Investigations to Introduce the Probability of Detection Method for Ultrasonic Inspection of Hollow Axles at Deutsche Bahn

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Automated Ultrasonic testing for wheelset axles with a bore

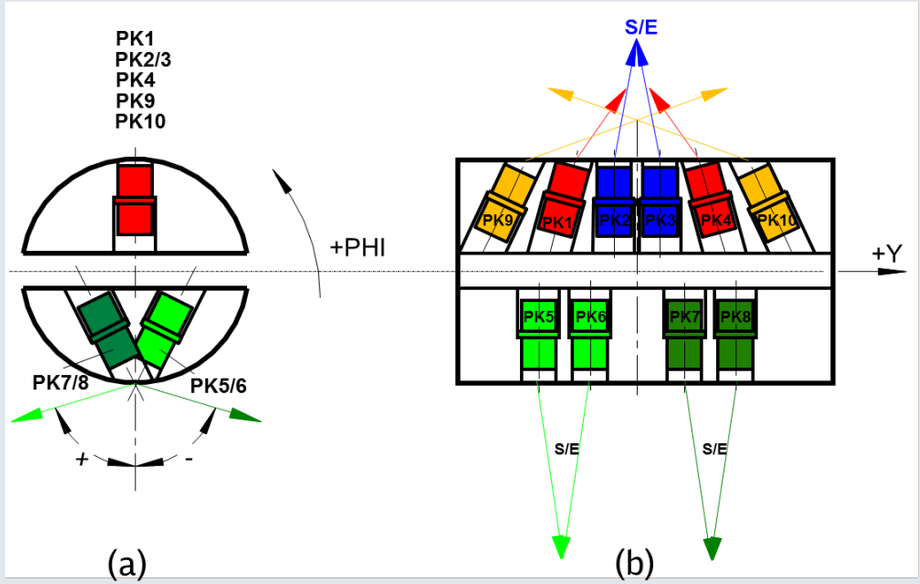
HPS-inspection device applied at a train

Currently 140 ultrasonic inspection devices (HPS) are in use in maintenance at Deutsche Bahn for testing wheelset axles with a bore hole.

- 134.767 tested wheelset axles per year *(2013)*
- testing time approx. 12 minutes per axle

The probe head contains 10 probes, with these 10 probes 8 different so called „testing functions“ are carried out:

- longitudinal defects +/- 57° (S/E) green
- circumferential defects +/-37° red
- circumferential defects +/- 70° yellow
- internal defects and coupling check blue

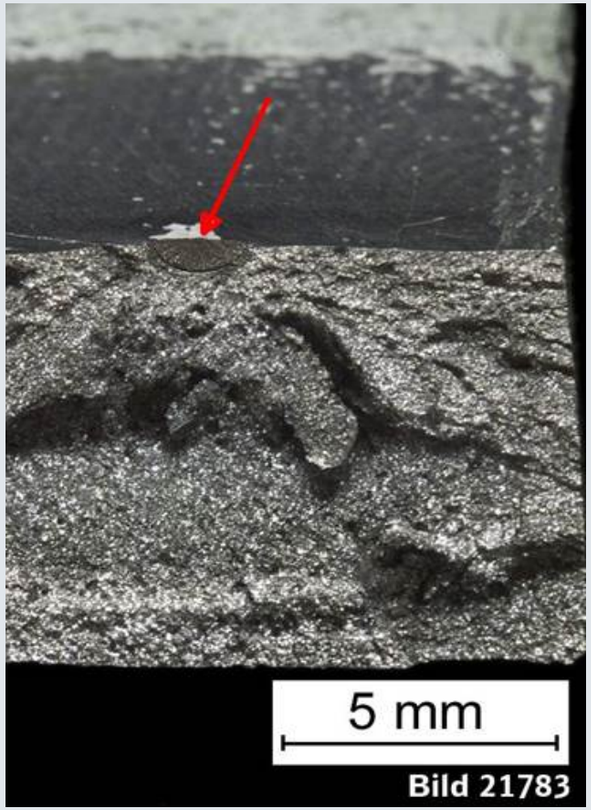


Arrangement of probe head. Lateral (a) and longitudinal (b) cross section.

The sensitivity settings are done in accordance with DIN 27201 part 7: An acceptance level for ultrasonic testing equal to a secant notch of 2 mm in depth and an additional safety margin of 6 dB is recommended.

Actual Indications: true indications

The experiences of the last years have shown that automated ultrasonic inspection systems for wheelset axels with a bore hole (HPS) are able to detect even smaller defects than required.



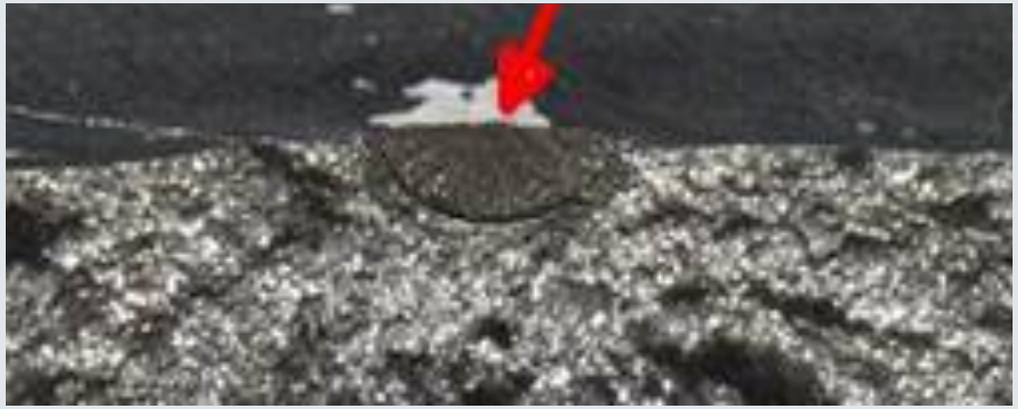
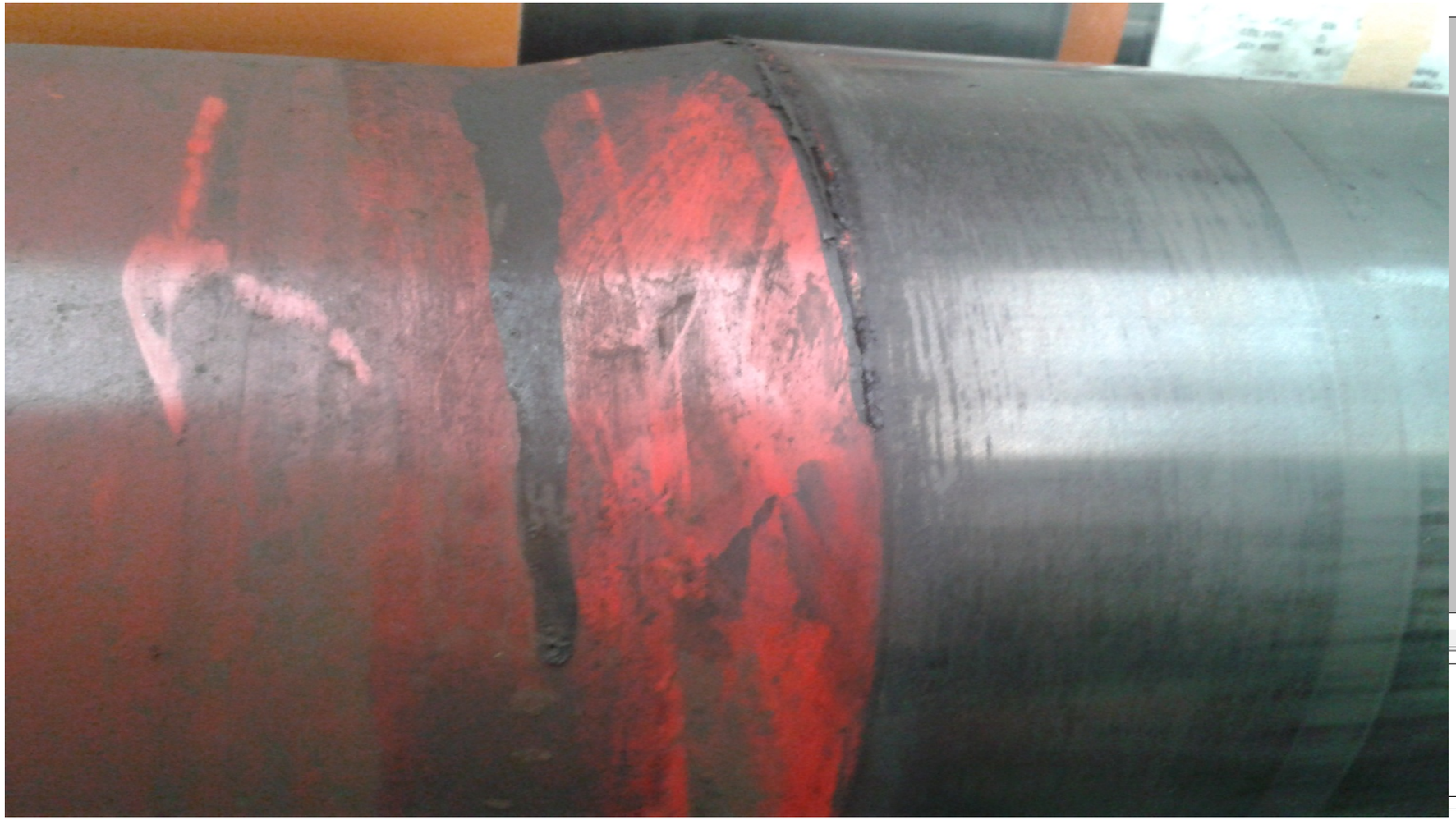


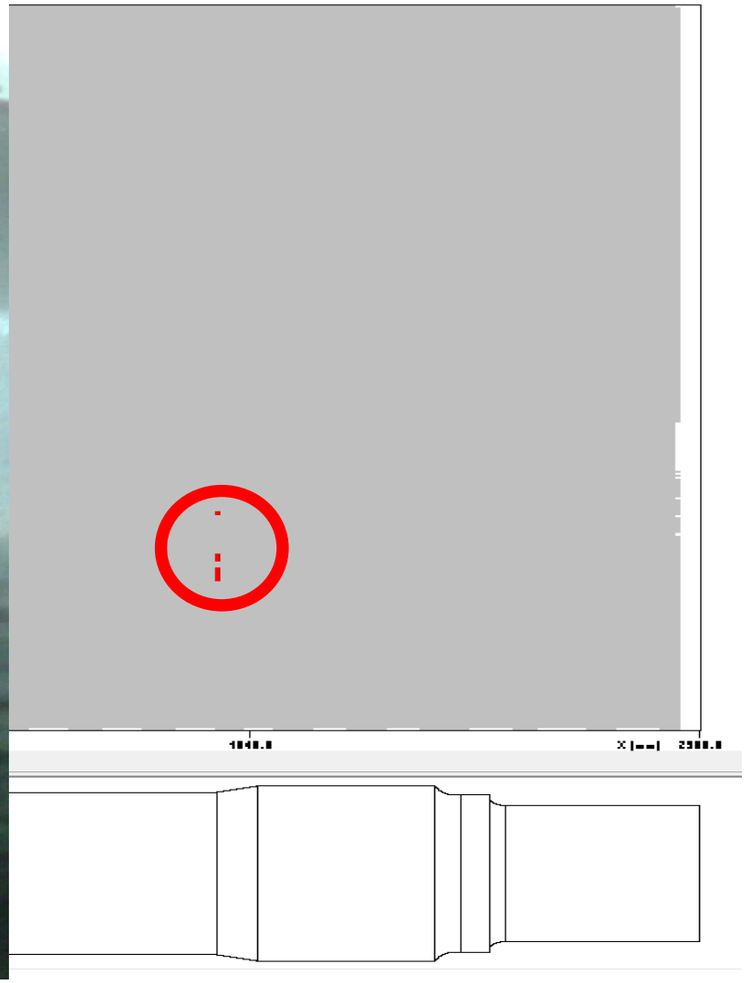
Photo of a crack after crack-opening, found during maintenance inspection.
Crack depths 0,75 mm

Example of an UT-indication. Estimated depth after crack-opening was 0,75 mm.

Due to this experiences it can be assumed that the automated ultrasonic inspection systems are testing substantially more sensitively than required.

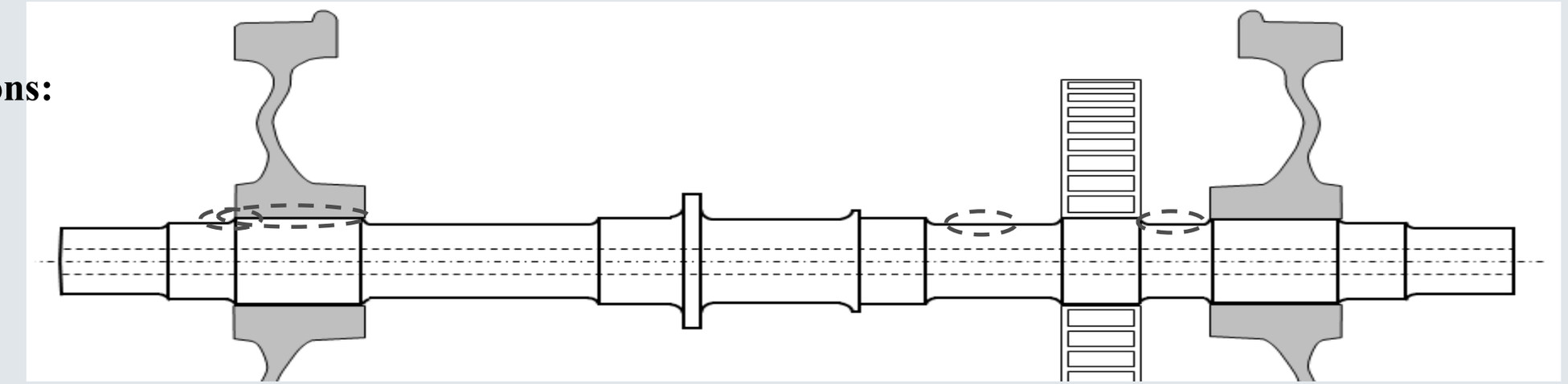
False Indications





False Indications

Reasons for false indications:



accumulations of dirt

press fit

coating defects

False indications are leading to:

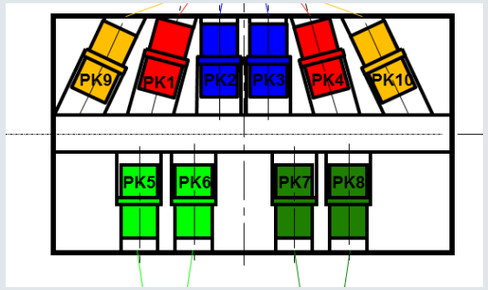
➔ demounting and disassembling of the wheelset

Focal point of the research cooperation between DB Systemtechnik and BAM

For the determination of the effective flaw detection sensitivity by the POD $a_{90/95}$

Influencing parameters have to be considered:

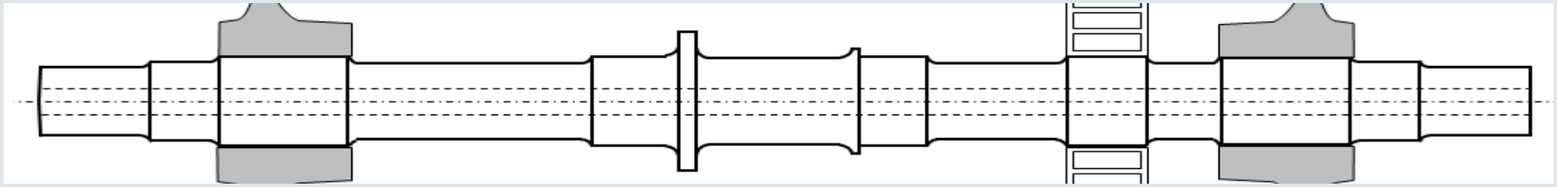
- use of several probes with different beam directions and angles
- crack shape and orientation
- axle geometry
- and further parameters



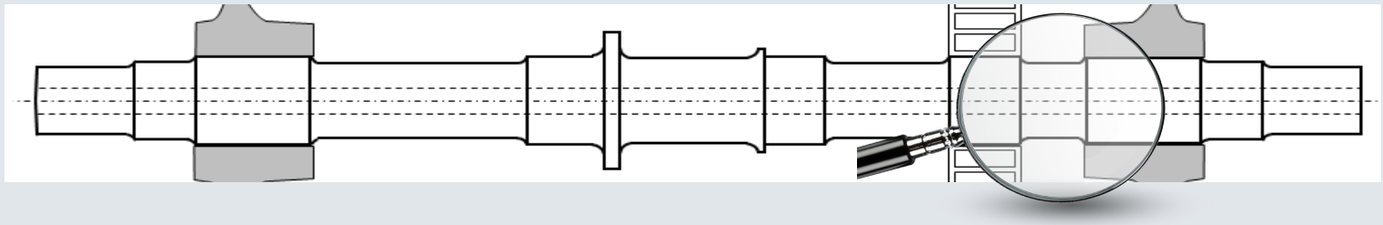
secant notch 2 mm

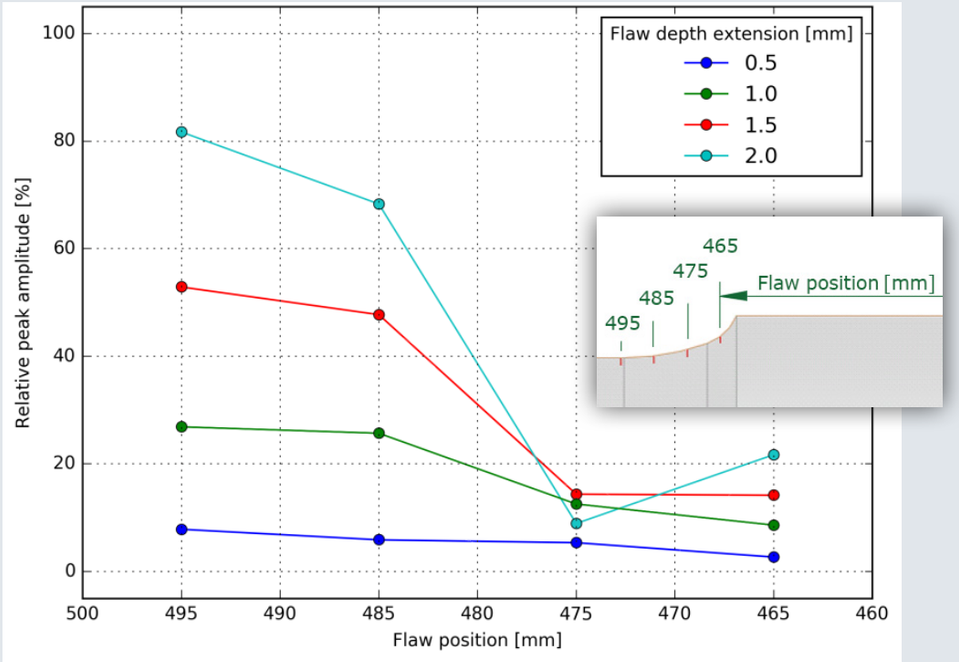
a/c

crack 2 mm



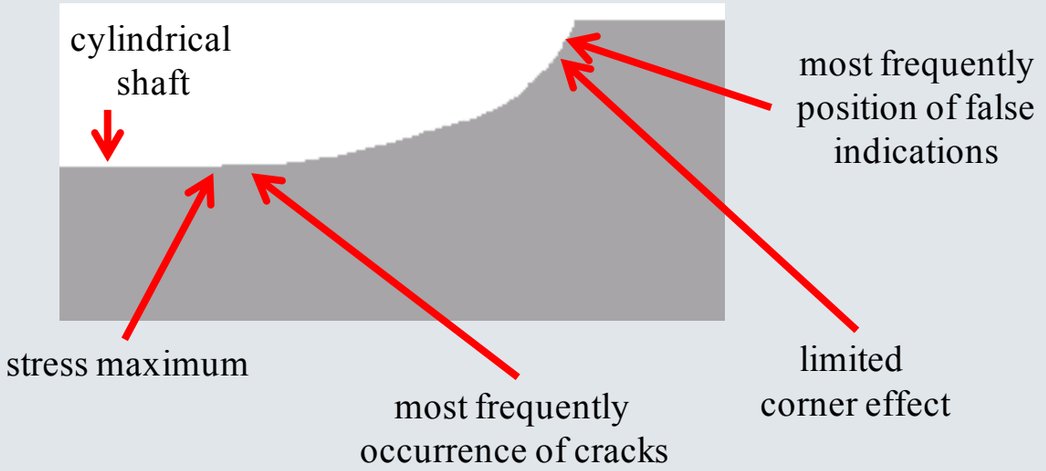
Influencing Parameter: Geometry





Simulation of echo heights in percent of an reflector with an a/c ratio of 0,8 at different positions in the transition between shaft and wheel receiver

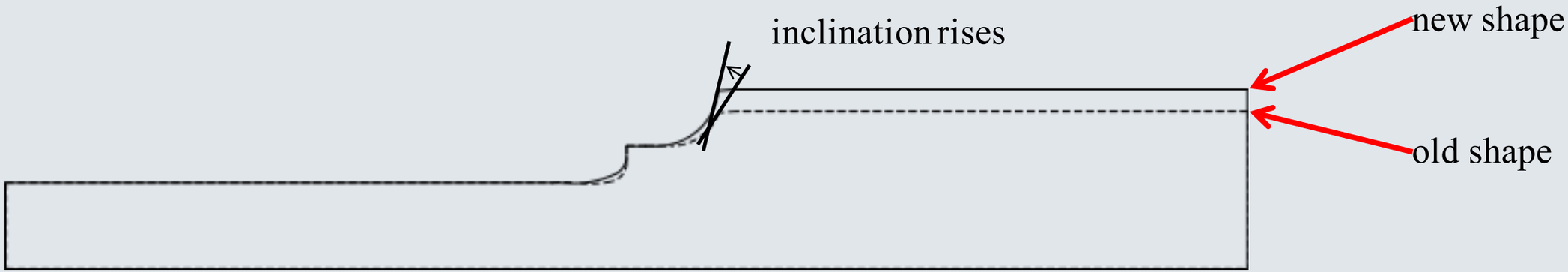
The zone studied here is most relevant for ultrasonic as well as for fracture mechanics



The reflectivity is affected by the crack depth, shape **and** influenced by geometry.

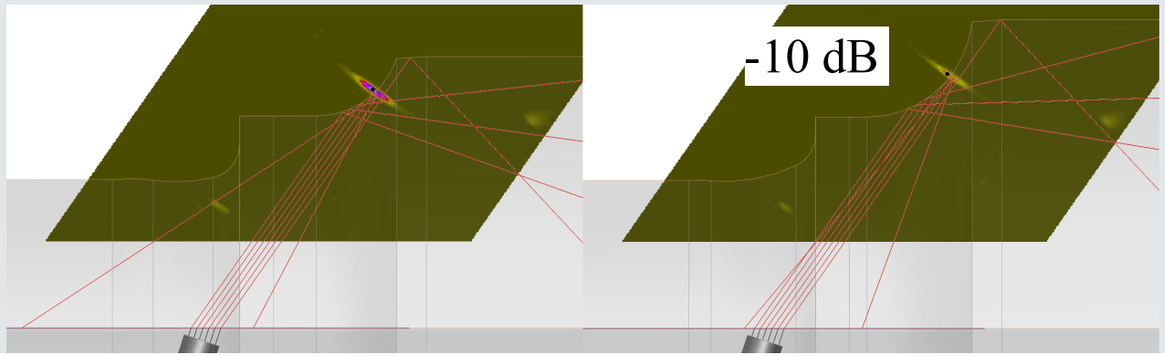
Axel Shapes from an Ultrasonic Point of View

For new axle constructions, a more intense inclination in the diameter transitions can be observed.



Comparison of the transition of two axles between shaft journal and wheel sleeper

35°



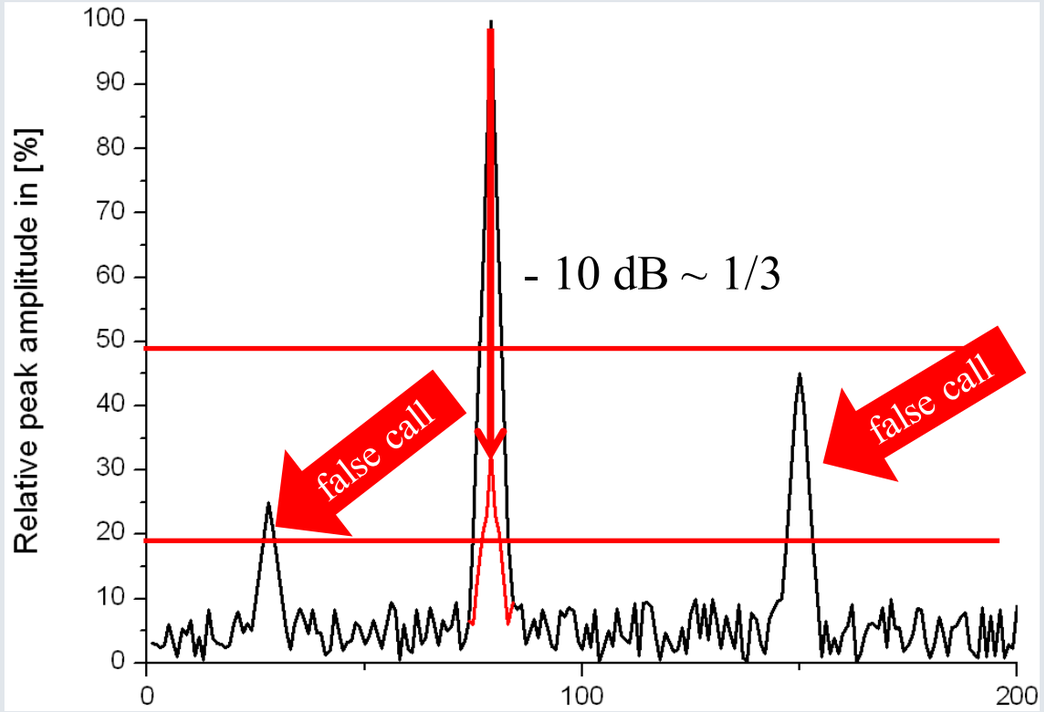
10 mm from the outer wheel seat
the amplitude shifts down 10 dB (factor 3.2)

Simulation of amplitude decrease in the transition area due to the different axle shape
Simulation by Mato Pavlovic, BAM

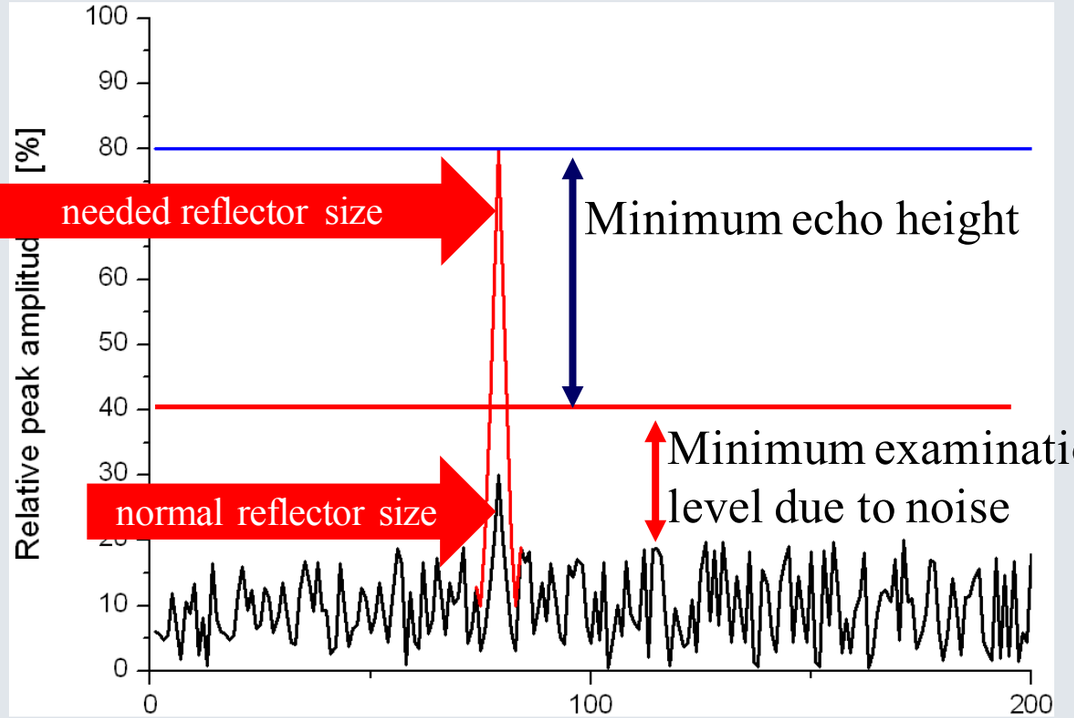
Axel Shapes from an Ultrasonic Point of View

- If the ultrasonic verifiability gets worse:

1) Examination levels have to be reduced
- false indication ratio rises

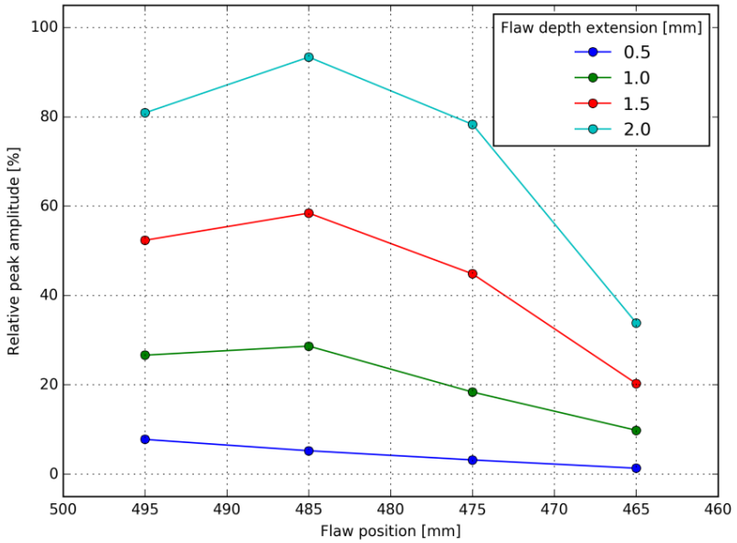


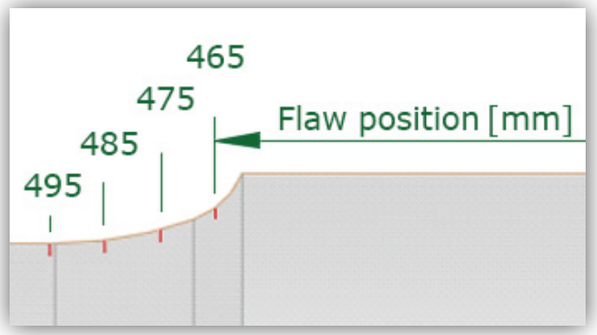
2) flaw detection sensitivity decreases
– ultrasonic interval decreases



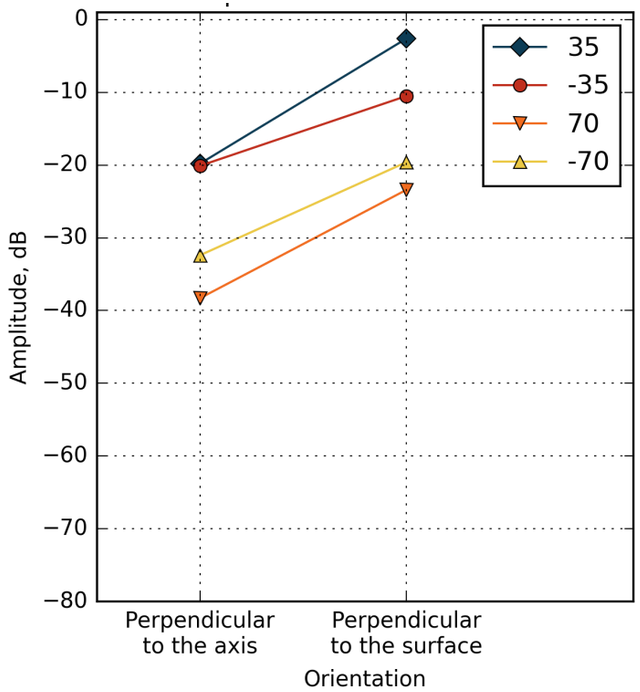
Reliability of NDT

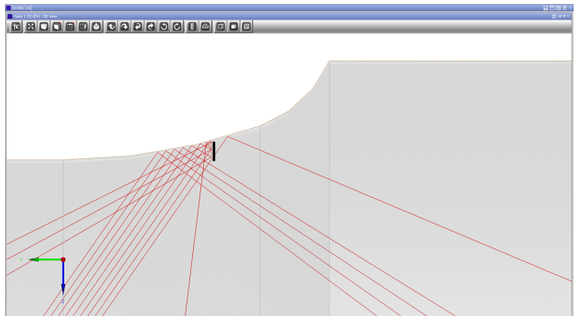
Factors influencing the POD

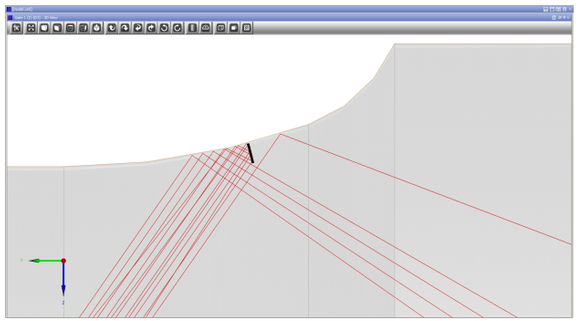




POD = POD(crack position)

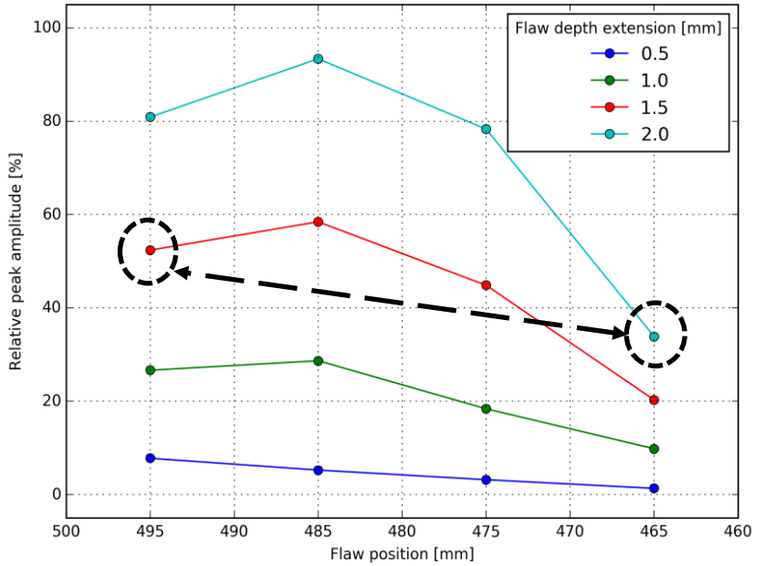




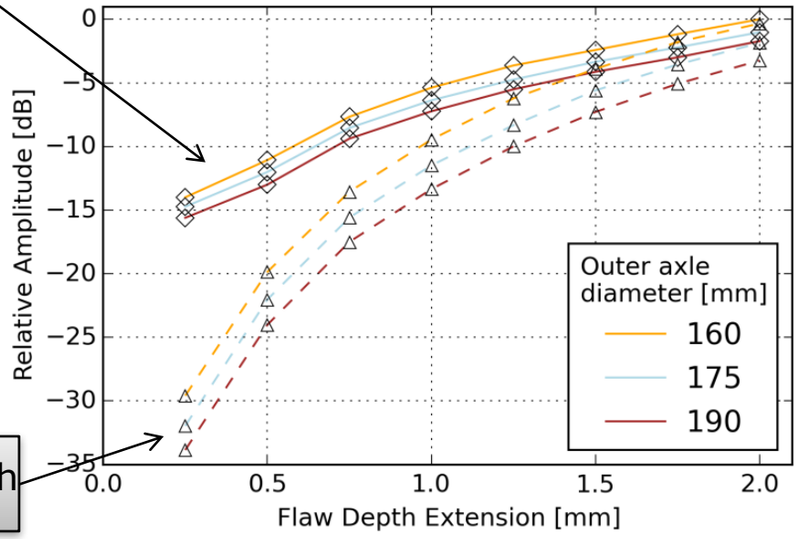


POD = POD(crack orientation)

Factors influencing the POD



Saw cut

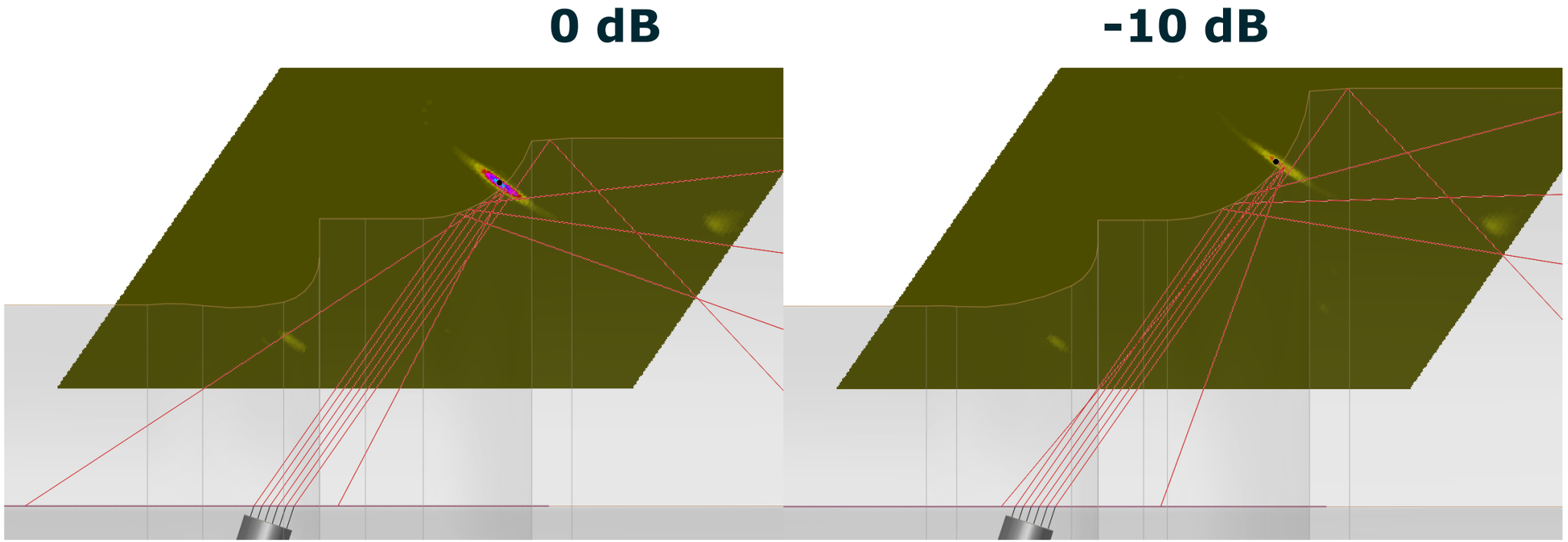


Semi-elliptical notch

POD = POD(crack depth extension)

POD = POD(crack shape)

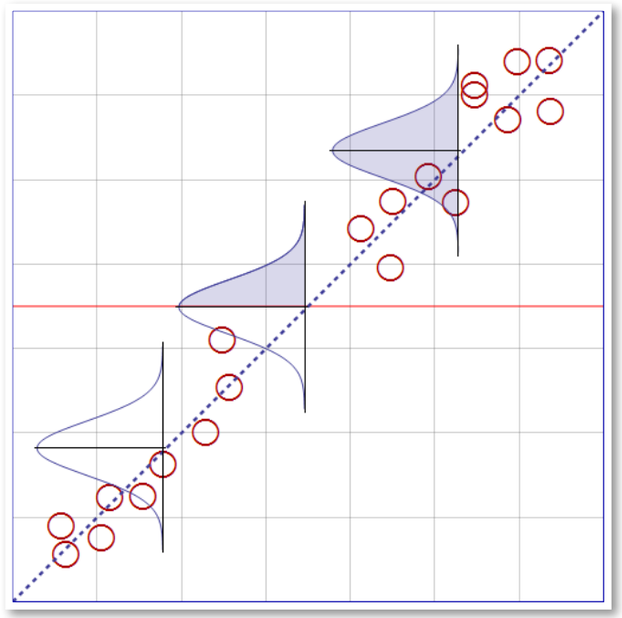
Factors influencing the POD

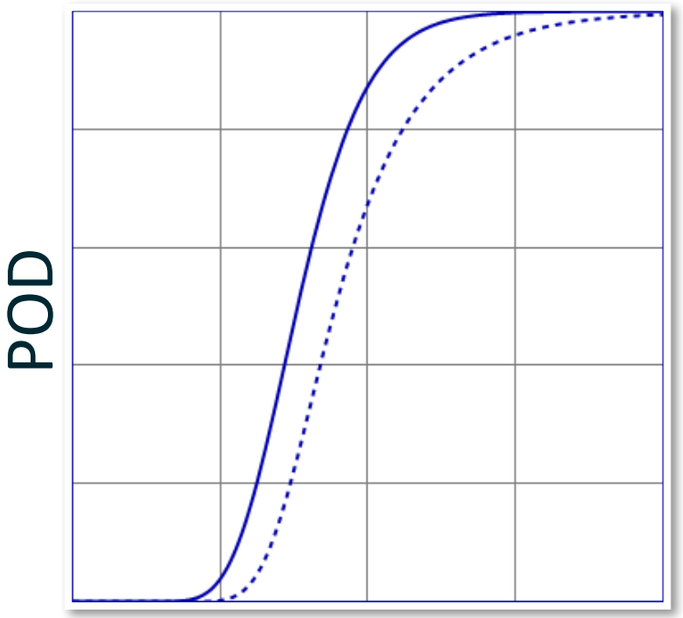


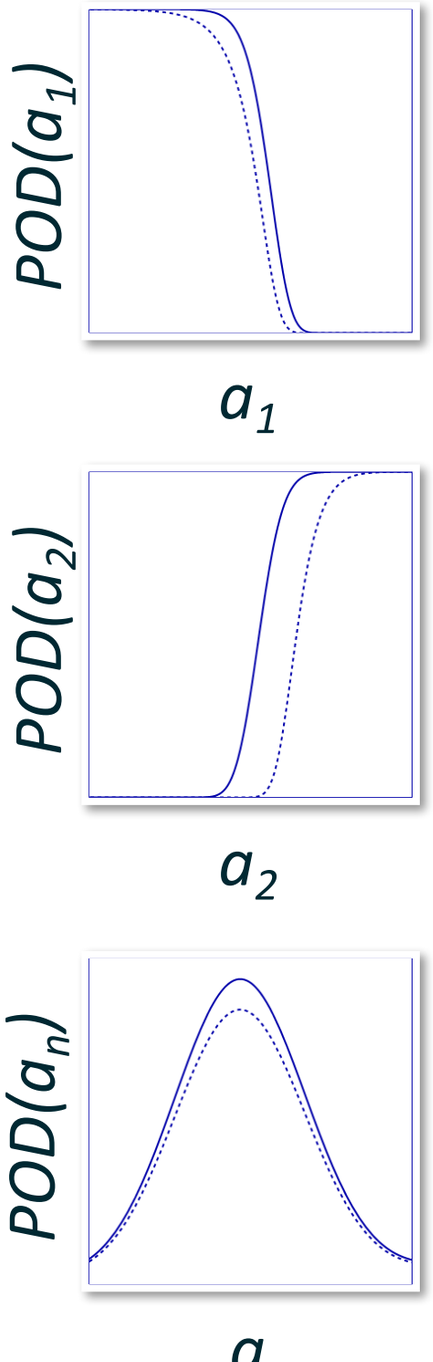
POD = POD(axle geometry)

Multi-Parameter POD

$$POD\,(a_{MP}) = 1 - \Phi\left[\frac{\hat{a}_{dec} - (B_0 + B_1\, a)}{\sigma_{\delta_{MP}}}\right]$$





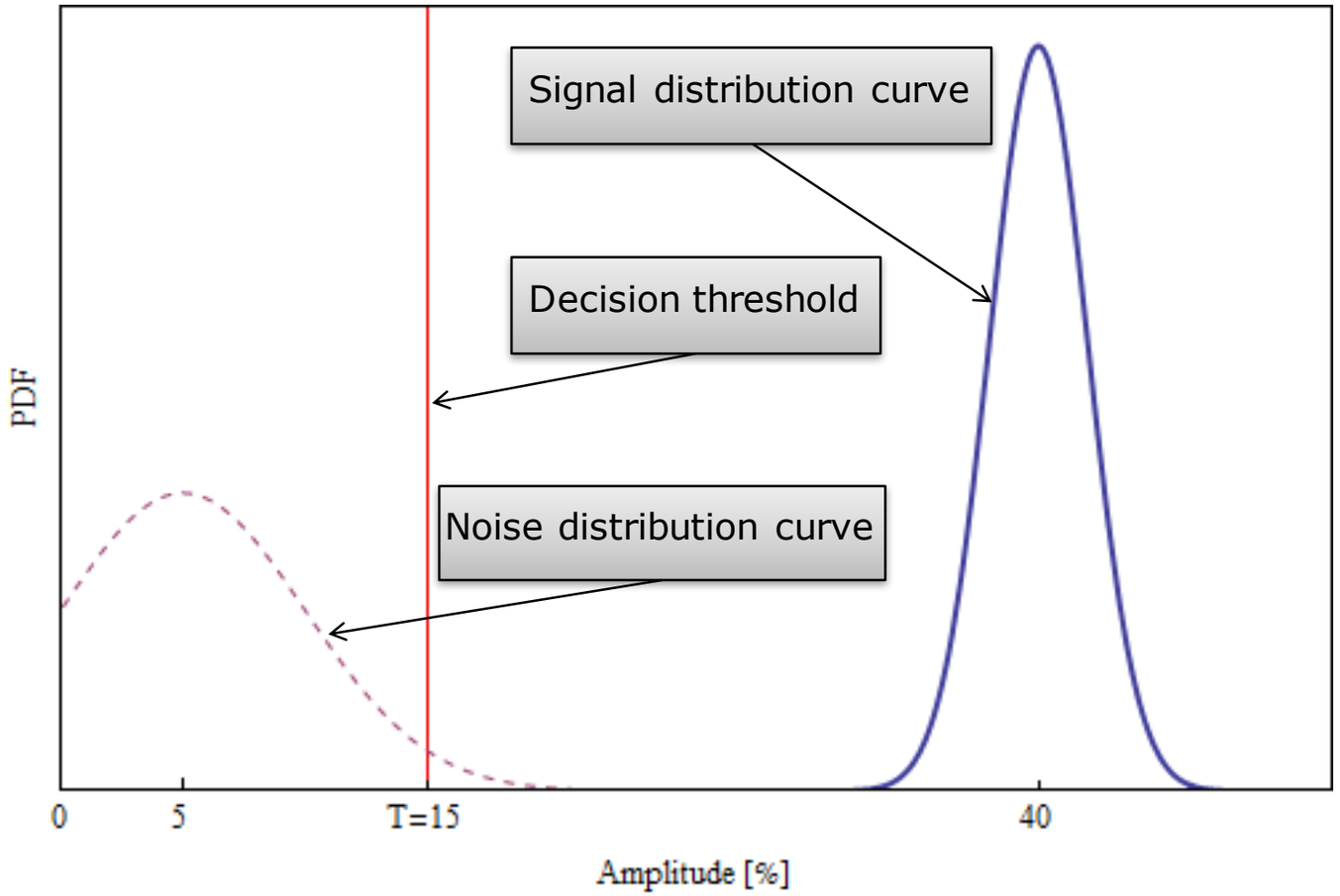


$$a_{MP} = f\,(a_1,\, a_2,\, \ldots\, a_n)$$

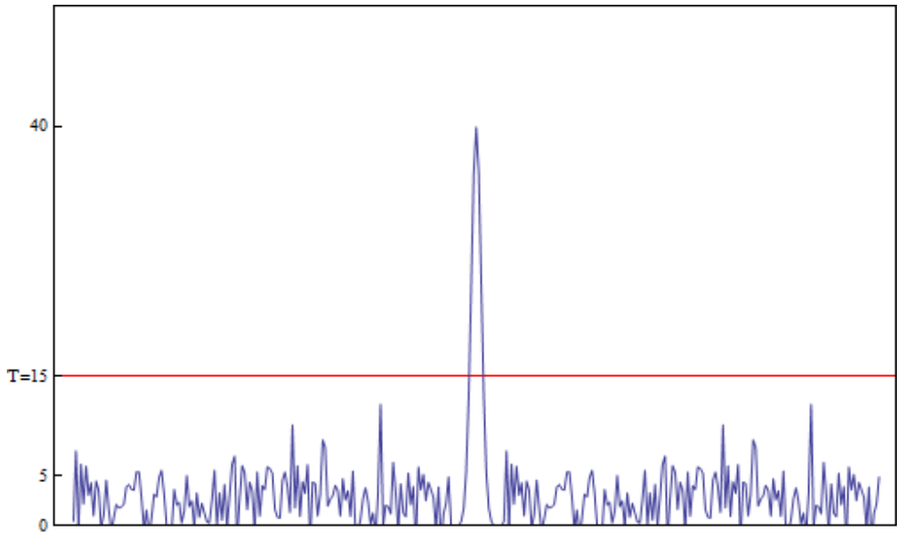
Influence of the amplitude drop on the POD

Good signal-to-noise ratio

Probability distributions



Screen reading



Signal to noise ratio, SNR = **8**

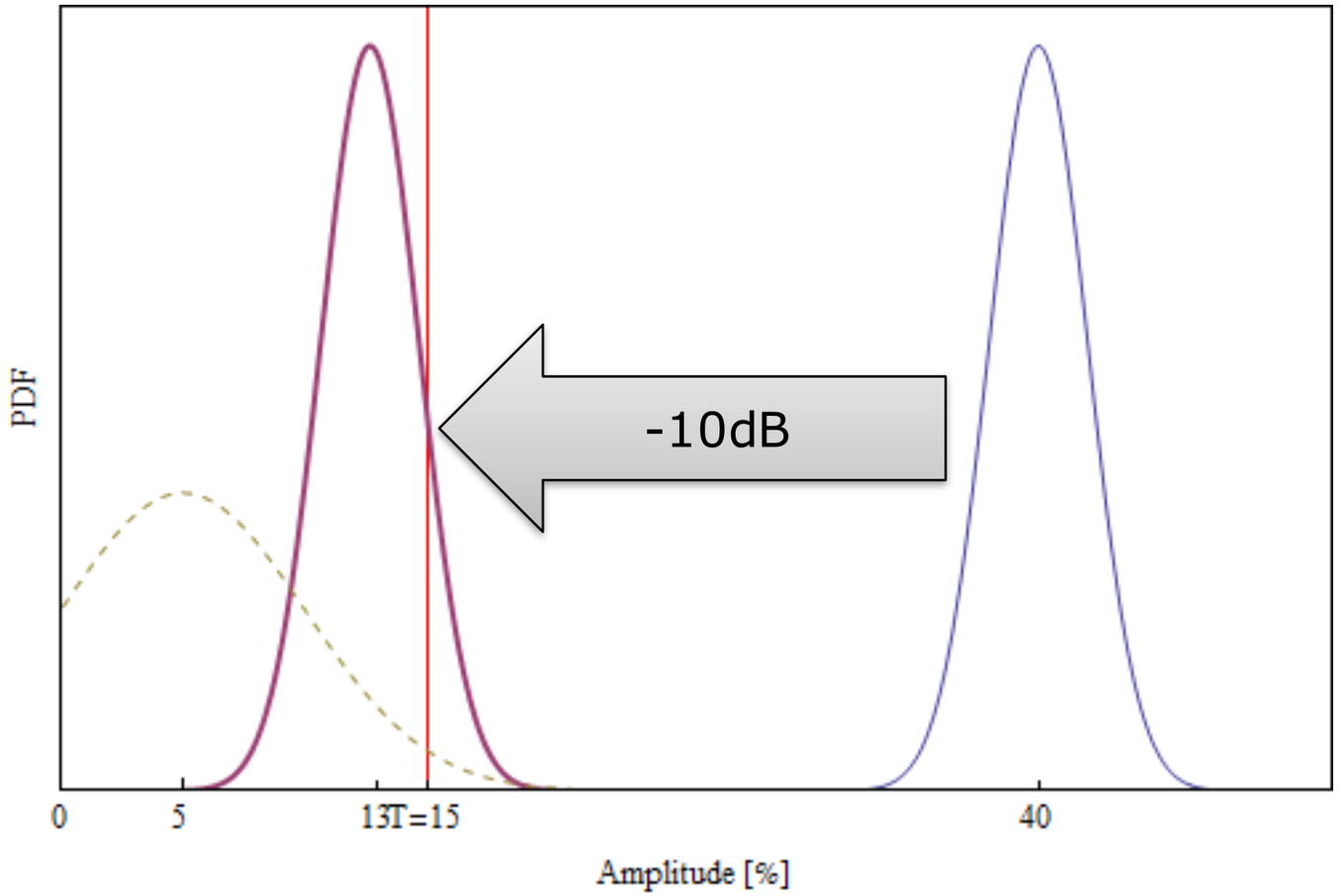
Decision threshold = **3** x noise

Probability of detection, **POD ≥100%**

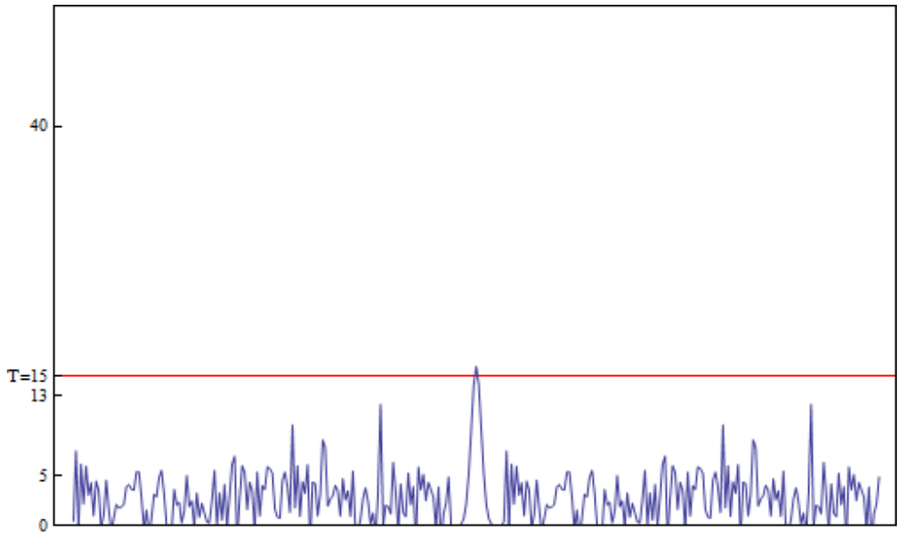
Probability of false calls, **PFC = 2%**

Influence of the amplitude drop on the POD

Probability distributions



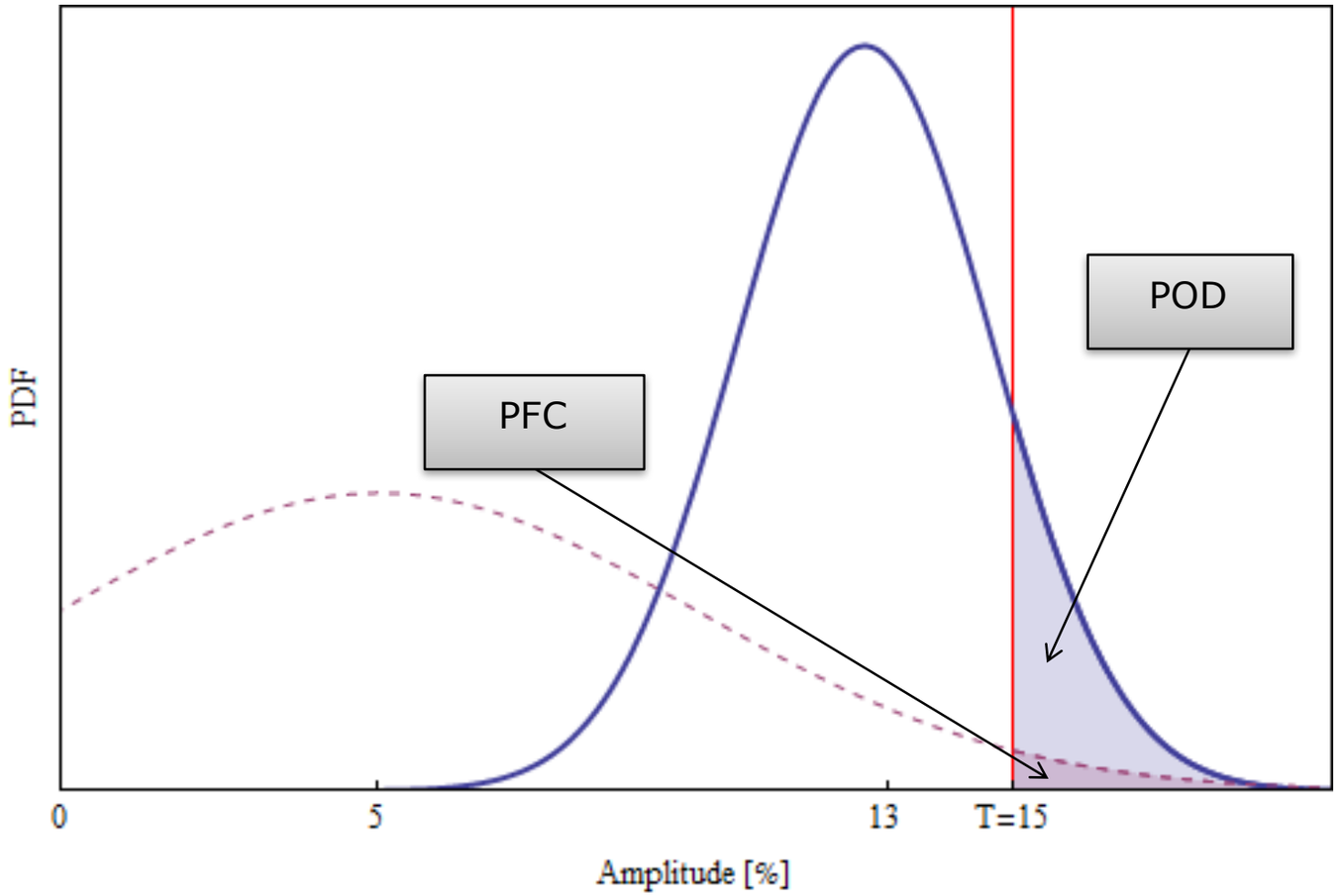
Screen reading



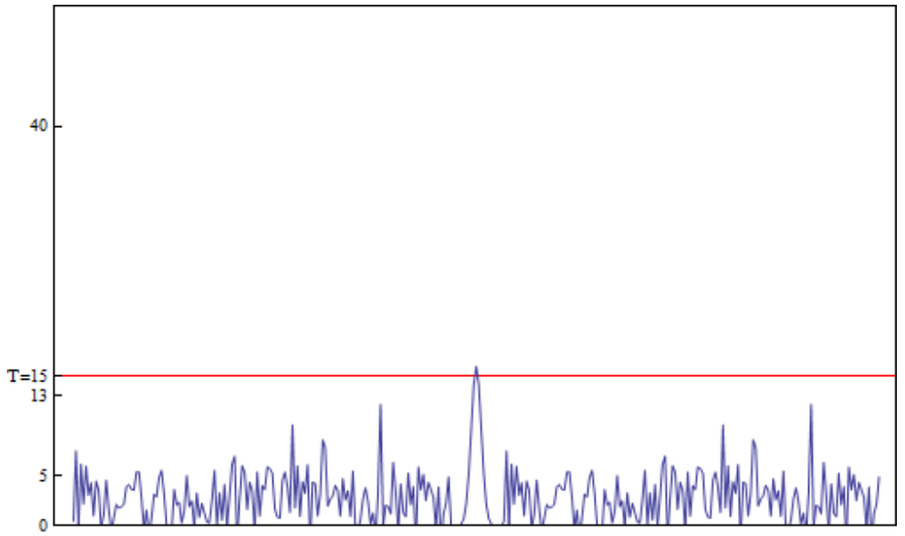
Influence of the amplitude drop on the POD

Bad signal-to-noise ratio

Probability distributions



Screen reading



Signal to noise ratio, SNR = **2.5**

Decision threshold = 3 x noise

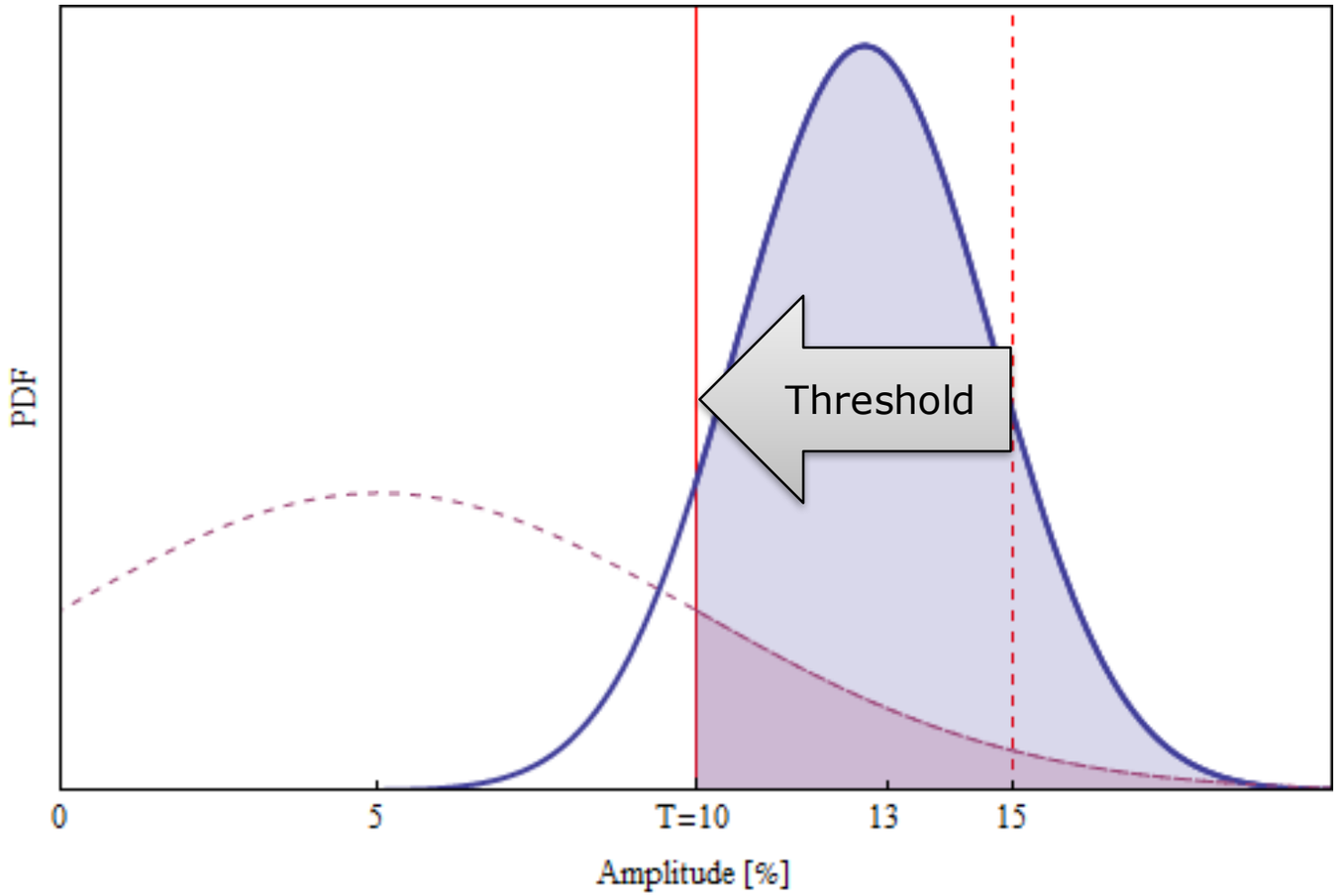
Probability of detection, **POD = 12%**

Probability of false calls, **PFC = 2%**

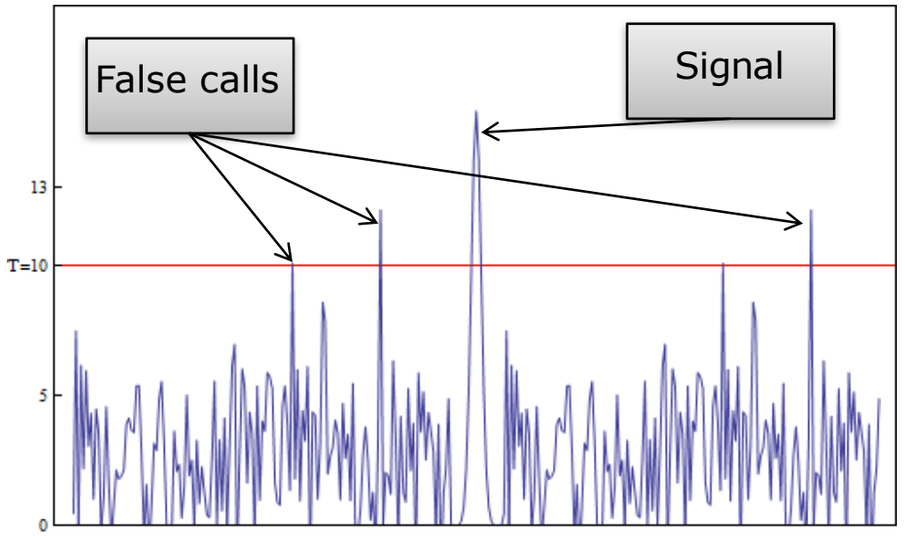
Influence of the amplitude drop on the POD

Bad signal-to-noise ratio

Probability distributions



Screen reading



Signal to noise ratio, SNR = 2.5

Decision threshold = **2** x noise

Probability of detection, **POD = 91%**

Probability of false calls, **PFC = 16%**

Conclusions

- There are many factors that influence the POD of the cracks.
- Our analysis showed that crack position, crack orientation, crack depth extension, crack shape and geometry of the axle are all influencing factors.
- Only by including all these factors in the reliability analysis, the capability of the NDT system to detect cracks can be determined.
- Multi-paramater POD model allows POD to be calculated and expressed as a function of several factors

Thank you for your attention