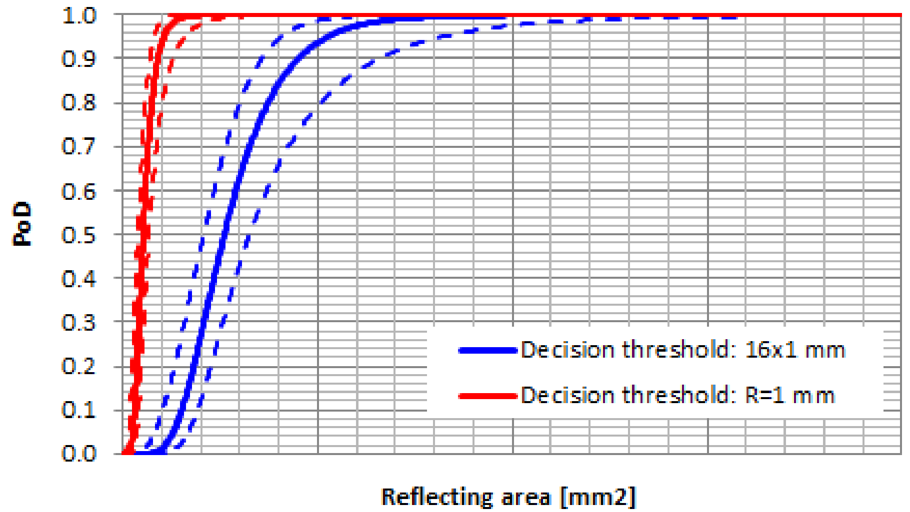
Crack growth algorithm



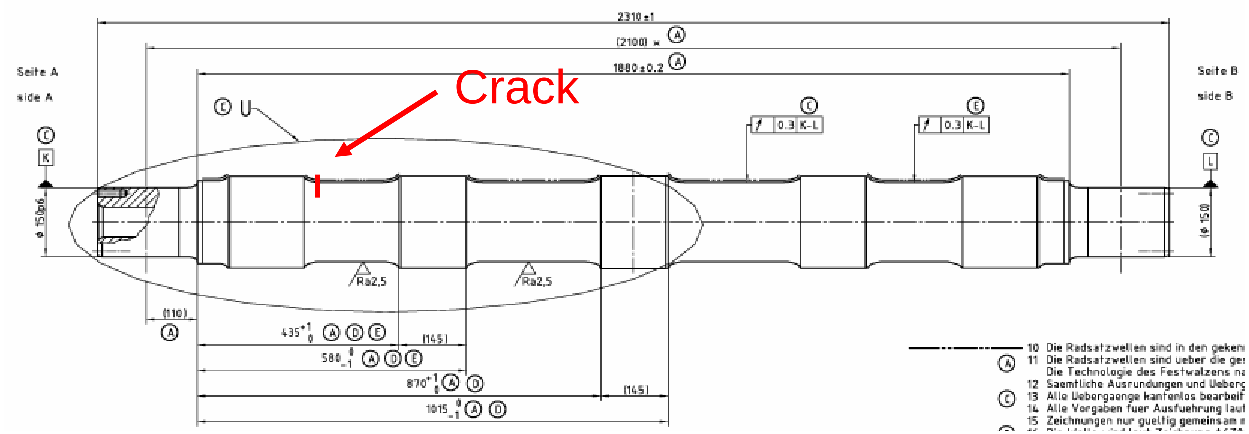
Inspection interval

The Model now includes POD curves experimentally drawn by an unique set of 17 natural cracks from 0,4 to 12 mm;





- ✓ “Signal response” approach
- ✓ Each axle was inspected from both ends
- **Decision threshold #1**: concave defect 16x1 mm (Lucchini RS QUA IT 065 procedure)
- **Decision threshold #2**: convex defect R=1 mm (absolute performance of the boreprobe)



Material: A4T

d_{body} = 176 mm

d_{bore} = 65 mm

Reflecting area of the initial crack: 5 mm²

2 analyzed cases

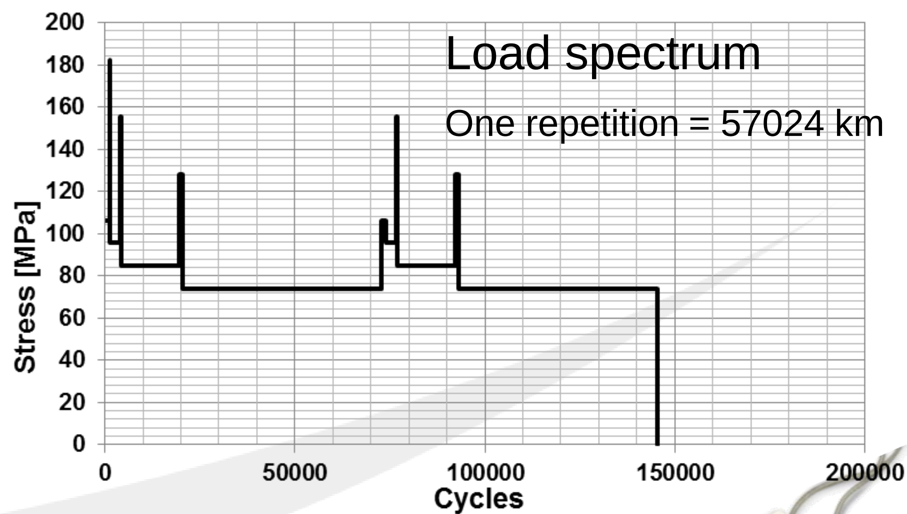
Semi-circular crack:

R = 1.78 mm

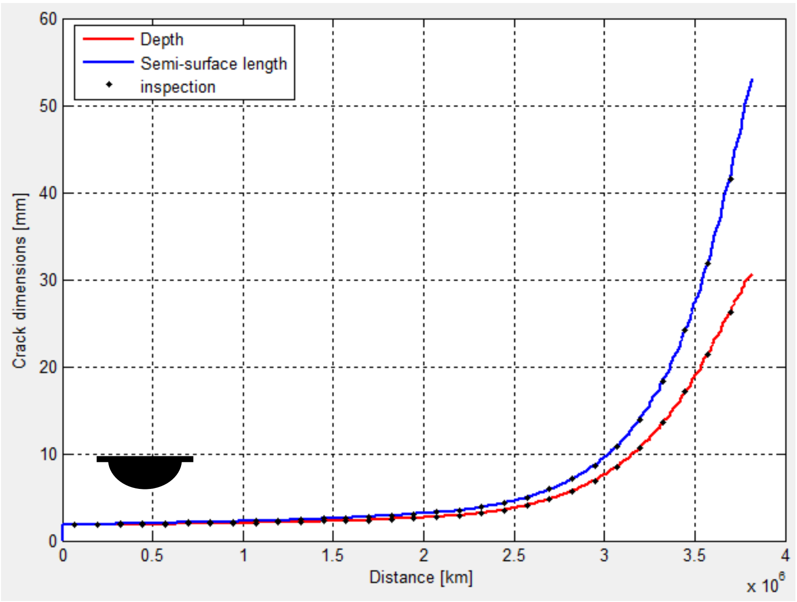
Shallow crack:

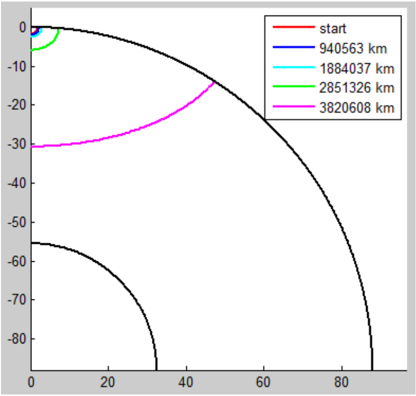
depth = 0.707 mm

a/c = 0.1

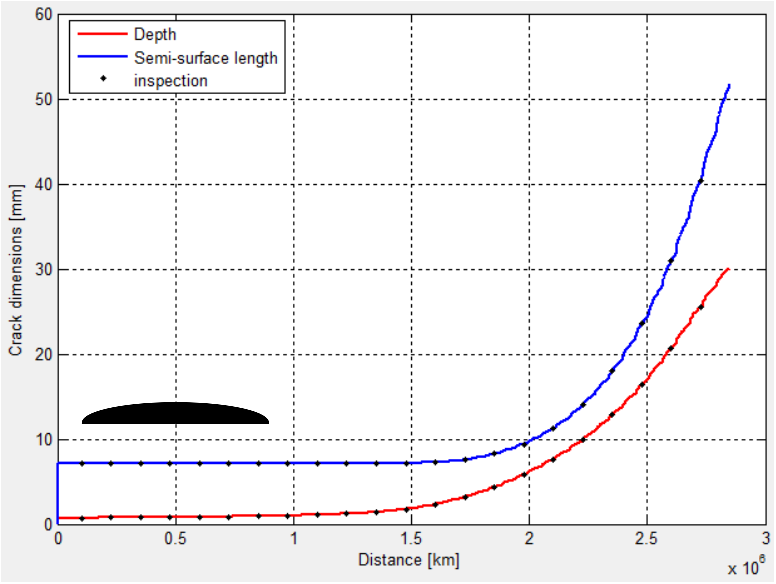


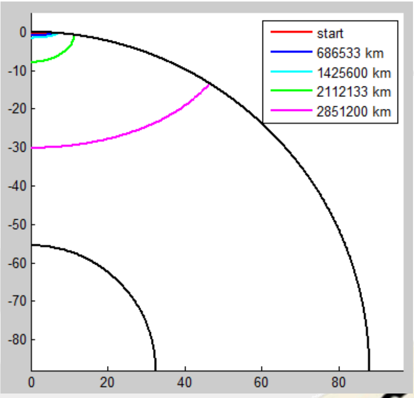
Semi-circular crack





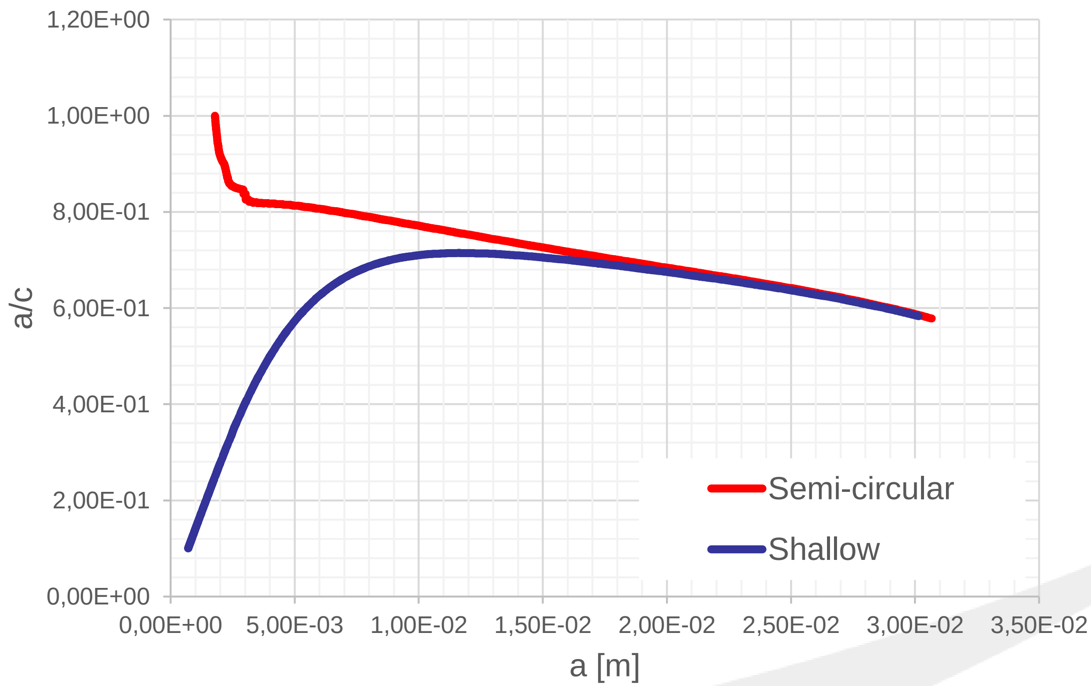
Shallow crack (a/c=0.1)





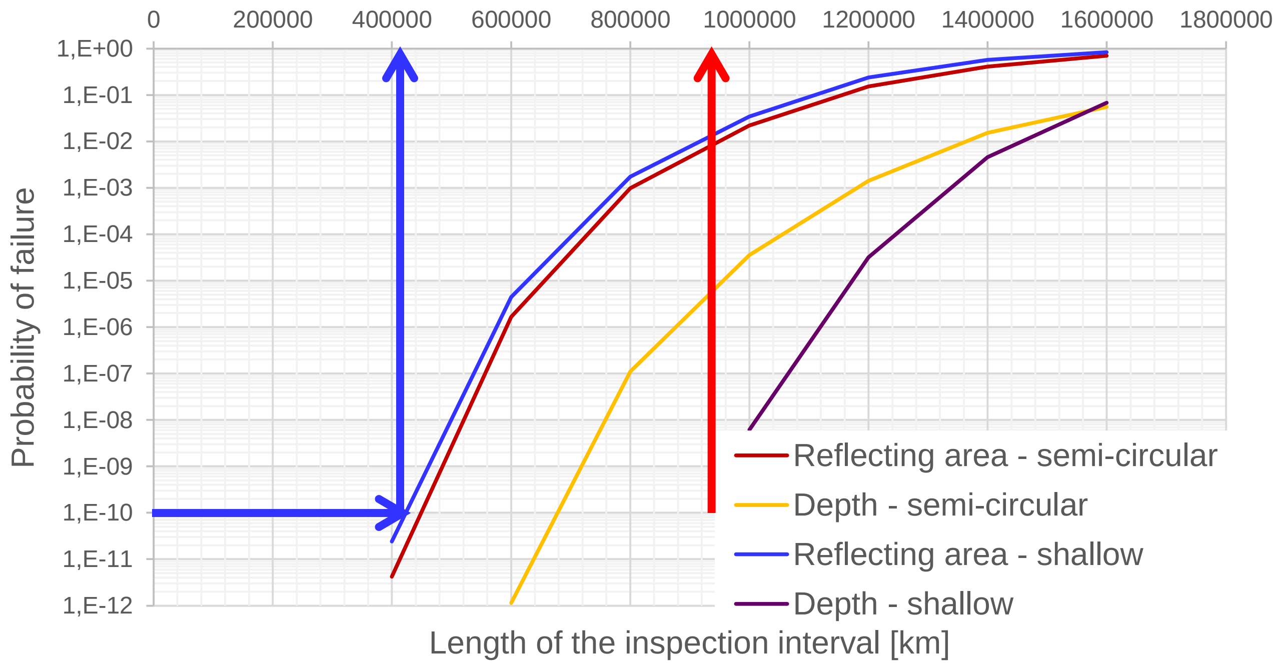
An applicative example - 3

→ Lifetime of initial shallow cracks is 30% shorter with respect to semi-circular ones
→ Cracks tend to the same shape during their fatigue propagation.



An applicative example - 4

Probability of failure for a given inspection interval



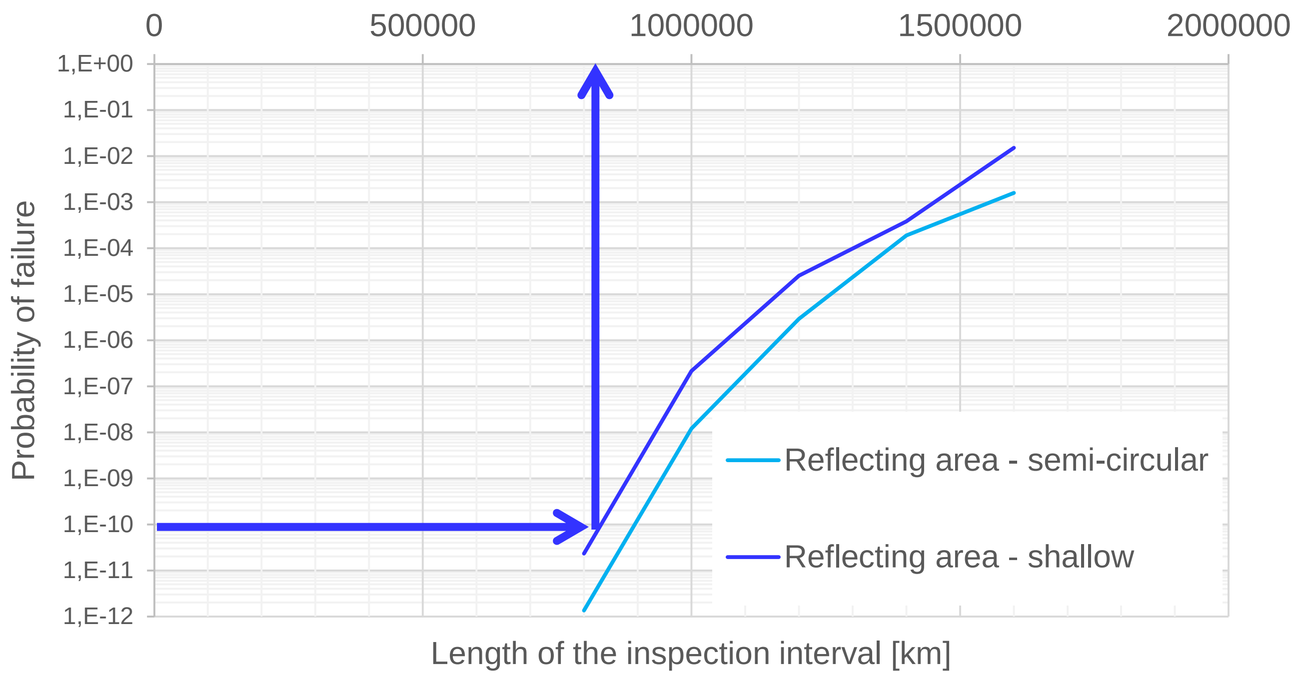
POD (95%) with 16x1 notch calibration

→ The traditional POD approach to defect depth, in case of a shallow defect, is very critical (leading to 0,9 Mkm inspection interval) because it overestimates POD

→ Advanced POD approach to defect shape is much more consistent

An applicative example - 5

Probability of failure for a given inspection interval



POD (95%) with R=1 notch calibration (Maximum equipment sensitivity)

→ Only theoretically, by employing the maximum sensitivity of the UT equipment, the inspection interval could be doubled.

Concluding remarks

Usually fatigue cracks nucleate from **surface scratches** (i.e. shallow defects) or **corrosion pits**.

During the propagation a fatigue defect **changes quickly its shape** up to a semicircular one.

Defect shape strongly affects POD, therefore advanced POD must take into account of reflecting area rather than linear depth.

For a given depth:

- Shallow defects are more detectable than semi-circoular ones
- Shallow defects propagate faster (but they reach semicircular shape quite quickly)

A standard approach to defect depth both in terms of POD and crack propagation is potentially inconsistent.

A modern approach shall keep into account of **defect shape evolution.**

Further tuning of LRS-POLIMI inspection intervals model needs to integrate human error function.

Thank you for your attention