Probability of Detecting Planar Defects in Heavy Wall Welds by Ultrasonic Techniques according to existing Codes

"Probabilité de la détection par ultra-sons de défauts plats dans les joints de soudure de parois épaisses, en concordance avec les codes actuels."

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Summary

Size estimation of a defect depends upon the proportion of the ultrasonic beam reflected back to the probe. The reflection behaviour of a defect, or what we call "reflectivity", is thus a largely decisive factor in estimating the size of a defect. The larger the size of a planar defect the greater is the directional sound pressure distribution. In other words, the steeper the angle of a planar defect relative to the perpendicular sound beam the smaller are the chances of distinguishing between ultrasonic indication and actual flaw size. This is a matter which must be taken into account by the codes; the selection of special inspection techniques (different beam angles, tandem technique) and other evaluation criteria, such as for instance the frequency of indications, must also warrant the detection of planar defects in unfavourable orientations to enable such defects to be repaired whenever they exceed the acceptable limit.

Résumé:

La détermination de l'importance d'un défaut dépend de la quote-part réfléchie de rayon qui retourne au palpeur ultrasonore. Le comportement d'un défaut à la réflexion, la "réflectance", est ainsi un facteur décisif dans l'évaluation de l'importance d'un défaut. La directivité augmente proportionnellement à l'importance d'un défaut plat, ce qui signifie qu'avec l'inclinaison augmentante d'un défaut plat par rapport à la direction perpendiculaire de l'arrivée de l'ultra-son, se perdra la corrélation entre vraie grandeur du défaut et indication ultrasonore. Les codes doivent en tenir compte et assurer - par la détermination de techniques particulières de contrôle (différents angles d'incidence, méthode Tandem), et par d'autres critères d'évaluation tels que p.ex. la fréquence d'indication - que même des défauts plats mal orientés soient reconnus et retouchés lorsqu'une certaine valeur-limite est dépassée.

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1. Introduction

It was in the early sixties that ultrasonic inspection of welds was started in the FRG and continued on a constantly increasing scale for production quality control. Soon afterwards the method of ultrasonic inspection was combined with conventional radiographic inspection techniques. In some cases the method of ultrasonic inspection was even given preference as the main inspection method for steam boilers and pipework [1].

As in all measuring and inspection methods the main problem from the outset of ultrasonic inspection was the reproducibility of the results and their evaluation to establish the actual size of the flaw.
Unlike radiographic inspection where a defect in the direction of the radiation beam is projected onto a film, ultrasonic inspection must place the proportion of the beam reflected by the defect in relationship to the actual size of the defect. This was done by placing the proportion of the beam reflected by the defect in relation to known artificial reflectors, such as notches, edges or cylindrical boreholes located normal to the ultrasonic beam. Actual practice revealed that notches and edges are very unsuitable reference defects [2], but very good results were obtained by the use of cylindrical boreholes and many national codes adopted the cylindrical borehole as a reference reflector [3] .

The indications of circular reflectors of certain diameters at various distances [4] can be determined without the use of artificial reflectors. The "reflectivity diagrams" used for this purpose agree both in theoretical calculation and practical amplitude with ideal flat-bottom holes in the sound beam axis. The only measurement to be made is that of the infinite back echo or a defined cylindrical borehole (e.g. of IIW-reference blocks).

590283

The correlations between amplitudes of cylindrical boreholes and circular reflectors as a function of distance and diameter are known from extensive work by Wüstenberg and Mundry [5] . This enables an evaluation with cylindrical bore-holes as reference reflector to be transposed into a reflectivity diagram evaluation.

Hereunder an attempt is made to investigate the indicative value of national codes for the performance and evaluation of ultrasonic inspection work. A comparison is made between Specification HP 5/3 (manufacture and inspection of pressure vessels) of the FRG [6] and the relevant ASME Codes.

2. Difficulties in Detecting Planar Defects in Welds

Fig. 1 illustrates various cases where it is problematic by ultrasonic techniques to detect and establish the size of planar defects in welds.

a) In cases where an ultrasonic beam does not hit a defect perpendicularly, the proportion of the beam reflected back to the probe will be small depending on the inclination and size of the defect. If the ultrasonic beam is introduced from the other side of the weld (if possible) the defect is better to recognize and it becomes easier to establish the size of the defect.

b) Planar defects located vertical to the surface, especially if the surface of the defect is smooth, are difficult to recognize from either side because the main proportion of the ultrasonic beam is reflected in a different direction. In such cases the tandem technique is recommendable.

c) Where laminations are present or inclusions run parallel to the surface it may happen that a planar defect is in the shadow range of such laminations or inclusions.

590284

d) Any lack of fusion between individual weld runs, due to surface curvature, tend to scatter the ultrasonic beam in different directions.

e) Shrinkage stresses within the weld are liable to compress a defect (crack) to such an extent that "ultrasonic transparency" occurs. In such cases the ultrasonic beam passes through the defect. Where surfaces are very smooth and frequencies are low, complete transparency is liable to occur from about 20 N/mm² [7] .

3. Inclination of Planar Defects

The behaviour of a sound beam as a function of size and angle of a planar reflector is shown in Fig. 2 .
According to the diagram a small reflector, although with higher amplification, will still be capable of being recognized and established in its size also if oriented at a steeper angle ($\Delta \vartheta$) due to its quasi spherical-shaped reflection characteristic. However, with increasing size of the reflector the beam will be deflected in the opposite direction and even at small angles of orientation no part of the beam will be reflected back to the probe. In such cases the conditions governing the single probe technique and the tandem probe technique are comparable.

4. Reference Levels according to ASME and HP 5/3

Fig. 3 is a plot of the various reference levels according to the ASME code. The cylindrical borehole used depends on the wall thickness. The primary reference response (position 3) is set at 75% of the full screen. Under conditions of constant amplification we obtain for the primary reference level the amplitudes of the probe positions 1, 5 and 7. Plotted in relation to this curve, depending on code interpretation, is

500285

the 50% reference curve (normal case) or the 20% reference curve as a type of "recording level". The reference block and the plots are shown again in Fig. 4 which simultaneously explains the method of setting the equipment according to the reflectivity diagram. Using the large or the small IIW block, th quasi reflector echo of R1 or R2 is taken after time base calibration with its peak into the circle R1 or R2 of an appropriately selected perspex scale. By applying the necessary amplification of 20 or 30 dB the screen indication of the 1.5 mm cylindrical borehole, subject to correct calibration and amplifier characteristic, must have its peak in the circles C1 or C2. The curves on the scales, numbered 1, 2, 5, 7 etc. now correspond to the equivalent reflectors as equivalent flat bottom holes of these diameters.

The reference levels for recording and acceptability can now be given as curves with definite equivalent reflectors or as curves with definite dB distances from a recording level depending on the wall thickness.

By calculating according to [5] the various levels for circular reflectors and cylindrical boreholes and plotting them in the amplification/distance curve, we obtain for the different wall thicknesses the conditions shown in Fig. 5 according to ASME and HP 5/3 [6] (20% reference level according to ASME). The 50% reference level would be 8 dB over the 20% level in each case.
A comparison between HP/3 and ASME (Fig. 5) reveals that the HP 5/3 provides a greater degree of differentiation in response to the wall thickness (10, 15, 20, 40 mm) whereas according to ASME there are border lines at 1 inch and 8 inches.

590286

Fig. 6 compares the recording level and acceptance level for the example of a weld between 4 and 6 inches thick. Here again the 20% curve has been plotted according to ASME. However, as a matter of our own experience, the 50% reference level which is 8 dB higher is given greater preference in the U.S.A.

5. Repair Criteria

According to HP 5/3 a definite dB distance (6 or 12 dB) above the recording level is the general criterion for repair. Between the recording level and the repair level there may exist a definite number of reflectors depending on the length and number of indications based on a weld length of 1 m. Fig. 7 shows the evaluation scheme for wall thicknesses between 40 and 60 mm. In III it is shown that, for instance, one indication in the range up to 12 dB over the recording level at a maximum length of 10 mm is still acceptable.

In the event of combined or clusters of indications (IV) the unacceptance level is generally lowered by 6 dB. According to the ASME code a case of repair does not exist until the primary reference curve is exceeded. Indications and clusters of indications between the recording level and the primary reference level are ignored. There is no reference to a definite length of weld, but instead the acceptable length of indications exceeding the primary reference level is placed in relation to the weld thickness (Fig. 8). Thus, for instance, with a wall thickness over 60 mm an indication which exceeds the primary level must have a length of over 3/4" to come under the unacceptance criteria.

6. Comparison between HP 5/3 and ASME

In Sections 4 and 5 various comparisons have already been made between the two comparable codes HP 5/3 and ASME. With

590287

the aid of symbols, Fig. 9 compares the two codes for the thickness range between 4 and 6 inches and shows where both codes are equivalent (++), where they differ (+o) or where HP 5/3 incorporates additional provisions which ASME does not (+-).

7. Results of Practical Application of the Codes

To investigate the indicative value of the codes with regard to planar defects at adverse angles, reference blocks with defined reflectors were used.

7.1 Reference block with flat-bottom holes:

Using the reference block with flat-bottom holes shown in Fig. 10, the flat-bottom holes located at an angle of 6° to the surface, and after accurate adjustment of the ultrasonic testing equipment, the reflectivity conditions were established and evaluated according to the codes duly observing all rules according to HP 5/3 and ASME. With this type of artificial reflector it was found to be a drawback that not only the surfaces of the flat-bottom hole act as a reflector, but most likely, under conditions of an inclined angle of incidence, also a certain adjacent area of the cylindrical borehole would act as a reflector. Fig. 11 is one example from a multitude of results obtained for evaluation:

The 20% curve according to ASME (a, b) was used as the recording level. All defects with solid black circles were above the recording level. The defects marked thus ⌧ exceeded the acceptance level and would have had to be repaired. It is clearly shown that at a recording level of 20% according to ASME there is but little difference between the two codes; however, owing to the different evaluation of the recorded indications (Section 5) there is a major difference between ASME and HP 5/3 in the unacceptance criteria.

590288

7.2 Pressure vessel wall, with welded-in disks as artificial reflectors:
Disks of differing diameter and shape (circular, elliptical, semi-elliptical) were welded into the 6° flank of a circumferential weld of a 145 mm thick pressure vessel wall.

Fig. 12 shows the results of the test using artificial reflectors of a definite size, location and inclination. For the test according to ASME the 50% recording level was used. It was found that the number of reflectors, no longer detected by the test according to ASME, was substantial. Regarding the repair criteria the same applies as has been said in 7.1.

8. Evaluation of Welds with different Quality Requirements
The comparison made so far between ASME and HP 5/3 has been based on pressure vessels which call for high weld quality standards. This quality level is not always applicable in evaluating a weld. FRG DIN Standard 8563, Part 3, differs between 4 evaluation categories A, B, C and D. For manufacturer's specifications a number of tables have been developed on the basis of such codes as the HP 5/3 for the evaluation of indications of ultrasonic inspection tests to satisfy the different quality standards. Fig. 13 gives an example of the evaluation scheme for quality category C, sub-divided into the evaluation of longitudinal and transverse flaws.

A strictly schematic evaluation of ultrasonic indications has proved its worth in our own inspection practice for quality assurance of welds, although this method differs from many other evaluation methods which require from the inspector an as accurate as possible statement on the type of defect, e.g. [9]. Predictions are that with the increasing

590269

acceptance of mechanized and automated ultrasonic inspection, individual evaluations will no longer be possible and decisions must be made on a schematic basis.

9. Measures for positive detection of planar defects

To reduce the uncertainty of detecting planar defects oriented at an adverse angle to the ultrasonic beam, it has been found to be advantageous to use several beam angles from several directions. In extreme cases the only alternative is to carry out a complete ultrasonic inspection as shown in Fig. 14. The tandem technique, tuned for definite depth zones, affords additional safety as shown in the comparison between the single-probe technique and the multi-probe technique in Fig. 15.

An improvement in the detection of defects and in size evaluation can also be achieved by reducing the testing frequency. Low frequencies result in an increased angle not only for the transmitter but also for the reflector on reflecting the beam (Fig. 16) [10].

590290

Literature:

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590291

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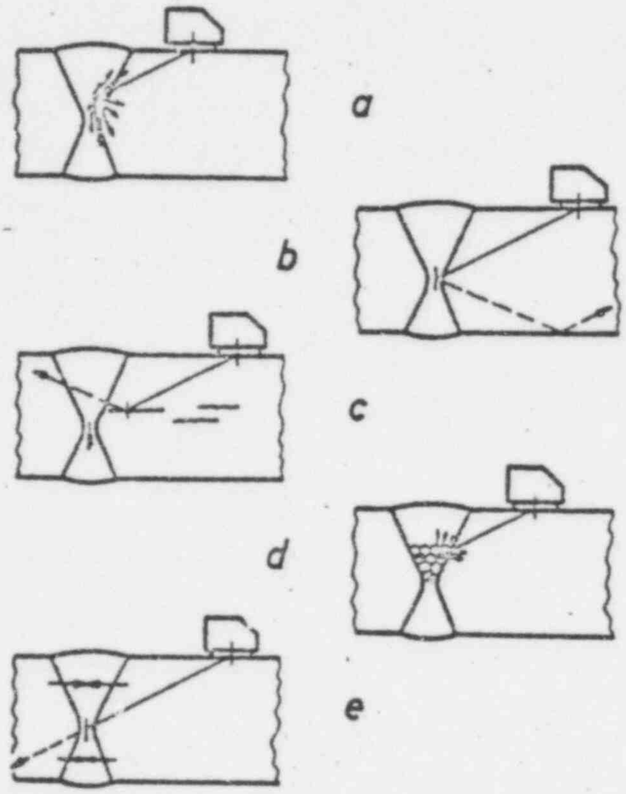
[10] Frielinghaus, R.: Zur Ersatzfehlergrößenbestimmung von Schweißnahtfehlern mit Ultraschall (Equivalent Flaw Size Determination of Weld Defects by Ultrasonic Inspection), Schweißen und Schneiden 25 (1973), Volume 12, Page 592/595

590292

Fig. 1:

Reasons for failures in detecting planar defects



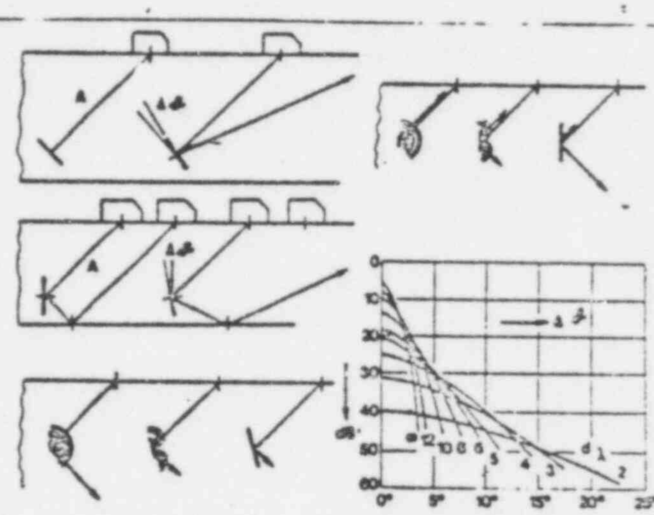
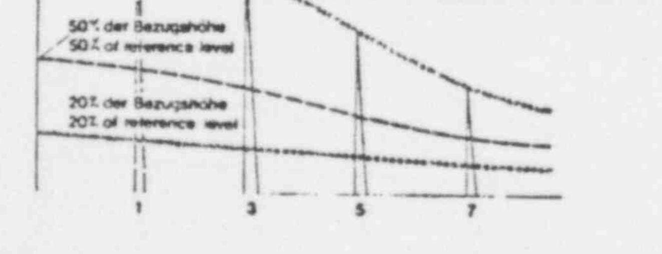


Fig. 2:

Behaviour of sound beam as a function of size and angle of a planar reflector



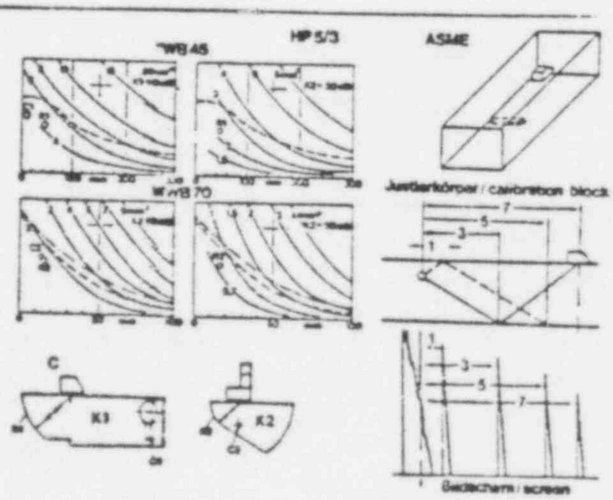


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Fig. 3:

DAC reference line according to ASME

Fig. 4:

Calibration sensitivity according to ASME and HP 5/3 for angle beam method

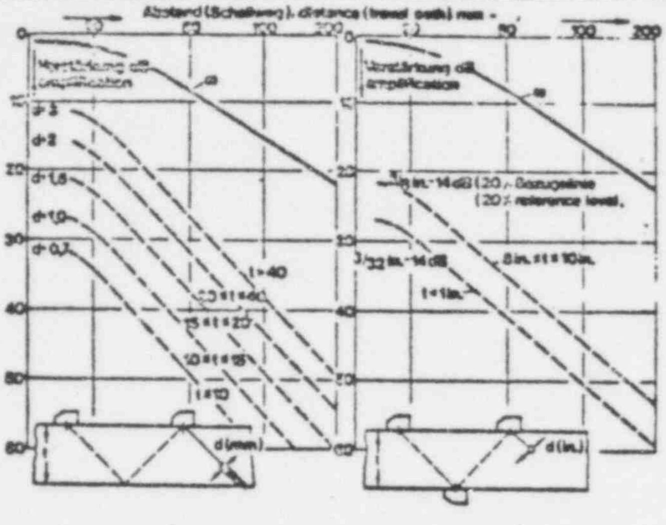

Fig. 5:

Comparison of recording level according to HP 5/3 and 20% reference level according to ASME
2MHz, Schwinger/crystal 8 x 9 mm²

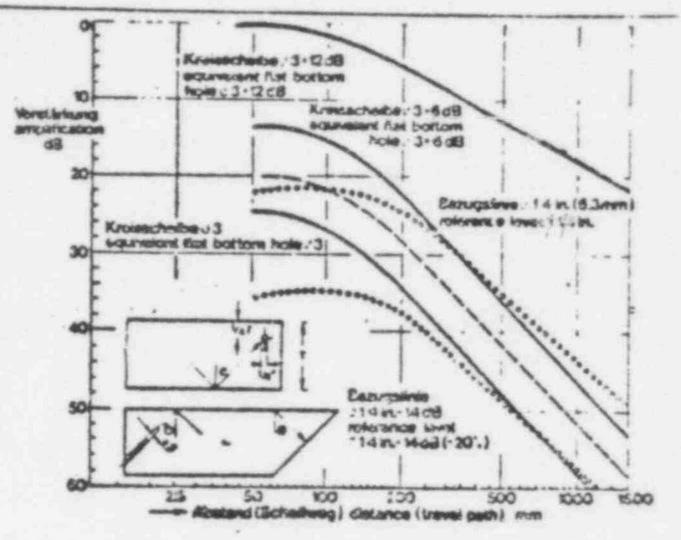

Fig. 6:

Comparison of calibration sensitivities according to ASME and HP 5/3 for wall thicknesses over 4 through 8 inches

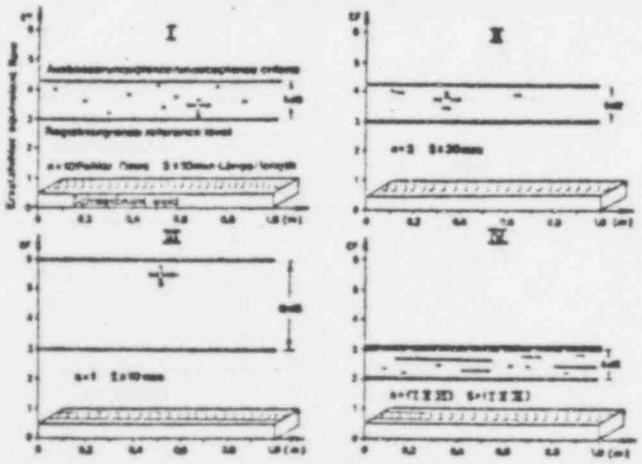

Fig. 7:

Evaluation of ultrasonic indications according to HP 5/3

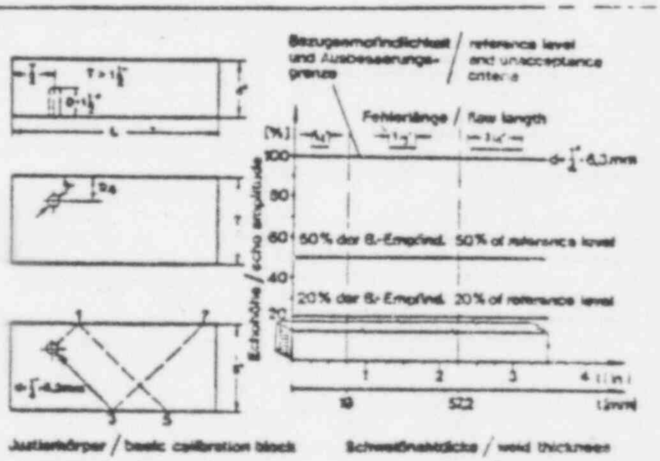

Fig. 8:

Evaluation of ultrasonic indications according to ASME

590234

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Empfindlichkeitseinstellung	Sensitivity Setting	HP 5/3	ASME
Justiermethode	Calibration method	+	O
Transferkorrektur	Transfer correction	+	O
Registriergrenze	Recording level	+	O
Ausbesserungsgrenze	Unacceptance level L	+	O
Empfindlichkeitserhöhung nach Befund	Higher sensitivity according to test result	+	–
Prüftechnik	**Examination technique**		
Längsfehler	**Longitudinal flaws**		
Zwei verschiedene Schallwinkel	Two different beam angles	+	+
Normaleinschallung	Straight beam technique	+	+
Prüfung von zwei Nahtseiten	Examination from both sides of the weld	+	+
Tandemprüfung	Tandem technique	+	+
Querfehler	**Transverse flaws**		
Zwei verschiedene Schallwinkel	Two different beam angles	+	+
Prüfung von einer Oberfläche	Examination from one surface	+	+
Tandemprüfung	Tandem technique	+	–
Fehlerbewertung	**Evaluation of flaws**		
Fehlergrößenbestimmung	Evaluation of flaw amplitude	+	O
Fehlerlänge	Length of flaw	+	O
Fehlertiefe	Depth of flaw	+	+
Fehlertiefenausdehnung	Height of flaw	+	O
Fehlerhäufigkeit	Number of flaws	+	–
Fehlerabstand bei gleicher Tiefenlage	Distance between flaws in same depth	+	–
Fehlerabstand in Dickenrichtung	Distance between flaws in direction of thickness	+	–

Symbole	Symbols	Bedeutung	Legend
+ +		Gleiche Prüfmethoden	Same examination methods
+ O		Verschiedene Prüfmethoden	Different examination methods
+ –		HP 5/3 Prüfmethode	HP 5/3 examination method

Fig. 9:

Comparison of weld examination according to HP 5/3 (level C) and ASME Code Section V for wall thicknesses over 4 through 6 inches.

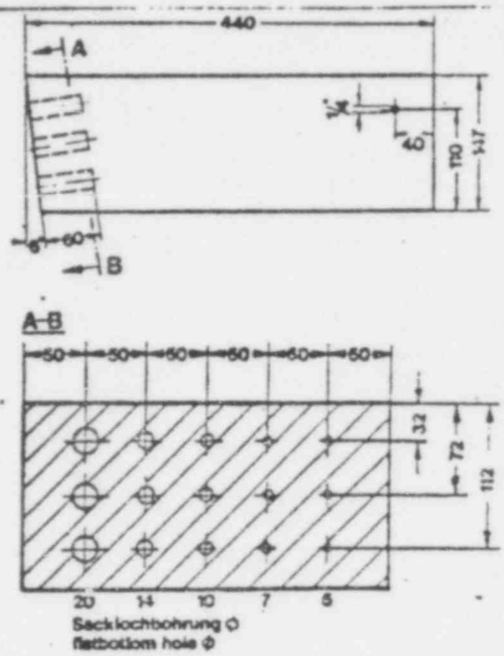

Fig. 10: Specimen

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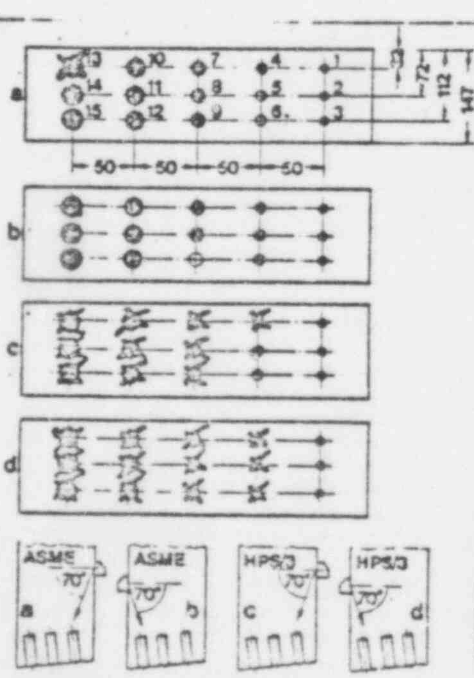

Fig. 11: Flaw detectability with angle probe WB 70

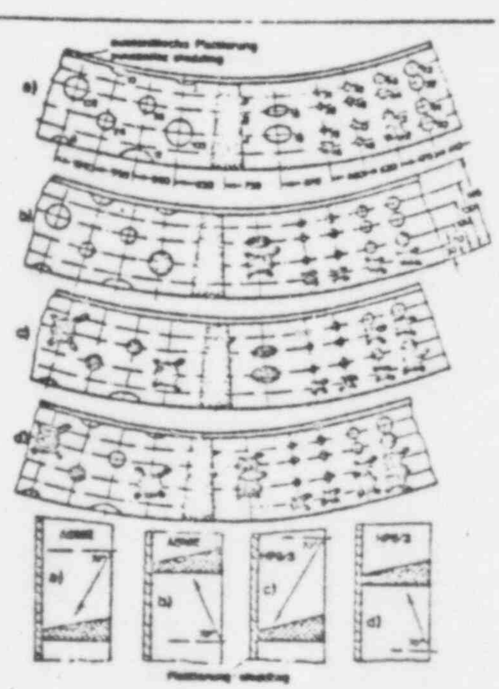

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Fig. 12: Flaw detectability with angle probe WB 70 (ASME recording

Bewertungs-gruppe evaluation group Din 8563 Teil part	Wanddicke wall thickness (mm)	Längsfehler Longitudinal flaws			Querfehler transverse flaws		
		Anzahl pro m Naht number per m weld	Fehler-länge flaw length (mm)	max. zul. Echo-höhe max perw. echo amplitude	Anzahl pro m Naht number per m weld	Fehler-länge flaw length (mm)	max. zul. Echo-höhe max perw. echo amplitude
AS AK*)	---	---	---	—	—	—	—
BS BK*)	---	---	—	—	—	—	—
CS CK*)	S≤10	5	10	15	3	10	15
	10≤S≤20	10 +	15	2	3	10	2
		3 +	30	2			
		1	10	3			
	20≤S≤40	10 +	15	3	3	10	3
		3 +	40	3			
		1	10	5			
	S>40	10 +	15	4	3	10	4
		3 +	50	4			
		1	10	6			
DS	---	---	---	---	---	---	---

*für Wanddicken>10 und Vollanschlüsse for wallthickness>10 and full penetrations

Fig. 13:

permissible indications with the ultrasonic inspection (example for CS/CK)

(nach/after Qm 05-001)

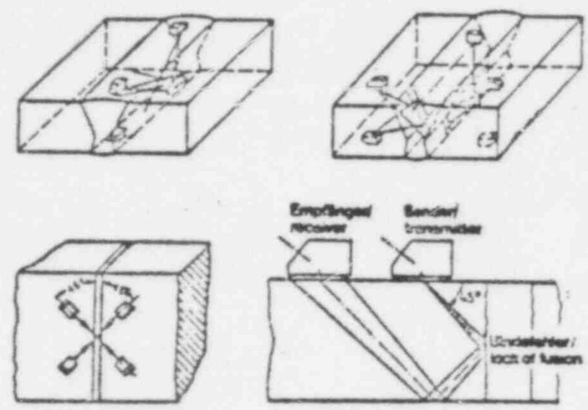

Fig. 14:

"complete" ultrasonic inspection of pressure Vessel walls

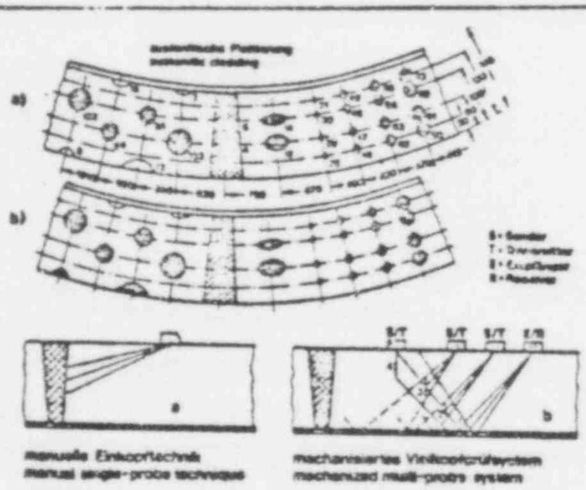

Fig. 15:

Comparison of flaw detectability

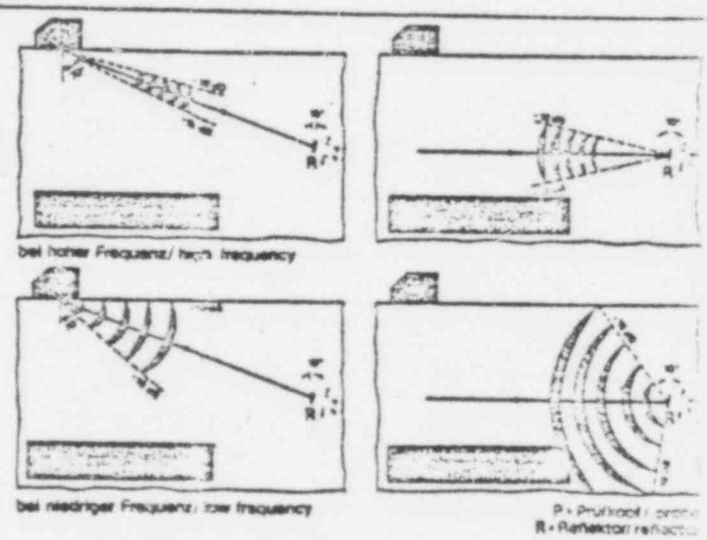

Fig. 16:

Reflectivity behaviour as a function of ultrasonic frequency

(Krautkrämer)

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MAT'L LOSS ____ DB/ ____

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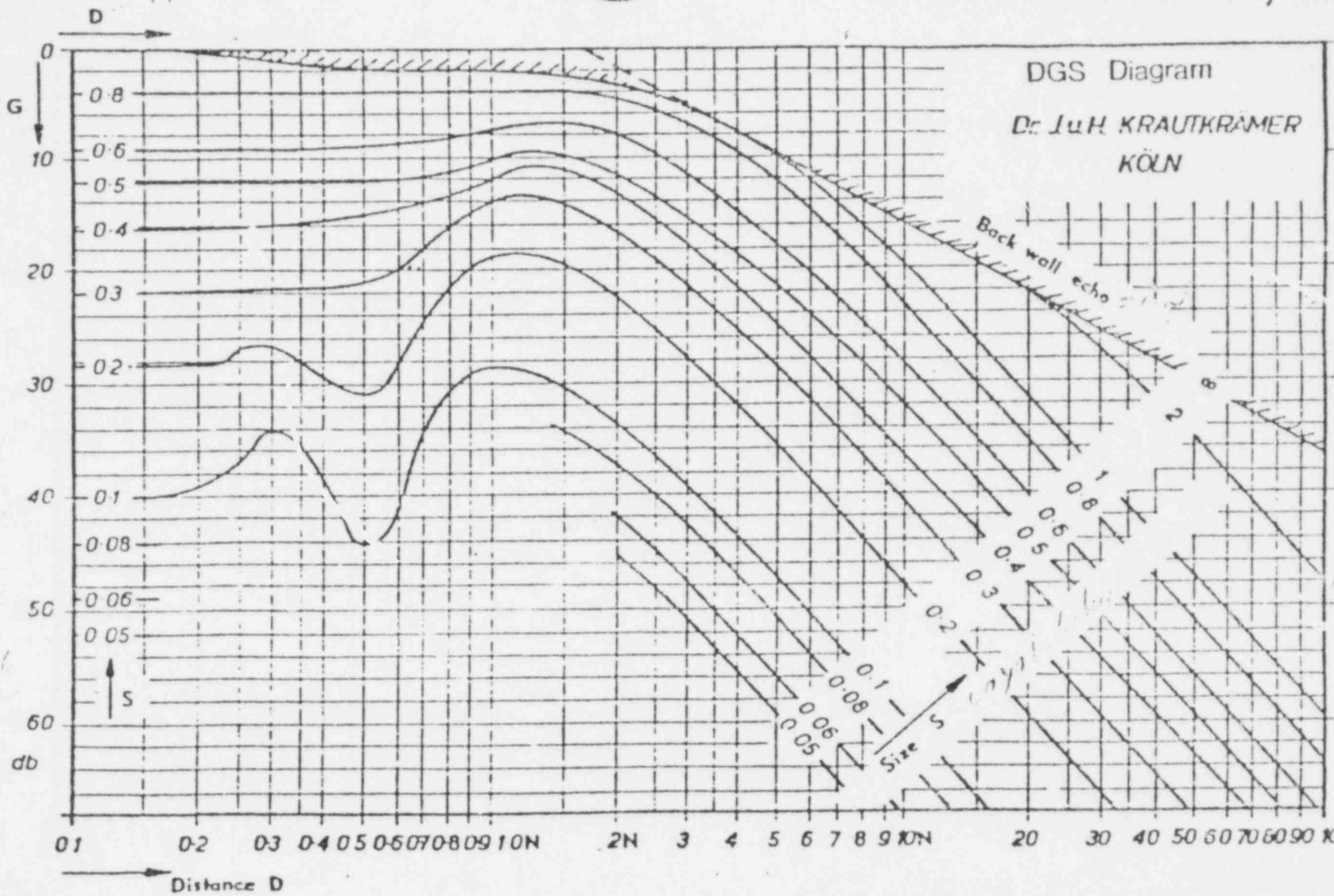

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GAIN F.E. ______________

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