Section 17

Non-Destructive Testing (NDT)

NDT techniques are in common use to check the integrity of engineering materials and components. The main applications are plate, forgings, castings, and welds.

17.1 Non-destructive testing acronyms

Non-destructive testing procedures, reports, and general literature are full of acronyms. The most common ones are listed below.

AE	Acoustic emission
AFD	Automated flaw detection
A-scan	Amplitude scan
ASNT	American Society for Non-destructive Testing
ASTM	American Society for Testing and Materials
B-scan	Brightness scan
BVID	Barely visible impact damage
CDI	Crack detection index
CRT	Cathode ray tube
C-scan	Contrast scan
CSI	Compton scatter imaging
CTM	Coating thickness measurement
CW	Continuous wave/compression wave
DAC	Distance amplitude correction
dB	Decibel
DGS	Distance, gain, size (diagram)
DPEC	Deep penetration eddy currents
EC	Eddy current
ECII	Eddy current impedance imaging
EPS	Equivalent penetrameter sensitivity
ET (ECT)	Eddy current testing
FFD	Focus-to-film distance

Engineers' Data Book, Fourth Edition. Clifford Matthews.

FSH	Full scale height
HAZ	Heat affected zone
HDR	High-definition radiography
HVT	Half value thickness
IF	Industrial fiberscope
IQI	Image quality indicator
IV	Industrial video-imagescope
LD	Linear detectors
LFECA	Low-frequency eddy current array
LPI	Liquid penetrant inspection
LW	Longitudinal wave
MFL	Magnetic flux leakage
MPI	Magnetic particle inspection
MPT	Magnetic particle testing
MR	Microradiography
MRI	Magnetic resonance imaging
MT	Magnetic testing
NDA	Non-destructive assessment
NDE	Non-destructive examination
NDI	Non-destructive inspection
NDT	Non-destructive testing
NMR	Nuclear magnetic resonance
PA	Peak amplitude
PCN	Personal certificate in non-destructive testing
PDRAM	Pulsed digital reflection acoustic microscopy
POD	Probability of detection
P-scan	Projection scan
PT	Penetrant testing
PVT	Pulse video thermography
QNDE	Quantitative non-destructive evaluation
RFET	Remote field eddy current testing
ROI	Region of interest
ROV	Remotely operated vehicle
RT	Radiographic testing
RT	Real time
RTUIS	Real time ultrasonic imaging system
RVI	Remote visual inspection

RVT	Remote visual testing
SAM	Scanning acoustic microscopy
SDT	Static deflection techniques
SEM	Scanning electron microscopy
SFD	Source-to-film distance
SH	Horizontally polarized shear waves
SI	Sensitivity indicator
SIT	Simulated infrared thermography
SMNR	Signal-to-material noise ratio
SNR	Signal-to-noise ratio
SPATE	Stress pattern analysis by thermal emission
TDR	Time-domain reflectometry
TOFD	Time-of-flight diffraction
TSE	Total spectral energy
TW	Transverse wave
US	Ultrasonic
UT	Ultrasonic testing
VAP	Variable angle (ultrasonic) probe
VT	Visual testing
WFMPI	Wet fluorescent magnetic particle inspection
WIR	Work and inspection robot
WT	Wall thickness

17.1.1 References

A useful reference on the subject is *The NDT Yearbook* (ISSN 0952-2395), published annually by The British Institute of Non-destructive Testing (Tel: 01604 893811, Fax: 01604 893861).

17.2 Visual examination

Close visual examination can reveal surface cracks and defects of about 0.1 mm and above. This is larger than the 'critical crack size' for most ferrous materials.

17.3 Dye penetrant (DP) testing

This is an enhanced visual technique using three aerosols, a cleaner (clear), penetrant (red), and developer (white). Surface defects appear as a thin red line.

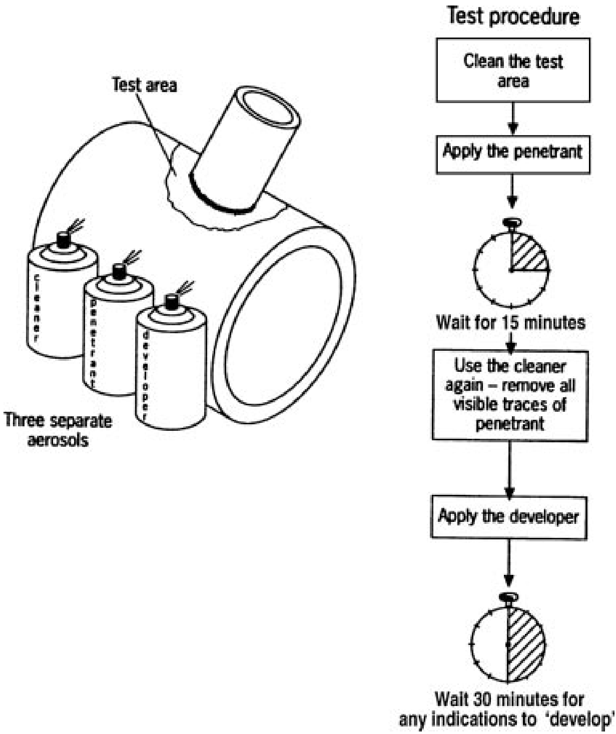


Figure 17.1

17.4 Magnetic particle (MP) testing

This works by passing a magnetic flux through the material while spraying the surface with magnetic ink. An air gap in a surface defect forms a discontinuity in the field which attracts the ink, making the crack visible. Defects are classified into:

- 'Crack-like' flaws
- Linear flaws (1 > 3w)
- Rounded flaws (1 < 3w)

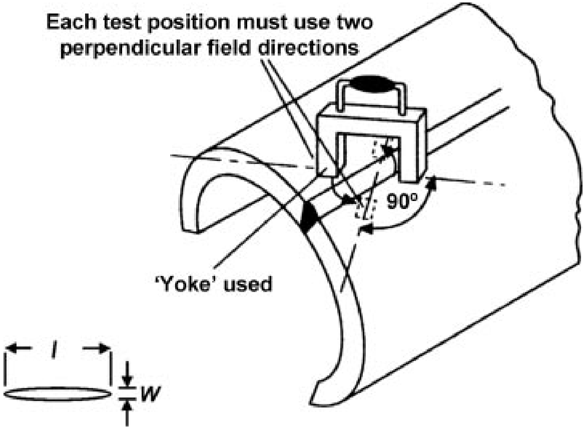


Figure 17.2

17.5 Ultrasonic testing (UT)

Different practices are used for plate, forgings, castings, and welds. The basic technique is the 'A-scope pulse-echo' method.

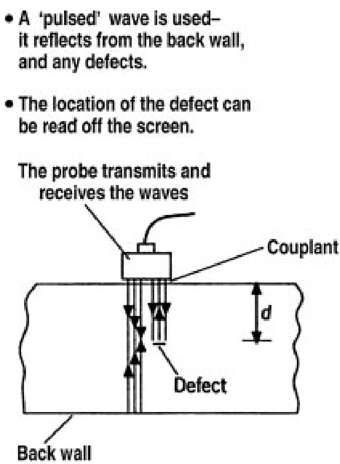


Figure 17.3

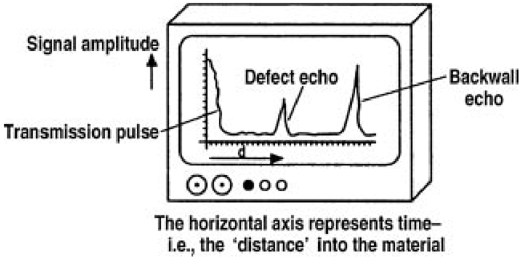


Figure 17.3 (Cont.)

17.5.1 UT of plate

Technical standards contain various 'grades' of acceptance criteria. Plate is tested to verify its compliance with a particular grade specified for the edges and body of the material. Typical criteria are given in Tables 17.1 and 17.2.

Table 17.1 Material 'edge-grades'

Acceptance 'grade'	*Single imperfection, max. length (area)*	*Multiple imperfections, max. no. per 1 m length*	*Above min. length*
E1	50 mm (1000 mm^2)	5	30 mm
E2	30 mm (500 mm^2)	4	20 mm
E3	20 mm (l00 mm^2)	3	10 mm

Table 17.2 Material 'body'-grades

Acceptance 'grade'	*Single imperfection max. area (approximate)*	*Multiple imperfections, max. no. per 1 m length*	*Above min. size (area)*
B1	10 000 mm^2	5	10 mm × 20 mm (2 500 mm^2)
B2	5 000 mm^2	5	75 mm × 15 mm (1 250 mm^2)
B3	2 500 mm^2	5	60 mm × 12 mm (750 mm^2)
B4	1 000 mm^2	10	35 mm × 8 mm (300 mm^2)

USEFUL STANDARD

BS 5996: 1993: Specification for acceptance levels for internal imperfections in steel plate, based on ultrasonic testing (equivalent to EN 160).

17.5.2 UT of castings

Casting discontinuities can be either planar or volumetric. Separate gradings are used for these when discovered by UT technique. The areas of a casting are divided into critical and non-critical areas, and by thickness 'zones', Figure 17.4. Typical grading criteria are as shown in Tables 17.3 and 17.4.

17.5.3 UT of welds

Weld UT has to be a well-controlled procedure because the defects are small and difficult to classify. Ultrasonic scans may be necessary from several different directions, depending on the weld type and orientation.

The general technique is:

- Surface scan using normal (0°) probe.
- Transverse scan (across the weld) to detect *longitudinal* defects.
- Longitudinal scan (along the weld direction) to detect *transverse* defects.

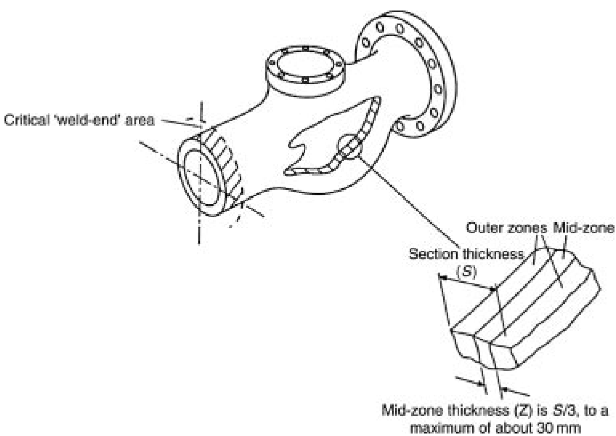


Figure 17.4

Table 17.3

Planar discontinuities	*Grade*			
	1	*2*	*3*	*4*
Max. 'through-wall' discontinuity size	0 mm	5 mm	8 mm	11 mm
Max. area of a discontinuity	0 mm	75 mm^2	200 mm^2	360 mm^2
Max. total area* of discontinuities	0 mm	150 mm^2	400 mm^2	700 mm^2

Table 17.4

Non-Planar discontinuities	*Grade*			
	1	*2*	*3*	*4*
Outer zone Max. size	0.2Z	0.2Z	0.2Z	0.2Z
Out zone Max. total area*	250 mm^2	1000 mm^2	2000 mm^2	4000 mm^2
Mid zone Max. size	0.1S	0.1S	0.15S	0.15S
Mid zone Max. total area*	12 500 mm^2	20 000 mm^2	31 000 mm^2	50 000 mm^2

*All discontinuity levels are per unit (10 000 mm^2) area

17.5.4 UT corrosion mapping

Corrosion mapping is an ultrasonic testing technique developed specifically for in-service inspection of engineering components. Its main use is in the petrochemical and offshore industries, where corrosion of pipework and vessels is a serious problem. Although the technique is straightforward in concept it requires a special equipment set-up, making it suitable for pre-planned rather than impromptu inspections.

How does it work?

Corrosion mapping uses a standard (normally 2 MHz) 0 degree ultrasonic probe, producing compression waves. This is the same type used for standard wall thickness measurement or lamination checks. The probe measures the thickness of the material being scanned using a simple back wall echo displayed on an A-scan screen. The main factors are listed below (see also Fig. 17.6):

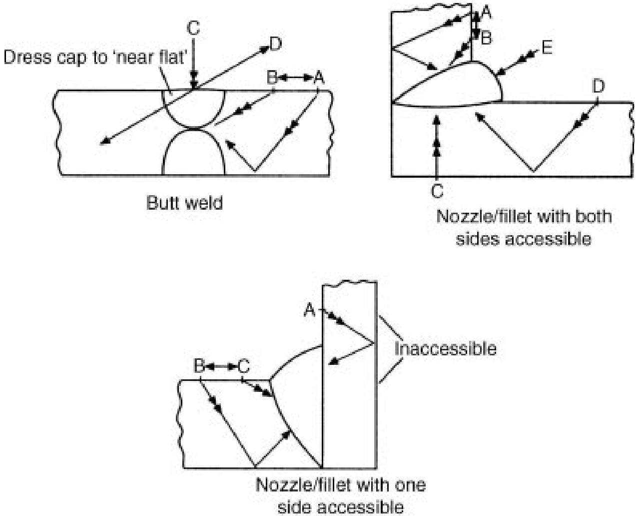


Figure 17.5

- *Scanning* The probe is scanned over 100 per cent of the surface, thereby building up a complete picture of the wall thickness.
- *Display* The display shows a colour representation of the wall thickness. The thickness readings that trigger each colour are pre-set to match the acceptance criteria for the specific job. For a 20 mm material wall thickness a typical display format would be:
  - <10 mm remaining wall thickness: Red
  - 10–15 mm remaining wall thickness: Yellow
  - 15–20 mm remaining wall thickness: Green
  - Reading not yet recorded: Black
- *Resolution* The resolution of the scan, in pixel size, can be chosen to suit the material, and the type of corrosion expected. A typical resolution set to detect pipe internal wall corrosion, including flow-accelerated corrosion and isolated oxygen pitting, would be 2 mm × 2 mm. Where corrosion is expected to be more widespread the pixels could be bigger, resulting in a quicker scan.

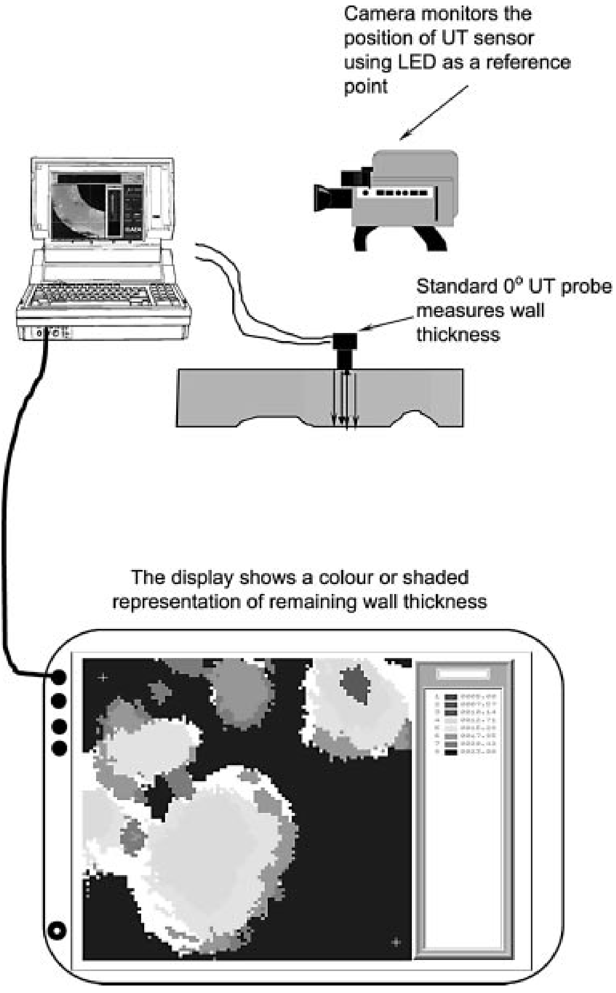

Camera monitors the position of UT sensor using LED as a reference point
Standard 0° UT probe measures wall thickness
The display shows a colour or shaded representation of remaining wall thickness

Figure 17.6

- *Location reference* The scanned area is mapped out using a set of *x:y* co-ordinates, referenced to a fixed origin point defined on the component – a light emitting diode (LED) is normally used for this. Scan location is then plotted via a fixture-mounted video camera respective to the LED 'origin'. To help with location, grid-lines or datum points may be marked on the surface of the component itself.

What are the advantages of corrosion mapping?
The main advantage of corrosion mapping is that it guarantees 100 per cent scan coverage of the area under examination. This gives a much-improved effectiveness over a standard 'random' UT wall thickness scan where it cannot be demonstrated whether a specific area has been fully examined or not. Tests with a corrosion mapping system will quickly show that, without the aid of a display confirming the unscanned areas (grey or black on the screen), even a competent technician doing a thorough technique will only cover about 60–70 per cent of the scan area. This percentage reduces when the scan is complicated by poor surface finish or irregular geometry. Another practical advantage is that corrosion mapping produces a permanent record of corrosion measurement. This allows comparisons to be made between subsequent in-service inspections to check the rate at which corrosion is progressing.

17.5.5 Remote UT thickness monitoring strips

This is a technique used for in-situ testing of buried pipelines. There are several similar methods marketed under proprietary tradenames. Figure 17.7 shows the principles. A number (10+) of simple 0 degree UT mini-probes (fixed frequency) are built into a flexible plastic strip, each one linked by a flat copper conductor strip to wire connectors at the end of the strip. The strip is wrapped around the pipeline, under any wrapping or lagging, and is connected by hard-wiring or radio link to a remote monitoring computer. The probes are triggered on a periodic basis, giving a crude measurement of the wall thickness at multiple radial points. The strips are fitted at

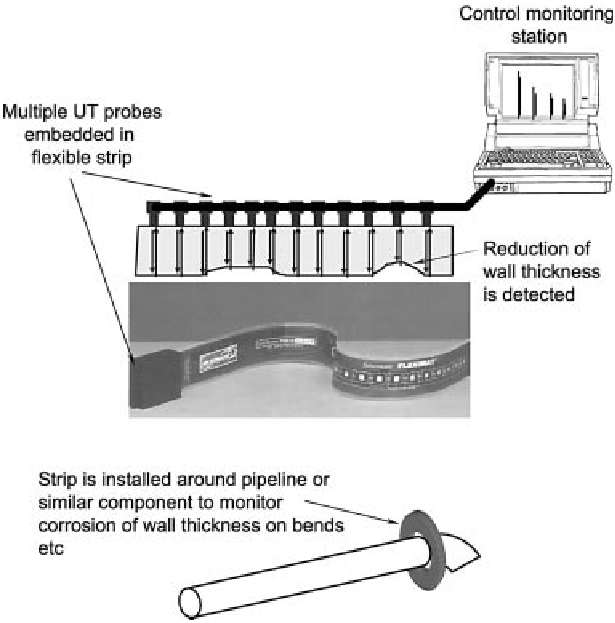


Figure 17.7

key wall thinning points such as changes of section, flow restrictions, and bends. This technique is particularly useful for buried or long-distance desert/mountain terrain pipelines where access is difficult. Two limitations of this method are given below.

- Only a 'first estimate' of wall thickness is given: the probes are not as sensitive as full-scale UT testing.
- Where low thicknesses are identified, the pipeline still has to be excavated for more detailed checks: spurious results are not unknown.

17.5.6 Time of flight diffraction (TOFD)

Time of flight diffraction (TOFD) is an advanced UT technique that has claimed advantages in the detection and sizing of defects. It has been in use for more than twenty years but has not yet achieved widespread recognition as a practical replacement for standard UT technique.

The TOFD principle

TOFD works on the principle of ultrasonic beam *diffraction* rather than *reflection*, as in standard UT techniques. Simplistically the amount of diffraction achieved is less dependent on ideal orientation of a defect than is reflection, with the result that TOFD is more sensitive than conventional UT techniques. Figures 17.8 to 17.10 show the principle: the ultrasonic wave

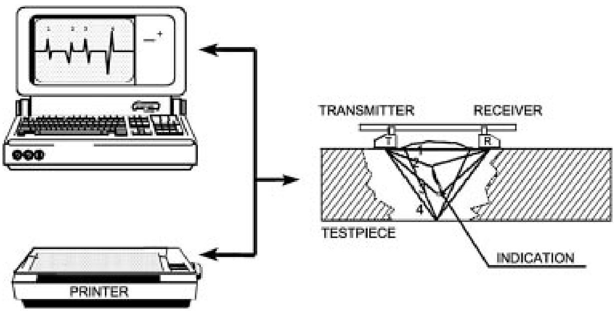


Figure 17.8

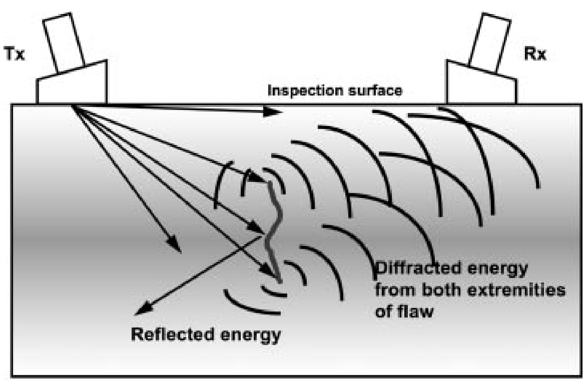


Figure 17.9

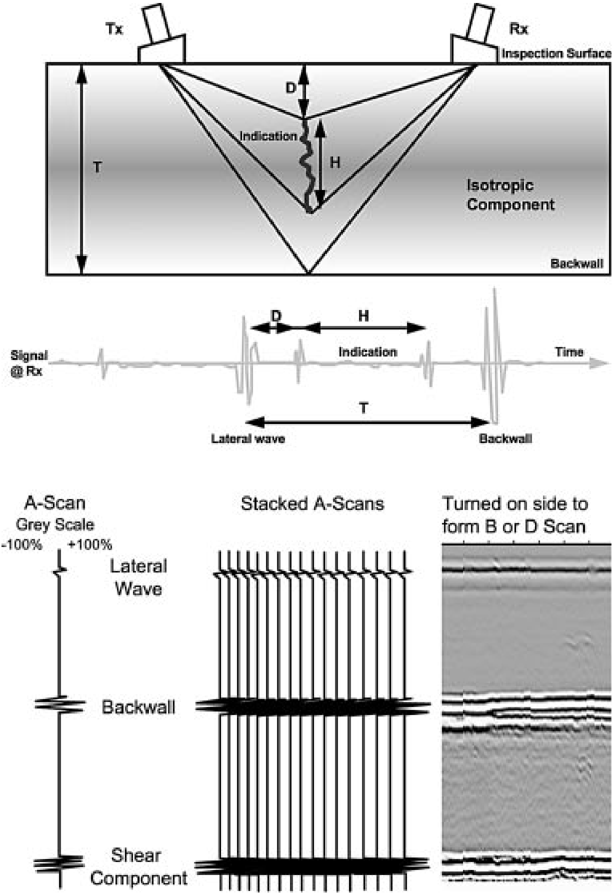


Figure 17.10

diffraction from the tip of a defect is almost independent of the orientation of the defect relative to the beam path. The intensity of the diffraction is increased if the defect is sharp edged. This is a useful characteristic as sharp-tipped defects pose a greater risk to integrity than blunt-tipped ones of the same length.

Unlike conventional UT compression and shear wave techniques, TOFD uses separate probes for emitting the ultrasonic beam input and receiving the diffracted 'output'. Beam angles are also restricted, which means that the two probes must be separated by a minimum spacing distance. This is achieved by mounting the probes on a custom-made frame – the whole assembly being pushed along the weld. This constitutes the full scan, replacing the traditional longitudinal and transverse shear-wave scans used in conventional UT. Maximum scanning speed is about 150 mm per second, so, once set up, the technique allows quick scanning of long, regular geometry weld joints. Figure 17.10 shows a typical arrangement, and the way that various common defects appear on the display.

17.6 Radiographic testing (RT)

Radiography is widely used for NDT of components and welds in many engineering applications.

- X-rays are effective on steel up to a thickness of approximately 150 mm.
- Gamma (γ) rays can also be used for thickness of 50–150 mm but definition is not as good as with X-rays.

17.6.1 Techniques

For tubular components a single- or double-wall technique may be used. Note the way the technique is specified.

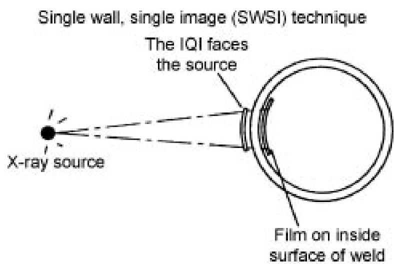
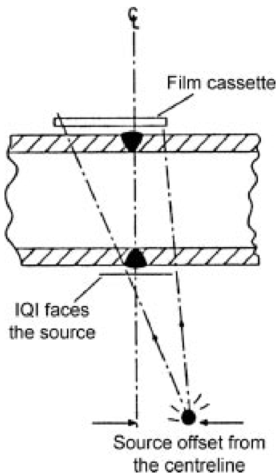


Figure 17.11

Specification	*Explanation*
Single wall	Only one weld 'thickness' shows on the film
Technique no. 1	A reference to BS 2910 which lists techniques nos 1–16
Class A	X-ray and single wall techniques give the best (class A) results
Fine film	BS 2910 mentions the use of fine or medium film grades
X-220kV	The X-ray voltage depends on the weld thickness



Specification	*Explanation*
Double-wall/image	Two weld 'thicknesses' show
Technique no. 13	A reference to BS 2910 which lists techniques nos 1–16
Class B	Double-wall techniques are inferior to single-wall methods
Fine film	BS 2910 mentions the use of fine or medium grades
Density 3.5–4.5	The 'degree of blackness' of the image

17.6.2 Penetrameters

Penetrameters, or image quality indicators (IQIs) check the sensitivity of a radiographic technique – to ensure that any defects present will be visible. The two main types are the 'wire' type and 'hole' type.

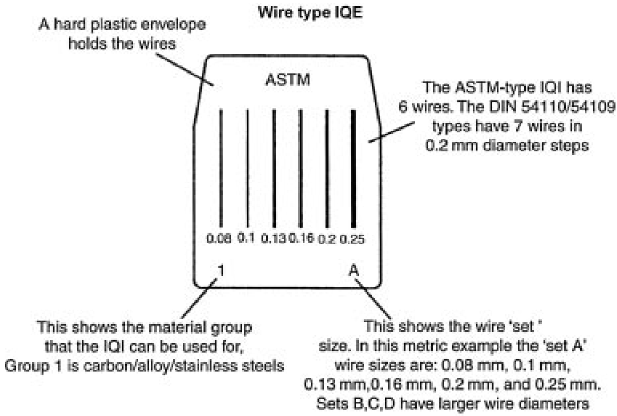
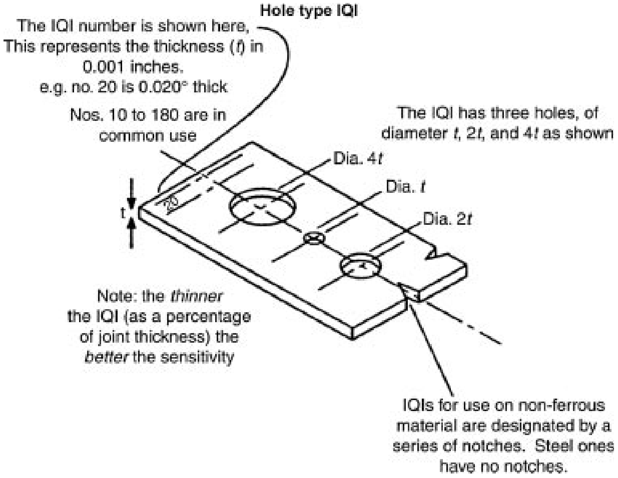


Figure 17.12

- The objective is to look for the smallest wire visible
- Sensitivity = diameter of smallest wire visible/maximum penetrated thickness of weld
- If the above IQI is used on 10 mm material and the 0.16 mm wire is visible, then sensitivity = 0.16/10 = 1.6%
- Check the standard for the maximum allowable sensitivity for the technique/application being used



IQI designation	*Sensitivity*	*Visible hole**
1–2t	1	2t
2–1t	1.4	1t
2–2t	2.0	2t
2–4t	2.8	4t
4–2t	4.0	2t

*The hole that must be visible in order to ensure the sensitivity level shown

Useful NDT Standards

1. EN 287-1: 1992: Approval testing of welders – fusion welding – Part 1: Steels.
2. EN 473: 2000: Non-destructive testing – Qualification and certification of NDT personnel – General principles.
3. EN 571-1: 1997: Non-destructive testing – Penetrant testing – Part 1: General principles.
4. prEN 764-6: 2002: Pressure equipment – Part 6: Operating instructions.

5. EN 583-4: 1999: Non-destructive testing – Ultrasonic examination – Part 4: Examination for discontinuities perpendicular to the surface.
6. EN 970: 1997: Non-destructive examination of fusion welds – Visual examination.
7. EN 1289: 1998: Non-destructive examination of welds – Penetrant testing of welds – Acceptance levels.
8. EN 1290: 1998: Non-destructive examination of welds – Magnetic particle examination of welds.
9. EN 1291: 1998: Non-destructive examination of welds – Magnetic particle testing of welds – Acceptance levels.
10. EN 1418: 1997: Welding personnel – Approval testing of welding operators for fusion welding and resistance weld setters for fully mechanized and automatic welding of metallic materials.
11. EN 1435: 1997: Non-destructive examination of welds – Radiographic examination of welded joints.
12. EN 1712: 1997: Non-destructive examination of welds – Ultrasonic examination of welded joints – Acceptance levels.
13. EN 1713: 1998: Non-destructive examination of welds – Ultrasonic examination – Characterization of indications in welds.
14. EN 1714: 1997: Non-destructive examination of welds – Ultrasonic examination of welded joints.
15. EN 1779: 1999: Non-destructive testing – Leak testing – Criteria for method and technique selection.
16. EN 12062: 1997: Non-destructive examination of welds – General rules for metallic materials.
17. EN 12517: 1998: Non-destructive examination of welds – Radiographic examination of welded joints – Acceptance levels.
18. EN 13445-2: 2002: Unfired pressure vessels – Part 2: Materials.
19. EN 13445-3: 2002: Unfired pressure vessels – Part 3: Design.
20. EN 13445-4: 2002: Unfired pressure vessels – Part 4: Fabrication.