

Section 5

Non-Destructive Testing

Introduction

Radiographic, ultrasonic, dye penetrant and magnetic particle methods are briefly described below. The relative advantages and limitations of the methods are discussed in terms of their applicability to the examination of welds.

1 Radiographic Methods

In all cases radiographic methods as applied to welds involve passing a beam of penetrating radiation through the test object. The transmitted radiation is collected by some form of sensor, which is capable of measuring the relative intensities of penetrating radiations impinging upon it. In most cases this sensor will be radiographic film, however the use of various electronic devices is on the increase. These devices facilitate so-called real-time radiography and examples may be seen in the security check area at airports. Digital technology has enabled the storing of radiographs using computers. The present discussion is confined to film radiography since this is still by far the most common method applied to welds.

1.1 Sources of penetrating radiation

Penetrating radiation may be generated from high-energy electron beams, in which case they are termed X-rays, or from nuclear disintegrations (atomic fission), in which case they are termed gamma-rays. Other forms of penetrating radiation exist but they are of limited interest in weld radiography.

1.2 X-rays

X-rays used in the industrial radiography of welds generally have photon energies in the range 30keV up to 20MeV. Up to 400keV they are generated by conventional X-ray tubes which, dependant upon output, may be suitable for portable or fixed installations. Portability falls off rapidly with increasing kilovoltage and radiation output. Above 400keV X-rays are produced using devices such as betatrons and linear accelerators, not generally suitable for use outside of fixed installations. All sources of X-rays produce a continuous spectrum of radiation, reflecting the spread of kinetic energies of electrons within the electron beam. Low energy radiations are more easily absorbed and the presence of low energy radiations, within the X-ray beam, gives rise to better radiographic contrast and therefore better radiographic sensitivity than is the case with gamma-rays which are discussed below. Conventional X-ray units are capable of performing high quality radiography on steel of up to 60mm thick, betatrons and linear accelerators in excess of 300mm.

1.3 Gamma-rays

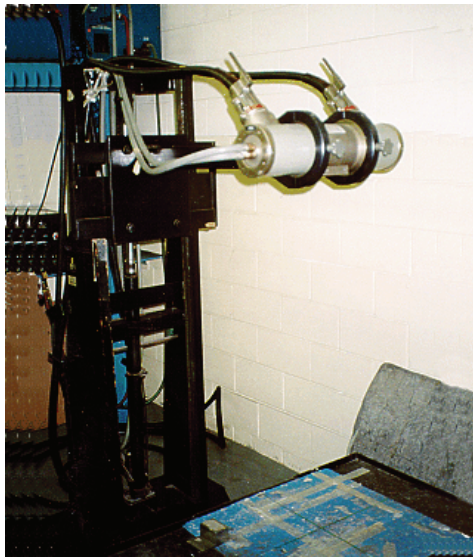
The early sources of gamma-rays used in industrial radiography were in general composed of naturally occurring radium. The activity of these sources was not very high, therefore they were physically rather large by modern standards even for quite modest outputs of radiation and the radiographs produced by them were not of a particularly high standard. Radium sources were also extremely hazardous to the user due to the production of radioactive radon gas as a product of the fission reaction. Since the advent of the nuclear age it has been possible to artificially produce isotopes of much higher specific activity than those occurring naturally and which do not produce hazardous fission products. Unlike the X-ray sources gamma-sources do not produce a continuous distribution of quantum energies. Gamma-sources produce a number of specific quantum energies which are unique for any particular isotope. Four isotopes are in common use for the radiography of welds, they are in ascending order of radiation energy: Thulium 90, Ytterbium 169, Iridium 192 and Cobalt 60. In terms of steel Thulium 90 is useful up to a thickness of 7mm or so, it's energy is similar to that of 90keV X-rays and due to it's high specific activity useful sources can be produced with physical dimensions of less than 0.5mm. Ytterbium 169 has only fairly recently become available as an isotope for industrial use, it's energy is similar to that of 120keV X-rays and it is useful for the radiography of steel up to approximately 12mm thick. Iridium 192 is probably the most commonly encountered isotopic source of radiation used in the radiographic examination of welds, it has a relatively high specific activity and high output sources with physical dimensions of 2-3mm are in common usage, it's energy is approximately equivalent to that of 500keV X-rays and it is useful for the radiography of steel in the thickness range 10-75mm. Cobalt 60 has an energy approximating to that of 1.2MeV X-rays, due to this relatively high energy, suitable source containers are large and rather heavy. Cobalt 60 sources are for this reason not fully portable. They are useful for the radiography of steel in the thickness range 40-150mm. The major advantages of using isotopic sources over X-rays are:

- a) the increased portability;
- b) need for a power source;
- c) lower initial equipment costs.

Against this the quality of radiographs produced by gamma-ray techniques is inferior to that produced by X-ray techniques, the hazards to personnel may be increased (if the equipment is not properly maintained, or if the operating personnel have insufficient training), and due to their limited useful lifespan new isotopes have to be purchased on a regular basis (so that the operating costs of an gamma-ray source may exceed those of an X-ray source).

1.4 Radiography of welds

Radiographic techniques depend upon detecting differences in absorption of the beam ie, changes in the effective thickness of the test object, in order to reveal defective areas. Volumetric weld defects such as slag inclusions (except in some special cases where the slag absorbs radiation to a greater extent than does the weld metal) and various forms of gas porosity are easily detected by radiographic techniques due to the large negative absorption difference between the parent metal and the slag or gas. Planar defects such as cracks or lack of sidewall or interrun fusion are much less likely to be detected by radiography since they may cause little or no change in the penetrated thickness. Where defects of this type are likely to occur other NDE techniques such as ultrasonic testing are preferable to radiography. This lack of sensitivity to planar defects makes radiography an unsuitable technique where a fitness-for-purpose approach is taken when assessing the acceptability of a weld. However, film radiography produces a permanent record of the weld condition, which can be archived for future reference; it also provides an excellent means of assessing the welder's performance and for these reasons it is often still the preferred method for new construction.



X-ray equipment.



Gamma-ray equipment.



X-ray of a welded seam showing porosity.

1.5 Radiographic testing

Advantages	Limitations
Permanent record	Health hazard. Safety (Important)
Good for fixing non-planar defects/flaws	Classified workers, medicals required
Can be used on all materials	Sensitive to defect orientation
Direct image of defect/flaws	Not good for planar defect detection
Real-time imaging	Limited ability to detect fine cracks
Can be positioned inside pipe (productivity)	Access to both sides required
Very good thickness penetration	Skilled interpretation required
No power required with gamma	Relatively slow
	High capital outlay and running costs Isotopes have a half life (cost)

2 Ultrasonic Methods

The velocity of ultrasound in any given material is a constant for that material and ultrasonic beams travel in straight lines in homogeneous materials. When ultrasonic waves pass from a given material with a given sound velocity to a second material with different velocity refraction, and a reflection of the sound beam will occur at the boundary between the two materials. The same laws of physics apply equally to ultrasonic waves as they do to light waves. Ultrasonic waves are refracted at a boundary between two materials having different acoustic properties, so probes may be constructed which can beam sound into a material at (within certain limits) any given angle. Because sound is reflected at a boundary between two materials having different acoustic properties ultrasound is a useful tool for the detection of weld defects. Since velocity is a constant for any given material and sound travels in a straight line (with the right equipment) ultrasound can also be utilised to give accurate positional information about a given reflector. Careful observation of the echo pattern of a given reflector and its behaviour as the ultrasonic probe is moved together with the positional information obtained above and a knowledge of the component history enables the experienced ultrasonic operator to classify the reflector as say slag, lack of fusion or a crack.

2.1 Equipment for ultrasonic testing

Equipment for manual ultrasonic testing consists of:

- A flaw detector::
 - Pulse generator.
 - Adjustable time base generator with an adjustable delay control.
 - Cathode ray tube with fully rectified display.
 - Calibrated amplifier with a graduated gain control or attenuator.
- An ultrasonic probe:
 - Piezo-electric crystal element capable of converting electrical vibrations into mechanical vibrations and vice-versa.
 - Probe shoe, normally a Perspex block to which the crystal is firmly attached using a suitable adhesive.
 - Electrical and/or mechanical crystal damping facilities to prevent excessive ringing.

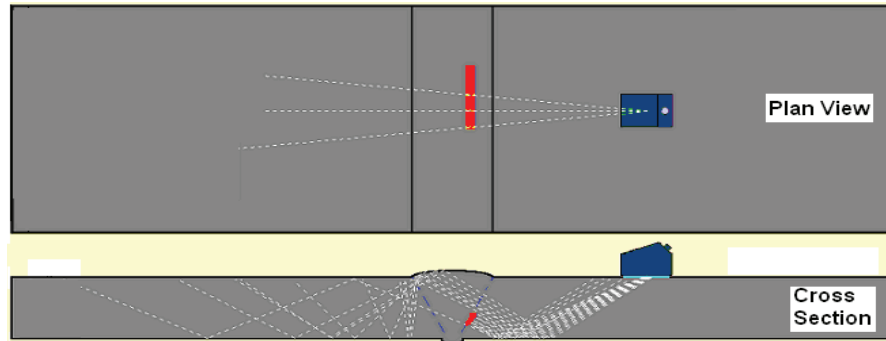
Such equipment is lightweight and extremely portable. Automated or semi-automated systems for ultrasonic testing utilise the same basic equipment although since in general this will be multi-channel equipment it is bulkier and less portable. Probes for automated systems are set in arrays and some form of manipulator is necessary to feed positional information about the probes to the computer. Automated systems generate very large amounts of data and make large demands upon the RAM of the computer. Recent advances in automated UT have led to a reduced amount of data being recorded for a given length of weld. Simplified probe arrays have greatly reduced the complexity of setting-up the automated system to carry out a particular task. Automated UT systems now provide a serious alternative to radiography on such constructions as pipelines where a large number of similar inspections allow the unit cost of system development to be reduced to a competitive level.



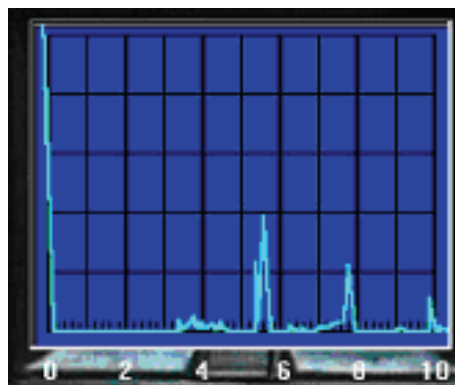
Ultrasonic equipment.



Compression and a shear wave probe.



Example of a scanning technique with a shear wave probe.



Typical screen display when using a shear wave probe.

2.2 Ultrasonic testing

Advantages	Limitations
Portable (no mains power) battery	No permanent record
Direct location of defect (3 dimensional)	Only ferritic materials (mainly)
Good for complex geometry	High level of operator skill required
Safe operation (can be done next to someone)	Calibration of equipment required
Instant results	Special calibration blocks required
High penetrating capability	No good for pin pointing porosity
Can be done from one side only	Critical of surface conditions (clean smooth)
Good for finding planar defects	Will not detect surface defects
	Material thickness >8mm due to dead zone

3 Magnetic Particle Testing

Surface breaking or very near surface discontinuities in ferromagnetic materials give rise to leakage fields when high levels of magnetic flux are applied. These leakage fields will attract magnetic particles (finely divided magnetite) to themselves and this leads to the formation of an indication. The magnetic particles may be visibly or fluorescently pigmented in order to provide contrast with the substrate or conversely the substrate may be lightly coated with a white background lacquer in order to contrast with the particles. Fluorescent magnetic particles provide the greatest sensitivity. The particles will normally be in a liquid suspension, usually applied by spraying. In certain cases dry particles may be applied by a gentle jet of air. The technique is applicable only to ferromagnetic materials, which are at a temperature below the curie point (about 650°C). The leakage field will be greatest for linear discontinuities lying at right angles to the magnetic field. This means that for a comprehensive test the magnetic field must normally be applied in two directions, which are mutually perpendicular. The test is economical to carry out both in terms of equipment costs and rapidity of inspection. The level of operator training required is relatively low.



Magnetic particle inspection using a yoke.



Crack found using magnetic particle inspection.

3.1 Magnetic particle testing

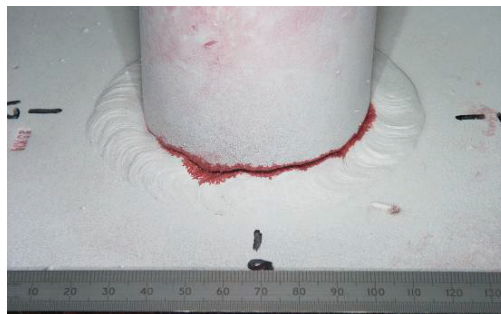
Advantages	Limitations
Inexpensive equipment	Only magnetic materials
Direct location of defect	May need to demagnetise components
Not critical of surface conditions	Access may be a problem for the yoke
Could be applied without power	Need power if using a yoke
Low skill level	No permanent record
Sub-defects surface 1-2mm	Calibration of equipment
Quick, instant results	Testing in two directions required
Hot testing (using dry powder)	Need good lighting - 500 Lux minimum
Can be used in the dark (UV light)	

4 Dye Penetrant Testing

Any liquid that has good wetting properties will act as a penetrant. Penetrants are attracted into surface-breaking discontinuities by capillary forces. Penetrant, which has entered a tight discontinuity, will remain even when the excess penetrant is removed. Application of a suitable developer will encourage the penetrant within such discontinuities to bleed out. If there is a suitable contrast between the penetrant and the developer an indication visible to the eye will be formed. This contrast may be provided by either visible or fluorescent dyes. Use of fluorescent dyes considerably increases the sensitivity of the technique. The technique is not applicable at extremes of temperature, as at low temperatures (below 5°C) the penetrant vehicle, normally oil, will become excessively viscous and causing an increase in the penetration time with a consequent decrease in sensitivity. At high temperatures (above 60°C) the penetrant will dry out and the technique will not work.



Methods of applying the red dye during dye penetrant inspection.



Crack found using dye penetrant inspection.

4.1 Dye penetrant

Advantages	Limitations
All materials (non porous)	Will only detect defects open to the surface
Portable	Requires careful space preparation
Applicable to small parts with complex geometry	Not applicable to porous surfaces
Simple	Temperature dependant
Inexpensive	Cannot retest indefinitely
Sensitive	Potentially hazardous chemicals
Relatively low skill level (easy to interpret)	No permanent record
Relatively low skill level (easy to interpret)	Time lapse between application and results
	Messy

5 Surface Crack Detection (Magnetic Particle/Dye Penetrant): General

When considering the relative value of NDE techniques it should not be forgotten that most catastrophic failures initiate from the surface of a component, therefore the value of the magnetic particle and dye penetrant techniques should not be under-estimated. Ultrasonic inspection may not detect near-surface defects easily since the indications may be masked by echoes arising from the component geometry and should therefore be supplemented by an appropriate surface crack detection technique for maximum test confidence.

Section 6

WPS/Welder Qualifications