Non Destructive Testing

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ENGINEERING DEPARTMENT

MECHANICAL & MATERIALS ENGINEERING
FOR PARTICLE ACCELERATORS AND DETECTORS

Outline

1. **What is NDT and why do we use it?**
2. **Methods and principles**
    1. Surface methods: **PT / MT / ET/ VT**
    2. Volume methods: **RT / UT**
3. **Regulatory aspects. Examples**
4. **Conclusions**

What is NDT and why do we use it?

- Non-destructive testing (NDT) or Examination (NDE) involves various methods used to assess the integrity of structures, components or materials without causing damage that could prejudice their subsequent use.

- One of the oldest industrial uses of NDT was the “oil and whiting” process used since the late 1800’s for detecting cracks in railroad components

- NDT methods are based on scientific principles of physics and chemistry.
- Some are similar to those used in medical diagnostics: radiography, echography, endoscopy, …
- EN ISO 9712 Qualification of NDT personnel

- NDT intervenes:
  - On raw materials
  - During manufacture: on automatized production lines / ancillary test benches / welding sites
  - In service: during maintenance or after anomalies

ISO 9712:2021

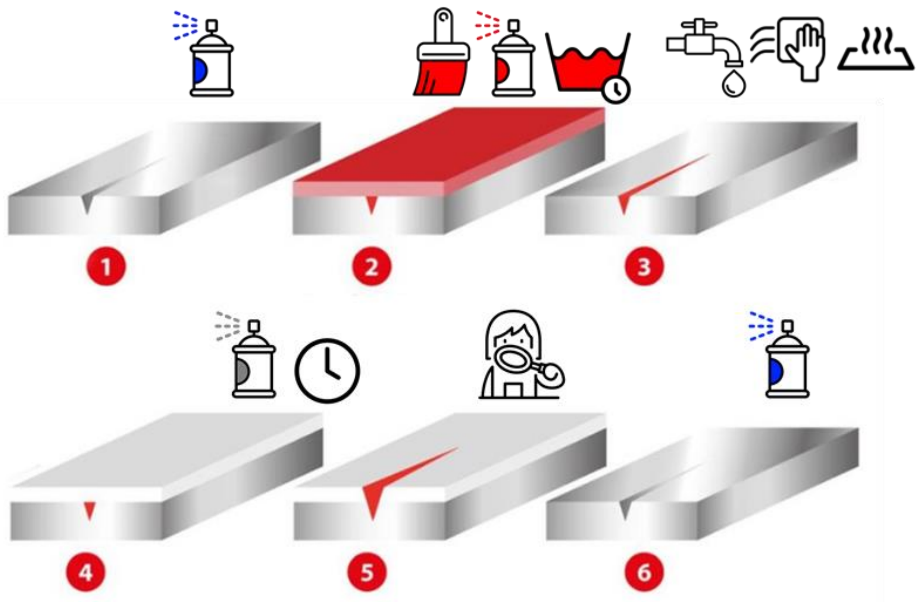
Table 1 — Methods and abbreviated terms

NDT method	Abbreviated terms
Acoustic emission testing	AT
Eddy current testing	ET
Leak testing	LT
Magnetic testing	MT
Penetrant testing	PT
Radiographic testing	RT
Strain gauge testing	ST
Thermographic testing	TT
Ultrasonic testing	UT
Visual testing	VT

Penetrant Testing PT

Principle

- Capillary action of low surface tension dye penetrating into surface-breaking discontinuities
- Enhanced defect visibility: dye spread out on powder coating, red dye on white background contrast, fluorescent dye in dark UV lighting.

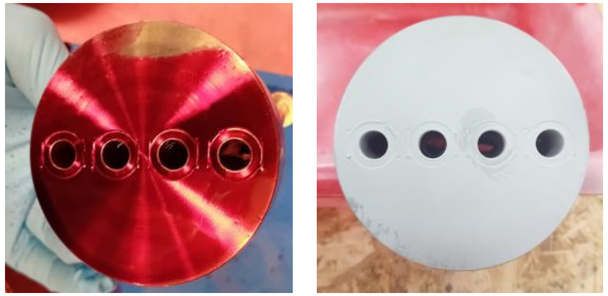


Sequence

1. Surface preparation (cleaning, degreasing, etching, blasting* - not smear metal over the flaws)
2. Penetrant application (colour or fluorescent) and dwell time
3. Excess penetrant removal, thorough and gentle
4. Developer application, waiting time to draw penetrant out of defects and spread
5. Inspection (white light or UV)
6. Cleaning

Very widely used

- Manufacture and maintenance
- Cast, forged, rolled, heat treated parts
- Welding

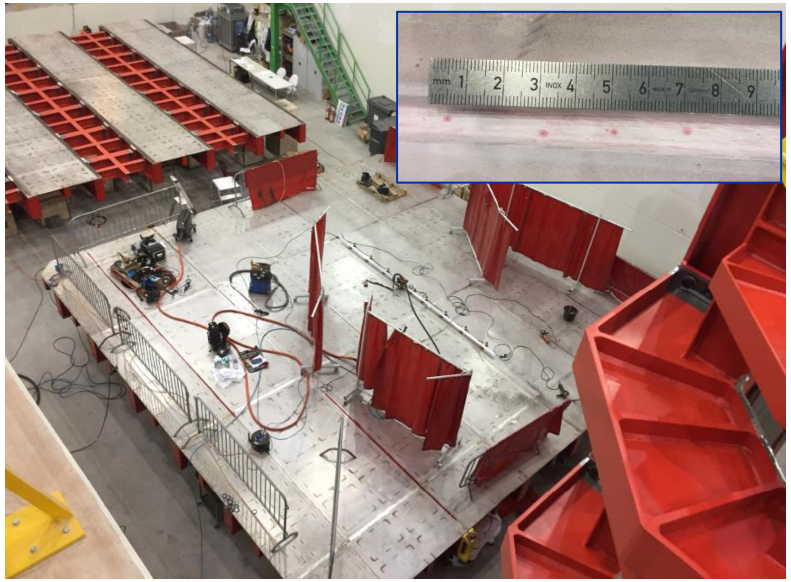


Tubes/plate welds in cooling system of 120 A current leads

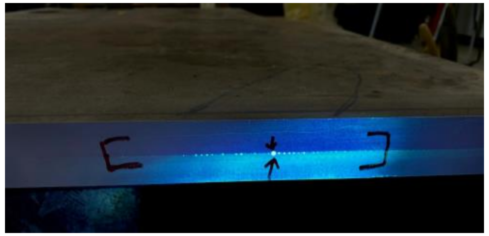
Penetrant Testing PT

Characteristics

- ✓ Simple and economical (training, equipment, products)
- ✓ High sensitivity to small discontinuities
- ✓ Very reliable for detecting cracks, porosities, pitting…
- ✓ Global: a full part or a large series of small parts can be tested at once
- ✓ Reliable regardless of the part size and position of discontinuity
- Detectability depends on surface state, surface preparation, sensitivity level of products
- ✗ Handling and disposal of chemicals
- ✗ Only surface-breaking and not clogged discontinuities on accessible surfaces
- ✗ Not applicable to porous components
- ✗ Not applicable to components incompatible with the products (UHV, difficult to clean thoroughly…)



Welds of cryostat in WA105 neutrino experiment



Explosion bonded bimetallic of n_TOF target

HIP capsules, SPS TIDVG5

Trough PT in leaking bellow, LHC TDIS collimator

Magnetic Testing MT

Principle

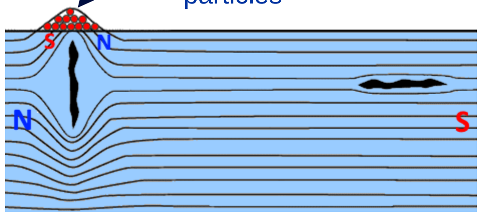
- The piece is magnetized and the presence of a surface or subsurface discontinuity causes a magnetic flux leakage
- Ferromagnetic particles gather at magnetic flux leakage fields revealing the discontinuity

Many variants

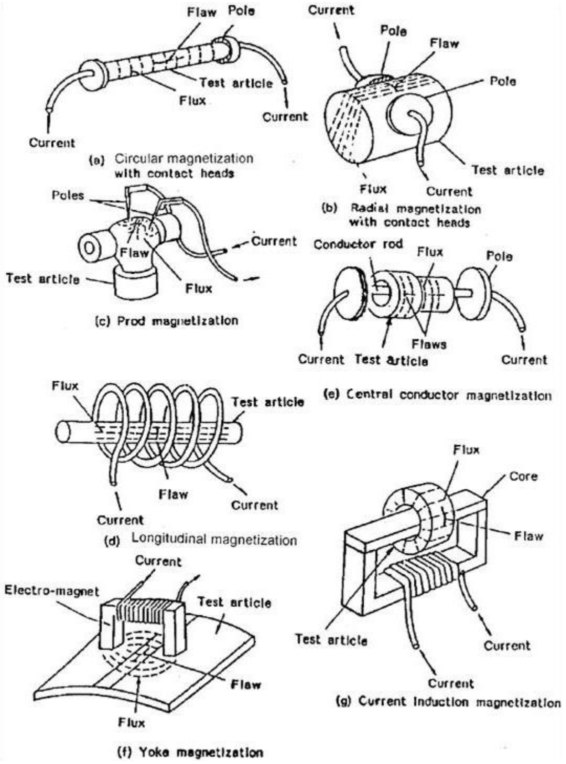
- Magnetization direct /indirect (magnetic field applied/electric current flow)
- Simultaneous/residual magnetization
- Dedicated magnetic benches or portable equipment: permanent magnets, portable electromagnets (yokes), current generators
- AC or different rectifications of the current
- Magnetic particles in wet suspension/dry powder, black/coloured/fluorescent, white contrast paint

Compared to PT

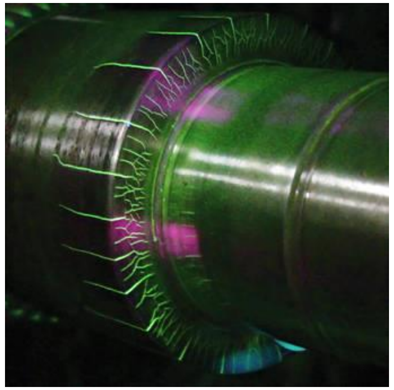
- ✓ Surface-breaking and near surface discontinuities
- ✓ Faster when applicable
- ✗ Detectability depends on relative orientation magnetisation/discontinuities. Various field orientations needed
- ✗ Limited to ferromagnetic materials
- ✗ Needs cleaning and demagnetization of the part



Principle



Various magnetization configurations


Fatigue cracks in an axel seen with residual magnetization/fluorescent magnetic particles

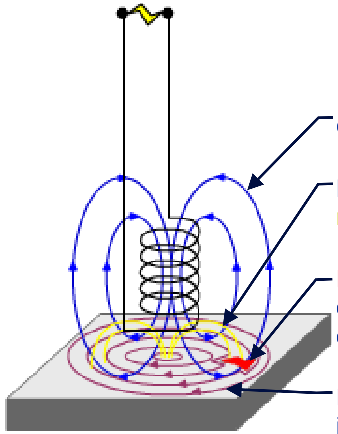


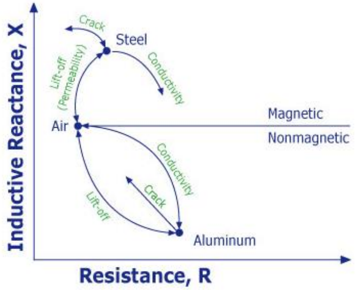
Crack on shipping frame for DUNE cryostat

Eddy Current Testing ET

Principle

- A coil carrying an alternating current is placed near the piece and induces eddy currents in it
- Disruptions in the flow of eddy currents caused by defects affect the impedance of the coil, which is measured to detect and characterize flaws

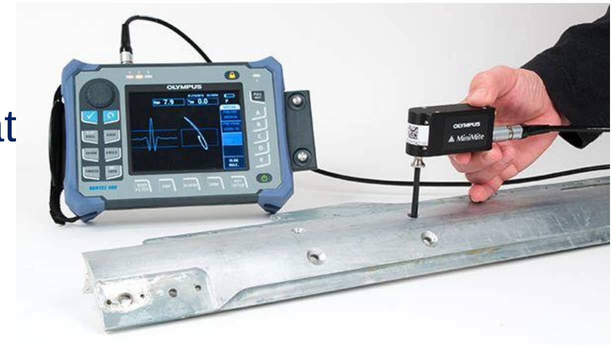




Impedance plane responses

Applications.

- Surface inspection, coating thickness measurements
- Fabrication of long products: tubes, bars, sheets…
- Maintenance tests (appearing of cracks or corrosion) in heat exchangers, aeronautics, transport, bridges, …
- Variety of manual probes: pencil, encircling, hole, arrays



Fastener hole inspection

Inspection of heat exchanger

Testing bench for continuous inspection of tubes with various ET heads and coils

Characteristics

- ✓ Surface-breaking or near surface defects
- ✓ Contactless: no damage, no contamination
- ✓ Automatized for long uniform parts
- ✗ Extensive skills and training requirements for signal interpretation

Visual Testing VT


Direct visual on piping weld, cooling water circuit in CERN BA4


Mirror inspection. Undercut in the weld of a heat exchanger

Principle

- Examining materials and components with the naked eye
- Or with the aid of optical tools to enhance sensitivity or to reach restrictive areas of interest.

Optical aids

- Mirrors, magnifying glasses


- Endoscopes:

Type	Image transfer	Diameters	Lengths	Options
Borescopes	Lenses	1÷12 mm	0.1÷1 m	Fixed head
Fibrescope	Optical fibre bundle	0.5÷10 mm	0.1÷3 m	Articulating head
Video endoscope	Image sensors (CMOS CCD)	2.5÷12 mm	1÷30 m	Articulating head
Inspection camera	Image sensors (CMOS CCD)	20÷200 mm	3÷1000 m	Rotating head, push rod, crawler

Monitoring the cleanliness of a cooling serpentine in a magnet thermal screen 2 m away of the entry



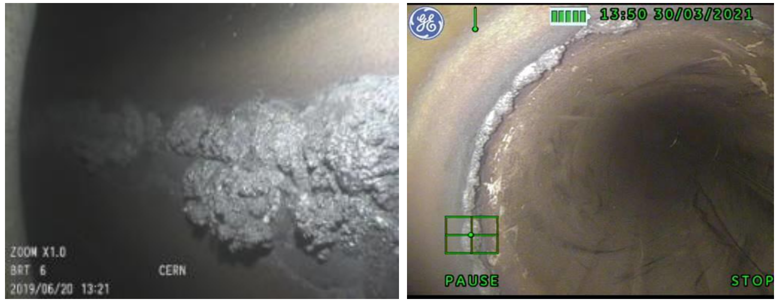




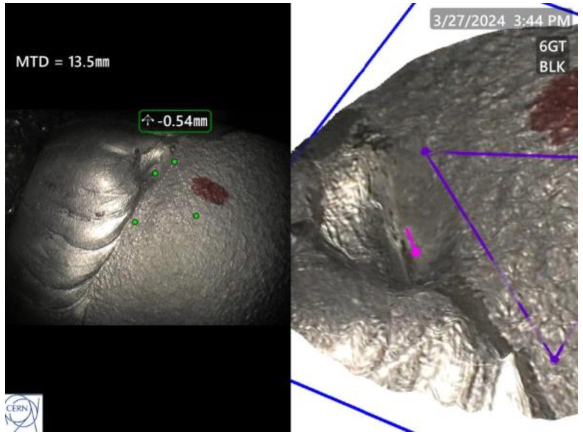
Visual Testing VT

Exchangeable or selectable tip optics of endoscopes

- Direction of view: forward, radial, angle, backward
- Depth of field: 1 mm to infinity
- Field of view: narrow (50°) to large (120°)
- Measuring capacity: stereo, structured light



Weld root porosities observed in narrow access (LHC MB diode box) and large pipe (He recovery line) situations require different probe size and tip optics



Measuring the depth of a weld undercut with a video endoscope with the 3D capabilities

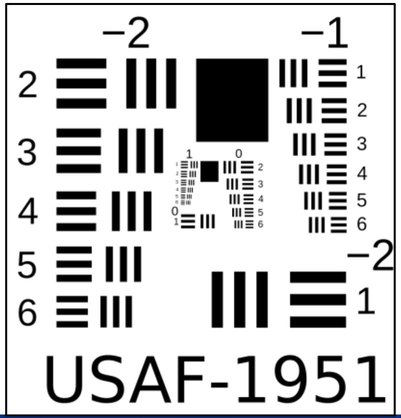
Resolution test charts

Applications

- Used in all sectors and stages
- Detecting surface defects such as cracks, corrosion, misalignments, surface finish issues, pollution, migrant bodies

Characteristics

- ✓ Simple, low cost, immediate results
- ✓ Access to hidden regions with dimensioning capacity
- ✓ Not use of effluents
- ✗ Limits on sensitivity, and affected by lighting conditions and surface finish
- ✗ Time consuming if small defects in large parts



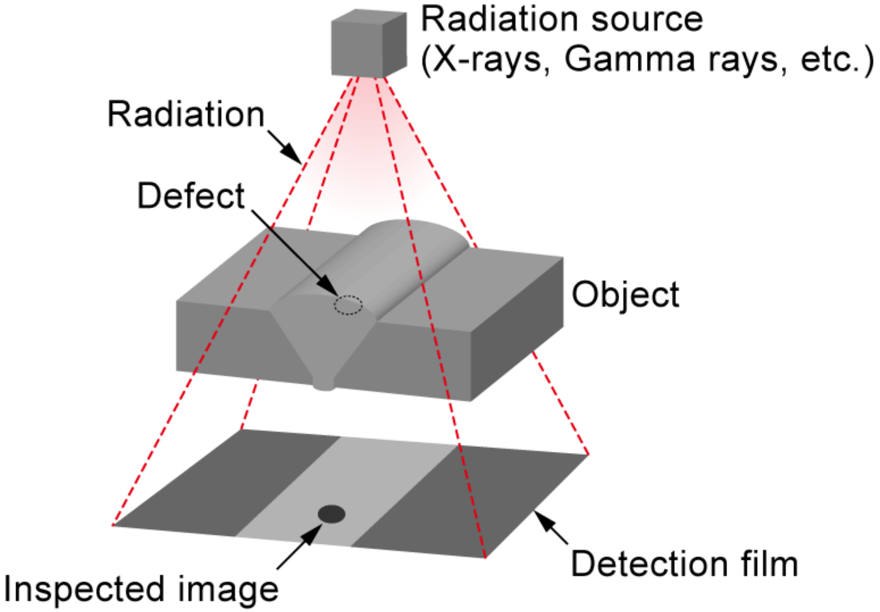
Resolution test target USAF-1951 with groups -2, -1, 0 and 1.
Table: width of a line in µm

Element	−2	−1	0	1
1	2000.00	1000.00	500.00	250.00
2	1781.80	890.90	445.45	222.72
3	1587.40	793.70	396.85	198.43
4	1414.21	707.11	353.55	176.78
5	1259.92	629.96	314.98	157.49
6	1122.46	561.23	280.62	140.31

Radiographic Testing RT

Principle

- The object is positioned between a radiation source and a detector (radiographic film or digital sensor).
- Radiation passes through the object, and the varying material density affects the amount of radiation that reaches the detector.
- The detector captures an image that reveals the internal features and any defects based on the differential absorption of radiation.



Sequence:

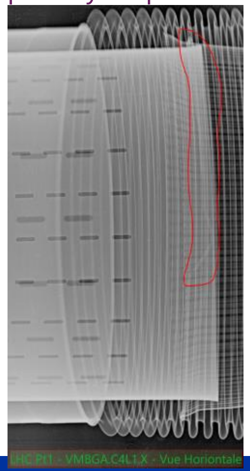
1. Selection of parameters: test arrangement / detector / exposition / no. of views
2. Safety precautions: shielded room& interlocks / marking exclusion zone & patrol
3. Positioning: source / film / IQI / lead marks
4. Exposure: time-kV-mA / time
5. Image development: chemical development / scan / direct reading
6. Evaluation: check of image quality / check of piece quality

Applications

- Welds
- Castings with limited thickness variations
- See inside of components

Radiography of butt weld in concentric pipe for ATLAS CO2 MTL

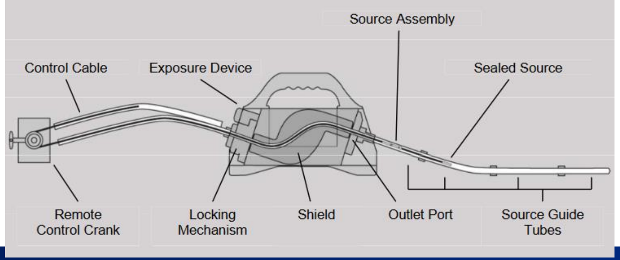
Spring in LSS1LWM partially off-position

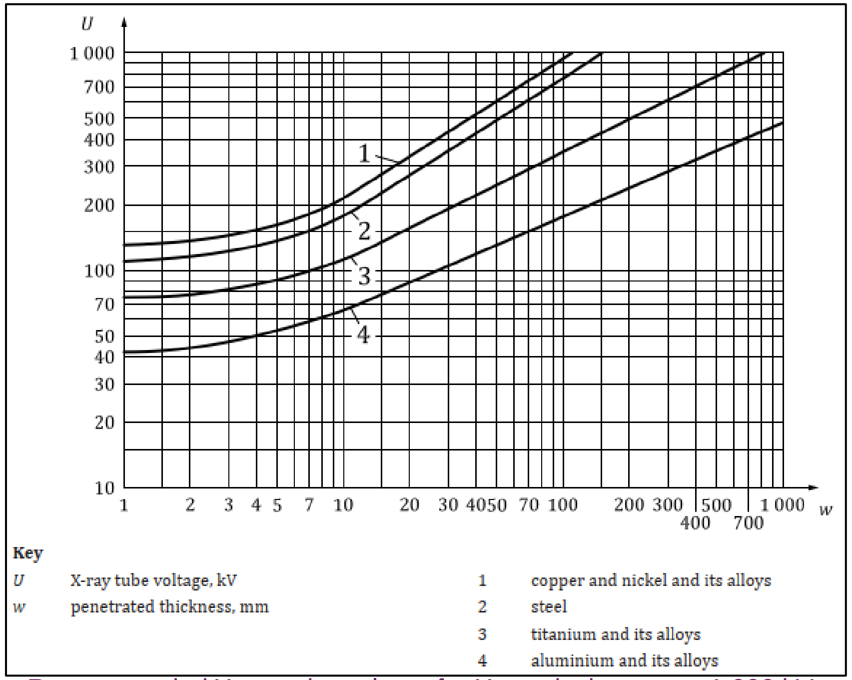


Radiographic Testing RT

Sources

- X-ray generators
  - Configuration: modules, portable
  - Max voltage: 75 to 600 kV
  - Focal spot: 0.4 to 5 mm
  - Power: 700 to 4500 W
  - Beam Type: directional, fan, panoramic
- Linacs
- Radioactive sources
  - Isotope: Se-75, Ir 192, Co-60
  - Activity: 0.5 to 8 TBq
  - Source size: 1 to 3.5 mm





Recommended X-ray tube voltage for X-ray devices up to 1 000 kV as a function of penetrated thickness and material

Table 2 — Penetrated thickness ranges for gamma-ray sources and X-ray equipment with X-ray potential, U, above 1 MV for steel, copper and nickel-based alloys

Radiation source	Penetrated thickness w mm	
	Testing class A	Testing class B
Tm 170	$w \leq 5$	$w \leq 5$
Yb 169[a]	$1 \leq w \leq 15$	$2 \leq w \leq 12$
Se 75[b]	$10 \leq w \leq 40$	$14 \leq w \leq 40$
Ir 192	$20 \leq w \leq 100$	$20 \leq w \leq 90$
Co 60	$40 \leq w \leq 200$	$60 \leq w \leq 150$
X-ray potentials 1 MV < $U \leq$ 4 MV	$30 \leq w \leq 200$	$50 \leq w \leq 180$
X-ray potentials 4 MV < $U \leq$ 12 MV	$w \geq 50$	$w \geq 80$
X-ray potentials U > 12 MV	$w \geq 80$	$w \geq 100$

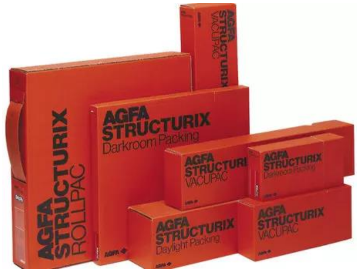
[a] For aluminium and titanium, the penetrated material thickness is 10 mm $\leq w \leq$ 70 mm for testing class A and 25 mm $\leq w \leq$ 55 mm for testing class B.

[b] For aluminium and titanium, the penetrated material thickness is 35 mm $\leq w \leq$ 120 mm for testing class A.

Radiographic Testing RT

Detectors

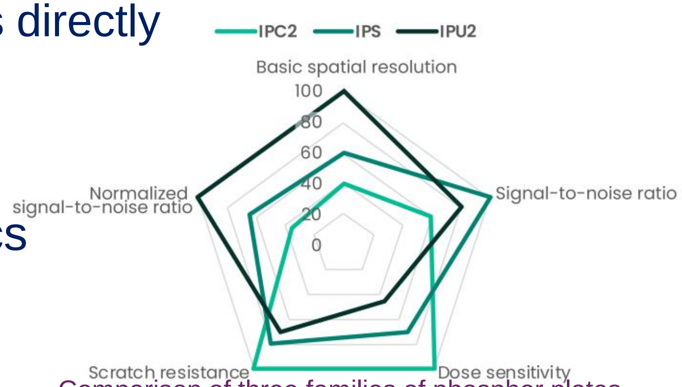
- Silver film
  - developed manually or in an automatic machine
  - studied in a negatoscope with an intense light source
- Phosphor plates (Computed Radiography CR)
  - latent image revealed using a scanner
  - digital image as a grey-levels file
  - flexible
- Digital detector array, flat panels (digital radiography DR)
  - produce digital images directly
  - rigid
- Balance of characteristics


Various formats of silver film


Developing machine


Checking film density over the negatoscope


Phosphor plates of various formats, scanner and scanning/image treatment software



Comparison of three families of phosphor plates from the same producer

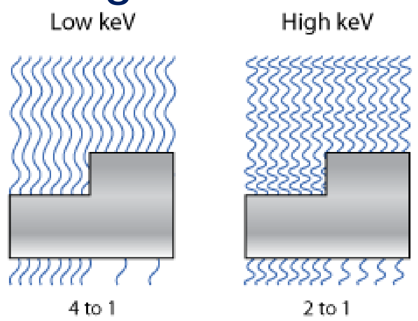
Flat panels of various formats. Direct reading on field testing

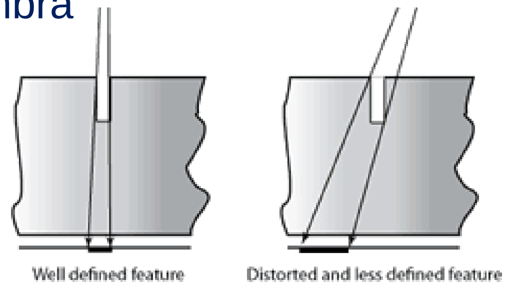
Radiographic Testing RT – Image quality

Radiographic sensitivity is dependent of variables affecting the **contrast** and the **definition** of the image

- **Subject** factors affecting image **contrast:**
  - Absorption differences in the subject
  - Wavelength (energy) of the primary radiation
  - Secondary radiation from scatter
- **Geometric** factors affecting image **definition**
  - Size of the source
  - Source to film distance
  - Subject to detector distance
  - Sharpness of specimen thickness changes
  - Movement of the subject during exposition

(Size of the source, Source to film distance, Subject to detector distance: geometric penumbra)





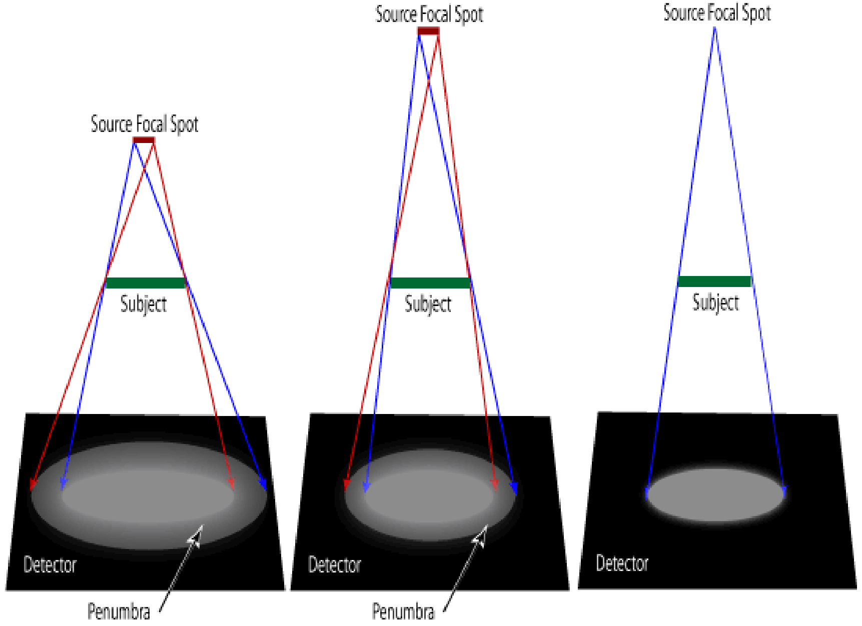
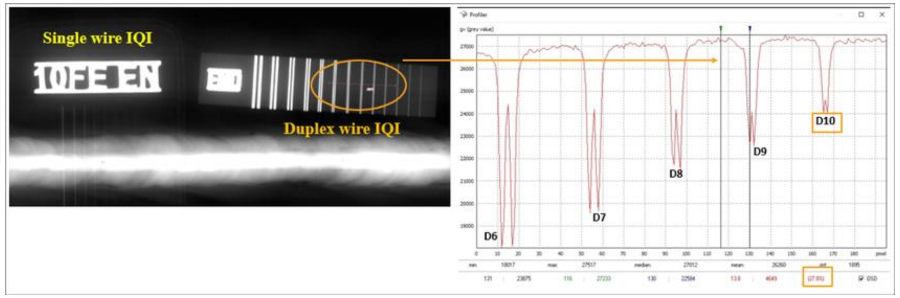


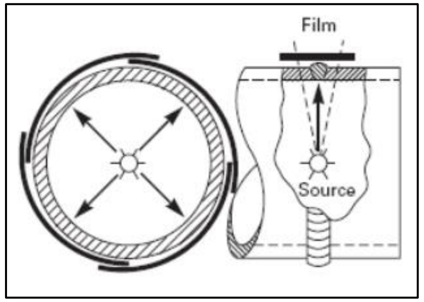
Image quality indicators (IQIs)

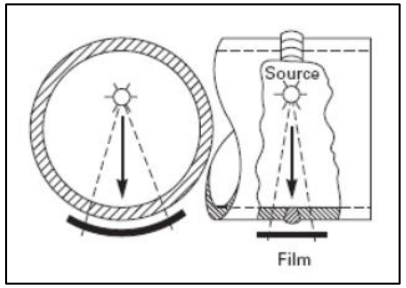
- wires or plates with holes of decreasing dimension
- added to the subject
- used for visually checking the contrast and definition of the radiography

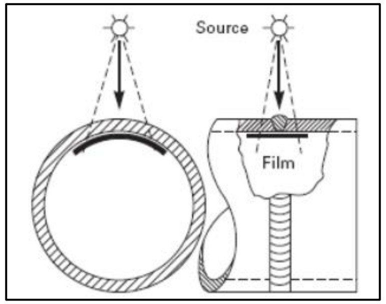


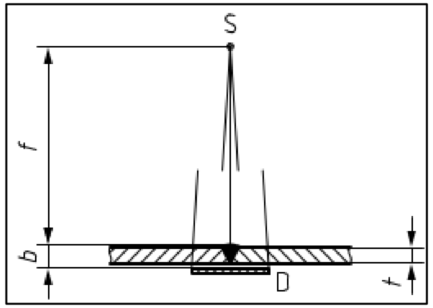
Radiographic Testing RT

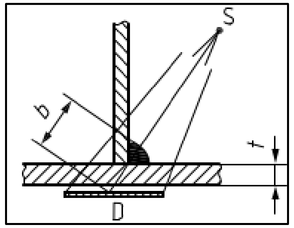
Tests arrangements Single Wall

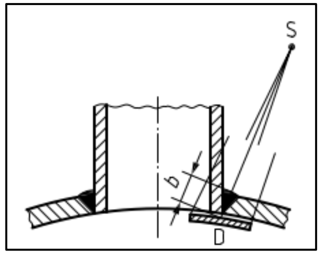


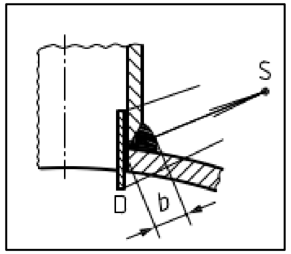


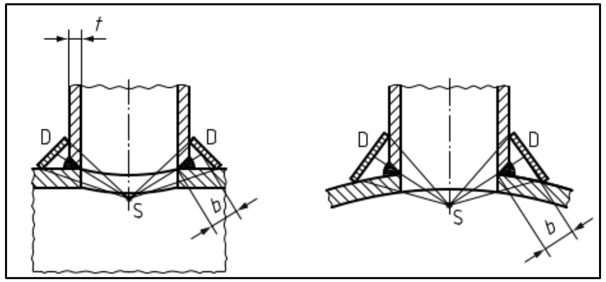


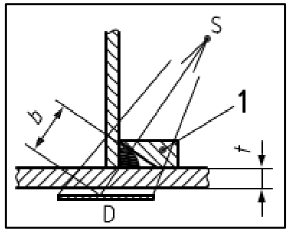




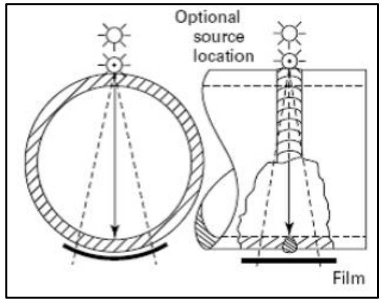


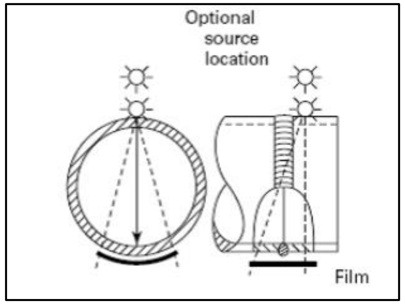




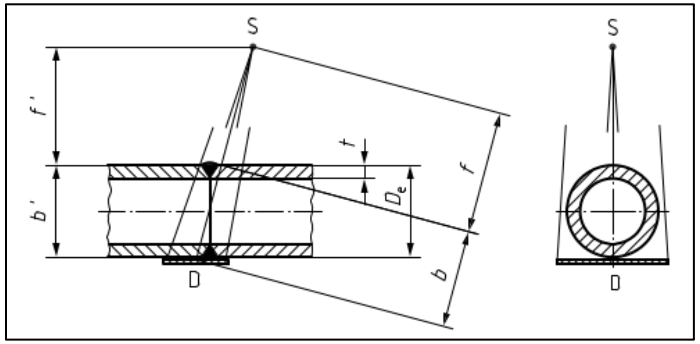


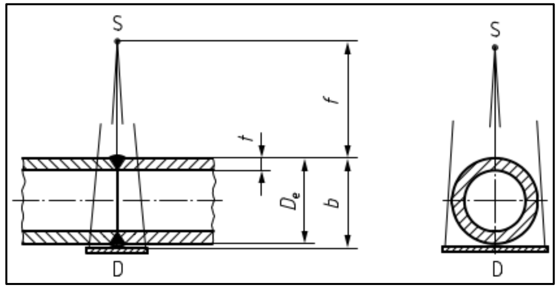
Test arrangements Double Wall



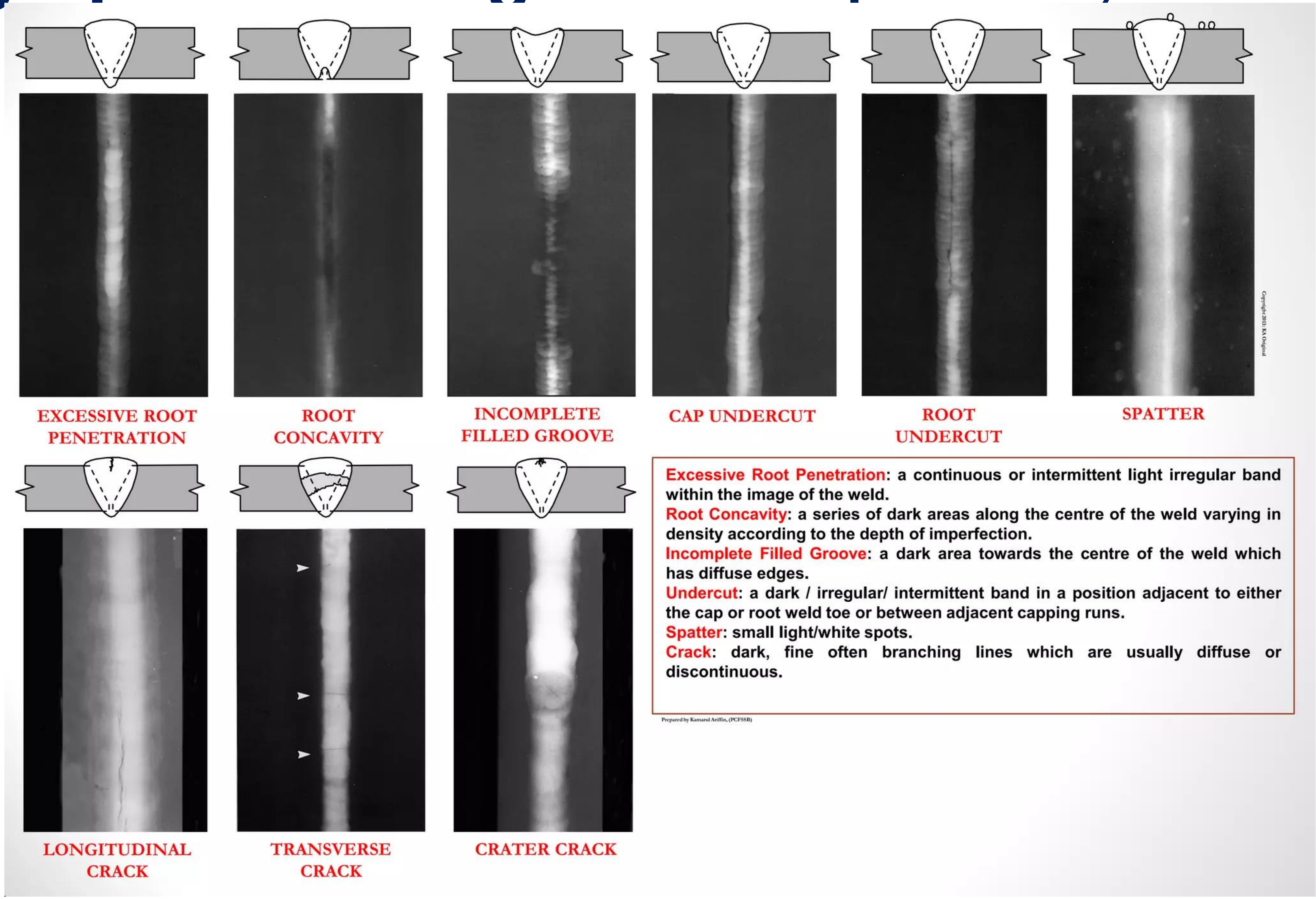


Double Wall and Double Image

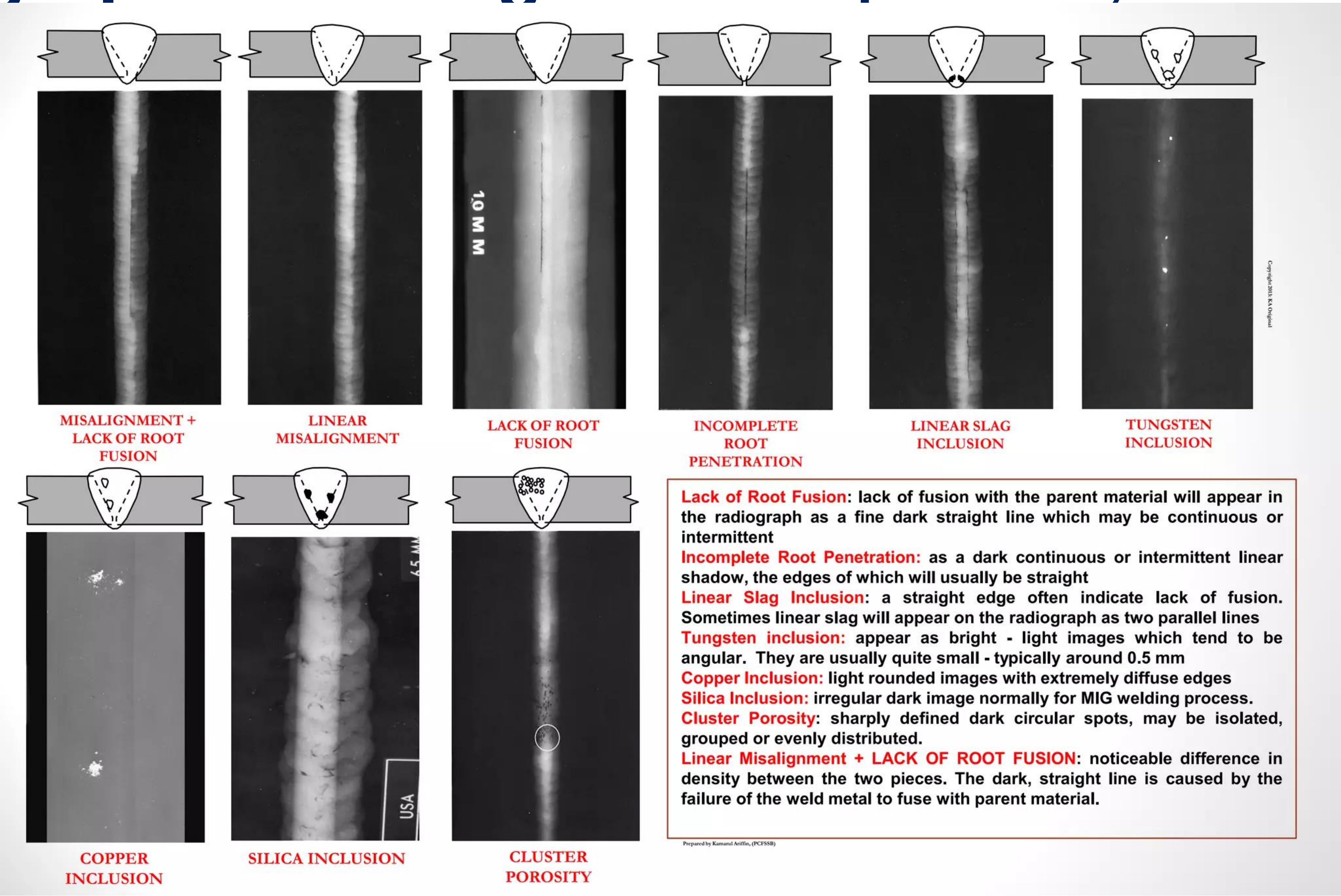




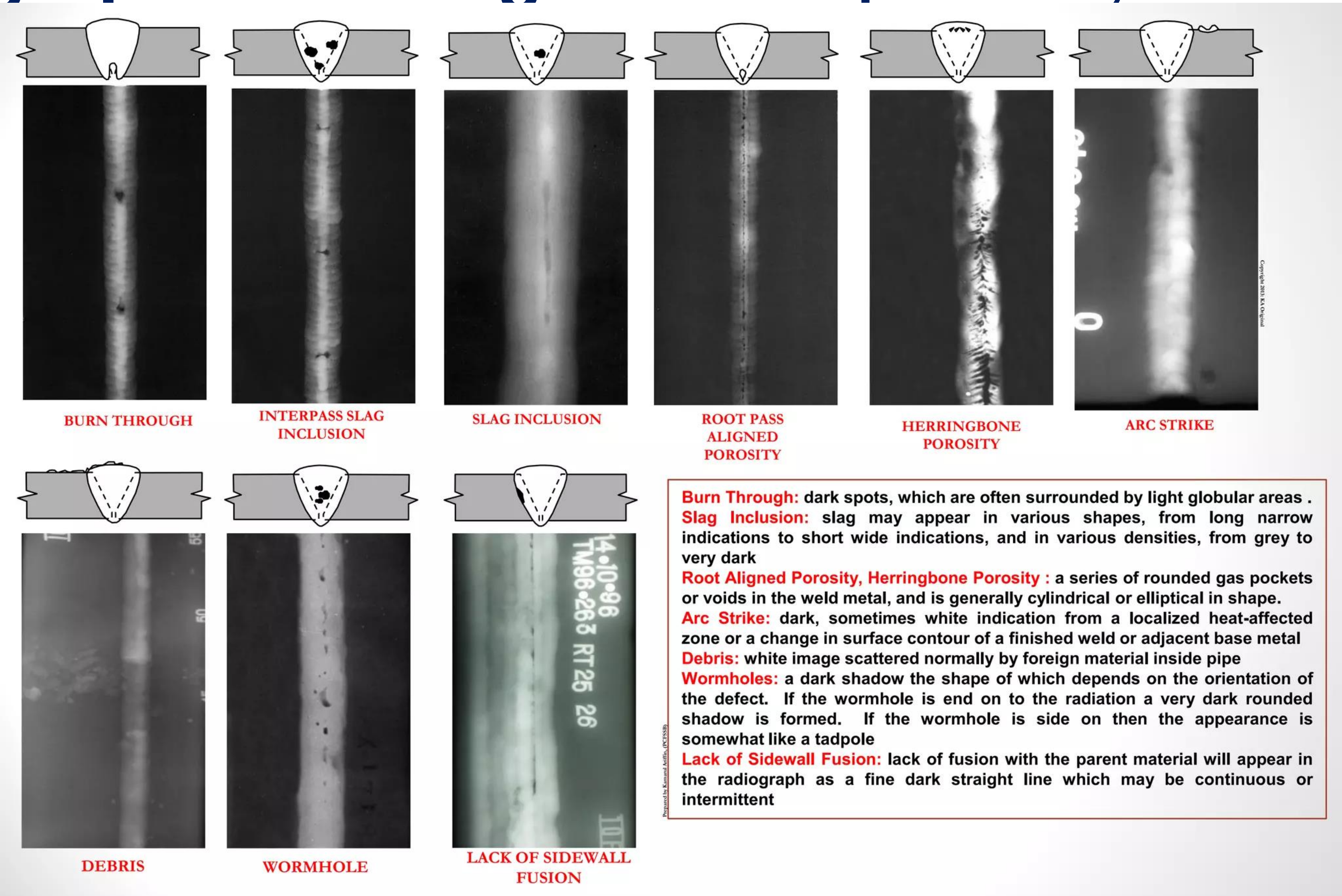
Radiographic Testing RT – Interpretation, welds

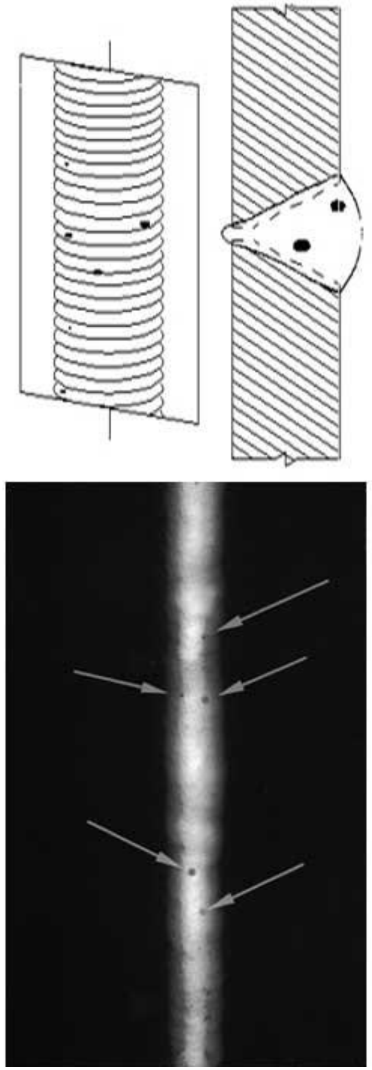


Radiographic Testing RT – Interpretation, welds



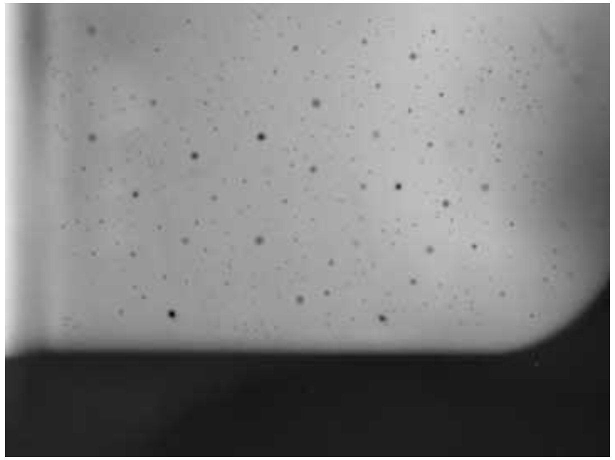
Radiographic Testing RT – Interpretation, welds



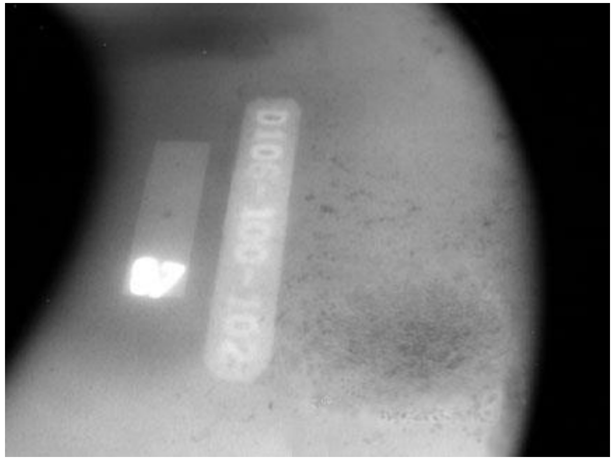


Gas pore

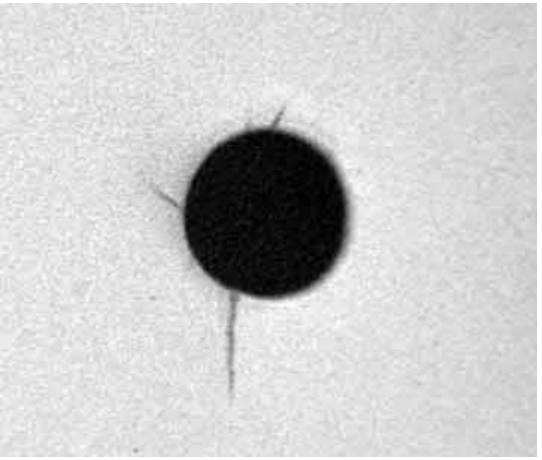
Radiographic Testing RT – Interpretation, castings



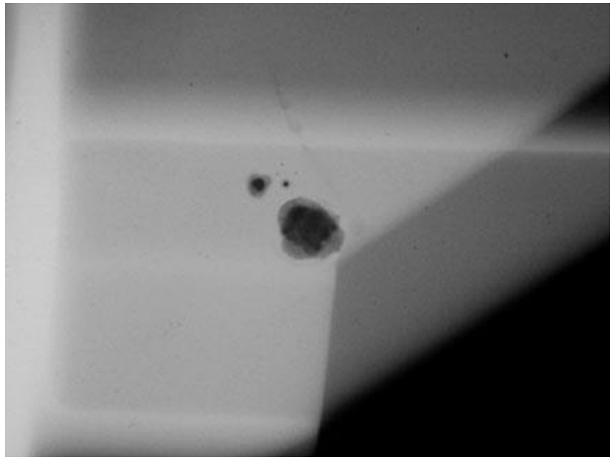
Gas porosity



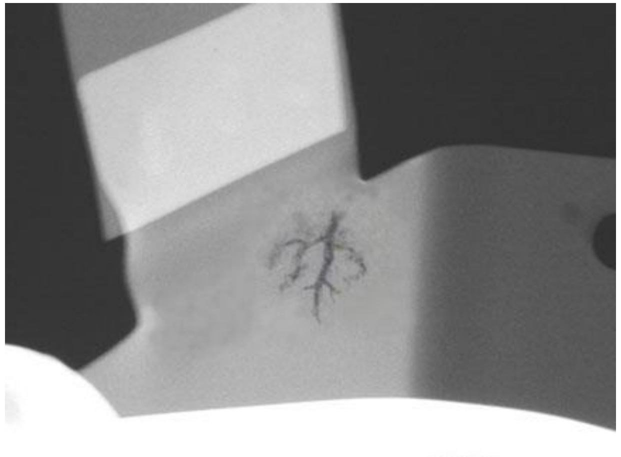
Sponge shrinkage



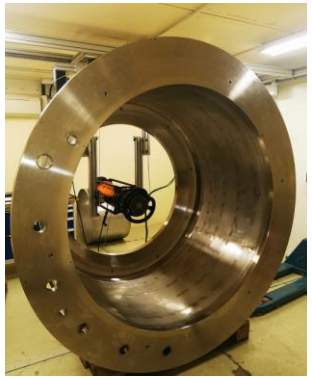
Cracks

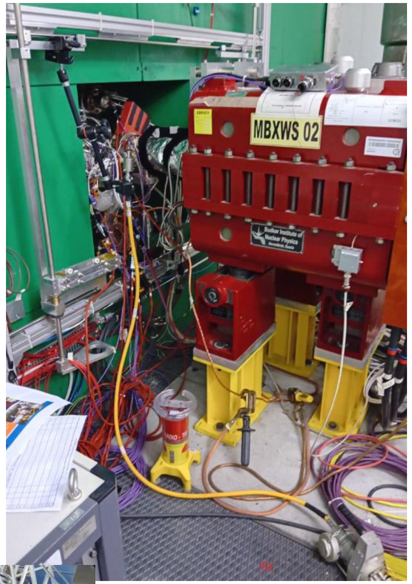


Sand inclusions and dross



Dendritic shrinkage

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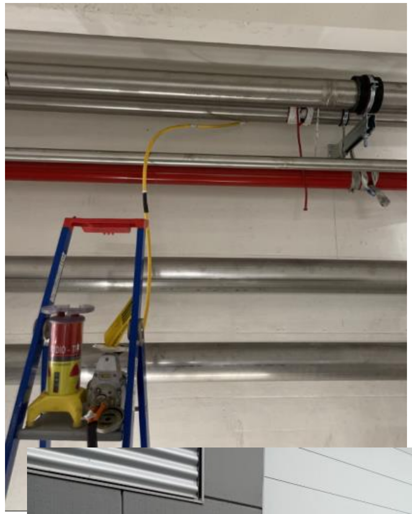
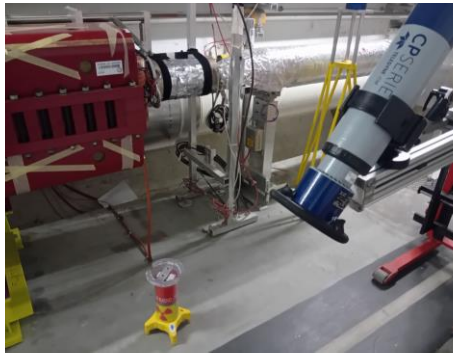







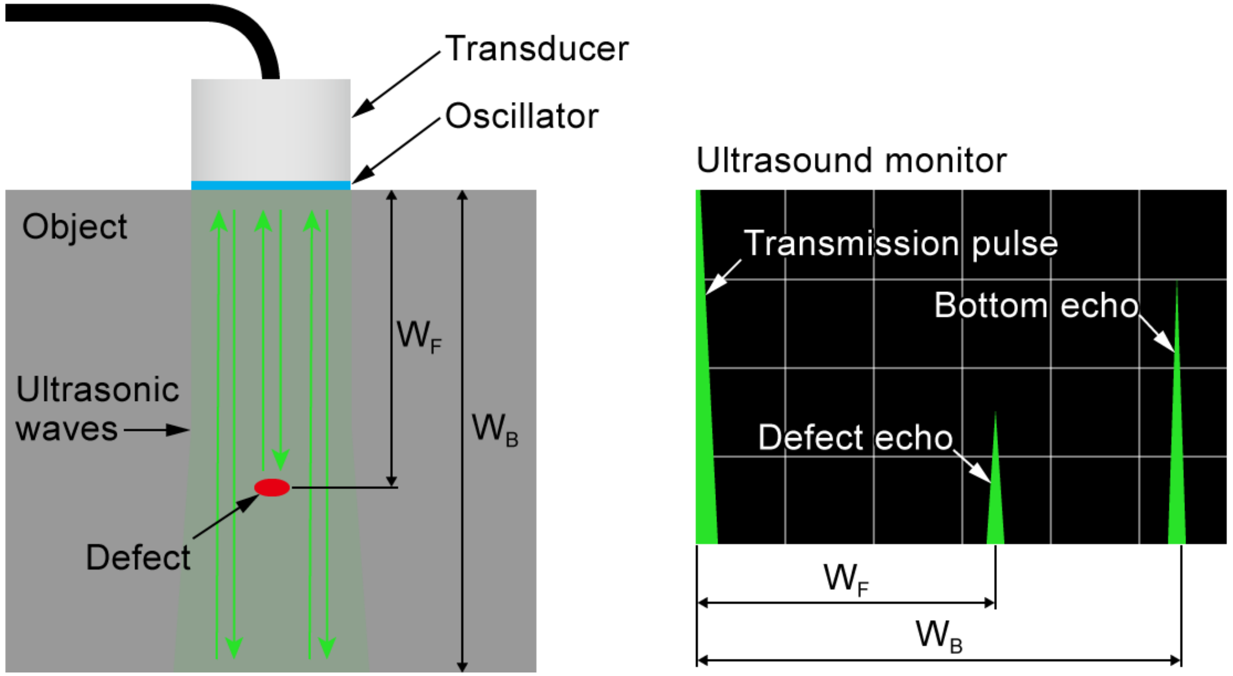




Ultrasonic Testing UT

Principle

- Sending high-frequency sound wave pulses into a material (0.5 to 20 MHz)
- The most frequently used is the pulse-echo technique.
  - Detect echoes from flaws and/or from the back wall.
- The basic representations is a diagram of amplitude vs time of flight (or depth if the speed of sound is known)



Ultrasonic Testing UT

Two zones of the sound field of a transducer

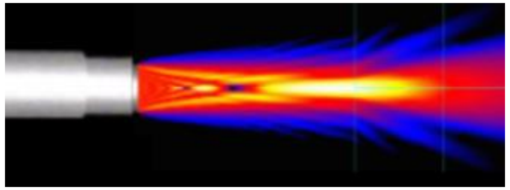
- **Near field**: region close to the transducer
  - Sound pressure goes through a series of maximums and minimums
  - Difficult to accurately evaluate flaws using amplitude-based techniques
  - Ends on axis maximum at distance N.

$$\text{Near field length} = \frac{D^2 f}{4c} = \frac{D^2}{4\lambda}$$

D = element diameter or aperture
f = frequency
c = sound velocity in test medium
λ = wavelength = $\frac{c}{f}$

- **Far field**: region beyond N,
  - Sound pressure gradually goes down as the beam diameter expands and its energy dissipates
  - Spread angle

$$\alpha = \sin^{-1}\left(\frac{0.514c}{fD}\right)$$



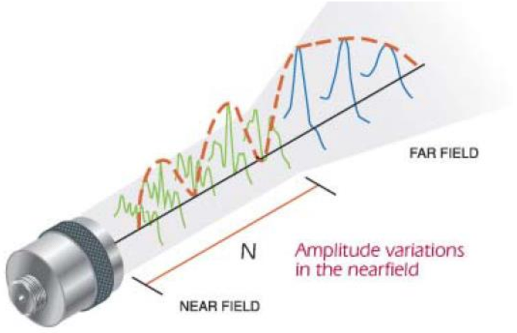
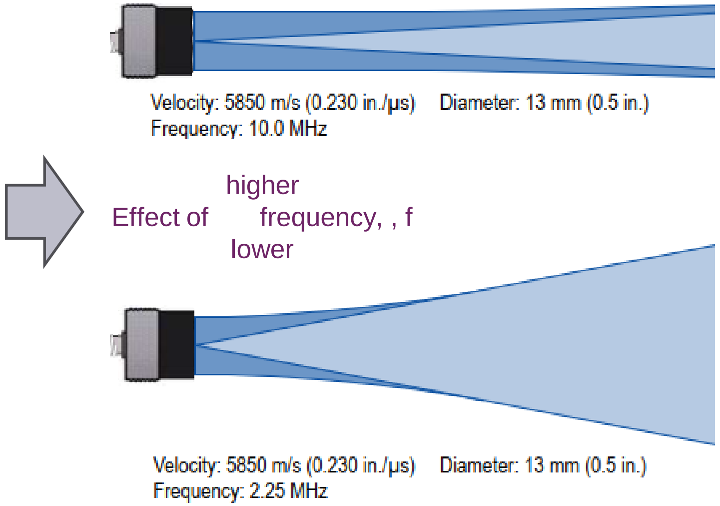
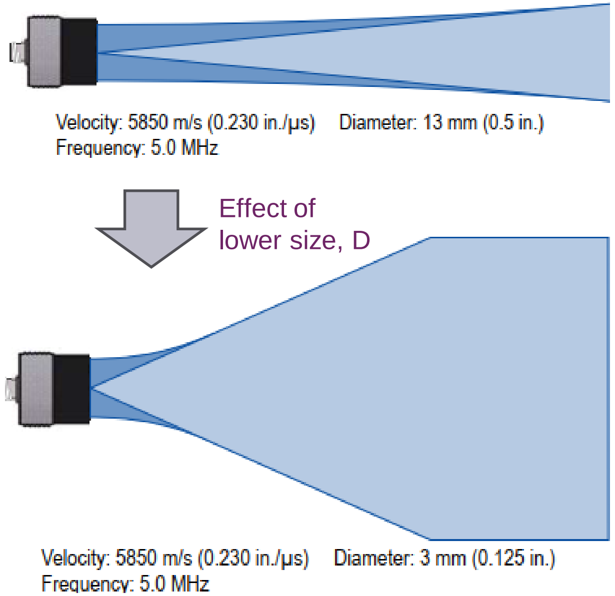


Figure 2-4 The sound field of a transducer

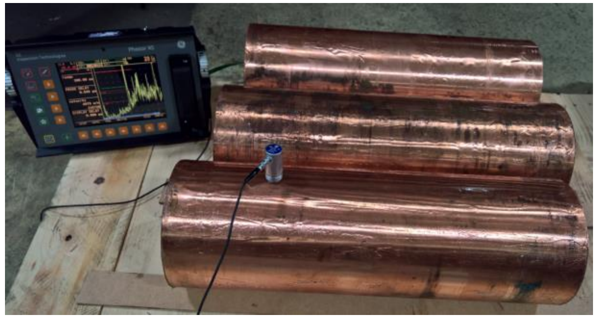




Ultrasonic Testing UT

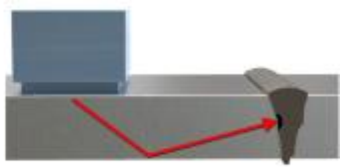
Straight beam—single element

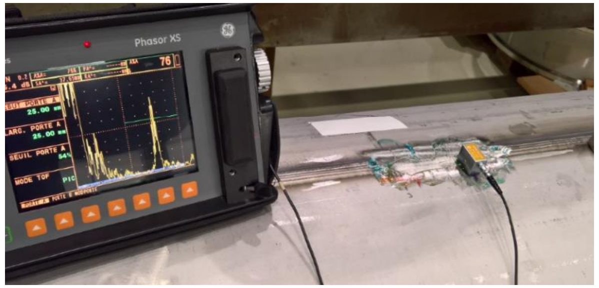
- Flaw or backwall parallel to surface
- Preferred for penetration of thick sections



Angle beam

- Mounted on a wedge
- Uses refraction to transmit shear (most times) or longitudinal wave at a predetermined angle
- Preferred for parts with inclined flaws, such as welds



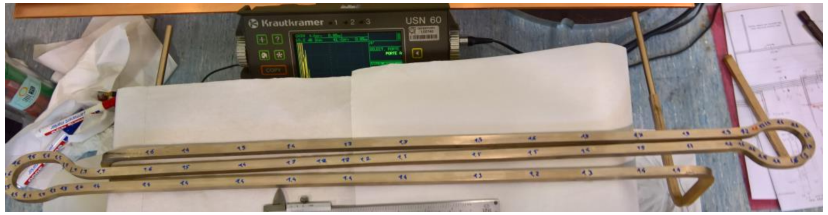


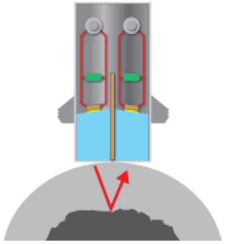
Contact probes:

- Requires couplant layer, gel, oil, or water
- Typically used for manual inspection
- Parts with regular geometry and relatively smooth contact surface
- Flat or curved contact surface

Straight beam—dual element (TR)

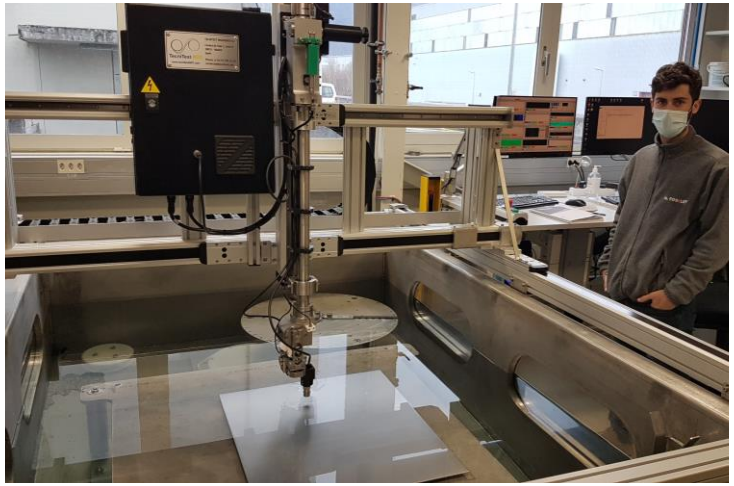
- Transmit and receive elements separated by crosstalk barrier
- Flaw or backwall parallel to surface or detectable with beam normal to surface
- Best for thin sections, near surface resolution





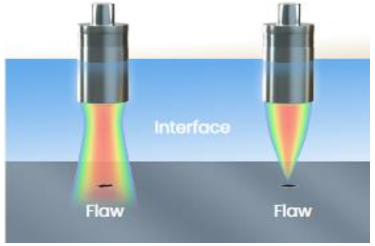
Ultrasonic Testing UT

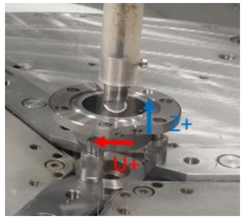
Nb plates for Crab Cavities



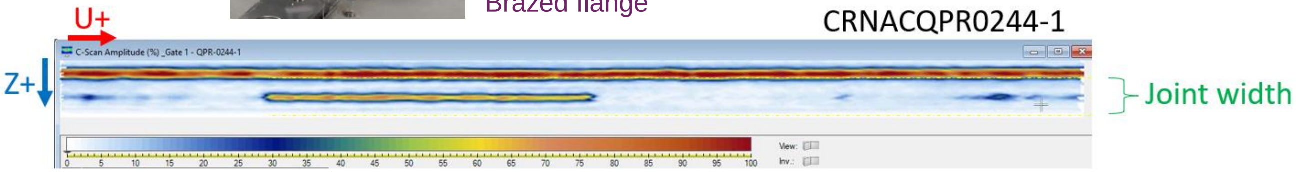
Immersion transducers

- Commonly used in mechanized or automated testing
- Suited to joints with interface parallel to entry faced (brazing, explosion, diffusion)
- Best method for consistent coupling and reproducible results
- Large parts can be tested using probe holders or water jets
- Transducers can be focused to improve results

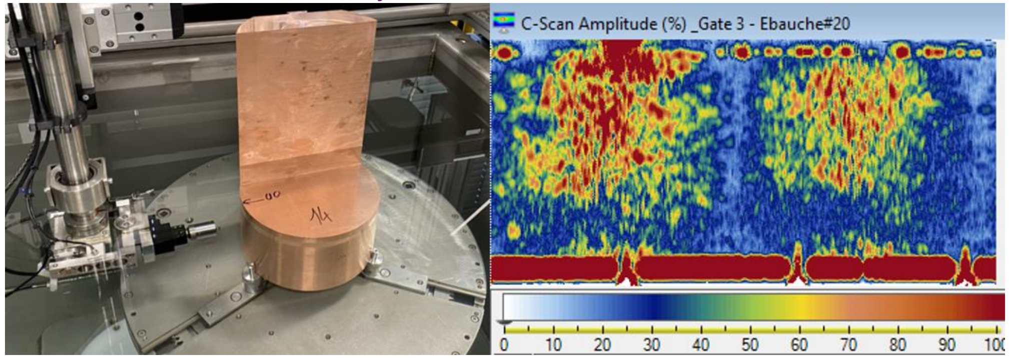




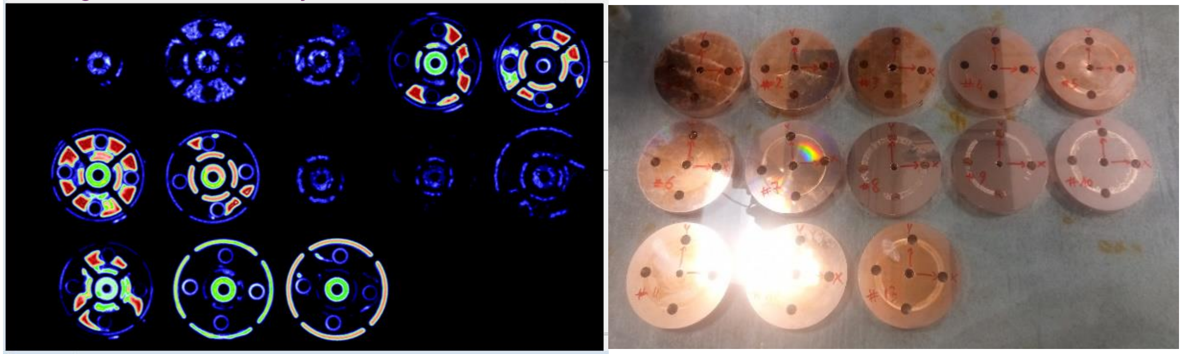
Brazed flange



Cracks developed after brazing thermal cycle in a machined Cu blank, revealed by immersion UT



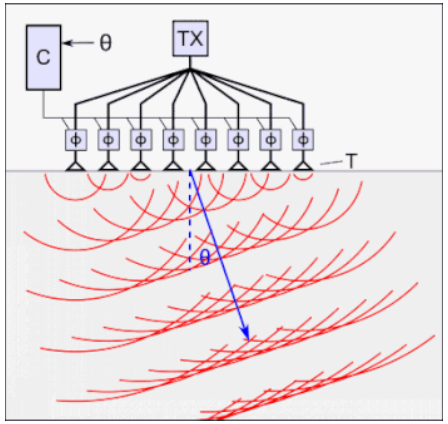
Brazing tests of Clic cavity discs



Ultrasonic Testing UT

Phased array Techniques PAUT

- PAUT probes are composed of a **matrix of** small **transducer** elements
- The excitation is computed controlled to apply convenient **delay laws** to individual elements
- The effect is that the combined sound beam can be **tilted** or **focused**
- Different tilting angles can be produced sequentially resulting in an angular scan
- Focusing at different depths can be produced sequentially resulting in a dynamic focusing



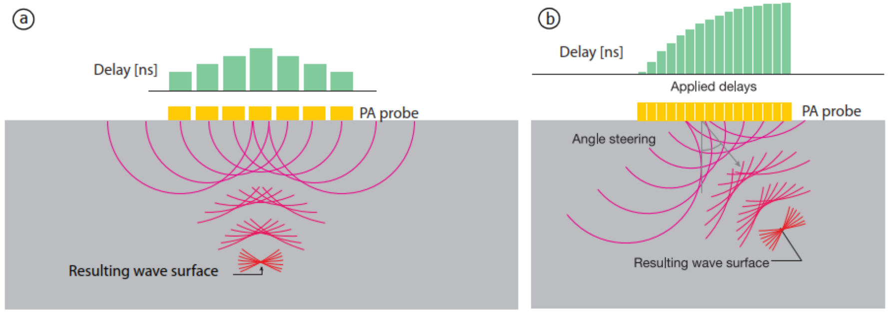


Figure 1-3 Beam focusing principle for (a) normal and (b) angled incidences.

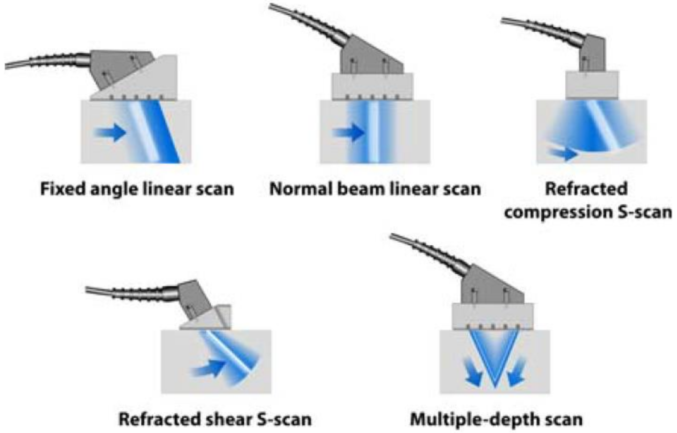


Figure 2-23 Focal law sequences

Ultrasonic Testing UT

Basic representations

A-Scan
- Static position
- Depth vs Amplitude

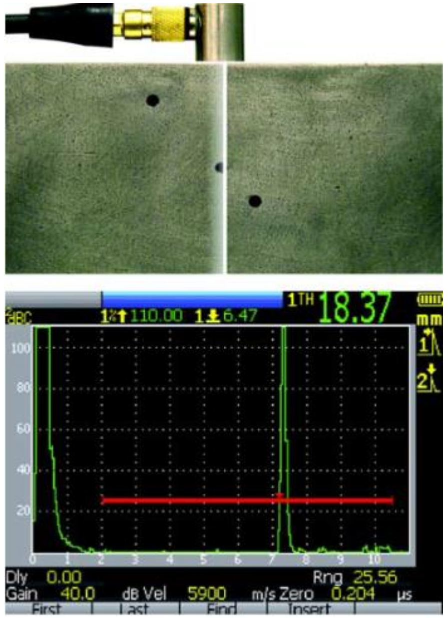


Figure 3-1 A-scan data

B-Scan
- Lateral displacement X
- X position vs Depth
- + Colour Amplitude

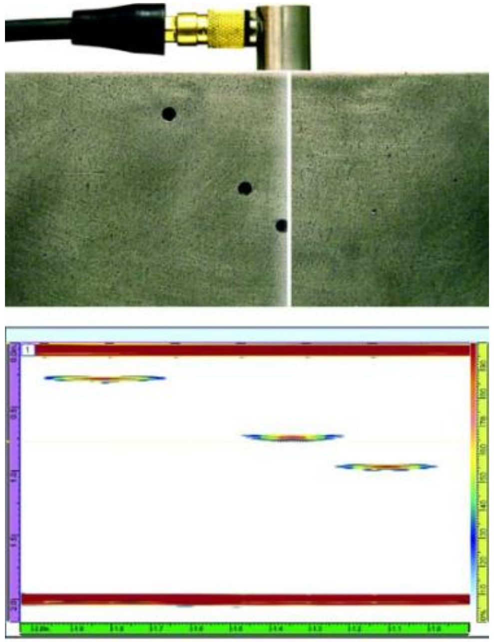


Figure 3-3 Cross-sectional B-scan

C-Scan
- Displacement
- X position vs Y position
- + Colour Amplitude
- (or colour depth)

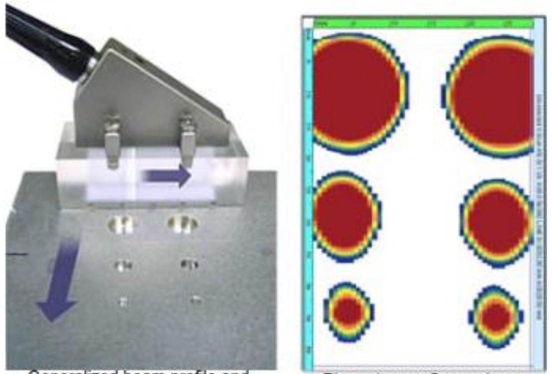


Figure 3-6 C-scan data using 64-element linear phased array probe

S-Scan
- Angular scan at fixed position
- Set of angles vs depth
- + Colour Amplitude

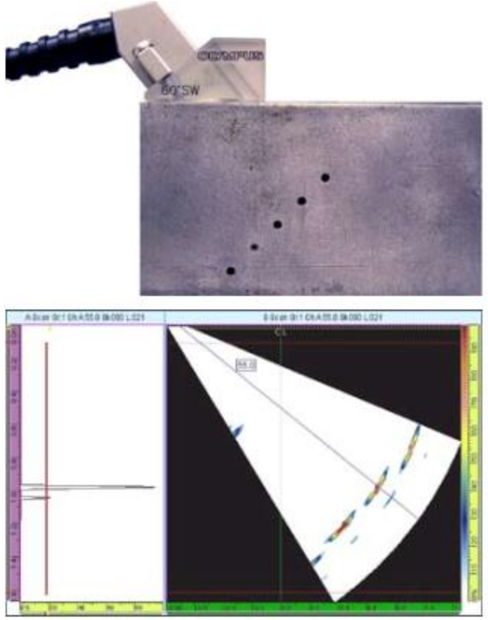
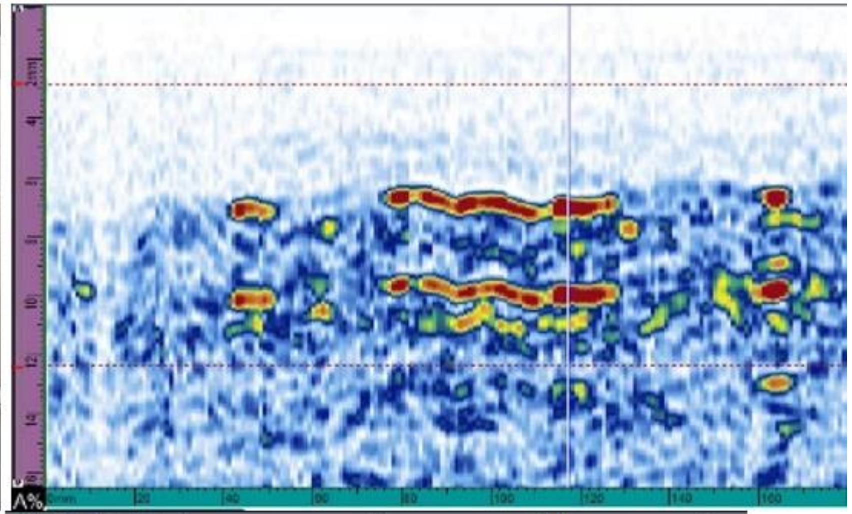


Figure 3-9 +35° to +70° S-scan

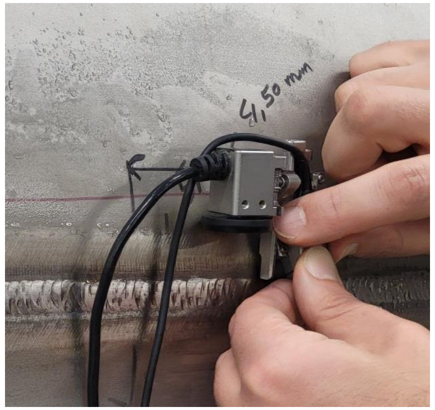
Ultrasonic Testing UT

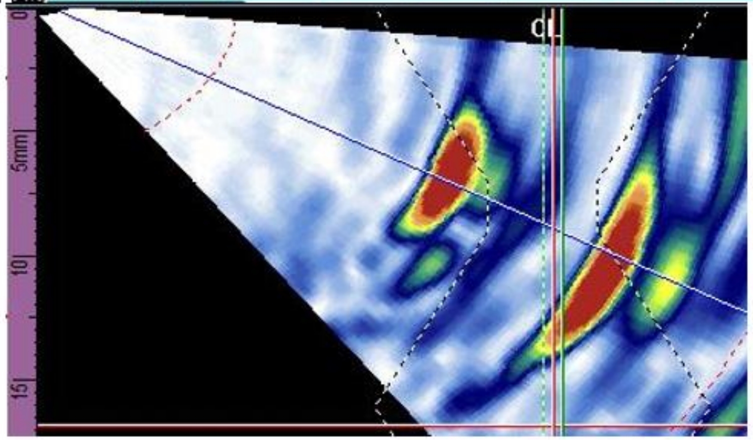
PAUT of longitudinal welds in cold mases of of HL-LHC magnets

Indications of a line of lack of fusion between passes



B-Scan





S-Scan

CERN
Engineering Department

INTERNATIONAL STANDARD ISO 17635:2016(E)

Non-destructive testing of welds — General rules for metallic materials

Table 3 — Generally accepted methods for detection of internal discontinuities for butt- and T-joints with full penetration

Materials and type of joint	Nominal thickness of the parent material to be welded t mm		
	$t \leq 8$	$8 < t \leq 40$	$t > 40$
Ferritic butt-joints	RT or (UT)	RT or UT	UT or (RT)
Ferritic T-joints	(UT) or (RT)	UT or (RT)	UT or (RT)
Austenitic butt-joints	RT	RT or (UT)	(RT) or (UT)
Austenitic T-joints	(UT) or (RT)	(UT) and/or (RT)	(UT) or (RT)
Aluminium butt-joints	RT	RT or UT	RT or UT
Aluminium T-joints	(UT) or (RT)	UT or (RT)	UT or (RT)
Nickel and copper alloy butt-joints	RT	RT or (UT)	(RT) or (UT)
Nickel and copper alloy T-joints	(UT) or (RT)	(UT) or (RT)	(UT) or (RT)
Titanium butt-joints	RT	RT or (UT)	—
Titanium T-joints	(UT) or (RT)	UT or (RT)	—

NOTE 1 Methods in parentheses are only applicable with limitations.

NOTE 2 For ultrasonic testing of austenitic joints, see ISO 22825.

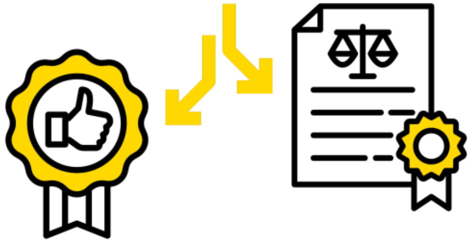
Table 2 — Generally accepted methods for detection of accessible surface discontinuities for all types of welds, including fillet welds

Materials	Testing methods
Ferritic steel	VT VT and MT VT and PT VT and (ET)
Austenitic steel Aluminium and nickel Copper and titanium	VT VT and PT VT and (ET)

NOTE Methods in parentheses are only applicable with limitations.

Regulatory aspects – Codes, standards, qualifications

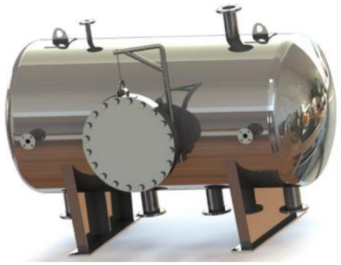
- **Using NDT can sometimes assume a regulatory aspect** (e.g. pressure equipment, aerospace, ski lifts, nuclear, …) **but can be a quality policy decision of manufacturers or procurers.**



- **and of personnel Qualification and Certification schemes**
  - **EN ISO 9712**, examination/certification by an accredited third-party certification body
  - **ASNT**, training/exam can be within an employer-based scheme
  - **EN 4179**, **NAS 410**, aerospace employer-based certification schemes

- **Body of Codes and Standards**
  - **Standards**: documents that establish engineering or technical requirements for products, practices, methods, or operations
    - ISO, EN (CEN), ASTM, ASME, AWS, NAS …
  - **Codes**: adopted by one or more governmental bodies and has the force of law or incorporated into a business contract. Provide a set of rules that specify the minimum acceptable level of safety for manufactured, fabricated, or constructed objects. Will provide acceptance and rejection criteria for the required inspections
    - EU Pressure Equipment Directive (PED) 2014/68/EU and harmonised standards
    - ASME Boiler & Pressure Vessel Code (BPVC). Section 5: Nondestructive Examination
    - ASME B31.1: Power Piping
    - ASME B31.3: Process Piping
    - AWS D1.x: Structural Welding Codes
    - RCC-M, RSE-M: Design and construction (or in-service inspection) rules for French nuclear industry
    - …

Regulatory aspects – Example: NDT in PED 2014/68/EU



EN 13445 Unfired pressure vessels

- Part 1: General
- **Part 2: Materials**
- Part 3: Design
- Part 4: Fabrication
- **Part 5: Inspection and testing**
- Part 6: … spheroidal graphite cast iron
- Part 8: … aluminium and aluminium alloys
- Part 10: … nickel and nickel alloys

Ex1: Stainless steel forging (→ Part 2: Materials)
- shall be *free from defects*
- NDT if agreed
- NDT aspects left for agreement

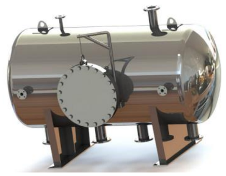
Ex2: Weld joints (→ Part 5: Inspection and testing)
- minimum extent of NDT fixed and = f(weld type, material group, testing group, NDT method)
- Quality Level C of EN ISO 5817 for standard conditions, stringer for fatigue and creep

EN 13480 Metallic industrial piping

- Part 1: General
- Part 2: Materials
- Part 3: Design and calculation
- Part 4: Fabrication and installation
- **Part 5: Inspection and testing**
- Part 6: Additional requirements for buried piping
- Part 8: … aluminium and aluminium alloy
- Part 9: … nickel and nickel alloys

Ex3: Weld joints (→ Part 5: Inspection and testing)
- minimum extent of NDT fixed and = f(weld type, material group, PED category, NDT method)
- Quality Level C of EN ISO 5817 for standard conditions, stringer for fatigue and creep

Regulatory aspects – Example: NDT in PED 2014/68/EU



Ex1. Pressure Vessels. Stainless steel forging

➔ only “free from defects”, NDT aspects left for free agreement

EN 13445-2 Unfired pressure vessels - Part 2: Materials

4.1.3 The materials shall be free from surface and internal defects which can impair their intended usability.

EN 13445-2:2021 **Table E.1-1 — European Standards for steels and steel components for pressure purposes**

Product form	General requirements	Room temperature grades [a]	Elevated temperature grades	Fine grain steels: Normalised	Fine grain steels: Thermo-mechanically treated	Fine grain steels: Quenched and tempered	Low temperature grades	Stainless steels
Plate and strip	EN 10028-1	—	EN 10028-2	EN 10028-3	EN 10028-5	EN 10028-6	EN 10028-4	EN 10028-7
Rolled bar	—	—	EN 10273	—	—	—	—	EN 10272
Seamless tube	—	EN 10216-1	EN 10216-2	EN 10216-3	—	EN 10216-3	EN 10216-4	EN 10216-5
Electric welded tube	—	EN 10217-1	EN 10217-2	EN 10217-3	—	—	EN 10217-4	—
Submerged arc welded tube	—	EN 10217-1	EN 10217-5	EN 10217-3	—	—	EN 10217-6	—
Fusion welded tube	—	—	—	—	—	—	—	EN 10217-7
Fitting	—	EN 10253-2	EN 10253-2	EN 10253-2	EN 10253-2	EN 10253-2	EN 10253-2	EN 10253-4
Forging including forged bars	EN 10222-1	—	EN 10222-2	EN 10222-4	—	—	EN 10222-3	EN 10222-5
Casting	EN 10213	—	EN 10213	—	—	—	EN 10213	EN 10213
Steel for fastener	—	—	EN 10269	—	—	—	EN 10269	EN 10269

[a] room temperature values are given in all standards of this table

6.8 Internal soundness **EN 10222-1:2017**

Where appropriate, requirements together with the conditions for their verification may be agreed at the time of enquiry and order (see Table 1 and 9.8).

9.8 Ultrasonic testing

In case of ultrasonic testing, the test shall be carried out in accordance with EN 10228-3:2016 or EN 10228-4:2016.

The acceptance criteria shall be agreed at the time of enquiry and order. The quantity of forgings tested shall be a statistically controlled sample or 100 % as agreed between purchaser and supplier.

EN 10222 Steel forgings for pressure purposes

EN 10222-1:2017 **Table 1 — Type of tests and extent of testing**

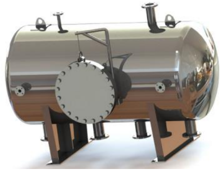
Type of inspection and test		Extent of testing	Refer to
Mandatory tests	Cast analysis	1 per cast	6.4.1
	Tensile test at room temperature	1 per test unit	7.2.1, 8.2.2 and 9.3
	Impact test (by agreement at time of enquiry and order the testing of impact properties may be optional for austenitic stainless steels according to EN 10222–5, see 5.2 Option 20).	1 per test unit	7.2.1, 8.2.2 and 9.5
	Dimensional inspection	each product[c]	6.9 and 9.11
	Visual testing	each product[c]	6.7.2 and 9.12
Optional tests	Product analysis	1 per cast	6.4.2, 7.2.1 and 9.2
	Tensile test for (simultaneous) verification of one, all, or any combination of $R_{p0,2}$, $R_{p1,0}$ and R_m at elevated temperature	1 per test unit[b]	8.2.2 and 9.4
	Additional impact test at different temperatures	a	7.2.1, 8.2.2 and 9.5
	Magnetic particle testing	a	6.7.3 and 9.6
	Penetrant testing	a	6.7.3 and 9.7
	Ultrasonic testing for verification of internal soundness	a	6.8 and 9.8
	Test for resistance to intergranular corrosion for steels of EN 10222–5	a	9.9
	Hydrostatic test for hollow sections	each product[b]	9.10

a As agreed.

b Unless otherwise agreed.

c For batches greater as 25 pieces, the extent of inspection shall be agreed at time of enquiry and order.

Regulatory aspects – Example: NDT in PED 2014/68/EU



Ex2. Pressure Vessels. Welded joints

➔ Joint coefficient for design depends on extent of NDT of the weld (through "Testing groups")

A minimum extent is fixed per testing group, weld type and material

EN 13445 Unfired pressure vessels - Part 5: Inspection and testing

EN 13445-5:2021 Table 6.6.1-1 — Testing groups for steel pressure vessels

Requirements	Testing group [a] 1 1a	1 1b	2 2a	2 2b	3 3a	3 3b	4 [b,j]
Permitted materials [g]	1 to 10	1.1, 1.2, 8.1	8.2, 9.1, 9.2, 9.3, 10	1.1, 1.2, 8.1	8.2, 9.1, 9.2, 10	1.1, 1.2, 8.1	1.1, 8.1
Extent of NDT for governing welded joints [e,h]	100 %	100 %	100 % - 10% [d]	100 % - 10 % [d]	25 %	10 %	0 % [k]
NDT of other welds	Defined for each type of weld in Table 6.6.2-1						
Joint coefficient	1	1	1	1	0,85	0,85	0,7

…

EN 13445-5:2021 Table 6.6.2-1 — Extent of non-destructive testing

TYPE OF WELD [a, p]			TESTING [b]	EXTENT FOR TESTING GROUP [o] 1a	1b	2a [i]	2b [i]	3a	3b
				EXTENT FOR PARENT MATERIALS [l,m,n] 1 to 10	1.1, 1.2, 8.1	8.2, 9.1, 9.2, 9.3, 10	1.1, 1.2 8.1	8.2, 9.1, 9.2, 10	1.1, 1.2, 8.1
Full penetration butt weld	1	Longitudinal joints	RT or UT MT or PT	100 % 10 %	100 % 10 % [d]	(100-10) % 10 %	(100-10) % 0	25 % 0	10 % 0
	2a	Circumferential joints on a shell, including circumferential joints between a shell and a non-hemispherical head	RT or UT MT or PT	25 % 10 %	10 % 10 % [d]	(25 -10) % 10 %	(10 - 5) % 0	10 % 0	5 % [c] 0
	2b	Circumferential joints on a shell, including circumferential joints between a shell and a non-hemispherical head, with backing strip [k]	RT or UT MT or PT	NP NP	NA 100 %	NP NP	NA 100 %	NP NP	NA 100 %
	2c	Circumferential joggle joint, including circumferential joints between a shell and a non-hemispherical head [k]	RT or UT MT or PT	NP NP	NA 100 %	NP NP	NA 100 %	NP NP	NA 100 %
	3a	Circumferential joints on a nozzle d_i > 150 mm	RT or UT	25 %	10 %	(25 -10) %	(10 - 5) %	10 %	5 % [c]

…

➔ Quality Level C as per EN ISO 5817 for standard conditions (quality level B, stringent, if subject to fatigue / creep)

6.6.3.2 Quality level — EN 13445-5:2021

The quality level shall be quality level C in accordance with EN ISO 5817:2014, with the following additional requirements for some imperfections:

…

For cyclic loaded vessels, see Annex G; for vessels or parts subject to creep, see Annex F.

Regulatory aspects – Example: NDT in PED 2014/68/EU

Ex3. Industrial piping. Welded joints

EN 13480-5:2017

➔ Minimum extent of NDT is fixed depending on weld type, material group, category NDT method.

Table 8.2-1 — Extent of testing for circumferential, branch, fillet and seal welds

Material group [a]	Category	All welds VT %	Circumferential welds Surface testing e_n mm	Circumferential welds Surface testing MT/PT [c] %	Circumferential welds Volumetric testing [b] RT/UT %	Branch welds Surface testing Branch diameter	Branch welds Surface testing e_n [h] mm	Branch welds Surface testing MT/PT [c] %	Branch welds Volumetric testing [b,k] Branch diameter [i]	Branch welds Volumetric testing e_n [h] mm	Branch welds Volumetric testing RT/UT %	Socket/fillet welds Surface testing e_n mm	Socket/fillet welds Surface testing MT/PT %	Seal welds Surface testing e_n mm	Seal welds Surface testing MT/PT %
1.1, 1.2, 8.1	I	100	0 (5) [f,g]		5	All		0 (5) [f,g]	All		0	All	0	All	0
	II				(10) [g]										
	III				10			10	> DN 100	> 15	10		10		10
1.3, 1.4, 1.5, 2.1, 2.2, 4.1, 4.2, 5.1, 5.2, 8.2, 8.3, 9.1, 9.2, 9.3, 10.1, 10.2	I	100	≤ 30	5	10	All [e]		10 (25) [g]	All		0	All [e]	10	All [e]	5
			> 30	10	10										
	II		≤ 30	5	10										
			> 30	10	10										
	III		≤ 30	5	10 (25 [d]) [f,g]	All			> DN 100	> 15	10	All	25	All	25
			> 30	10	10 (25 [d]) [f,g]										
3.1, 3.2, 3.3, 5.3, 5.4, 6.1, 6.2, 6.3, 6.4, 7.1, 7.2	I	100	≤ 30	10	25	All		25	> DN 100	> 15	25	All	25	All	10
			> 30	25	25										
	II		≤ 30	25	25										
			> 30	25	25 (25 [d]) [f,g]										
	III		≤ 30	100	25 (100) [f,g]			100			100		100		100
			> 30	100	25 (100 [d]) [f,g]										

a Material group, see CEN ISO/TR 15608.
b For the selection of the appropriate NDT-method for volumetric testing, see 8.4.4.3.
c See 8.4.4.2.
d Additional testing for transverse defects from weld surface (see EN ISO 17640:2010, testing level C).
e Only if PWHT has been carried out.
f Value in brackets applies to piping where creep or fatigue is the controlling factor in design.
g Value in brackets applies to piping with pneumatic pressure test with 1,1 times the maximum allowable pressure.
h e_n is the nominal thickness of the branch pipe at the weld (see W3, W3.1 and W6 in EN 13480-4:2017, Figure 9.14.4-1 and Figure 9.14.4-2).
i For parts without DN designation d_i > 120 mm may be used instead of DN > 100.
k Volumetric testing is required if both criteria (branch diameter and nominal thickness) are satisfied.

Table 8.3-1 — Extent of NDT for longitudinal welds

Joint coefficient z	VT %	MT or PT [a] %	RT or UT [b] %
$z \leq 0{,}7$	100	0	0
$0{,}7 < z \leq 0{,}85$	100	10	10
$0{,}85 < z \leq 1{,}0$	100	100	100

a See 8.4.4.2
b See 8.4.4.3

➔ Quality Level is fixed per service conditions and testing method.

Table 8.4.2-1 — Quality level according to EN ISO 5817:2014 depending on service conditions and test methods

Service conditions	Surface Imperfections and Imperfections in joint geometry: Visual testing VT	Surface Imperfections and Imperfections in joint geometry: Surface testing	Internal Imperfections: Volumetric testing
Standard level	C	C	C
Fatigue	B	B	C
Creep	B	B	B

Conclusions

A large pallet of NDT resources are available.

Many possibilities but also many limitations, get informed.

Consider NDT in advance

- **In your fabrications but also in your procurements**
- **Not only because of the minimum required, as a quality decision**
- **To make it possible, easier or more efficient**
- **Not to squeeze it in the schedule**

Questions and discussion

Thank you for your attention

Credits, references, resources:

Iowa State University's Center for Nondestructive Evaluation (CNDE). https://www.nde-ed.org/

Evident. https://www.olympus-ims.com/en/learn/

Waygate Technologies. https://www.bakerhughes.com/waygate-technologies/non-destructive-testing

Cofrend. https://www.cofrend.com/

Olympus. Phased array testing. Basic theory for industrial applications