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

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

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.

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\textsubscript{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
Influencing Parameter: Geometry

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.

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.
Axel Shapes from an Ultrasonic Point of View

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

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

![Graph showing relative peak amplitude in %](image)
Reliability of NDT
Factors influencing the POD

POD = POD(crack position)

POD = POD(crack orientation)
Factors influencing the POD

POD = POD(crack depth extension)

POD = POD(crack shape)
Factors influencing the POD

 POD = POD(axle geometry)
Multi-Parameter POD

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

\[ a_{MP} = f(a_1, a_2, \ldots a_n) \]
Influence of the amplitude drop on the POD

**Good signal-to-noise ratio**

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Amplitude [%]
Influence of the amplitude drop on the POD

Probability distributions

-10dB

Screen reading
Influence of the amplitude drop on the POD

**Bad signal-to-noise ratio**

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**

- 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

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