A COMPARISON BETWEEN ASTM E588 AND SEP 1927 RELATING RESOLUTION LIMITS AT DETERMINATION OF THE PURITY GRADE

Daniel KOTSCHATE[1], Dirk GOHLKE[1], Rainer BOEHM[1] and Maite PEREZ-ALONSO[2]
[1]Bundesanstalt für Materialforschung und -prüfung, Germany
[2]Gerdau Investigación y Desarrollo Europa S.A., Spain
contact e-mail: daniel.kotschate@bam.de

Abstract: With increased usage of highly demanded, modern materials on safety relevant parts (e.g. railway wheel sets, generator shafts, turbine disks, medical implants, etc.) comprehensive analyses regarding the quality of the material are requested. This gives a focus to non-destructive methods using ultrasound immersion tank testing for classifying the degree of purity. Two autonomous standards, ASTM E588 and SEP 1927, have been established for the definition, execution and evaluation for this high resolution ultrasonic measurements on steel products.

The propagation of ultrasonic waves and the resulting sound field are strongly dependent on the acoustical properties of the inspected material and the geometry of probes and specimen. The definition of the measurement setup and the evaluation methods appear to differ significantly in the given standards. ASTM E588 and SEP 1927 prescribe the requirement for surface roughness and probe selection, are using threshold based methods for cleanliness detection, but differ in computation for the degree of purity. This has been the motivation for a comparison between both standards with the main focus on amplitude depth dependency and overall spatial resolution taking the influence of different material characteristics, geometry of the specimen and sound fields into account.

A performance comparison between the use of non-focusing and focusing probes respective to the threshold based detection will be presented in this contribution. In addition, the usage of complex reconstruction algorithms (e.g. SAFT, echo tomography) is compared with the traditional approaches of inclusion detection and estimation of the degree of purity.

Introduction

Focused on detection and characterization of different material properties (e.g. micro-sections, flaw orientation and position statistics), guided by SEP 1927 and ASTM E588, was compared to each other during the research work concerning the founded project *INCAFAT*. Highly focused on achieve a better characterization of the investigated materials, the dependency of spatial resolution, sensitivity and the applied evaluation method was studied. This contribution compares both standards concerning and is divided into parts: equipment operating parameters, calibration and result interpretation.

1 Equipment

Both guidelines describe the purity grade estimation under usage of automated immersion tank testing setups. Therefore the coupling medium for SEP 1927 and ASTM E588 is water and the used testing frequency is about 10 MHz for both setups. The main differences between these guidelines is dependent on the kind of searching unit which is used for investigations. The SEP1927 states the usage of an unfocused transducer with 6.3 mm diameter, which is widely available. By using a focusing the searching unit, the ASTM E588 demands to enhance the lateral resolution. The guideline states the usage of a transducer with 19.1 mm diameter and focal length (in water) at about 208.3 mm (±7.6 mm).

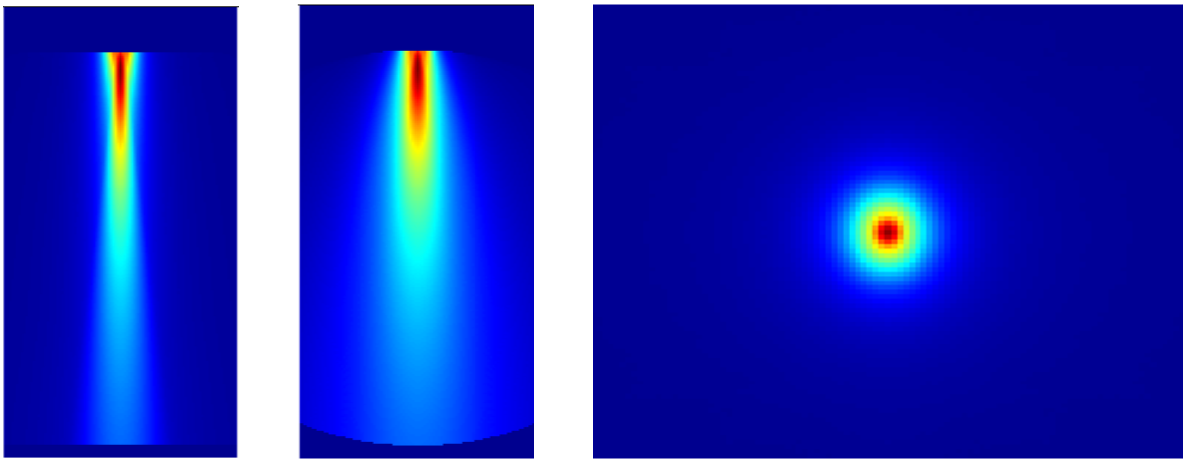


Figure 1: Directivity pattern of the transducer stated by SEP1927 x-zone (top left), y-zone (bottom left) and focal point (right) in material

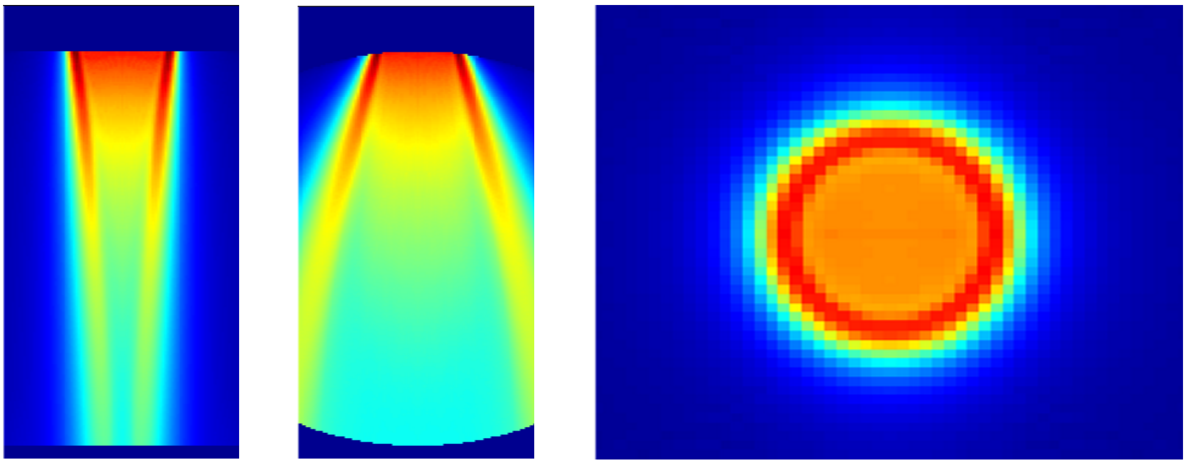


Figure 2: Directivity pattern of the transducer stated by ASTM E588 x-zone (top left), y-zone (bottom left) and focal point (right) in material

2 Calibration

For better estimation of flaw size with ultrasonic testing methods an amplitude or sensitivity calibration is necessary. Both guidelines, SEP 1927 and ASTM E588, are using different testing equipment, so the sensor calibration for maximum sensitivity differs. Calibration of the measurement setup concerning the SEP1927 uses a reference block described by the SEP1927 itself (fig. 3). As reference flaw a 1 mm disc shaped reflector (*DSR*) in 3 mm depth, with at least 4 different values of wand thickness is used. For obtaining the acoustical behavior of material and used transducer, it is free to add additional reference flaws to increase the sound path resolution.

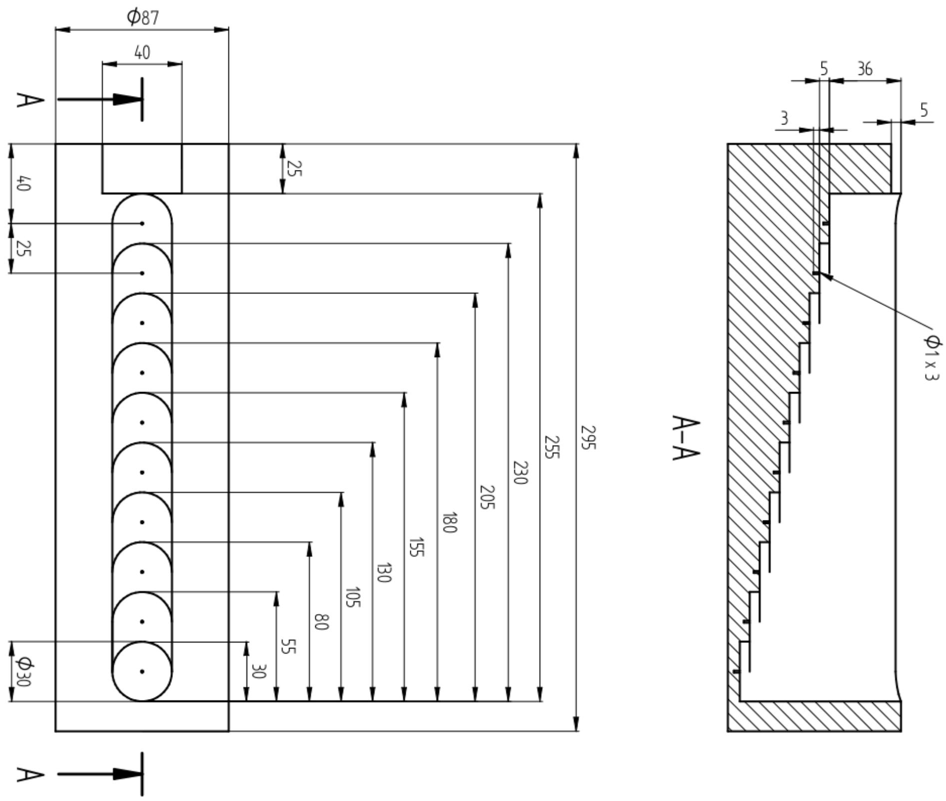


Figure 3: SEP 1927 reference block

Figure 3 shows the machined reference block for investigations during the INCAFAT project. The investigated specimen has a diameter of 87 mm, so 10 reference flaws were machined for a good resolution concerning the needed distance amplitude correction (*DAC*). With aligning the acoustical axis of the ultrasonic probe perpendicular to the surface and the bottom of the reference flaw, the needed amplification for each depth step has to be evaluated and the needed depth dependent gain is applied. Figure 4 illustrates an example curve and it's corresponding gain, investigated and used during the project.

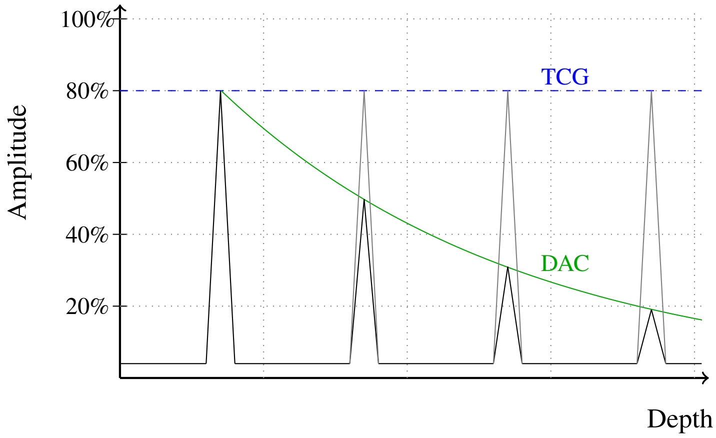


Figure 4: Distance amplitude correction (DAC) and corresponding time gain correction (TGC)

In general the calibration according to ASTM E588 is realized by using three different ball shaped reflectors (diameter: 12 mm, 7 mm and 4 mm). The guideline offers to replace the 7 mm diameter ball by an alternative 8 mm reflector. For finding the right sensitivity settings, the largest ball is placed at the focal point of the used searching unit. By increasing the distance of the ball, the point of maximum amplitude is found by an iterative search along the acoustical axis. On this point, the used amplifier stage is adjusted to gather a full screen height of 80 %. This procedure also defines the threshold which is needed to classify large inclusion. In other words, each indication which exceeds 80 % is counted as high level indication (equation 6). For medium and low level indications the smaller balls (7 mm / 8 mm and 4 mm) are placed with same amplification at the transducers focal length. Nearly the same procedure is applied for these reference flaws, the only exception being the modification of the amplifying stage.

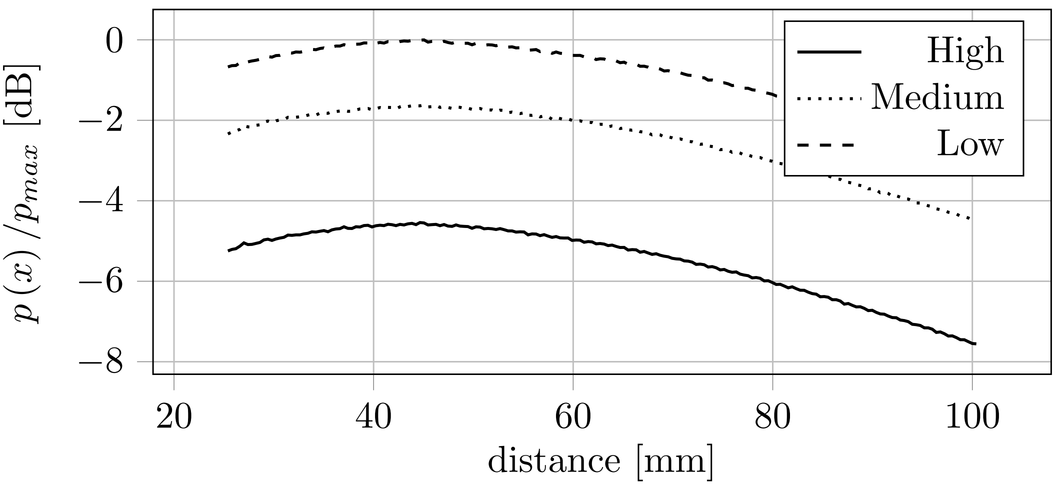


Figure 5: ASTM E588 reference levels for gate counter alignment over distance

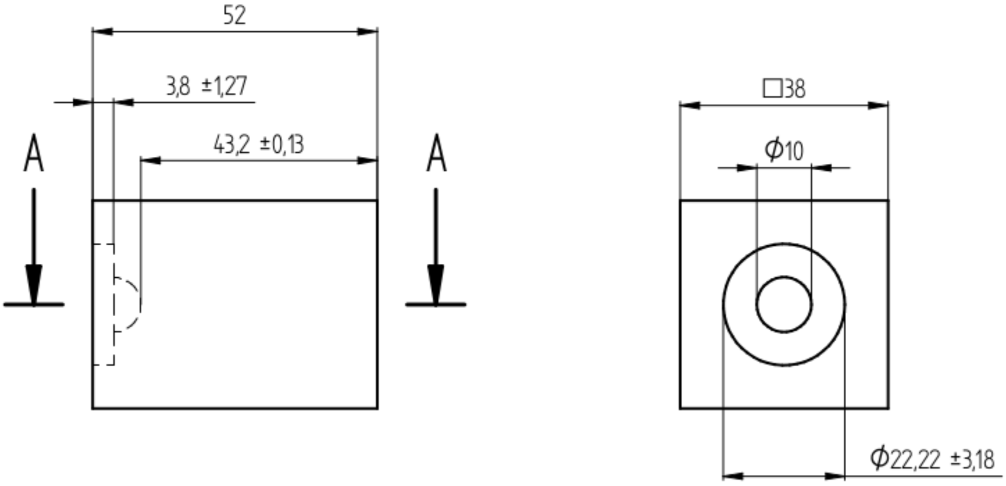


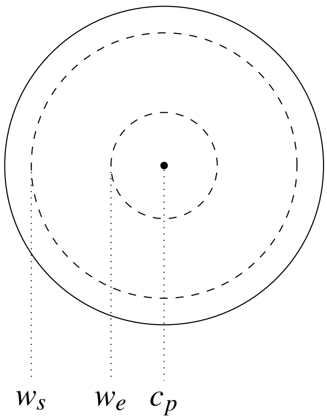
Figure 6: ASTM E588 reference block

3 Result interpretation

As both guidelines describe the amount of inclusions per volume, the same formula could be used to gather the information about the investigated volume for rotationally symmetrical specimens (formula 1 - 2).

$$V = 2\pi \cdot h \cdot w \quad (1)$$

$$V \approx 2\pi \cdot h \cdot \left({w_s}^2 - {w_e}^2\right) \quad (2)$$



w : gate depth
w_e : gate start
w_s : gate end
h : height of specimen
c_p : center point specimen

Figure 7: Schematic illustration for gated volume

Table 1: Sensitivity classes accord. SEP1927

sensitivity class	SC1	SC2	SC3	SC4	SC5
additional gain [dB]	+6	+12	+15	+18	+21
full screen height [%]	80	40	28.32	20	14.1

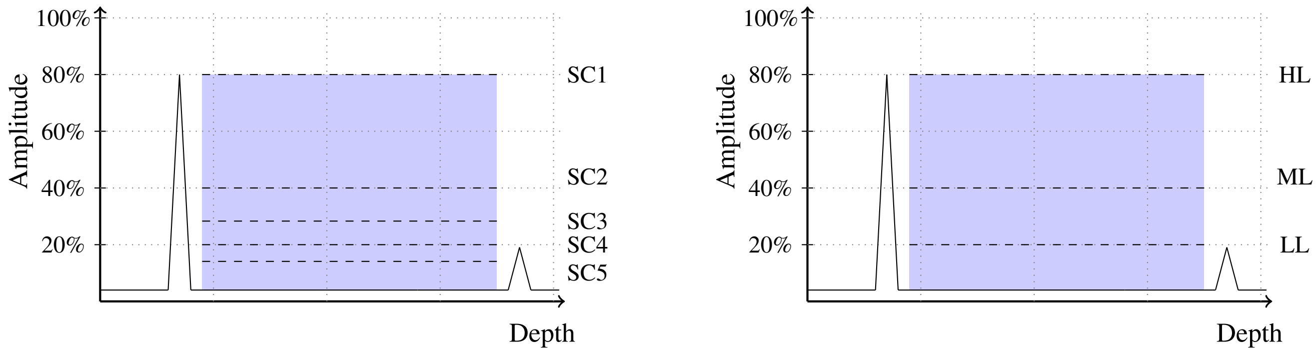


Figure 8: ROI comparison SEP 1927 (left) and ASTM E588 (right)

Figure 8 illustrates the main difference - in result interpretation - between both guidelines is the kind of indication counting. The SEP 1927 indicates each inclusion which overrides the amplitude criteria, given by the demanded sensitivity class, defined by amplitude in full screen height or addional gain steps (table 1).

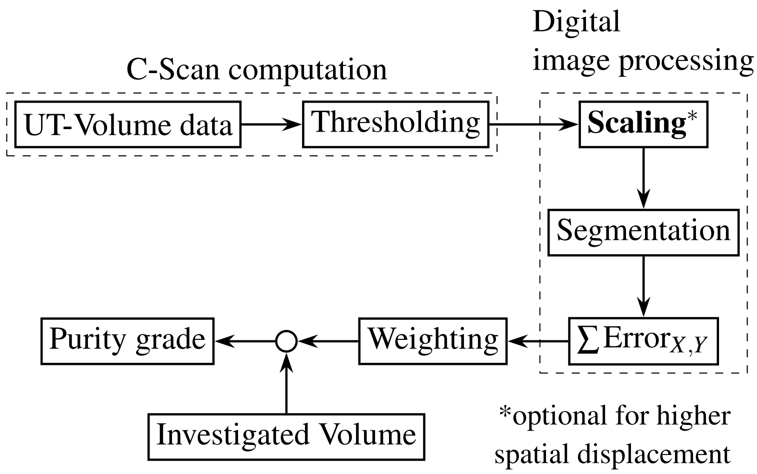


Figure 9: SEP1927 workflow using a ultrasonic volume scan

This means each inclusion, whose reflected amplitude is lower than the calibrated gate level, will not be counted. The number of positions where the amplitude overrides the threshold will be set in a binary C-Scan. To guarantee a comparison between different ultrasonic immersion tank testing setups, the SEP1927 defines a minimal spatial resolution.

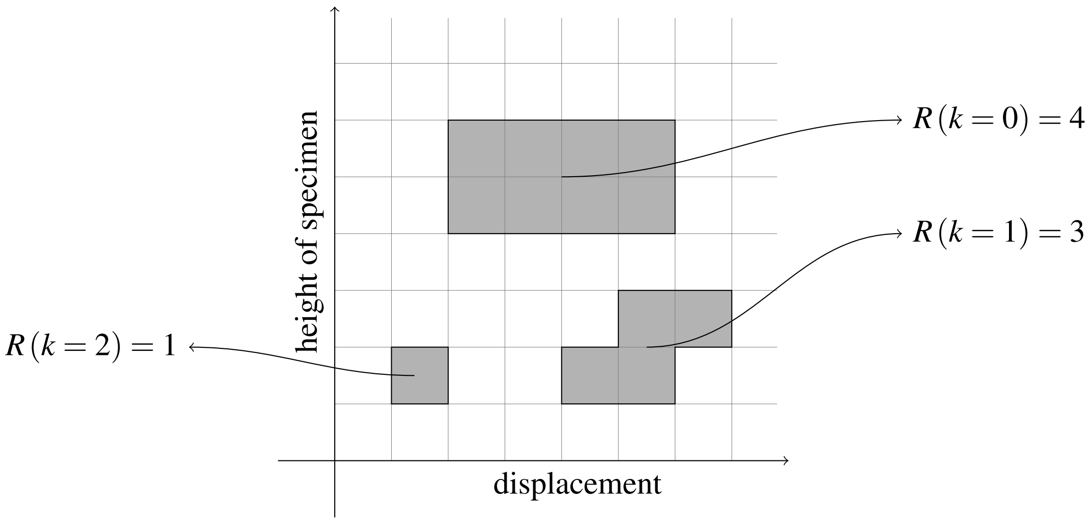


Figure 10: Example of a binary C-Scan interpretation by SEP1927

The counted inclusions were summed up according to equation 3 and will, in respect of the investigated volume, end up as degree of purity (equation 4). Inclusions which are only one pixel in size , be weighted by factor 2.

$$e = \sum_{k=0}^{N-1} \mathbf{R}(k) \cdot g(k) \qquad (3)$$

$$g(k) = \begin{cases} 2 & \mathbf{R}(k) = 1 \\ 1 & \mathbf{R}(k) > 1 \end{cases}$$

$$d = \frac{e}{V} \left[{}^{\mathrm{mm}}/_{\mathrm{dm}^3}\right] \qquad (4)$$

N : number of regions
e : weighted error count
$\mathbf{R}$: length per region and direction
g : weight

The ASTM E588 interprets an inclusion by the calibrated amplitude of the used reference ball shaped reflectors and defines the amplitude criteria as gate levels for high, medium and low level indications. Each indication is summed up to the number of indication per level and finally ends up - regardless of their level, but in respect to the investigated volume - to the severity rating (equation 6). For better comparison the equation for the severity grade regarding the ASTM E588 was adapted (equation 3 and 6).

$$e = \sum_{k=0}^{N-1} \mathbf{R}(k)$$

$$e = N_l + N_m + N_h \qquad (5)$$

$$d = \frac{e}{V} \left[{}^{1}/_{\mathrm{dm}^3}\right] \qquad (6)$$

e : error count
$\mathbf{R}$: indexed inclusion
N_l : number of low level indication
N_m : number of medium level indication
N_h : number of high level indication

On the one hand the evaluation by SEP 1927 is always in respect to a sensitivity class and no amplitude criteria involves equation 3, on the other hand the evaluation of the ASTM

E588 is only counting the gate overrides for three different amplitude criteria. Additionally, the SEP 1927 maps the geometrical size for weighting the number of inclusions per volume. So the error count proceeding is compared between these guidelines.

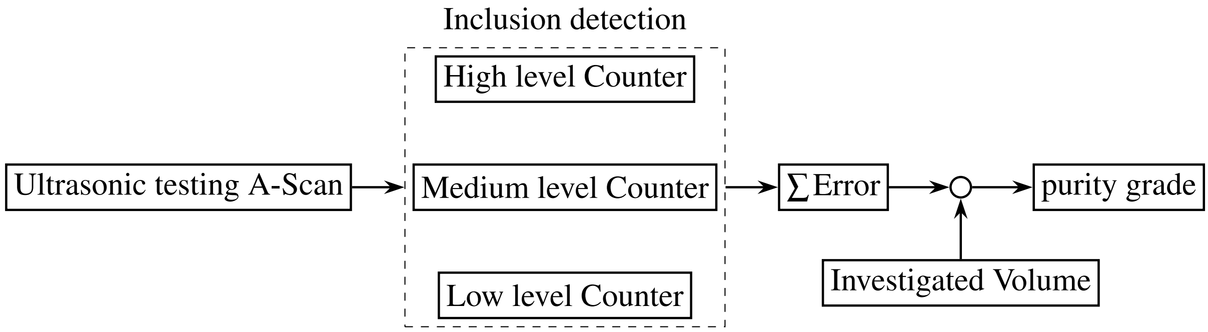
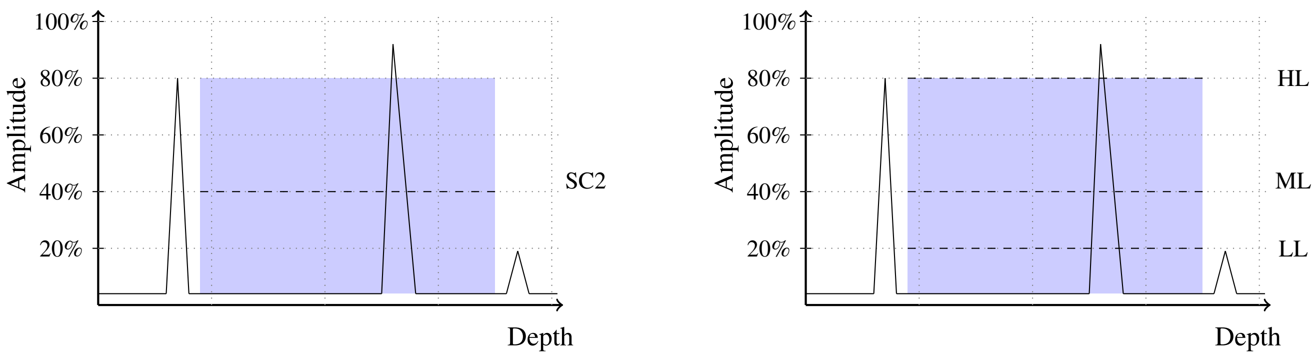


Figure 11: ASTM E588 workflow using a ultrasonic gate counter

Single inclusions

The indication of single shot inclusions is only considered by the weighting of the SEP 1927. For these results, especially for smaller inclusions, the amount of reported inclusions is similar to the results produced by the ASTM E588.

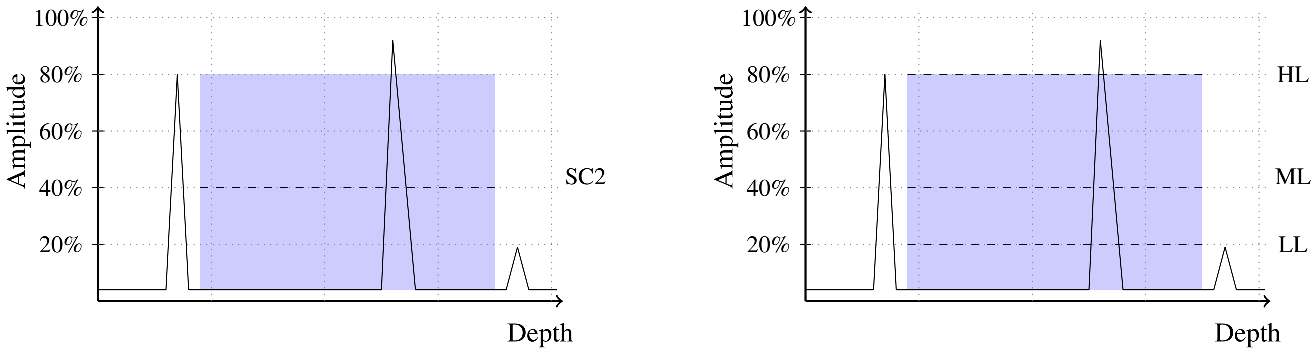


$e = 1 \cdot 2 = 2$ $\qquad$ $e = 1 \cdot 3 = 3$

Figure 12: Interpreation of the same single shot inclusion

Volume distributed inclusions

In case of volume distributed inclusions (distributed in circumflex direction), an inclusion is detected (in respect of lateral and spatial resolution) in a discrete number of A-Scans. For C-Scan evaluation by the SEP 1927 the dimension of the indicated region is increased. In dependency to the applied three gate levels, the gate counter approach of the ASTM E588 is also increasing scalar. If the number of indicated positions **G** is a scalar integer, the type of increasing the error count is linear.

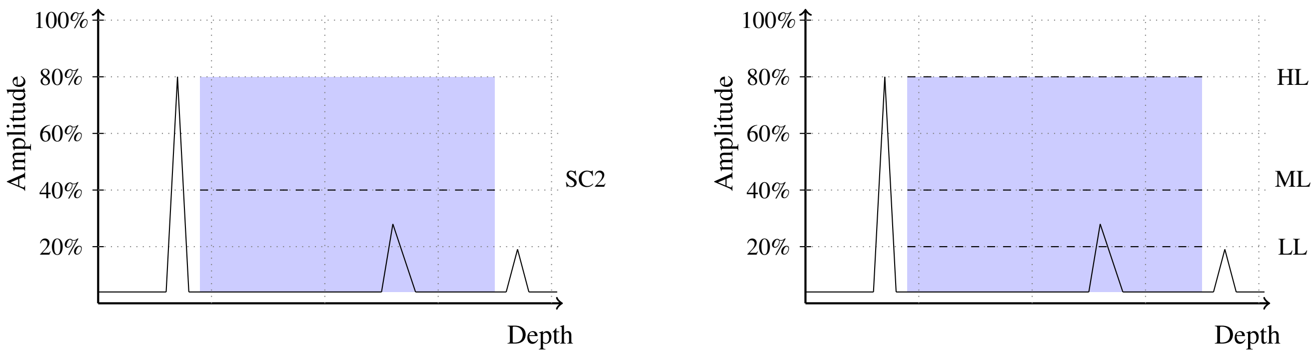


$e = G \cdot 1$ $e = G \cdot 3$

Figure 13: Interpretation of a volume distributed indication

Small volume distributed inclusions

For classification of small inclusions, the reflected amplitude is decreased dramatically. The evaluation by SEP 1927, sensitivity class dependent, results in a smaller error count. In the worst case, an underrated inclusion results in an error count near zero. In this case, the ASTM E588 is more conservative and will report a detected indication.



$e = G \cdot 0$ $e = G \cdot 1$

Figure 14: Interpretation of the small volume indications

4 Conclusion

Both guidelines, SEP 1927 and ASTM E588, are highly industry orientated and present two independent approaches for cleanliness estimation. The benefits of sensitivity class dependent indication reporting and geometric evaluation of the SEP 1927 sets the requirement for an available C-Scan visualization regarding the ultrasonic testing equipment. Due to the lack of variation through different threshold levels, the definition and usage of three gate levels the ASTM E588 is more conservative.

5 Acknowledgment

The research leading to these results has received funding from the European Union's Research Fund for Coal and Steel (RFCS) research programme under grant agreement n°RFSR-CT-2013-00014.