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NON-DESTRUCTIVE TESTING

FOR PLANT MAINTENANCE

by

C. Campkin
Central Electricity Generating Board
United Kingdom

Organised in co-operation with the German Foundation for Developing Countries and the German Association of Machinery Manufacturers (VDMA)

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In undertaking the task of producing a paper on Non-Destructive Testing for Maintenance for the under developed countries, I have drawn upon 20 years of interchange of ideas and experience with people from many organisations and many countries. This paper then would not have been possible without such co-operation, which is indeed one of the pleasures of N.D.T. I welcome this opportunity to express my thanks to all those people who directly and indirectly have assisted me in this important task.

I would in particular express my appreciation to R.H.Coates Esq., B.Sc.(Eng.), C.Eng., M.Inst.C.E., F.I.Mech.E., F.I.E.E., M.Inst.F., Regional Director, South Western Region, Central Electricity Generating Board, for support and encouragement in the presentation of this paper.

C. Camphin.

DIAGRAMS

TABLES

1. INTRODUCTION

1.1 Non-Destructive Testing (N.D.T.) consists of methods of inspecting and testing materials and components without detriment to their physical properties and subsequent performance. N.D.T. for maintenance is now established but needs to be expanded in application and scope. Whilst the range of N.D.T. methods includes a number of advanced and complex systems a lot of valuable work can be done by the use of the simpler and well established methods, provided the following points are adhered to. Test procedures, preferably written must be clear and unambiguous and have due regard for the capabilities and limitations of each N.D.T. method. The operations must be conscientiously carried out by test personnel who have been properly trained for this work.

2. TERMINOLOGY AND UNITS

2.1 Letter symbols, signs and abbreviations conform to British Standard 1991.

Technical terms conform to British Standard Glossaries, I.S.O. (International Organisation for Standardisation) or International Institute of Welding Publications.

2.2 NOTE:

At the present time there is not single universally accepted word or term which can be used to denote the cracks, pits, voids, leaks, etc. in materials which it is the function of Non-Destructive Testing to locate and describe. Current usage includes: defect, discontinuity, flaw, imperfection, inhomogenity, etc. In the manufacture and production of new components where acceptance Standards and customer/inspection/producer interests are involved discontinuity is often the preferred or obligatory term, although the term defect is aloo very well established in the welding field.

Implicit in the use of all such terms as those listed above are levels of quality and fitness for service. Perhaps it is somewhat easier in plant maintenance than in production to accept that plant or components may function satisfactorily whilst being less than perfect, particularly as the environment and service conditions may be more predictable. In this paper the term defect is therefore used to denote the cracks, pits, voids, leaks, etc. which occur in plant and which it is the function of Non-Destructive Testing to locate and describe.

3. **N.D.T. METHODS**

3.1 Whilst there are exceptions the majority of N.D.T. methods comprise:

(a) A source (transmitter) from which energy radiates and flows outwards.

(b) The test object with which the energy interacts, e.g. by reflection at a surface or internal interfaces, or by absorption/attenuation.

(c) A detector, which receives some or all of the transmitted/reflected energy and presents the result as a visual or audible indication which can then be interpreted by trained personnel.

3.2 Eight of the range of current N.D.T. methods are discussed in this paper as applicable to plant maintenance:

(a) Magnetic

(b) Penetrant

(c) Visual Aids

(d) Leak detection and location

(e) Ultrasonic

(f) Radiographic

(g) Eddy Current and Electrical

(h) Thermal and Other

Technique is an application of a method, e.g. magnetic current flow technique.

1.3 Reasons for Use of N.D.T.

In times of emergency when failure of plant has occurred, perhaps by explosion, the value of N.D.T. in checking remaining plant is readily appreciated, but to use N.D.T. on a routine basis as an aid to maintenance, involving employing a permanent N.D.T. team or contractors may appear an expensive luxury. However, whilst the number of published papers on the cost benefits of N.D.T. are few a large number of modern managements find it economically worthwhile. In many cases these are industries where the cost of an unscheduled outage of a unit is high in terms of money, and an accident costly in terms of human life and money.

N.D.T. methods are therefore used to assist operation and maintenance staff in reducing costs by:

(a) Assisting personnel safety. Accidents arising from failure of plant or components can affect morale and productivity. The use of N.D.T. as a safety inspection tool is indicative of management safety awareness.

(b) Elimination or reduction of unscheduled outages and loss of availability in high cost plant, by the detection of potential failures.

(c) Reducing the time and labour required for maintenance, by the provision of inspection and test methods which can operate remotely and 'see' through bodies opaque to light, and by regular N.D.T. of areas subject to wear and wastage, thus reducing the amount of dismantling and opening-up required to provide information on plant condition.

(d) Determination of the number and extent of defects and confirming that they have been eliminated from critical areas before welding or other repair work is carried out, allied to quality control during the repairs to ensure a satisfactory job is obtained

(e) Enabling the location and extent of certain types of defects to be determined and their growth, if any, monitored thus it is sometimes possible to leave such defects in place and avoid the expense of repairs. In the case of time-expired plant which is retained for stand-by duties, or pending replacement N.D.T. can provide assurance that the plant is fit for this work.

(f) Enabling quality levels to be checked on spares and replacement parts and ensuring that they comply with specifications and the possibility of a failure is avoided.

FURTHER READING

1. **The Non-Destructive Testing Handbook.**

   Editor: Dr. Robert-C. McMaster.

   2 Volumes (1,800 pages, 1,250 illustrations) covering in detail all major forms of N.D.T. Price $30.50, for members of ASNT price $24.50.

   From: American Society for Non-Destructive Testing,
   914 Chicago Avenue,
   Evanston, Ill. 60202. U.S.A.

2. **Non-Destructive Testing**

   J.P. Hinsley, F.I.M.,
   Macdonald and Evans Ltd. 1959
   8 John Street,
   London W.C.1,
   England.

SECTION 4.0 MAGNETIC

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4. [illegible]

4.1 Scope

Magnetic defect detection processes can be used on the majority of iron and steel castings, forgings, fabrications, welds, rolled and bar stock, pipe and tubes, etc., to find fine or coarse surface cracks and similar type defects, whilst sub-surface defects to approximately 10 mm in depth can also be detected using suitable high current techniques.

The sensitivity of the method is high. Surface cracks as small as 1 millimetre in length and 0.025 mm in depth can be identified using powerful magnetising equipment and very fine magnetic particles.

4.2 Principles

4.2.1 A magnetic flux is established in a ferromagnetic test object and at a break in the surface or where a substantial sub-surface defect is present the path of the flux is distorted and an external magnetic leakage field exists.

This external field can be utilised in several ways to indicate the defect. The simplest method is to apply fine particles of magnetic iron oxide Fe_3O_4 suspended in a suitable liquid by spraying by immersion or as a dry powder, these particles are attracted by the magnetic leakage field and remain clustered there indicating the defect so that the position of the latter can be seen. The resulting indication will outline the size and extent of the defect. The density of the magnetic indication will be affected by the depth, width and length of the defect and its relationship to the direction of the induced magnetic flux.

Whilst sensitivity is greatest when the defect is at 90° to the direction of magnetic field, indication of cracks at an angle of 30° will be given; an angle of 45° to the direction of the field should be regarded as the practical limit. Thus two tests at right angles may be the minimum necessary to ensure complete coverage.

4.2.2 A basic requirement of the magnetic method is that an adequate magnetic field strength shall be present in the test object or workpiece. This field can be provided in two different ways. The first is by the use of permanent magnets or electromagnets which provide a magnetic field between their pole faces. When the workpiece is placed across or between the pole faces the magnetic circuit is completed and that part of the workpiece between the pole faces is magnetised. This is called - Magnetic Flow Magnetisation. The second way of providing the required magnetic field strength is by the use of an electric current. There are a number of specific techniques which need a substantial current so collectively they are known as - Current Magnetisation Techniques.

Whenever an electric current flows through a conductor it sets up a magnetic field at right angles to the direction of the current flow. The strength of this magnetic field is directly proportional to the current. If a current flows via contacts through a ferromagnetic workpiece a magnetic field will be established in that workpiece and the area or volume between the contacts will be magnetised. An alternative to passing the current directly through the workpiece is to use an insulated conductor which can be threaded through an opening in the workpiece or placed round it in the form of a coil. There are a number of arrangements of coils, conductors and jigs for magnetising different types of components which are dealt with later in this paper.

4.2.3 In addition to controlling the direction of the magnetic field by the physical arrangement of contacts and conductors the depth of penetration below the surface can also be controlled by the nature of the electric current.

The two basic types of current supply are a.c. (alternating current) or d.c. (direct current). The magnetic field produced by a.c. current tends to flow close to the outer surface of the workpiece, and hence will not be much affected by sub-surface defects, but this feature gives a high sensitivity to surface defects. Direct currents have a greater depth of penetration than a.c. and are more sensitive to sub-surface defects. Variations on the two basic types of current supply are half-wave rectified a.c. and surge or flash magnetisation. In all cases the magnetic field is proportional to the peak value of the current.

4.2.4 Magnetic Field Strength

The importance of ensuring that the magnetic field is at right angles to the defect has been pointed out in 4.2.1. and this is the reason for the number of techniques available to produce a magnetic field with the correct orientation to an expected defect. In addition to the correct defect orientation it is also necessary to control the strength of the magnetic field, if too weak some defects may be missed, if too strong saturation and furring, i.e. build-up of magnetic particles may occur causing confusing indications. With permanent magnets there is little control possible, except by introducing a piece of non-metallic material to make a "gap" in the magnetic circuit. With all other techniques which use an electric current then magnetic field strength control, either in steps or continuously, can be achieved by control of the current. To enable calculations to be made and recorded there are two quantities which can be measured, firstly ampere turns, and secondly direct measurement of magnetic field strength in air by a magnetometer. The unit for magnetic field strength in the S.I. system is, ampere per metre, symbol A/m. Thus the magnetic field strength can be calculated by counting the number of turns N, measuring the current I amperes and dividing their product by the axial length l in metres of the magnetising coil.

Magnetic Field Strength Symbol A/m

$$= \frac{NI}{l} \text{ amperes per metre.}$$

A magnetometer which has been calibrated in SI units will indicate magnetic field strengths in amperes per metre. The unit of magnetic field strength in the C.G.S. system, the oersted, symbol H is firmly established in practice. The relationship between the SI and C.G.S. units of magnetic field strength is:

$$\text{One Ampere/metre} = \frac{4\pi}{1000} = 0.9126 \text{ Oe}$$

$$\text{One oersted} = \frac{1000}{4\pi} = 80 \text{ amps/metre}$$

4.2.5 The theory of magnets and magnetic circuits has been largely developed by the need to design electric motors, generators and similar apparatus and not for magnetic particle testing. To assist the design of electrical machines and apparatus measurements of the magnetic flux density inside a special test specimen can be made using a flux meter, but this procedure has limited application to plant in-situ or the random type of test objects encountered in magnetic particle testing.

It has therefore been necessary to adopt an empirical approach to determining the magnetic field strengths necessary for particular types of test objects and defects. Tables have been compiled setting out current values for a number of types and shapes of components which are used in conjunction with a natural or artificial test specimen to establish a technique or procedure. However, magnetometers or Magnetic Field Strength meters specifically designed for magnetic testing purposes are now available, as these instruments are generally calibrated in oersteds, they are sometimes referred to as oersted meters. A magnetometer which has a direction sensitive sensing element, i.e. a Hall effect probe can be used to measure the tangential component of the magnetic field at the surface of the workpiece, because the value of this component is the same on either side of the boundary between air and steel, the value measured in air is a measure of the field strength immediately below the surface of the workpiece.

Using such a magnetometer it is possible to reduce the reliance on the experimental approach to establishing ampere turn values. Thus assisting the establishment of techniques and specifications and in the maintenance of equipment and procedure standards in magnetic testing.

4.2.6 Magnetic inks and powders provide the visual indication and form an essential part of the process. In the U.K. the majority of applications are carried out using an ink, although for castings powder may be preferred. If powder is used it is necessary to provide a suitable powder blower, if ink is used, then means of applying it, by equipment such as sprays, immersion baths or ladle and drip trays must be available. The size of the magnetic particles can be varied to suit different applications. Fine particles are used to indicate defects invisible to the human eye, whilst coarse magnetic particles are used to indicate defects which could be found but for which the use of the magnetic process is quicker and more reliable.

The liquid media used for carrying the particles can be either water, with inhibitors to prevent corrosion plus a wetting agent, or a light kerosene oil. Magnetic inks and powders are available as Fluorescent or non-fluorescent. The fluorescent inks and powders require a black light lamp and the inspection area shall be darkened. They are more sensitive to fine defects and by providing a more readily seen indication reduce the concentration required by inspectors when carrying out magnetic particle testing on a routine basis. For in-situ plant testing on where the majority of defects are not so fine the non-fluorescent ink is used, but to facilitate observation of the indications it is desirable to achieve a good contrast between the particles and the background. Normal magnetic particles are black and are excellent on polished or machined parts, but there is little contrast on a dark surface, it is therefore desirable on such a surface to apply a coating of white contrast material. This can be a proprietary contrast paint or a mixture which dries quickly, although where drying time is not important whitewash can be used. As an alternative the magnetic ink can be coloured during manufacture, generally grey, red or yellow colourings are used.

When the stage of examination of the surface is reached then it is necessary to ensure that good lighting is available, visible light for non-fluorescent inks and powders, black light for fluorescent inks and powders.

4.2.7 De-magnetisation after magnetic crack detection may be required particularly on components on which machining or other work is to be done or where in a machine shop ferrous particles could be picked up and taken into a situation where they could cause harm.

De-magnetisation can be done by placing the test object in a coil with alternating current flowing which is gradually reduced to zero; or by withdrawing the object(s) slowly from the coil.

The effectiveness of the de-magnetisation can be checked by hanging a pin on a thread and seeing if the test object attracts it. Make sure the pin is not magnetised before starting. Field strength meters and magnetometers provide a more quantitative method. Alternatively the aircraft "compass test" can be used. This consists of rotating the specimen through 360° stationed East or West of the test compass at a specified distance. If the deviation of the test compass is not more than 1° the specimen is adequately demagnetised.

4.3 Applications of Magnetics for Maintenance

The magnetic particle method is used for the examination of a wide range of magnetisable materials in a large number of industries. It is used for crane hooks, hand tools such as hammers and chisels.

Tractor forks
Chain links
Shackles
Crankshafts
Gears
Axles
Spindles
Pins
Studs
Bolts
Keyways
Connecting Rods
Turbine Blades
Castings such as Valve bodies
Welds, etc.

in and on ships, railways, power stations, collieries, steel plants, chemical works, cars, trucks, buses, air planes, etc.

Magnetic particle inspection is used during plant overhaul to locate or confirm a visual observation of cracks and similar type defects. When repairs are being carried out it is used to ensure that the defects have been completely eliminated before welding commences and for quality control when repairs are completed.

4.3.1 [illegible]

(a) Magnetic particle inspection of lifting equipment, e.g. crane hooks, c hooks, sheet lifters, tractor forks, ross carriers and ladle bales is carried out as part of an N.D.T. programme by Dominion Foundaries and Steel Limited, Hamilton, Ontario, Canada. The inspection frequency for heat crane hooks is 4 months, and for other items 12 weeks. This preventive maintenance, which includes other methods of N.D.T. and vibration analysis has been carried out since 1959. See Planned N.D.T. as Preventive Maintenance for Steel Plants - William H. Tait - Materials Evaluation April 1968, pages 54-58.

(b) In the large diesel engines used for ships, top and bottom end bolts, eccentric studs, tie rods and piston rods may all be subject to fatigue cracking. To avoid fatigue failure in bolted connections the bolt should be tightened until it maintains a tensile load higher than the maximum service load. Fatigue cracking occurred in the screw thread of the piston rods of a number of two stroke, double acting diesel engines, of 550 mm cylinder bore. The screw threads at the cross-head are subject to reversed stresses due to the double action. Controlled pre-stressing to a level higher than the maximum working stress was introduced with magnetic particle crack detection stipulated at each survey, or not less than once per year for every rod. With these measures the incidence of cracking decreased to virtually nil. See N.D.T. as a metallurgical aid in ship maintenance and failure prevention - J.F. Deegan, British Journal of N.D.T. - December 1969, pages 86-92.

(c) The hook of the auxiliary hoist of an overhead electric crane in a foundry fractured, failure being in a brittle manner initiated by a surface transverse fissure at the intrados. Following this incident a further 41 hooks were subjected to a magnetic crack detection, 16 were found to have similar surface fissures, these were blended out by local grinding until proved clear by further magnetic testing. See British Engine Boiler and Electrical Insurance Co. Ltd. Technical Report 1965. Vol. VI pages 81-87.

(d) <u>Magnetic testing during repairs to ensure cracking had been machined out</u>

Magnetic examination of a blade root groove in a steam turbine disc. Following removal of blading and cleaning to produce a suitable surface for examination, the blade groove was magnetically tested as follows:

A coat of white background paint was applied and each side had a one-turn magnetising coil wound adjacent. During the passage of 400 amperes through the coil, the blade groove was sprayed with black magnetic ink. An examination of the magnetised blade groove revealed a crack running circumferentially for the entire blade groove on the "up-stream" side. The crack was almost continuous, being broken in a number of places over a short distance, approximately $\frac{3}{8}$" to $\frac{1}{2}$". This test was also repeated during the machining out of the blade root groove, to ensure that all cracking was removed.

(e) <u>Magnetic checking of extent of cracking</u>

Cracking was discovered in cast iron feed pump covers and magnetic tests were carried out. Number of cracks were located and shown up. One crack extended three quarters of the way round the circumference and could be seen visually. The magnetic test revealed that cracking of a lighter nature was also present on the remaining quarter of the circumference. This test was carried out using a permanent magnetic kit.

4.3.2 Techniques and Procedures

The basic steps in carrying out magnetic particle inspection are as follows:

(a) check that the test object can be magnetised, i.e. it is ferromagnetic.

(b) Clean the surface and prepare as necessary.

(c) Consider the position and type of defect expected, the shape, size and geometry of the test object and select a magnetisation technique and that will produce a magnetic filed which will be at right angles to the defect.

(d) Select a magnetic ink and contrast paint, if required, provide adequate lighting.

(e) Establish the magnetic field strength value.

(f) Carry out the test.

(g) Interpret the indications.

(h) Repeat the test if necessary to confirm.

(i) Demagnetise if required.

(j) Clean the test object.

An example of a Procedure for Permanent Magnet Kit is given. (4.3.6)

4.3.3 Techniques of Magnetisation

Current Flow

The magnetising current is passed through the test object via prods, contact heads or clamps. Care must be taken to avoid burning or depositing copper on the surface of the test object.

If used in magnetic machines the test object is placed between adjustable clamps or contacts. If used in-situ the clamps can be attached to heavy duty cables or can be in the form of a pair of prods, which can be either mounted in a handle keeping them a fixed distance apart or they can be used independently. This technique has extensive application for castings, forgings and welds. In the U.S.A. this technique is called circular magnetisation.

Threading Bar and Conductor

Hollow cylindrical or ring shaped objects can be threaded on to a non-magnetic bar, the "Threading Bar" which is then placed between the current contacts of a magnetic machine. As in the current flow technique this is suitable for defects whose major axis is parallel to or within 45° of the direction of current flow.

Alternatively a heavy duty flexible cable can be used which is threaded through suitable holes or openings in the test object.

Encircling Coil

Encircling coil. In this case the magnetisation is provided by a solenoid or loop wound round the test object. Defects which are transverse to the axis of the coil will be detected.

If used on a magnetising machine the gap between the coil and test object should be as small as possible. A significant decrease in magnetisation for a given current will occur if the gap is increased beyond about 1% of the radius. Where a small cylindrical object has to be tested in a large coil the best results are obtained by placing the test object as closely as possible to one side of the coil. This will necessitate repeating the complete test procedure a number of times, rotating the specimen until the whole circumference has been covered.

Induced Current Flow

This is used to establish a circumferential current flow in large rings and similar test objects, by in effect making them a single turn secondary winding of a transformer. As the induced current will be in a circumferential direction this should also be the direction for the major axis of defects.

Magnetic Flow

In this technique the defects which are transverse to the direction of the magnetic field between the two pole pieces of an electromagnet or permanent magnet will be most readily detected.

The techniques described consist of:

(a) Current Flow

(b) Threading Bar and Conductor

(c) Encircling Coil

(d) Induced Current Flow

(e) Magnetic Flow

4.3.4 Recommended current values are given in a number of publications. Those given below are extracts from British Standard 4124: Pt. 2: 1968. Methods for Non-Destructive Testing of Steel Forgings - Pt. 2 Magnetic Particle Flaw Detection. Section 9.

(This extract and other information on British Standards is produced by permission of the British Standards Institution, 2 Park Street, London W1Y 4AA from whom copies of the complete standards may be obtained).

9. TECHNIQUES OF MAGNETISATION

9.1 General

The entire forging or specific area on the forging to be tested shall, where practicable, be magnetised in two mutually perpendicular directions by any of the methods described in 9.2 to 9.5. The current shall flow for a time sufficient to ensure that steady state conditions are attained in the inductive circuit. All conductors other than prods shall be insulated. Care shall be taken to ensure that magnetic saturation, usually indicated by a build-up of particles at edges and corners of the forging, does not occur.

Generally a magnetic field strength (H), of not less than 2400 ampere/metre (30 oersteds) is required, and the values given in 9.2 to 9.4 are based on this minimum figure. One or more of the following magnetisation techniques shall be used.

9.2 Current Flow Technique (Fig. 1)

9.2.1 The magnetising current shall be fed directly to the forging, either by means of contacts at each end (see Fig. 1a), or by means of prods (see Fig. 1b) at intermediate distances.

9.2.2 When current is fed directly to the forging at each end piece the current strength shall be not less than:

(1) for cylindrical shapes: 5300 A/m of diameter (a.c. r.m.s. value)
7500 A/m of diameter (d.c. or a.c. peak value)

(2) for non-cylindrical shapes: 1680 A/m of periphery (a.c. r.m.s. value)
2400 A/m of periphery (d.c. or a.c. peak value)

9.2.3 When prods are used at intermediate distances, the distance between them shall be not greater than 200 mm (8 in) and the spacing of the prods between successive checks shall be as shown in Fig. 1c.

9.2.4 For prods at a distance apart of 200 mm (8 in), the current strength shall be not less than:

(1) for forgings of a 100 mm (4 in) diameter or less, the current strength as specified in 9.2.2.

(2) for forgings larger than 100 mm (4 in) diameter, a minimum current strength of 600 A (a.c. r.m.s. value) or 850A (d.c. or a.c. peak value).

If it is necessary to use prods at less than 200 mm (8 in) separation, the current strength may be reduced in direct proportion to the distance between the prods. It should be borne in mind that the current through the prods is contributing to the overall field strength

9.3 Threading bar and coil technique (Fig. 2)

9.3.1 If the forging is hollow, flaws in a longitudinal direction may be detected by passing the magnetizing current through a bar or cable held within the bore of the forging (Fig. 2a). Alternatively a threading coil may be used (Fig. 2b).

9.3.2 The current strength shall be equivalent to not less than 10,500 ampere turns (a.c. r.m.s. value) or 15,000 ampere turns (d.c.) per metre of the maximum distance of the bar or cable from the surface of the bore of the forging.

9.3.3 Because of limitations of the equipment, it may be necessary to magnetize the forging at several positions within the bore, with the bar or cable lying on the bore surface, in which case the distance between spacings of the conductor or coil for successive checks shall be not greater than 100 mm (4 in).

9.4 Encircling Coil (Figure 3)

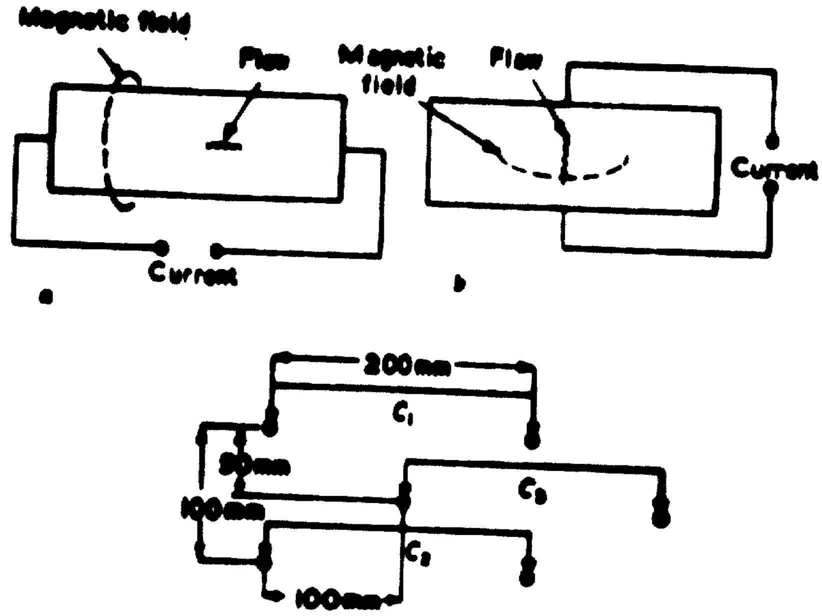
9.4.1 The magnetizing current shall be fed, either to a coil encircling the forging, or to an insulated cable wrapped around the forging. The coil or cable shall be placed as close as possible to the surface of the forging and shall overlap between successive checks. If the length/diameter ratio of the forging is less than 5:1 extension pieces shall be used.

9.4.2 The following table should be used as a guide to the current required to provide the necessary magnetic field strength (H):

Coil dia D	Coil Length L	Number of effective turns	Minimum Current	
			r.m.s.	d.c. or a.c. peak
mm	mm		A	A
100	175	5	150	210
200	200	5	210	300

9.5 Magnetic flow technique (Fig. 4)

The magnetic field shall be produced in the forging or that part of the forging under examination by means of an electro-magnet or permanent magnet. When using an electro-magnet, the coil winding shall, whenever practicable, be situated as close as possible to the pole pieces of the magnet. Because of the presence of air gaps, tests using a permanent magnet are relatively insensitive and wherever possible other methods of magnetization shall be used. The magnetic field strength (H), shall be not less than 2400 A/m (30 Oe).



c Distance between successive checks (see 9.2.3)

Fig. 1. Current flow technique

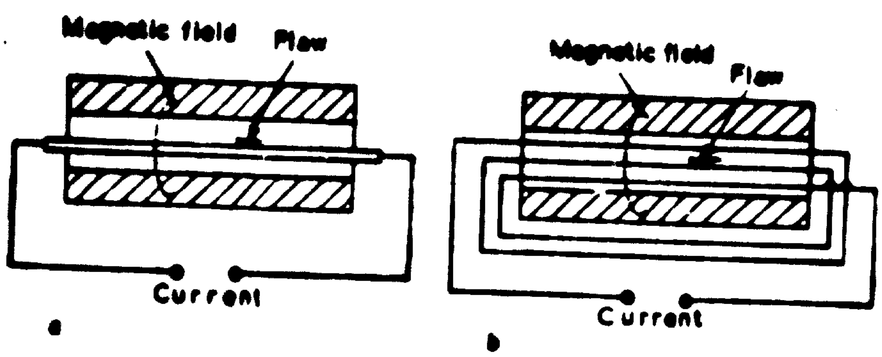


Fig. 2. Threading cable technique

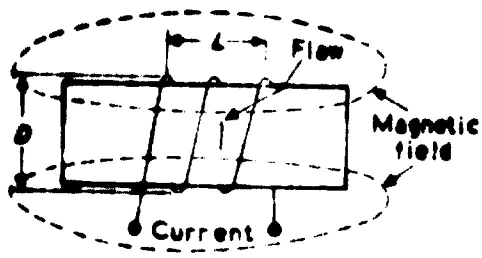


Fig. 3. Encircling coil technique

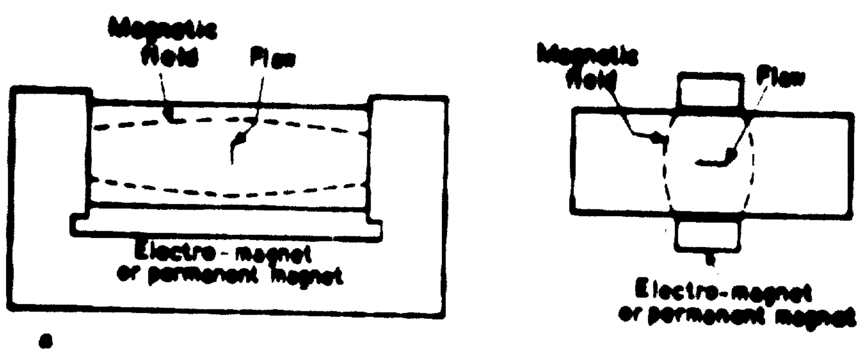


Fig. 4. Magnetic flaw technique

4.3.5 Application of Magnetic Particles and Examination

The application of the magnetic particles may be prior to, or whilst the workpiece is being magnetised, or after the magnetising current has ceased, the latter is to be avoided because remnant magnetism is always less than that achieved during the magnetisation process.

The surface to be examined should be uniformly coated with magnetic particles. The coating may be applied by spraying, dusting, brushing, ladling or immersion. Except for the flash magnetisation technique the current should always be maintained for not less than 0.5 seconds. When contacts or prods are being used in the current flow technique care must be taken to avoid "burning" of the contact area due to the current being on too long or too high, or the contacts broken whilst the current is flowing.

Inks should always be agitated before being used and if stored in cans in a make-up condition they must be vigorously stirred before being decanted.

To assist the viewing of non-fluorescent inks and powders it is necessary to ensure a good contrast between the magnetic ink/powder and the surface. This can be achieved by application of a contrast paint, selection of a coloured ink or by modifying the surface of the component by grinding or other means.

A good standard of illumination is necessary of the order of 500 lux. As a guide this will be obtained by using a 100 W tungsten filament pearl lamp at a distance of 0.2 m or an 80 W fluorescent tube at a distance of 1 m.

When fluorescent inks/powders are employed then the inspection area should be darkened, for critical components the value of the ambient white light should not be greater than 5 lux. The surface under examination should be illuminated by Black light lamps, either strip lights which provide a general level enabling a large area to be examined, or in the form of spot lamps which may be hand held or mounted in stands or ceiling supports.

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4.3.6 Interpretation of Indications

Interpretation depends very much on the skill and experience of the operator and any aids to that can be provided will assist in establishing confidence.

Defects which can be detected have been classified by the American Society for Testing Materials,(A.S.T.M. designation E.125-63) into eight groups. Some guidance on interpretation is given in a number of publications, including A.R.B. and Civil Aircraft Inspection Procedures BL/8-5, 1959 and the paper Magnetic Methods by W.G. King No. 2 Further Reading. The Author has found it a useful practice to clean off and re-test twice any indications which if correct will result in an expensive plant outage. A high speed pistol type pneumatic grinder with a collection of various shapes and sizes of small grinding heads is also invaluable in grinding out cracks either to eliminate them if shallow or confirm their depth and extent

Recording of indications is possible, one method is detailed below, other proprietary methods are available, including the Magnaprint method developed by the U.K. Ministry of Defence (Navy) and now marketed commercially. The procedure is as follows:

1. Ensure that the surface and ink or powder pattern are completely dry.

2. Cover the indications with a piece of transparent adhesive tape, carefully peel off the tape and re-apply on to a card or paper.

Photographic recording provides a permanent record, a pocket rule or a coin should always be included to provide a scale. It is also useful to include details of the test object etc. Black ink used with a white contrast paint makes good clear photographs.

Follows 6.3.6

INSTRUCTIONS FOR MAGNETIC TESTING OF FERROUS METALS FOR SURFACE CRACKS USING PERMANENT MAGNET KITS

1. CHECK THAT THE METAL CAN BE MAGNETISED BY USING THE SMALL MAGNET.

2. SEE THAT THE SURFACE IS FREE FROM DIRT, GREASE, LOOSE SCALE, ETC., WIRE BRUSH IF NECESSARY.

3. (a) IF USING A NON-FLUORESCENT MAGNETIC INK ON A DULL SURFACE, APPLY A COAT OF WHITE CONTRAST PAINT AND ALLOW IT TO DRY.

   (b) IF USING A FLUORESCENT MAGNETIC INK NO CONTRAST PAINT IS REQUIRED, BUT A "BLACK LIGHT" LAMP AND DARKENED AREA ARE NECESSARY.

4. REMOVE THE KEEPER FROM THE MAGNET.

5. PLACE THE MAGNET AT RIGHT-ANGLES TO SUSPECTED CRACK. THE MAGNET SHOULD SUPPORT ITS OWN WEIGHT; THIS ENSURES ADEQUATE FLUX.

6. ALWAYS SHAKE THE MAGNETIC FLUID THEN SPRAY AREA UNDER MAGNET.

7. BLOW OFF ANY SURPLUS FLUID. CRACKS WILL THEN APPEAR AS A BLACK LINE.

8. TURN MAGNET THROUGH 90 DEGREES AND REPEAT 6 AND 7.

9. CLEAN OFF WITH ABRASIVE CLOTH AND REPEAT IS NECESSARY TO CHECK RESULTS.

10. REPLACE MAGNET KEEPER.

NOTE: DO NOT DROP OR THROW MAGNETS

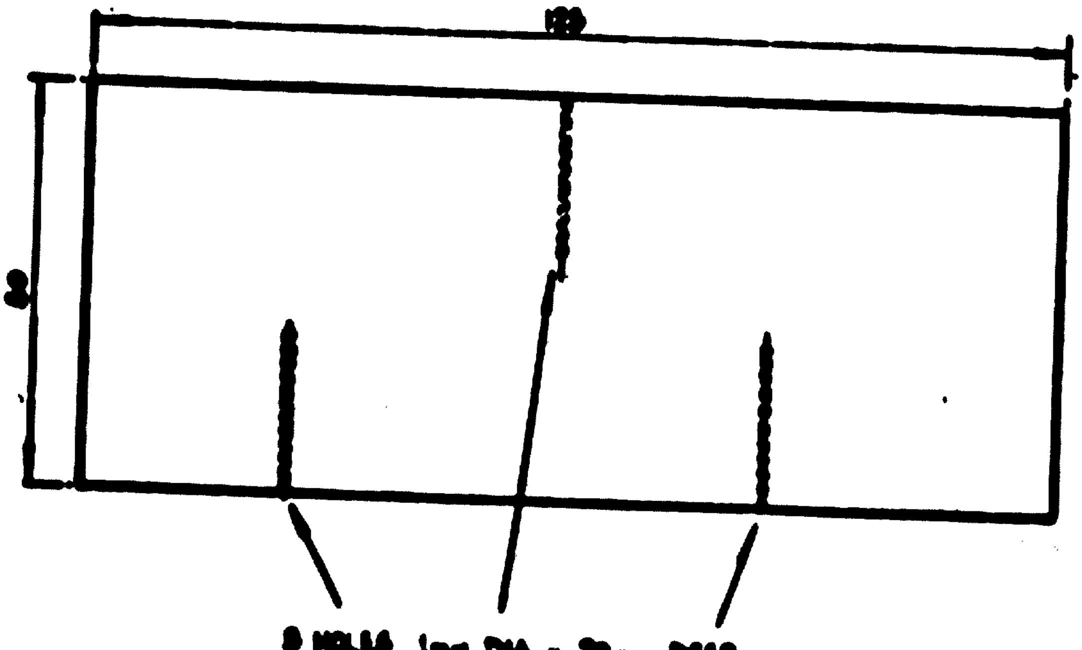
The sensitivity of the magnetic test may be increased by using a fluorescent magnetic ink. This requires a black light lamp, such as the Magnovia Model 10, and viewing should be carried out in a darkened area, away from direct sunlight.

Checking the Strength of the Magnet

As the field strength of permanent magnets will decrease with age the magnet keeper has a number of holes drilled in it so that it can serve as a calibration piece. When the magnet is new if magnetic ink is sprayed over the keeper the outline of the 3 drilled holes can be seen.

If after use this result cannot be obtained then the magnet must be remagnetised by the supplier.

PERMANENT MAGNET KEEPER & TEST BAR.



ALL DIMENSIONS ARE IN MILLIMETRES.

MATERIAL :- COLD ROLLED MILD STEEL.

WITH BAR BRIDGING MAGNET POLE PIECES SPRAY MAGNETIC INK ON. ALL 3 HOLE INDICATIONS SHOULD BE VISIBLE.

Figure 5.

4.3.7 Calibration procedures for magnetic equipments, inks and lighting are available in British Standards BS.4069:1966 Specification for Magnetic Flaw Detection Inks and Powders. BS.4489:1969 Method for Assessing Black Light used in N.D.T. BS - Method for Magnetic Particle Flaw Detection in Materials and Components. To be published. Compiled by A.C.E./50.

This latter covers a test of ammeter accuracy and an equipment functioning test using a standard test piece for the current flow technique.

For electro-magnets and permanent magnets a field strength between the poles of at least 16000 A/m (200 oersteds) across a 50 mm (2 inch) air gap is considered satisfactory. This can be checked by a suitable magnetometer. An alternative is to use a magnet keeper as shown in Figure 5.

4.4 Safety and Preparation

4.4.1 Safety

As with all N.D.T. methods involving access to plant or working with machinery and processes established safety precautions must be followed. Because magnetic inks may necessitate the use of materials which are toxic inflammable or volatile, areas where magnetic inks/powders and contrast paints, etc. are to be used should be well ventilated and heat, flames and electric arcs from contacts should be avoided. Where work in confined spaces or pressure vessels, etc. is involved forced ventilation and other precautions may be essential.

Some of the inks and powders may cause dermatitis with prolonged handling where magnetic equipment is installed in a repair shop, and the use of a barrier cream or gloves are recommended.

Lighting

The same precautions as set out in 5.4.1 Penetrants - apply.

Electrical supplies. Some magnetic machines and equipments require a 440 v 3 phase supply, or 240 v 1 phase and neutral connection, if trailing cables are needed then electrical protection against accidental damage must be incorporated.

4.4.2 Surfaces should be dry, clean and free from loose scale, grease, paint or other foreign matter. A thin even tightly adhering coating of paint may be permissible depending on the fineness of the defects sought. If surfaces are plated some plating materials such as nickel and chromium can affect the formation of indications of fine defects in the base material, consideration must be given to the nature of the plating. Cleaning may be by degreasing, use of a solvent, wire brushing, emery cloth, blasting, or acid pickling and light grinding for castings.

4.5 Equipment and Costs

4.5.1 Equipment can be classified as:

(a) Portable

(b) Transportable

(c) Fixed

(a) Permanent magnets, electromagnets, and magnetising transformers can be obtained in a variety of forms. A permanent magnet kit designed by the author for use in power stations cost less than £20. Commercial permanent magnet and electromagnet kits are available at prices somewhat above this figure. Portable magnetising equipments weighing 11 Kg to 22 Kg for coil and prod magnetisation, with the larger units providing full wave in half wave rectified a.c. output cost from £90 to £350.

(b) For a transportable machine on a pair of wheels providing an output of 2,000 amps a.c. or 1,700 amps half wave a.c. the cost is £400. Such a machine can form part of a magnetic equipment by being combined with a cabinet with a lathe bed type slide for contact heads, for a further £300.

(c) Fixed equipments range from small manually operated types costing less than £300, through equipments for testing a larger number of more complex components, perhaps on a semi-automatic basis the cost of which ranges from £1,000 to £1,500. Large units for production work may cost several thousands of pounds. The cost of materials, i.e. magnetic inks and powders is modest, particularly if they are purchased in the concentrated form and mixed with the liquid carrier by the user, a figure of 1/- per product ton for oil based ink and 1d. per product ton for water based ink has been quoted

4.3.2 The cost of operations has been stated as 25/- per ton of forgings including electrical power and replacement of ink or powder. The cost of magnetic particle testing of castings using a semi-automatic unit with a throughput of 2000 small castings to 60 large castings per hour has been given as 24/- per ton for small castings and 10/- per ton for large castings. The above figures are for production, for plant maintenance the load factor on the magnetic equipment may be much less when used for in-situ testing, but the difference may not be so great if used in a repair shop for a large transport organisation, where engines and other pieces of equipment are systematically dismantled and checked with worn parts renewed; magnetic equipment in such a repair shop fills an essential function in ensuring only sound components are retained in the engine rebuild.

4.5) Savings

Magnetic Particle Testing is one of the oldest, most widely used yet least publicised N.D.T. method. Records of financial savings are mostly found in periodicals published in the U.S.A. The key to the use of magnetic testing lies in the need for the reliability of a large volume of ferrous products in a wide range of industries.

The key to the use of magnetic testing and consequent savings lies in the ability to positively and inexpensively find surface defects such as fatigue and other cracks in a wide range of components, saving man hours in repairing defective machines or money in scrapping plant which can be retained in service once the true extent of cracking has been determined and repairs carried out. Plus the avoidance of losses due to high cost plant outages by the finding of defects at maintenance outages.

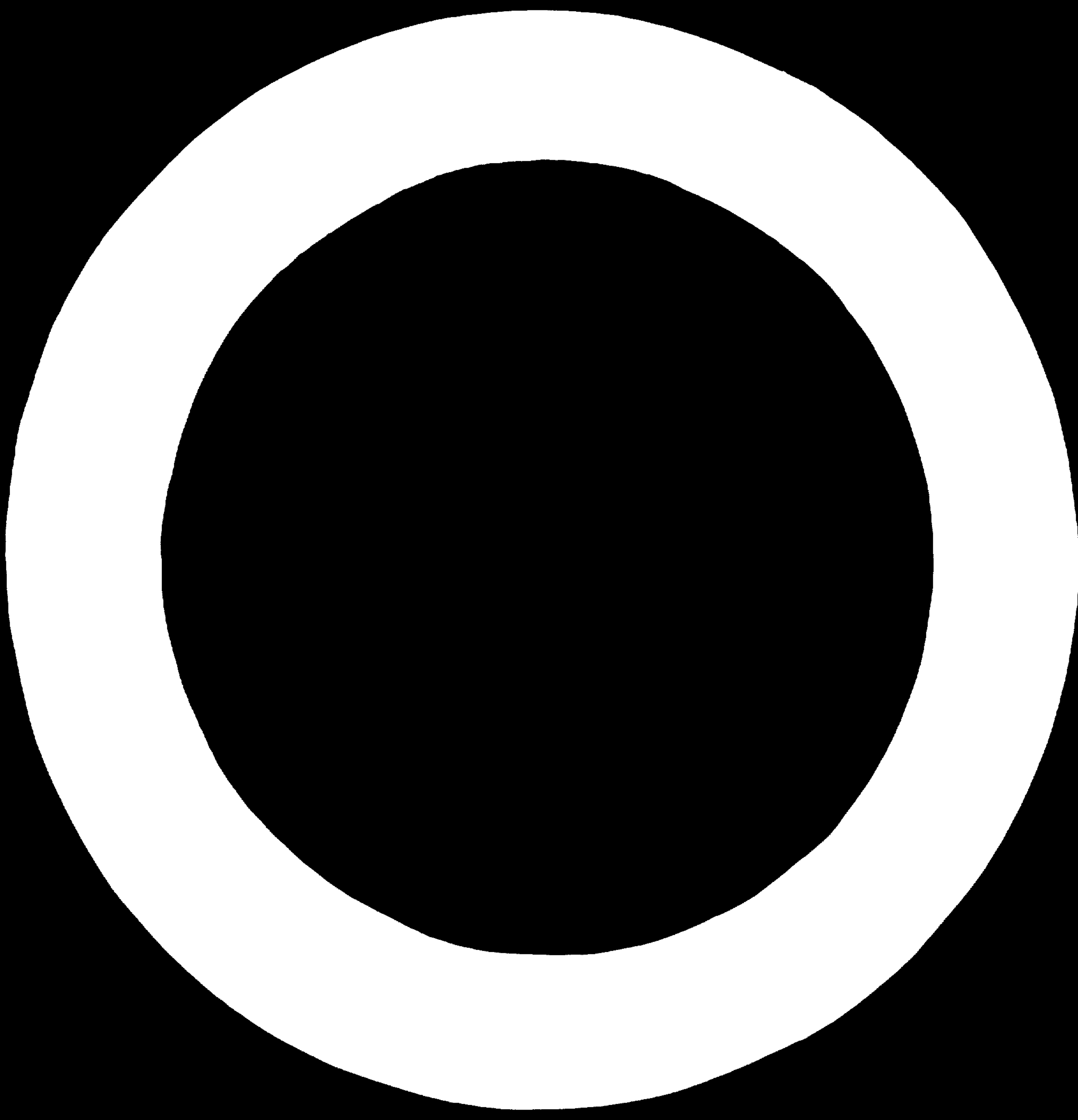
Further Reading

1. Principles of Magnetic Particle Testing C.E. Bots 1967
Magnaflux Corporation. Chicago, Illinois, U.S.A.
585 pages, 26 chapters, 8 tables. Numerous illustrations.

2. Magnetic Particle Testing. Pages 56-130 W.G. King.
Electrical, Magnetic and Visual Methods of Testing Materials
J. Blitz, W.G. King, D.G. Rogers.
Butterworth, London 1969. Price £3.25 (£3.5.0)

3. Air Registration Board,
Civil Aircraft Inspection Procedures.
Leaflet BL/8-5 June 1959.
Magnetic Flaw Detection.

4. British Standards. See Section 14.



SECTION 5 PENETRANTS

5.1	Scope
5.2	Principle
5.3	Applications and Test Procedures
5.3.1	Applications
5.3.2	Types of Pentrants and Test Procedures
5.3.2.1	Hot Oil and Chalk
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Section 5.0 Penetrants.

5.1 **Scope**

Penetrant flaw detection processes can be used on the majority of materials; metallics, non-metallics, magnetic or non-magnetic, to detect surface cracks, porosity, leaks and other defects provided that the defect is open at the surface and clean. Penetrants are unique amongst N.D.T. methods by being very little affected by geometry factors. Penetrants provide a method of replacing or assisting visual examination reducing both the time required and the fatigue arising from sustained concentration of inspection personnel. Penetrants improve reliability reduce the cost and improve the sensitivity of surface inspection.

5.2 **Principle.**

The surface area to be examined is made as clean as is possible. A penetrating liquid specially formulated for this purpose is then applied and enters surface defects after a short period. After removal of excess penetrant from the surface and subsequent application of a development process, any defects present give a visual indication when viewed under appropriate lighting conditions. Penetrants can be classified as dye penetrant processes where viewing is by white light and fluorescent processes where viewing is by black light.

5.3 **Applications and test procedures.**

5.3.1 The major users of penetrants are the aero space industry where the majority of the materials are non-magnetic. In other industries such as electricity undertakings penetrants may be the only practical method of examining fillet and other welds in austenitic steels and also the non-magnetic coil binding rings on alternator rotors. Penetrants may be taken to the plant for detecting fatigue or stress cracks or other defects and to check that defects have been completely removed before re-welding. Small kits are available for these purposes. Alternatively the plant items may be such that they can be dismantled and taken to a penetrant inspection bay in an inspection or workshop area. In the latter case a range of engine and other parts such as spindles, connecting rods, gas turbine blading, valves, small castings, brazed and welded joints etc. can be put through the penetrant process. For in-plant inspection the red dye process is most applicable because no black light lamp which would need an electrical supply is required.

5.3.2 Types of penetrants and test procedures.

5.3.2.1 Hot oil and chalk.

Hot oil and chalk which was the original penetrant method is still used for the preliminary inspection of roughly fettled castings. One type employs a mixture of 25% lard oil and 75% kerosene heated to 80°C. The component is immersed in the hot solution for twenty minutes or longer to allow penetration into surface cracks or porosity. Whilst still hot the surface of the component is cleaned by washing with detergent or by the use of dry sawdust and is then covered by athin film of French chalk whilst still warm. The seepage of the oil from any defects stains the white film and enables the defect to be located. The main limitation of this technique is the low contrast between tight defects and the background. It is unsuitable for critical applications but has the advantage of being relatively easy to use.

5.3.2.2 Red dye penetrants.

Red dye penetrants are available in kits for site use which consist of three aerosol or pressurised cans containing penetrant, penetrant remover and developer. The steps in the process are as follows:-

1) Pre-cleaning of surface. The surface under examination should be as clean as possible. Surface soil such as oil, grease, dirt should be removed by scrubbing with petroleum solvents or the penetrant remover.

Where paint and carbon etc is on the surface this should be removed by suitable paint removers and rust and scale should also be removed. Before application of the penetrant the surface should be cleaned by spraying with the penetrant remover and wiped with a clean cloth and this operation should be repeated if necessary until no contamination is visible on the cloth.

2) Application of penetrant. Spray the surface with penetrant making sure that it is thoroughly wetted. Allow the penetrant to remain in contact with the surface for fifteen to thirty minutes. The shorter time is adequate where large defects are sought on castings, thirty minutes should be allowed where fatigue cracks or other fine defects are sought on machined surfaces. For certain applications such as austenitic steel with tight cracks a period of up to 24 hours has been found to be necessary. The temperature for penetrant inspection should be that which is comfortable for the human body. If the temperature is too high or if the component itself is too hot the penetrant may dry on the surface.

3. Removal of excess penetrant. Wipe the surface with a clean dry cloth or disposable tissue and follow this by wiping with a further cloth or tissue which has been moistened with a penetrant remover. Finally dry with another clean cloth. It is very important to be sure that the surface is thoroughly clean and that no trace of red dye stains the cloth after the final wipe down. This operation should be repeated if necessary. No traces of penetrant should be allowed to remain on the surface spurious indications will result. An alternative to the dry cleaning is to use water.

The cleaning tissue or cloth may be moistened with water which should be used in the same way as the penetrant remover. However, there are situations such as electrical alternator rotor coil binding rings where the presence of water is not allowable. This factor must be taken into consideration when planning the work.

4. Application of developer. Thoroughly shake the aerosol container before spraying in order to ensure dispersal of the powder suspension. Spray the developer on to the surface in a thin even film. It is important not to have the film too thick or fine indications may be masked.

5. Inspection for defects. Inspection of the surface should be carried out with sufficient general illumination and within a period of not less than fifteen minutes and not more than 60 minutes after the application of the developer. Defects are revealed as bright red marks on a white background. Cracks and crack-like defects are revealed as lines or if they are fine, as a series of red dots. Porosity, shrinkage or leaks are revealed as a series of red dots or as a red tint. Some estimation of the depth of a defect can be obtained by the degree and rapidity with which spreading of the penetrant through the film of developer takes place.

5.3.2.2 Fluorescent Penetrants.

Better contrast between the defect and its background can be obtained by the replacement of the red dye with a fluorescent compound which emits visible light when irradiated with black light. A variety of fluorescent penetrants exists which involve a number of stages in their processing, also the provision of black light illumination for viewing and good surface cleaning facilities which may involve the use of tri-chlor-ethylene vapour de-greasing.

This makes the process more complicated and requires more planning and preparation, preferably in consultation with the supplier of penetrant materials. It is a good rule in all applications of penetrants apart from the simple cases to have consultation with the manufacturer of supplier of the penetrant before embarking on an installation because the selection of the penetrant for the job and the pre-cleaning processes and procedures are an essential part of the successful use of this method. In all cases manufacturers will be found ready to give such advice and assistance.

9.3.3.3. <u>Interpretation of results.</u>

All indications revealed by penetrant inspection do not necessarily represent defects, as spurious indications may occur. Indications believed to be spurious should be explored by visual aid methods and if necessary the test area should be thoroughly cleaned and re-tested.

9.3.4 <u>Standardisation.</u>

It is desirable to standardise the penetrant processes. In the case of the red dye aerosol cans the check consists of having a penetrant specimen, either a naturally cracked piece of material or an artificial test specimen which must be cleaned thoroughly each time it is used. Where a penetrant tank system is installed it is necessary to check that the penetrants have not deteriorated or become contaminated to an extent where they are no longer effective. Information on these two matters is given in the Air Registration Board. Civil Aircraft Inspection Procedures, Leaflet BL/10-9 Issue No. 1. 15th April 1965. Specification MIL-I-25135C (ASG) has detailed performance requirements including test methods and equipment for groups of dye and fluorescent penetrant systems, and DTD 929 described the general requirements for visual and fluorescent penetrants. British Standard 4489:1969, Method for Assessing Black Light used in Non-Destructive Testing has information on checking black light lamps, and a control test for checking fluorescence of penetrant solutions. The apparatus described in this Standard for checking black light lamps can also by the simple substitution of a mirror for the fluorescent screen, be used for checking visible light lamps for use with red dye processes as the photometer is scaled in lux and this enables both forms of illumination to be checked with the one photometer.

5.4 Safety and preparation

5.4.1 Safety

As with all other N.D.T. methods involving access to plant or working with machinery conventional safety precautions must be followed. The additional precautions necessary in the case of penetrant methods arise from the fact that they may require the use of toxic, inflammable and volatile materials. Areas where penetrants are to be used should be well ventilated and heat, open fires and flames should be kept away. Where confined spaces and the interior of pressure vessels etc are involved forced ventilation may be essential.

Lighting. Where visible light is used then the normal safety precautions regarding electrical supplies are needed. Where black light is used, whilst in normal use this is harmless to the skin and eyes, care should be taken to ensure that the radiation is never directed at the eyes and that inspection personnel do not look directly into black light lamps either intentionally or unintentionally, because of the angle at which they are held or mounted. It is also necessary that the black light lamps should be inspected at regular intervals to ensure that the glass filter is maintained in good condition. The design of the lamp should be such that the emission of unfiltered radiation is kept to a minimum.

5.4.2. Surface preparation

As previously discussed surfaces should be dry, clean, and free from scale dirt grease paint or other foreign matter that will interfere with the interpretation of the test. The method used for cleaning and preparing the surfaces should not cause excessive surface roughness or scratches because these can result in confusing indications. Care must also be taken in cleaning surfaces by blasting grinding or by the use of emery cloth in that cracks may be burred over. Heavy grinding of the surface of all materials is to be avoided.

5.5 Equipment and costs.

5.5.1 Penetrants are low in initial and running costs. They are adaptable to in situ and fixed installation use. No figures giving a direct measure of the savings arising from the application of penetrants are available to the author, but the continuing expansion of their use indicates that they are reducing inspection costs.

5.5.2 Dye penetrants.

a) Aerosol Kits.

Consisting of four cans in a polished wooden box with instructions. Representative prices in the United Kingdom £4 to £6 each. A set of replacement aerosole cans if purchased in batches of 6 or 12 will cost less than 30/-d to replace a set. An alternative to the aerosol cans is a set of glass jars each of which in turn is attached to a separate gas propellant pack. A set would cost £2 to £3. The bulk penetrant materials for transferring to glass jars as needed, or for use with spray equipment as made up by users, or for use in fixed installations are purchasable in 1 gallon (4.55 l) and 5 gallon (22.73 l) cans and drums.

5.5.2 **Fluorescent Penetrants.** The cost of fluorescent penetrants are of the order of £1.7 per 1 gallon (4.55 litre) can.

5.5.3 **Spray Guns.** The cost of spray guns and ancillary equipment will vary according to the volume of work.

5.5.4 **Black Light Lamps.** The black light lamps required cost from £35 to £45 each, complete with transformer and control equipment and suitable for 110 or 240 volt 50/60 cycles input.

Further Reading. Principles of penetrants C.E. Betz. Magnaflux Corporation, Chicago 1963 Library of Congress Catalogue Card No. 63 15800.

Article W.G. Cook Esq., Progress in Applied Materials research Volume 4 Heywood and Company Limited London 1962.

Penetrant Manufacturers Technical Literature.

The following British Standards are applicable:

BS 3683 Part 1: 1963 Glossary of terms used in Non-Destructive Testing. Penetrant Flaw Detection.

BS 3889 Part 3a: 1965. Methods for N.D.T. of pipes and tubes. Part 3a: penetrant testing of ferrous pipes and tubes.

BS 4080: 1966 Methods for N.D.T. of steel castings

BS 4124 part 3 1968 Methods of N.D.T. of steel forgings

BS 4416 1969 Method for penetrant testing of welded or brazed joints in metals

BS 4489: 1969. Method for assessing black light used in non-destructive testing.

6.0 Visual Aids

6.1 Scope

Visual aided examination of internal and external surfaces can locate cracks, breaks, scratches and other surface markings, corrosion, erosion and weld features such as over-penetration. In pipes and ducts blockage and debris can be located. Visual Aids assist in the assembly of components and the testing and diagnosis of machines. Visual Aids do not provide information on subsurface or interior features of bodies opaque to light. Visual Aids can be used in situations where human beings cannot penetrate or exist, and by the use of photography records can be made.

6.2 Principles.

A Visual Aid system consists of:

6.2.1 (a) A source of light which is emitted on to the surface (b) of a test object, is reflected onto (c) a mirror and/or a lens and (d) transmitted to the human eye. Visual Aids take two forms.

Firstly methods for positioning a light source and an optical lens adjacent to the surface to be examined, and then transmitting the resultant image to the human eye via a system of lenses, electronic devices or photographic film. In effect transferring the observers eye to the opposite end of the system.

Secondly, methods of extending the resolution of the human eye by means of optical lenses. Visual Aids comprise, Light Probes, Endoscopes, rigid and flexible, piped light sources, closed circuit and photographic tube cameras, magnifying glasses and special mirrors magnifying and plain.

6.2.2 **Light Sources.** The commonest source of light is an electric filament lamp. These are available in a range of sizes and light outputs. Such lamps require a source of electric current either from a dry or rechargeable battery or from a mains supply via a stepdown transformer. The light output may be in the form of a spotlight useful for "throwing" the light into recesses and highlighting certain features or it may be in the form of uniform illumination over an area. The latter enables a larger area to be scanned by the eye more quickly. Where the lighting is independent, that is not attached to an instrument there should be facilities for moving its position and directing the beam. When the lighting is local to a visual aid instrument, or attached, then there should be provision for controlling the intensity of illumination, this is very important as too much light is as bad as too little. As light sources filament bulbs have some disadvantages, they generate heat and need electrical connectors thus if they are to be used in flammable atmospheres or electrical circuits where heat or electrical conductors are a risk either their use is limited or special precautions are necessary. At the low voltages, 6 volts or less, used on instruments the light output is limited to a few watts, although in recent years the quartz/halogen lamp giving higher light output has made an improvement. Whilst the use of quartz and perspex rods has enabled light to be transmitted through light guides whilst keeping the light source away from the area under examination, and also enabled higher intensity light sources to be used, these devices are rigid and limited in length. An advancement in lighting for visual aids is the availability of flexible fibre-optic bundles.

Optical fibres are constructed of a fine glass core surrounded by a glass cladding of a lower index of refraction, such fibres transmit light by total internal reflection, thus light rays entering one end of the fibre are carried by multiple internal reflection to the opposite end. Fibre diameters are usually about 10,000 to 15,000 nano meter (0.004" to .0006", 10 to 15 microns). A bundle of glass fibres can be laid up in two ways. Either in a random fashion, this is called an incoherent bundle and is used for the transmission of light only. Alternatively if the bundle of glass fibres is laid-up so that individual fibres are in correct orientation, with both ends arranged in an identical pattern, then this type of bundle will transmit an optical image by breaking it up into thousands of separate components, one for each fibre, and conducting them independently from one end of the bundle to the other. This is a coherent bundle. The number of fibres usually lies between 50,000 and 300,000 with bundle sizes ranging from 2 to 3 millimeter (.1") to 12 mm (½") square. It is possible to have a coherent bundle of aligned fibres to transmit an image surrounded by incoherent or randomly laid fibres for transmitting light to the area under examination. This eliminates the necessity and problem of providing a separate light source. Again by tapering the bundle, generally over a short length image magnification is possible.

By using an incoherent fibre bundle sheathed in a protective cover, it is possible to pipe the light from a high wattage lamp contained in a carrying case with switching facilities and intensity control to an instrument such as an endoscope. The light cable may be 2 metres or more in length with an external diameter of 8 mm or larger or smaller as required. The light cable can also be used to introduce light into an enclosed area which will be examined from another or the same entry hole.

[illegible] Light Probes. These consist of a cylindrical dry battery container (handle) with a detachable hollow stem on one end terminating in a miniature filament bulb or a mirror. A variety of attachments in the form of magnifying lenses and mirrors are available. Light probes are available in kits or sets.

Magnifying Glasses. (Magnification 1.5 x to 8 x).

In the simplest inspection system a hand lens may be the only aid involved, either used in conjunction with an independent light source or forming part of a Light Probe Assembly. A circular or rectangular hand held lens of 2x magnification allows binocular vision and has a large field of view. With the smaller pocket type of magnifier with magnification of 5x, 6x or 8x the field of view will be much smaller and concentrated. Whilst this will enable finer detail to be distinguished it will considerably extend the time taken for an examination of anything other than a small area. In addition to magnifying lens magnifying mirrors are also available, again 2x is a convenient magnification. In general the use of the 2x hand lens or mirrors are not too slow for search purposes, with magnifications of up to 8x for checking purposes.

Magnifications above this are entering the field of defect investigation and measurement.

[illegible] Endoscopes (Endon within, skopeo view from the Greek).

The basic instrument consists of a rigid metal tube housing a number of lenses and prisms with a light source and objective lens at one end and an eyepiece, which may have a focusing adjustment at the other end.

The diameters of endoscopes range from 3 - 50 millimeter with length varying from 100 mm to 3m and above according to diameter. For special cases endoscopes up to 30 metres or longer have been provided. Endoscopes over 1 metre in length are usually made in sections for ease of handling and transport. A right-angled attachment is also available enabling a 90° bend to be negotiated. Means are provided to permit viewing in different directions, generally by the provision of interchangeable objective heads. Lighting can be provided in one of three ways, either by housing a low voltage filament lamp in the objective head with electrical connections via the metal tube or by having a higher wattage filament lamp in a housing adjacent to the eye-piece end of the endoscope and transmitting the light to the objective end via a quartz rod. This provides a high intensity white light source at the objective end or if desired a black light (ultra violet) source for use with fluorescent magnetic particle processes. The third method uses a fibre light guide which enables high intensity lighting to be provided at the objective end which is also cold. This is advantageous when the examination is to be conducted where electrical circuits or flammable atmospheres are present.

6.2.A <u>(a) Closed circuit television.</u> C.C.T.V. In the visual aids discussed in preceding paragraphs light reflected from a surface under examination conveys the information to the eye of the observer. In the closed circuit television system the reflected light is focused by a lens on to the target of an electronic vidicon camera tube which with the associated circuits converts the electro-magnetic light waves into electrical signals. These signals then travel along a co-axial cable to a receiver which incorporates a cathode-ray tube on which is displayed a black and white image of the original scene. As the electrical signals are not broadcast, and can only be received via the coaxial cable, the system is referred to as closed-circuit television. The heart of the system is the vidicon camera tube which is available in two sizes, 25.4 millimeter and 12.5 millimeter diameter. Vidicon tubes are incorporated in several types of c.c.t.v. cameras which range in outside diameter from 0.94" to 3" and vary in length from 6" to 2'. There are generally three units in a c.c.t.v. camera chain, the camera incorporating the vidicon, the camera control unit with power supplies and the monitor which includes the cathode ray tube. Electrical supplies from mains or a portable generator are required. The length of the coaxial cable ranges from 15 metres (50') to a kilometre or more if required. Lighting is necessary for the operation of the vidicon tube and is supplied either by filament bulbs set round the lens or by a lamp placed ahead of the camera or in such other positions as are suitable. A control is incorporated in the camera control unit to vary the intensity of the illumination. Recording of information can be done either by photographing the monitor screen with a 35 millimeter, or a polaroid camera or by channelling the information into a video tape recorder. The latter enables the information to be played back if required, and displayed on a monitor magnification of the image can be achieved by the use of large screen monitors.

(b) Photographic tube camera. During the period when the miniature and sub-miniature closed circuit television cameras were being developed for tube inspection a photographic camera was produced and used. This camera does not provide instantaneous presentation of the information but stores it on a photographic film which must be processed and then viewed, although this can be done as a negative and it is not necessary to produce positives or prints. As in the closed circuit television camera, light reflected from the surface under examination is focused by a lens on to a photographic film. The lighting is supplied by filament bulbs set round the lens or a flash tube is also available. Because this tube camera has been developed primarily for boiler tube inspections it does not incorporate a shutter. Exposure is made by switching on the lighting. The film is stored in a magazine and the whole operation is semi-automatic, the camera being lowered down the tube with the pictures being taken at intervals of 100 mm or other selected distances. The camera is capable of rapid photography of the interior of boiler-tubes which are normally inaccessible and has a capacity of 100 pictures. 10 pictures per minute can be obtained automatically. The film used is 8 mm cine film. A control box is connected to the camera by a cable which can be up to 70 metres long or longer. An electrical supply is needed, from the mains or a portable generator, and also a supply of compressed air or nitrogen to operate the mechanism. Nitrogen is conveniently supplied in cylinders of 10 cu.ft. capacity.

6.3 Applications to Plant Maintenance.

6.3.1 Inspection of Plant In Situ.

Examination of areas inaccessible to the human eye in pressure vessels, boilers and other heat exchangers, turbines, internal combustion engines, tanks, pipework, aeroplane structures, sewers, water and cable conduits and other items of plant for corrosion, erosion, cracks, pitting, weld over penetration and root run defects, tube blockage, tools and loose parts, functioning of mechanisms. Verification and diagnosis of defects such as cracks found by magnetic penetrant and other N.D.T. methods and confirmation that cracks and other defects have been ground out prior to commencement of repair by weld or other means.

6.3.2 Inspection in the workshop.

Confirmation and diagnosis of defects found by magnetic penetrant or other methods verification that cracks or other defects have been ground out or otherwise removed before welding repairs commence, checking set-up for weld over-penetration of root-run in areas which are inaccessible to the human eye.

6.3.3 Selection of equipment and interpretation of results. The selection of the appropriate equipment involves the frequency of examination, the significance of defects sought and the size and complexity of the plant involved. Requirements range from the provision of one or more light probe sets for general workshop and site use to the provision of closed circuit television cameras in an organisation with large plant items subject to blockage, corrosion etc. The major factor is that the cost of the equipment is almost directly proportional to the distance from the observer to the area to be examined and the degree of access and tortuous nature of the route.

Table I sets out a guide to selection. In those cases where the volume of inspection or risk of failure are high the purchase of specially designed endoscopes or fibrescopes may be warranted. The equipment manufacturers are always prepared to tailor endoscopes and fibrescopes for specific jobs. It is advantageous to purchase a

SELECTION OF VISUAL AIDS

TABLE I

Distance from observers eye to area to be examined	Access			
	No limitation on Access	Limited port or orifice entry. Box like structures and straight pipe runs, Turbine blading etc.	Access via ports. Severe restrictions 38.5 mm rad[illegible] bends in 5 mm d[illegible] pipe	No means of access. Drill or cut.
[illegible] mm ([illegible])	Hand magnifying glasses	Light probe sets. Dental and Inspection Mirrors rigid Endoscopes Fibrescopes	Fibrescope	Drill 6 mm ∅ hole or extract a rivet or fastening. Insert a miniature 3.65 mm OD or less, Endoscope or Fibrescope.
[illegible] mm to 1 m ([illegible] - [illegible])	-	Light Probe sets, Inspection Mirrors, Rigid Endoscopes with right angle head if required, Fibrescope	Fibrescope c.c.t.v. or photographic tube cameras.	Drill for Endoscope as above or cut to insert tube camera.
[illegible] mm to 9 m ([illegible] - [illegible])	-	Rigid Sectional Endoscopes Fibrescope to 2 metres. c.c.t.v. and Photo tube cameras.	Fibrescope to 2 metres. Combined Endoscope and Fibrescope for U tubes. Tube Cameras	As above
Above 9 m ([illegible])	-	as above	Tube cameras	As above

Because small diameter fibrescopes can be made in longer lengths than small diameter Endoscopes there may be occasions when their use will enable an examination to be made which would otherwise have been impossible.

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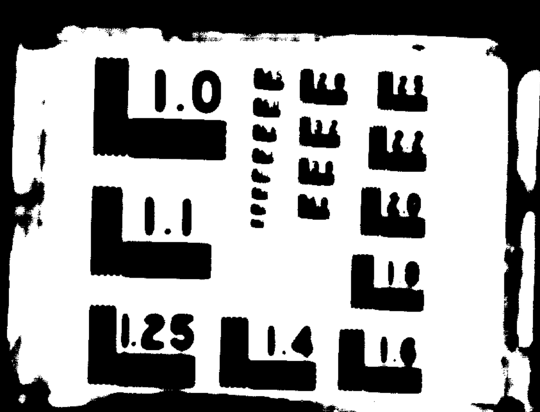


sectional endoscope if possible as there are always the one off occasions where the ability to look inside is valuable.

6.3.4 Interpretation.

Unlike some other N.D.T. methods visual aids do not provide indication or a meter which can be compared with that obtained from a specimen but provide a visual or photographic image which requires interpretation. Because of the effect of surface coloration, the position and intensity of the lighting and difficulty in viewing the area from more than one position, experience is necessary when using endoscopes and tube cameras. The following instructions have been compiled to assist people who are not familiar or experienced with endoscopes, closed-circuit television, or photographic tube cameras. The basic rule in using visual aids is to go from the known to the unknown or unfamiliar, that is, learn to use a visual aid instrument by using it on well known objects which can be readily recognised before going on to the job. This allows a mental adjustment to be made for any magnification or distortion of an image due for example to the angle of the camera or endoscope to the area under observation. Only after confidence has been established in this way should serious interpretation be undertaken.

Using Closed Circuit Television (C.C.T.V.) for Boiler Tube Inspection

1. Connect and set up camera, control unit and monitor as per Operating Instructions in an area where direct sunlight is excluded.

2. Before going into the boiler it is helpful to establish the optimum picture quality to assist interpretation.

3. Obtain two lengths of boiler tube (not less than 12" long) and the same I.D. as those in the boiler, one tube with internal conditions similar to those sought for, i.e. scale, corrosion scabs, pitting weld protrusion etc, and one tube with a clean internal surface.

4. On a piece of Scotch Tape write several letters or numbers ¼" to ½" high and stick this to the inner surface of the clean tube along the tube axis or circumferentially. Other familiar objects can also be placed in the tube, e.g. coins, a 6" rule etc.

Insert the camera in the clean tube. Adjust the camera and monitor controls until the best results are obtained. Experiment with effect obtained when adjusting lighting and other controls. Estimate the field of view and visualise the area under examination.

6. After becoming familiar with the controls on the clean tube using familiar objects, the camera can be transferred to the typical tube and the controls adjusted if needed.

7. Transfer the camera to the boiler house and take the reference tube with you. Do not pronounce judgement until you have examined as many tubes as possible and discuss results with an experienced camera user if possible before reporting.

6.A Preparation and safety.

6.A.1 Safety

The established requirements for safe and secure access and working on plant are applicable but a number of features require additional consideration. First the observer. With the exception of the tube cameras the observer has to place his eye against an eye-piece and probably operate the focus and light intensity control, whilst maintaining alert observation. It is therefore necessary to consider this when organising scaffolding and access to the object being tested. Concentration is also difficult if excessive vibration, dust, noise, and movement of other people are present. Secondly instruments will suffer damage if immersed in liquids or subjected to hot steam and water unless specifically designed for these conditions. Instruments are also adversely affected by dust and vibration. When instruments are to be used in areas where spills or leakage of inflammable fluids may have occurred or when inspecting fuel tanks or similar bodies it is necessary to ensure that lighting equipment or light sources on instruments are flame-proof and comply with relevant standards e.g. British Standard 229. For other situations safety requirements often restrict the voltage of portable lighting to 25 volts A.C. with 110 volts centre tap transformer supplies for portable tools and equipments.

6.A.2 Surface Preparation.

When the object of the examination is to locate or diagnose surface cracks etc, then a surface which is clean or has been cleaned is advantageous. However where the surface under examination is inaccessible this condition often cannot be fulfilled and interpretation becomes more difficult. When the object is to locate debris and blockage generally no surface preparation is required. When searching for corrosion pits e.g. in boiler tubes then pre-cleaning by mechanical rotating head such as a skatoscaler may lead to pits being filled with scale from the tube wall reducing the possibility of identifying them. On the other hand if the layer of scale on the surface is too thick the tube camera will knock it off and form a dustcloud which impairs visibility. In general, then, when searching for corrosion pitting do not clean first unless it is essential to allow the camera to progress through the tube. In other cases a clean surface assists interpretation.

6.9 Equipment, costs and savings.

6.9.1 Inspection mirrors, magnifiers, light probes and accessories are available either singly or in carrying cases, designated sets. These sets are either designed for specialised application e.g. automobile work, aircraft engine, or for general purpose use. The price range for single items can be less than £10 each, for sets from £15 to £100 or above per set. An average price for a general purpose set would be about £30.

6.9.2 Piped light source, comprising a light box with 2 high wattage low voltage lamps, transformer, light control switch etc. the output connected to a 1.8 meter (6') long flexible fibre bundle with a protective metallic outer sheath. The price will be £100 or above. Special safety light boxes are available for use in explosive factories, chemical works or other hazardous areas. The price will be somewhat higher. This system enables cold light to be used for endoscopes, fibroscopes or other applications.

6.8.3 **Endoscopes.** The price range of endoscopes reflects a variety of diameters, lengths, sectional arrangements and objective heads available. Commencing at £60 or less for the smaller non-jointed type without interchangeable objective heads prices range to £500 - £1,000 plus for very large models capable of being used at distances of 8- 15 metres or more. All endoscopes are supplied with a strong fitted carrying case which ensures all components spare bulbs etc. are kept together. As a guide to prices a jointed sectional endoscope of 12 millimetres diameter 2 metres in length with a range of interchangeable objective heads giving radial, forward and backward viewing could cost about £200.

6.8.4 **Fibroscopes.** Fibroscopes are now becoming established as fibre-optic manufacturing facilities and experience in production grow. So that it is now possible to purchase fibroscopes in lengths from 860 mm (34 inch) to 2 metres (6' 6") in diameters of 11 and 15 mm and other fibroscopes in a range of diameters from 3 to 16 mm with lengths up to 2 metres or above. The price range for fibroscopes is from about £150 for short simple fixed-focus units to £1,000 or more for longer remote focusing high quality models. In terms of length fibroscopes are limited to about 2 metres until further development has taken place and can cost as much for this length as a rigid endoscope four or six times as long. However, the flexibility of fibroscopes offers valuable possibilities of extending the scope of visual aids.

6.8.5 **Closed Circuit Television.** Two types of closed circuit television cameras are discussed in this paper, both specifically designed for industrial inspection purposes. The types are distinguished by their diameters. Type A. diameter 38 mm (1½") with forward view head, (slightly larger diameter with other heads) length 140 mm (5½") transmission standard 625 lines cable 15 m (50') this can be extended to 30 m (100'). Viewing head forward or right-angle with integral lighting, facilities for remote focus and rotation of right-angled head and for attachment to a 12.3 mm O.D. endoscope which can be up to 15 m in length. When using the forward view head the camera will negotiate a bend of mean radius 305 mm (12 in) in a tube of 57.2 mm (2.25 in) inside diameter. Complete equipment comprises camera, multicore cable, camera control unit and monitor. In use only four controls are required for operation. Price £1,400.

Type B. Diameter 2[illegible]5 mm (0.94 in) length. Transmission standard 625 lines. Cable 60 m (200') forward view head with integral lighting will negotiate a bend of mean radius 305 mm (12 in) in a tube of 57.2 mm I.D.

Complete equipment comprises camera cable, camera control unit and monitor. In use only 4 controls are required for operation. Price £2,500.

6.3.6 Photographic Tube Camera. Diameter 0.9 inches. Length approximately 75 mm (3 in). Lighting - flash or tungsten filament bulbs. Film 8 mm. Film magazine 914 mm (36") the flexible magazine is stored in the tail to the camera connected to the cable 60 metre long (200'). A control box has controls for manual or auto operation requiring electrical supply of 110/230 volt. Compressed air supply 120 lbs per sq. inch. or a nitrogen supply obtained in a litre (10 cu.ft.) cylinder. Price £700 approximately

6.8.9 Equipment costs and saving continued.

For an outlay of £50 - £100 light probe sets mirrors and magnifiers can be obtained which can save manhours spent on dismantling plant to see inside. For £100 to £500 endoscopes, fibrescopes and cold light sources can be purchased which will extend the number of occasions when examinations can be carried out and necessary information obtained without dismantling the plant or relying on intelligent guesswork. For plant where outage costs are high and close control of operations such as water treatment for boilers is essential then the expenditure of £1,000 to £5,000 will establish a pool of endoscopes, fibrescopes and closed circuit television or photographic tube cameras which will enable information on the condition of inaccessible areas of plant to be obtained which will make a contribution to plant availability, by enabling better control to be maintained. The cost of providing and maintaining visual aids must be offset by increased efficiency of inspection and by saving time and labour in dismantling plant to enable direct visual inspection to be made. Plant has been operated and maintained for many years on the basis of inspection by trained and experienced observers, thus visual aids are complementing existing procedures which have been proven by experience to be necessary and economic.

9.0 Leak Tests

9.1 Scope

The scope of leak testing ranges from ensuring a device can be on the bed of the Atlantic Ocean and operate reliably for 20 years; ensuring that moon astronauts depart on time, to locating a puncture in the inner tube of a bicycle. In this paper only a limited approach is made to this large subject, and the emphasis is on leak testing of non-ferrous heat exchangers, i.e. power station surface condensers.

For some time the development of improved methods for condenser leak testing have been in progress and the author hopes some information on this work may be of value.

9.2 Principles of Leak Tests.

9.2.1 There must be a passage or porosity through which a liquid or gas can pass from the inner to the outer surface or vice versa, and then it must be detected. It is necessary to establish a pressure differential across the wall of the object being tested by pressurising one side of the wall, by evacuating one side or by a combination of both. There are four components to leak testing.

a. Detection. Knowing that a leak is present

b. Location. Knowing where it is.

c. Description. Stating leak rate and size.

d. Assessment. Stating the significance of the leak rate and size.

For the majority of plant maintenance work it is usually sufficient to detect and locate a leak and repair or removal follows.

Leak testing techniques discussed in this paper are as follows.

1. Taper or candle
2. Penetrating liquid dye or fluorescent
3. Soap or foam solution
4. Halogen detector
5. Bubbler Tube
6. Ultrasonic Translator

Other techniques such as radioactive tracers, and mass spectrometers are not discussed.

7.2.2 The principles of these techniques are:-

(i) Taper or Candle. With one side of the wall under vacuum and atmospheric pressure on the other a search for a leak is made with a lighted taper or candle. A leak is indicated by the flame being drawn to it.

(ii) Dye penetrant testing. This involves pressurising one side of the wall with a liquid to which a dye has been added. The opposite side is then examined for traces of the dye using a penetrant developer or a Black Light (near ultraviolet) lamp which causes the dye to fluoresce and aids detection.

(iii) Immersion of the test object in a bath or tub of water or other liquid whilst maintaining an internal air or gas pressure and locating the leak by the emergent bubbles. Where it is inconvenient or impracticable to immerse the test object a soap or detergent solution can be applied to the outer surface and bubbles will indicate the leak.

(iv) When the plant or vessel to be leak tested can be pressurised with a gas such as Freon, or a mixture of carbon tetrachloride and air then a Halogen Leak Detector can be used to search for leaks on the external surface. If desired the vessel can be evacuated with the detector head in the extraction line and the gas applied externally.

The Halogen Leak Detector has a hand probe which houses the sensitive element in the form of a pair of concentric platinum cylinders supported by a ceramic mount. The inner cylinder (anode) is indirectly heated and operates at approximately [illegible]°C. The sample of air is drawn through the gap between the two platinum cylinders by a small motor-driven fan. The probe is connected by a 3 metre long flexible cable to the instrument which contains the indicating devices, loudspeaker light and meter, controls and power supplies.

(v) A simple apparatus designed specially for leak testing of power station condenser tubes has been described by R.H. Bloomer, Marchwood Engineering Laboratories, C.E.G.B. Report RD/M/N.225 May, 1968. The basic apparatus comprises a water jet pump to provide a vacuum, 1 or 2 vacuum gauges, a bubbler jar, rubber bungs, lengths of polythene tubing, on-off valve and other small items. The principle of operation is to create a vacuum in the test vessel by the water jet pump, with the bubbler jar and vacuum gauge in the extraction line. To pump down a sound test vessel to a predetermined vacuum when bubbling ceases takes a definite reproducible time, say 3 minutes. When the vessel has a leak the pump down time will be longer, or it will not be possible to reach the same degree of vacuum and bubbling will not cease.

(vi) The ultrasonic translator is the final technique discussed in this section. The instrument used can detect the ultrasonic pressure waves caused by a gas or air leak from a pressurised vessel, telephone cable, valve etc and convert (translate) them into an audible sound or a movement of an indicating meter. A hand probe which contains a directional microphone, or a contact probe are connected to the instrument by a 2 metre or longer flexible cable.

The instrument operates in a frequency band of 36 to 44 KHz it having been found that the majority of leaks of the type which can be detected by this ultrasonic translator i.e. a leak to atmosphere have a frequency within this band.

Applications and Procedures.

.1 The terminology of leak testing and the majority of the current procedures stem from vacuum technology, but in the past few years these have been increasingly applied to engineering plant, often large in size heavy in weight, particularly welded components for nuclear and aerospace plant. In this field of plant maintenance the penetrating liquid and soap techniques are well established, however with the increase in transportation and storage of petroleum and similar products and the growth of refrigeration and other plant employing heat exchangers other leak testing techniques are becoming more used.

.2 Procedures.

Information and guidance on procedures is given in B.S. 3636: 1963. Methods for proving the Gas Tightness of Vacuum or Pressurized Plant price 35/-. Appendix 6 includes a Bibliography, (pages 104-113) of papers and books on leak testing. The procedures for applying the techniques previously discussed to power station condensers may require a brief explanation. A power station condenser is a very large vacuum chamber, working with a vacuum in the region of 345.32 Kgf/M^2 (29 in. Hg) containing several thousand non-ferrous tubes expanded or otherwise fastened into the two end plates. Through the bore of these tubes passes the cooling water from sea, river, lake or cooling tower, which by condensing the exhaust steam from the turbine as it enters the condenser shell creates and maintains the vacuum. A leak in a tube will cause contamination of the treated boiler feed water by the untreated cooling water with consequent financial losses. The quality of the boiler feed water is monitored by measuring its conductivity using a Dionic recorder, which will indicate when a leak above a minimum size has occurred, so we can say a leak has been detected, but it is then necessary to locate it.

Access to the cooling water side and the ends of the tubes is obtainable for leak testing with the plant in three different conditions.

a. Shut down, atmospheric pressure both sides of the tube wall

b. Shut down, steam side filled with water, giving a pressure differential across the tube wall. Head of water pressure to atmosphere.

c. Load reduced, cooling water supply cut off to one half of the condenser, and vacuum maintained. Pressure differential across tube wall from atmosphere to vacuum. Only applicable to a twin or split condenser system.

9.3.2.1. Taper. Plant condition (c) Vacuum on steam side. A lighted taper or candle is passed over the ends of the tubes, a tube with a large or gross leak will draw the flame into the mouth of the tube. This technique requires the minimum of equipment and can still be useful when other more advanced techniques are not available. As a naked flame is used attention must be paid to possible presence of inflammable atmospheres.

9.3.2.2. Fluorescent Liquid.

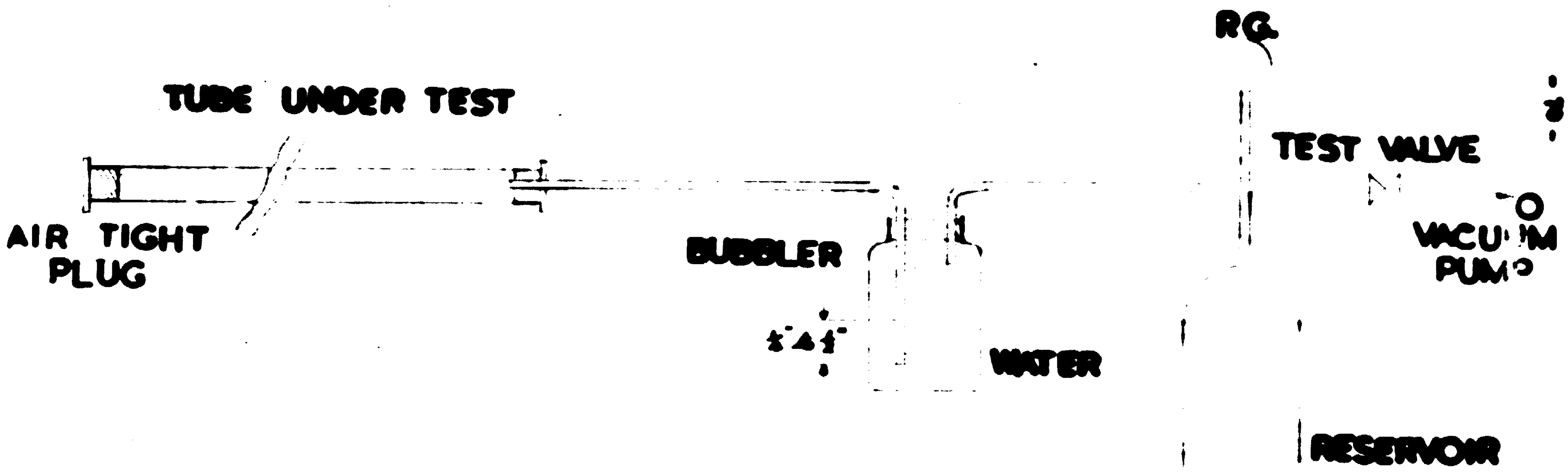
To locate leaks in a condenser by this technique the plant is shut down, the condenser shell filled with water to the exhaust flange, condition b, and a small amount of Fluorescein is added whilst filling is in progress, so as to obtain fairly even dispersion and solution in the water. The quantity of fluorescein required varies according to the circumstances. A dose of 50 p.p.m. (1 lb. per 10 tons of water) should be used where it is desired to avoid waiting for the tube plates to dry before examination, but much smaller doses, of the order of 10 p.p.m. or less, may be adequate where tube plates are dry and there is no dilution of the leaking fluorescein solution by moisture on the outside of the plates. Generally speaking, the cost of the higher doses is so small compared with the cost of the time wasted in drying out the tube plates and water boxes, and very small leaks are made so obvious, that the maximum dose should be used.

After the fluorescein solution has been in the condenser for a few minutes the tube plate is irradiated with Black Light from a lamp inserted through the man-hole in the water box doors, when leakage around ferrules, out of cracked or perforated tubes, or around stay-nuts is instantly revealed by a bright green fluorescence. Traces of grease and certain metallic oxides give rise to pale blue and white fluorescence, but these are distinguishable from the fluorescence due to the leaking fluorescein solution, particularly if the operator first makes himself familiar with the latter by direct examination of a few drops of the solution placed under the lamp.

The same procedure can also be used to detect and locate leaks in tanks and containers or a penetrating flaw testing oil may be used in both cases viewing the external surfaces under Black Light.

2.3 Soap Bubbles and Foam.

Whilst the use of a soap or detergent solution is well established for leak detecting and locating leaks when applied to the outer surface of a pressurised vessel, the application of a foam to a heat exchanger tube bundle uses the reverse



SKETCH. Fig. 6 BUBBLER IN USE

effect. In this case a leak in a tube results in the foam being sucked into the tube end, due to the vacuum in the condenser L.G. Smith, Combustion, 36 (9) 32-3, 1965 in an article entitled "Experience with the use of Foam for Condenser Leak Detection"..... discussed the advantages of this technique and investigations are being carried out by C.E.G.B. S.W. Region.

With plant in condition (c) the turbine on reduced load, and one half of the condenser accessible, a foam mixture is quickly spread on the tubeplates. With vacuum present on the steam side a leak in a tube is shown by foam being drawn into one of the tube ends. It is necessary to use a foam of the correct consistency and means of applying it quickly over the surfaces.

7.3.2.4. Halogen Leak Detector.

With plant in condition (c) i.e. turbine on reduced load condenser under vacuum with one half accessible from the water side, the halogen detector probe is put at the air extractor exhaust outlet. A nozzle is connected by a flexible hose to a cylinder of Arcton, dichlorodifluoromethane and then applied to the end of each condenser tube in turn. There is a wait of about 30 seconds to allow the gas to pass through a leak if present and for it to be detected. Thus this technique is used to verify suspect leaks rather than detect leaks. Alternatively to localise the area to be searched in detail the Arcton gas can be introduced into the top of one of the waterboxes with the doors closed and with the halogen detector close by the air extractor exhaust.

Bubbler Tube. Used to verify results obtained by other techniques e.g. Fluorescein or foam, may be applicable under conditions where they cannot be used.

Procedure.

1. The plant off load and shutdown.

2. Check by sighting through them that the tubes to be tested are not blocked.

3. Plug the far end of the tube, using a cork or bung which makes a leak tight joint.

4. Connect the vacuum pump to a suitable water supply and let water go to drains.

5. Insert the suction pipe bung firmly into the tube under test using a little vacuum grease containing a vacuum sealing compound.

6. Open the valve on the extraction line and vacuum will be raised in tube.

7. If there is a large leak full vacuum will not be raised and on shutting the valve the vacuum will fall and bubbling will continue while it is falling.

If there is a small leak, 20" to 25" Hg will be reached in about 2 minutes. Shut the valve, vacuum will fall too slowly to be observed but bubbling will continue.

A sound tube will be indicated if on reaching 25" Hg when the test valve is shut bubbling stops within 10 seconds.

If the standby condition the water pump is run continuously with the valve closed. Before stopping the water pump the extraction line must first be brought up to atmospheric pressure to prevent water being sucked back from the pump to the bubbler jar. Either of the bungs in the end of the tube may be eased out gently to do this.

7.3.2.6. Ultrasonic Leak Detectors are available from a number of manufacturers, and a wide range of applications are listed in their literature. These include leak detection on chemical and other plant, pressurized telephone cables, pressure and vacuum brake and control systems, seating of valves in enclosed or open systems and corona discharge from high voltage electrical supply systems. The majority of these applications require the microphone transducer or probe, for other applications, e.g. bearing noise a contact probe is used. Maintenance engineers have been accustomed to use some form of stethoscope to listen to the characteristic sounds of various components on plant, as the ultrasonic frequency is well above the audible range, there should be less interference from sounds arising from other sources. The procedure is simple the pressure inside the test object forcing air or gas out through the leak, no tracer gases or special lighting are required. Physical contact is not necessary when the microphone is used thus hot pipelines or pipework over high voltage transformers for fire prevention purposes can be tested without needing a plant outage. The microphone which is sensitive to ultrasound over an angle of approximately 20° is scanned over the area or object, and a leak when detected is followed to its source.

7.4.0 <u>Safety and Preparation.</u>

7.4.1 There are several aspects of safety to be considered. The ability of the vessel being tested to stand the pressures involved, e.g. weight of water and effect on supporting structures, or the case of a vessel designed to operate under vacuum conditions which is pressurized for leak testing. The effects of a failure of the vessel whilst under test with the consequent loss of a volume of water, or explosive or implosive action must be considered when planning a test procedure. The use of search or trace gases may involve a risk either because (1) the gas may form an explosive mixture with air or (2) it may have toxic or asphyxiant properties. If a search gas free from either risk can be obtained use it. Otherwise a gas with a toxic/asphyxiant risk which can be reduced to a minimum by precautions is preferrable to one with which there is a risk of an explosion. The handling, transport and storage of cylinders of gas must also be considered.

In general where gases are to be used means of ventilation must be adequate "Naked flames" as the taper and Halogen Leak Detector must not be used in areas where inflammable vapours can exist. The final aspects are electrical safety when electrical instruments and lighting are involved using low voltage Black Light lamps in wet situations, and safe means of access by provision of scaffolding platforms etc when required.

7.4.2 <u>Preparation.</u>

In general the degree of preparation required is not as great as in some other N.D.T. methods. Surfaces should be clean and free from loose debris, flaking paint and scale which could interfere with the test. If the surfaces can be dry this is generally preferable. When the halogen leak detector is to be used cleaning fluids such as trichlorethylene should be kept away from the testing area as they will affect the test.

7.4.3 <u>Equipment Costs and Savings.</u>

7.4.3.1. Water Soluble Fluorescein Dye, price about 55/- per kilogram in 5Kg pack obtainable from Chemical Suppliers. Black light lamps, low voltage less than £20. Halogen Leak Detectors approximately £75. Ultrasonic translators about £120. Bubbler tubes and apparatus not more than £20.

7.4.3.2 <u>Savings.</u>

A leaking radiator on a car or truck which allows the antifreeze to drain away and which in turn is replenished by water only can lead to a cracked cylinder block, cost of repair plus cost of non-availability may be less than £100 or considerably more. Loss of refrigerant in a transport tank could lead to a load of milk being wasted and the journey profitless. A leak through a weld in a storage tank containing inflammable, explosive or corrosive liquids or gases can result in loss of life, damage to property and loss of production, with consequent large financial losses. In power stations the costs of leaks in condensers can be placed under two headings:

a) loss in efficiency due to reduced vacuum and blowdown due to not being able to locate and plug a leaking tube whilst on load.

£1,000 blowdown losses per month

part of £3,000 vacuum losses per month

Figures for a station with 8 x 60 MW sets.

b) Cost of locating a leak.

The fluorescein technique, which is the standard one, requires that the set be shut down and the steam side filled with water, and access made to the waterboxes. Where a turbine is shut down for a short period of 3-4 hours overnight then a fluorescein test can be made, although for small or evasive leaks several such tests may have to be made on successive nights. Where a set is on base load and a special outage is required then the cost of taking it off load to carry out a fluorescein test ranges from £200 to £1,000 per hour. For this reason and because large modern turbines have pannier type condensers, which are on the same level as the L.P. cylinders alternatives to the fluorescein test which can be supplied with the set on loud are being sought. The term on-load as used here means that it is possible to obtain access to the tube plates of one half of a condenser, or one condenser of 2 or more whilst the set is on load and vacuum is maintained in the condenser. Because of the relationship between condenser leaks particularly in coastal power stations and boiler tube corrosion great emphasis is placed on achieving and maintaining high standards of feed water purity. If it were found necessary to take a 500 MW set off load specifically to locate and plug a leaking condenser tube and this required a 3 day outage the cost would be £60,000. Whilst these large figures refer to special case they serve to indicate that leak detection and location are now a must for plant maintenance.

Further reading.

(a) British Standard 3636: 1963
Methods for proving the gas tightness of Vacuum or pressurised plant 35/- net.

(b) British Standard 2951: part 1 1969.
Glossary of terms used in Vacuum Technology
Part 1 Terms of General Application 16/- net.

(c) Leak Testing in Heavy Engineering
C. Herrod. B. Sc M.N.D.T.S.
British Journal N.D.T. March, 1968, pages 2 - 10.

8.0 Ultrasonics.

8.1 Scope

Of the N.D.T. methods listed in this paper the ultrasonic method has the widest scope and application for locating and identifying sub-surface defects. It is used for testing welds and weldments; rivetted seams, shafts and axles for cracking. Corrosion and thickness surveys on tubes, tanks and ships. Testing bearing linings for adhesion and bolts, studs and rivets for transverse cracks. Ultrasonics can be used on a wide range of materials and products. The limitations in any application are:-

Material structure, shape and geometry of the test object, the accessibility of surfaces and surface condition and temperature.

8.2 Principles of Ultrasonics.

8.2.1 Transmission of ultrasonic energy.

The term "sound" defines that band of vibrational frequencies in air to which the human ear is responsive, i.e. 30 Hz to 20 kHz. Vibrations above this upper limit are called ultrasonic and range in frequency from 20 kHz to 1,000 MHz. Ultrasonic waves form part of the acoustic spectrum and are mechanical vibrations which can readily travel through homogeneous bodies which possess elasticity.

The basis of ultrasonic thickness measurement and defect detection processes is the fact that for a given type of material, e.g. steel or aluminium the velocity of ultrasonic energy through that material remains substantially constant. Thus by injecting a pulse of ultrasonic energy into the surface of a bar of steel, recording the start of the pulse and the time of its arrival at a receiver on the opposite side, the transmission or travel time of that pulse is known. The thickness of the bar can then be determined from the formula

$x = vt$ where v is ultrasonic velocity in the material metres/second. t is transit time in seconds. x is distance (thickness) in metres. (i)

Note the normal velocity of ultrasonic waves in steel is 5900×10^3 m/s.

[illegible] This transmission technique can also be used to detect certain types of internal defects by measurement of a decrease in the received signal, but this requires access to both sides of the test object and alignment of transmitter and receiver thus limiting its application.

[illegible] To enable testing to be carried out from one side only, use is made of the fact that some portion of a transmitted ultrasonic beam is reflected at a surface between two media with different acoustic impedances.

Acoustic Impedance, $Z = \rho v$ (ii)

where ρ is density of material

v is ultrasonic velocity in the material.

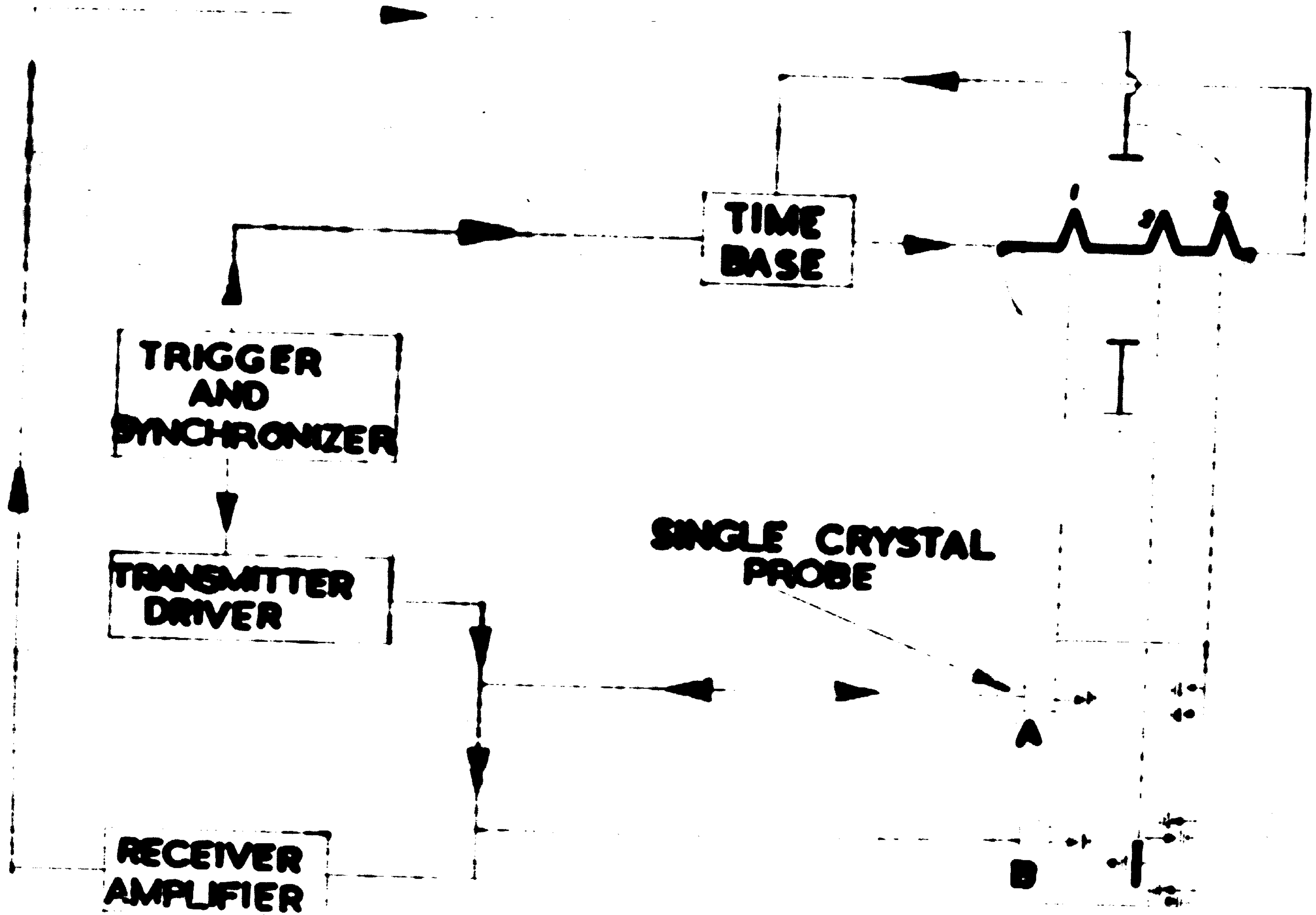
The surface may be external, e.g. between the bottom of a steel bar and surrounding air, or internal e.g. steel to entrapped gas or slag. The effect is to reflect the transmitted pulse back to the receiver, like an echo returning, so the pulse travels the length (thickness) of the specimen twice. This is known as the pulse echo technique.

Ultrasonic energy can be generated and transmitted either as continuous waves, or as short wave packets or pulses, continuous waves cannot be used with the echo technique and so the pulse echo type of equipment is almost universally used for thickness measurement and defect detection. For thickness measurement a continuous type of ultrasonic equipment is available, which makes use of the principle of resonance. Equipments of this type are used in the U.K. for production rather than maintenance and will not be discussed further in this paper.

8.2.3 General Diagram of Ultrasonic Pulse Echo Equipment, Fig 7

The sequence of events is as follows:-

The trigger unit sends an initiating signal to the transmitter driver, and time-base circuits. The time-base moves the electron beam across the C.R.T. screen, from left to right (x axis) at a uniform predetermined speed. At the same time the transmitter driver sends an electrical pulse to energise the piezo-electric crystal which converts it to a pulse of ultrasonic energy which passes into the test material, through which it travels until reflected at an internal or external surface. Some of the reflected ultrasonic energy is received by the piezo-electric crystal which transforms it to a voltage which is then amplified, and applied to the vertical deflection plates (y axis) of the C.R.T. appearing as a blip on the screen. This cycle is repeated 50 to 2000 times a second, the number of repetitions being governed by the synchroniser and trigger unit. In figure 7 the time-base is shown as set so that 10 mm on the horizontal scale corresponds to a steel thickness of 10 mm. A single crystal, zero angle, compression wave probe is positioned at A, signals 1 and 3 are seen. With the probe positioned at B, over a laminar type defect, signals 1, 2 and 3 are visible, with a decrease in the height of 3. Thus the distance of the defect from the surface can be stated and by



SCHEMATIC OF PULSE ECHO ULTRASONIC FLAW DETECTOR Fig 7

41

moving the probe over the surface the length and width of the defect can be mapped out.

8.2.4 Basic Requirements for pulse echo ultrasonic equipment.

The basic components for a general purpose pulse echo ultrasonic equipment are as under:

a) Electronic circuitry capable of generating electrical oscillations ranging from 0.5 MHz to 15 MHz in pulses of 1 microsecond or more duration.

b) Electronic trigger unit to initiate pulses and the C & T time base and to control the pulse repetition rate.

c) A piezo-electric transducer to convert electrical energy to mechanical energy and vice versa.

d) A receiver amplifier.

e) A means of accurately measuring time intervals from 1 microsecond to 2000 microseconds. This may be a cathode ray tube (C.R.T.) meter or a digital presentation. Items a, b and e are contained in a case with power supplies which is connected by a light flexible co-axial cable, which may be up to 20 metres in length to the transducer.

8.2.5 The transducers commonly used are quartz or ceramic discs, known as crystals which transform the electrical energy to mechanical energy, and vice versa, by the piezo-electric effect. The diameters of crystals in common use range from 3 mm to 34 mm. To protect the crystal and enable electrical connections to be made it is mounted in a metal holder with provision for a wear plate on the front face, from which the ultrasonic energy radiates in a beam, like light from a torch. The complete assembly of crystal and mounting is called a probe, and the type previously described is a compression wave probe. The other two main types of probe are the shear wave probe and surface wave probe.

A probe may contain a single crystal which alternately transmits and receives, or two separate crystals, one to transmit and one to receive. Alternatively, single crystal probes may be used in pairs, one to transmit and one to receive.

8.2. Wave Modes.

Ultrasonic energy can propagate through materials in a number of wave modes, of which three are normally used in testing. These are, Compressional (Longitudinal), Shear and Surface. Shear waves travel at 0.48 and surface waves at 0.45 the velocity of compressional waves. Only compressional waves are generated by the crystals normally used, but by mounting the crystal on an angled block or wedge of perspex or plexiglass so that refraction occurs at the surface of the workpiece, the compressional waves are reflected and a beam of shear or surface waves are transmitted. These are the shear wave probes and surface wave probes.

The degree of angle is decided by the materials of which the wedge and test object are composed, and the angle that the incident ultrasonic energy makes with the normal to the surface of the test object. (For details of the limitations on choice of angle one of the standard reference works should be consulted).

Thus the ultrasonic beam can be directed at an angle to the normal into or along the surface of the test piece, a matter of great importance in weld testing and other applications.

8.3 Applications of Ultrasonics for Maintenance.

8.3.1 The main reasons for using ultrasonics for preventive maintenance are firstly to measure loss of metal arising from wear, erosion and corrosion, secondly to locate cracks and similar defects, thirdly to test for adhesion or bonding and fourthly for weld testing.

Established applications include the following:-

1. Testing storage tanks for corrosion and thinning.
2. Thickness and corrosion surveys on ships.
3. Corrosion and thickness surveys on boiler tubes.
4. On-stream measurement of high temperature piping.
5. Testing rivetted boiler drum seams for inter-rivet cracking.
6. Testing turbine and compressor blades for cracks.
7. Testing bolts, studs and rivets for transverse cracks.
8. Testing compressor shafts and railway axles for cracking.
9. Testing rails for cracks.
10. Testing porcelain insulators for cracks.
11. Testing welds.
12. Testing bearing linings for adhesion.
13. Testing superheater tubes for blockages.

8.3.2 Examples.

Thickness measurement.

Thickness measurements were required on the cast-iron winding drum of a crane, which showed extensive grooving. After flats had been filed down to the bottom of the grooves, the ultrasonic probe could be accommodated. The ultrasonic measurements showed the thickness had decreased from the original 1¼ in to ¾ in at its thinnest. This information was required to enable a decision to be made on whether the drum could remain in use.

Ultrasonic crack depth estimation and thickness measurement.

Cracking on a steam trap cover. The cracking was both circumferential and radial, but as it was considered that a circumferential crack would be most serious, the ultrasonic test was centred on this. It was estimated that the crack was a little less than ½ in deep. The thickness of the cover measured ultrasonically was approximately 1⅛ in. One radial crack which ran into the bore of a drilled hole was also estimated to be a little less than ½ in in depth. This crack was then tested magnetically and the depth measured by a rule in the bore was approximately 0.4 in.

Ultrasonic testing of studs for transverse cracking.

The two types of studs were 10½ inches long, 2 inch diameter, and 12¾ inches long, 2.4 inch diameter. There were a total of 80 studs on one machine to be tested. The object of the examination was to check for transverse cracks in the cross-section.

The method of calibration was to use a new stud as a reference for setting the "bottom echo" position on the time base.

Results.

All studs were considered to be free from transverse cracks except the following.

No. 6 stud - flaw echo at a distance of 9 in - 9½ in from the top of the stud, the "end of the stud" echo being obtainable only in places, indicating the crack had not progressed entirely across stud diameter.

No. 9 stud - flaw echo at 9 in from the top of the stud. Complete loss of "end of stud echo", suggesting that the stud is cracked completely across.

Both studs were removed and cracking confirmed. No. 7 stud sheared on removal.

8.3.3 <u>Techniques and Procedures.</u>

When considering an ultrasonic application there are a number of factors to be borne in mind, the most important of which are set out below. However, for all but the simplest type of job, a study of the factors involved and some experimental work on typical specimens containing known defects, before commencing site testing, allied to "follow-up" work if repairs are involved help to ensure a successful application.

The factors are:-

8.3.3.1 <u>Type of Material and its structure and their effect on the absorption of ultrasonic energy and the selection of frequency.</u>

Ultrasonic energy is attenuated when passing through materials by scatter, absorption and spreading of the beam.

For a given material the shorter the wavelength of an applied ultrasonic beam the greater is the attenuation in passing through that material. Thus by increasing the wavelength a decrease in attenuation is obtained. The effect is that the coarser the structure of a material the longer the wavelength needed for transmission and hence the lower the ultrasonic frequency. In contrast to radiography where the radiant energy is classified by wavelength, in ultrasonics wavelength is not directly used. Instead ultrasonic energy is generally classified by frequency, expressed in Hertz (c/s).

The wavelength of an ultrasonic beam is determined by two factors, the frequency at which the crystal oscillates and the velocity of the ultrasonic energy in the test material. The relationship between wavelength, symbol λ frequency symbol f and ultrasonic velocity symbol v in a material is expressed in the formula. $\lambda = \frac{v}{f}$

If v is in m x 10^6 then λ will be in mm as shown in the following example. Velocity in steel = 5,900 m/s, f = 2.5 MHz, then

$$\lambda = \frac{5.9 \times 10^6}{2.5 \times 10^6} = 2.36 \text{ mm}$$

This is the wavelength in steel at a frequency of 2.5 MHz with the velocity generally quoted. Table 2 gives a guide to selection of frequency for different materials.

Table - 2

Frequency Range	Test Applications
25 - 100 kHz	Concrete, wood poles, rock and other course structured materials.
200 kHz - 1 MHz	Castings; grey iron, nodular iron, and relatively coarse-structured materials, e.g. copper and stainless steels.
400 kHz - 5 MHz	Castings; steel aluminium brass and other materials with refined grain size.
200 kHz - 2.25 MHz	Plastics and plastic-like materials such as solid rocket propellants and powder grains.
1 - 5 MHz	Rolled products; metallic sheet, plate, bars and billets.
2.25 - 10 MHz	Drawn and extruded products: bars, tubes and shapes (ferrous and non-ferrous).
1 - 10 MHz	Forgings; ferrous and non-ferrous.

However, there is another aspect in the choice of frequency and wavelength that may need to be considered, which is the minimum size of defect that should be detected. A rough approximation is that this corresponds to the wavelength of the ultrasonic energy, thus in the example previously given the minimum size defect will be approximately 2.4 mm. The choice of frequency is therefore determined by the grain structure of the material, the minimum size of significant defect and the range of probes available.

Ultrasonic instruments are provided with a switched range of frequencies, but each probe has a resonant frequency which is determined by the thickness of the piezo-electric crystal and circuit characteristics.

8.3.3.2 The position of the area to be explored by the ultrasonic beam and the orientation of expected defects must be considered in relation to the surface on which an ultrasonic probe(s) can be positioned. For best results the incident ultrasonic beam should be at right angles to the reflector. In thickness measurement and lamination testing of plate where a compression wave probe emitting a beam perpendicular to the surface of the plate is employed this condition is obtained, but for radial cracks through a pipe or for weld testing shear wave probes are necessary, whilst for transverse surface cracks on turbine blades surface wave probes would be required.

8.3.3.3 In considering the path of the ultrasonic beam through the material it is also necessary to decide how to couple the probe to the workpiece. There are 3 common methods. An ordered movement of a probe over a surface is referred to as a "scan".

Contact Scanning Techniques.

Probes are held by hand on the surface, the gap must be small and a liquid or paste couplant used. This technique is used for defect identification and is particularly useful for weld examination.

Gap scanning technique.

The probe carrier follows the contour of the material under examination, but the probe whilst not in direct contact with the surface is coupled to it by a layer or jet of water or other liquid which is maintained between the two surfaces. The liquid must be kept free of air bubbles. The probe carrier can be hand held as in boiler tube surveys, or mounted on a wheeled trolley as in plate lamination tests, or form part of an automatic ultrasonic weld testing rig.

Immersion Techniques.

The test object and the probe are placed in a tank containing water. The probe is held at a predetermined distance whilst there is a relative movement between the probe and test object giving a suitable scanning coverage to ensure no significant areas are missed.

Couplants are necessary.

To ensure transmission of the ultrasonic energy from the probe into the workpiece as air must be excluded from the interface. Couplants can be light oil, water, glycerine, starch or other paste.

8.3.4 **Procedure Sheets.**

8.3.4.1 To achieve consistent and reliable ultrasonic test results some form of report and/or procedure sheet should be used. These range from a simple statement giving details of -

Organisation or Firm.

Job Details.

Equipment

Technique(s) and Calibration

Work done

Results obtained

Person conducting test

Date

to the detailed procedure sheets found necessary by organisations such as the U.K. British Railways Board.

6.3.4.2 British Railways have employed ultrasonic testing for the inspection of axles since 1947 and have accumulated a vast amount of experience and know-how on this subject. Because of the routine nature and volume of work it is necessary to engage and train personnel with wide levels of technical knowledge, including some who have those personal qualities needed for a reliable and conscientious tester, but have little knowledge of engineering science. This is achieved by codifying the test procedure for each type of axle and by separating the general techniques from the particular. Methods of testing particular axles are set out in "Procedure Charts" which either deal with families of similar axle types e.g. carriage axles, waggon axles or D.M.U. axles or with specific designs for locomotives. A Procedure chart consists of drawings of the axle step by step procedure including calibration and illustration of typical trace patterns, with and without defect signals. The general techniques with explanatory material are gathered together as a series of chapters in a book -

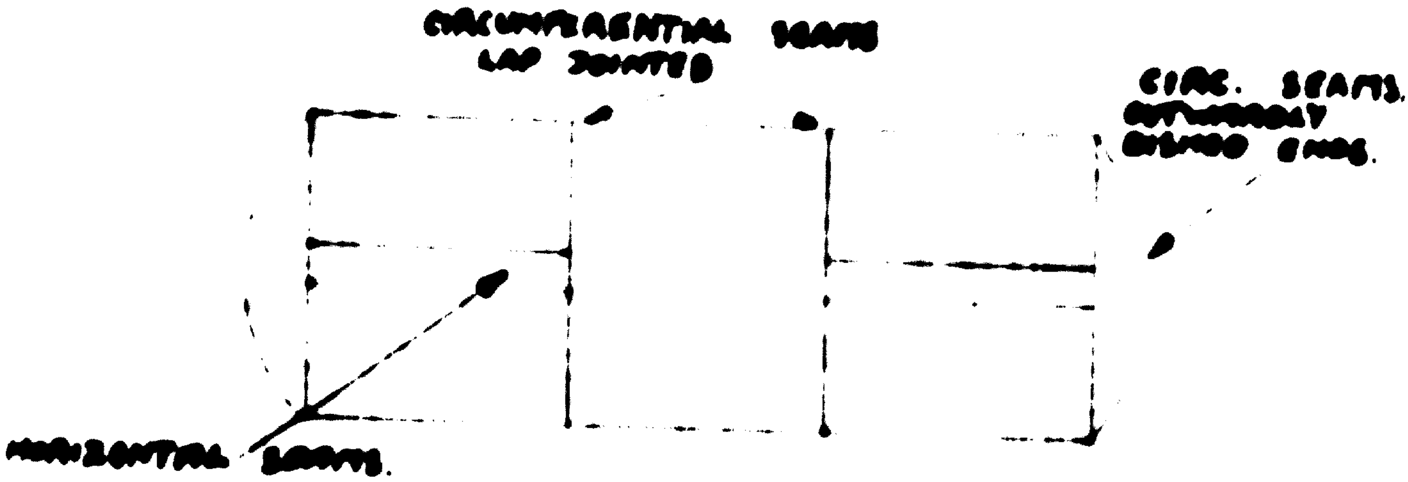
"The B.R. Handbook of Ultrasonic Testing". This describes the test principles, the equipments, including probes used by British Rail. All testers receive a copy

[illegible]

[illegible]

[illegible] Riveted Boiler Drum.

[illegible] Section through drum.

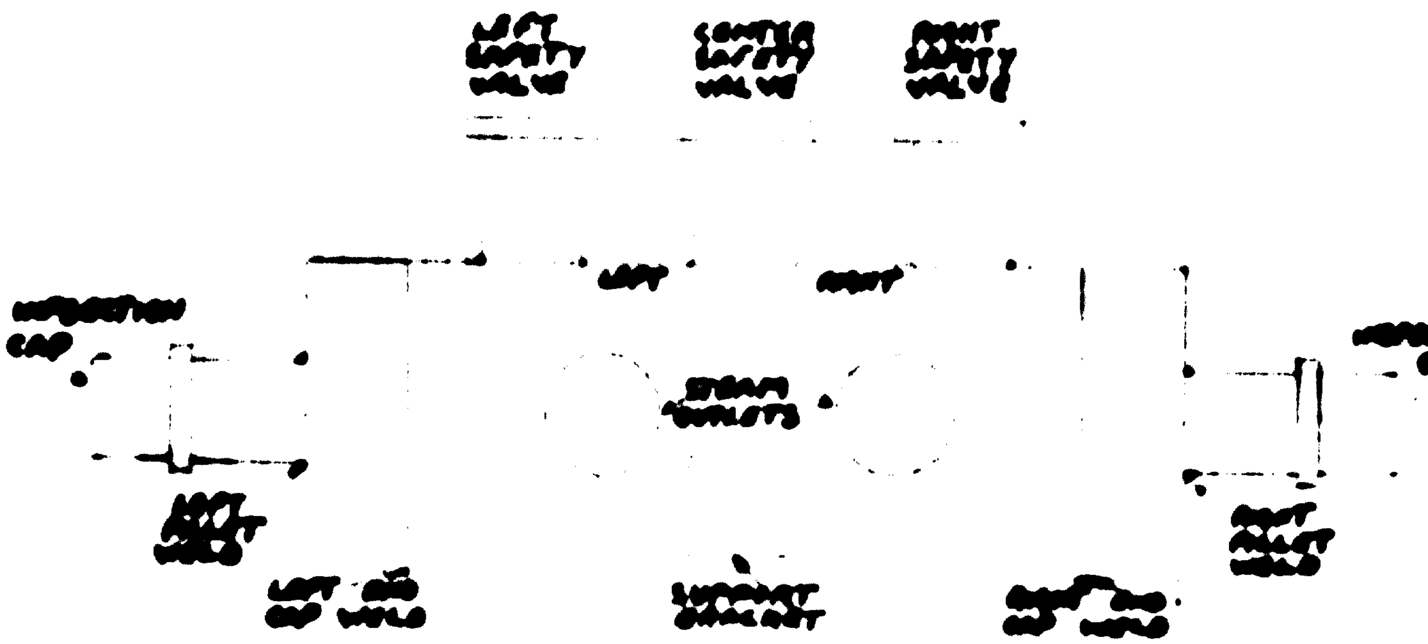


Item	Surface Preparation	Method & Technique	Type of Defect
Horizontal Seam [illegible] items	Vacum Blast	Ultrasonic 70° or 80° shear wave probe. Glycerol or paste couplant.	Radial cracking from rivet holes in parent metal
Circumferential Seams Inner or Outer dished ends [illegible] items.	Vacum Blast		"
Circumferential Seams Lap-jointed [illegible] items	Vacum Blast	"	"

CENTRAL ELECTRICITY GENERATING BOARD
[illegible] WESTERN REGION

N.D.T. Inspection Procedure No. 2

Title: Superheater Header Welds, Generating Station.



Item	Surface Preparation	Method & Technique	Type of Defect
Left & Right hand circular end cap butt welds 2 items.	None	Radiography. Source inside single panoramic shot.	Transverse cracking in weld
Left & Right hand 9" I.D. main steam outlets. 2 items.	Grinding, good finish essential	Magnetic 1,500 ampere turns minimum. White paint and black ink. Radiography (selective). Source inside and 8 areas on each pipe for 4 exposures per pipe.	Transverse and circumferential cracking on surface and within welds.
Safety valve stub welds. Left centre and right hand. 3 items	Grinding, good finish essential	Magnetic. 1,500 ampere turns minimum. White paint and black ink.	Transverse and circumferential surface cracking.
9" I.D. inspection port fillet welds. 2 items	Grinding, good finish essential	Magnetic. 1,500 ampere turns minimum. White paint & black ink	transverse and circumferential surface crackin

Item	Surface Preparation	Method & Technique	Type of Defect
Centre Support anchor Item 1.	Wire brush	Magnetic, permanent magnet or other technique	Surface cracking
Welds securing inspection caps replaced after job inspected 2 items	None	Radiography. Double wall technique. 3 shots per header cap.	
Superheater tube stub welds into header. Percentage of total as decided.	Grind	Magnetic loop technique	Circumferential cracking

The above procedure states the minimum requirements. If time permits, more than one test including ultrasonics may be used. If suspect areas are found further tests will beused to attempt to confirm the diagnosis.

	Repairs if faulty parts are replaced		
Item	Surface Preparation	Method & Technique	Type of Defect
All welds after repair	Clean and Bright	Magnetic for surface defects and radiography where applicable for internal defects.	Cracks, slag inclusions, blow holes & porosity lack of root penetration, over penetration lack of side wall fusion
9" diam. Left & right hand steam pipes. Butt welds. Not shown in sketch.	Clean and Bright	Radiography 3 films, 3 exposures Double wall. Magnetic after stress relieveing.	As above

of this book when trained and it is also available for sale, price £5. 0s. 0d. from the British Railways Board, 322 Marylebone Road, London, N.W.1. England.

8.3.4.3 British Standards often obtain considerable detail on techniques and procedures e.g. BS 4336: - 1A: 1965 Methods for N.D.T. of Plate Material Pt 1A Ultrasonic Detection of laminar imperfections in ferrous wrought plate.

Describes 4 techniques - Technique 1 20 dB drop.

Technique 2 flaw echo/bottom echo

Technique 3 Multiple echo pattern

Technique 4 Reference Blocks.

Followed by 4 procedure instructions all of which commence with a calibration procedure.

8.3.4.4 Two examples of simple N.D.T. Inspection Procedure sheets from the authors organisation are shown.

A valuable source of information for the compilation of such procedure sheets are the test or report sheets which are written-up after every job.

8.4 Preparation and Safety.

8.4.1 Safety.

As in other sections of this paper the established requirements for safe and secure access and working areas apply. Again in the majority of cases a person will need to come within reach of the test surface, which may be in pressure vessels, or chemical plant so ventilation, removal of noxious fumes, means of exit and freedom from excessive dirt and heat must be considered. Because ultrasonic thickness measurements can be successfully carried out under water training in this type of work must be given before attempting same. From the electrical safety aspects, and weight problems when working at heights the use of lightweight 6-8 kg, battery operated transistorised equipments has eliminated many problems. There are no radiation precautions required.

8.4.2 Surface Preparation

Surface roughness and the presence of dirt, rust, scale etc, on the material will require pre-cleaning, either by wire brushing, grit-blasting, flame washing or other means. Ultrasonic energy can be transmitted through a tightly adhering film, e.g. paint, but unsuitable surface conditions can reduce the reliability of a test, render it invalid, or cause an excessive time to be taken. For example, to successfully carry out ultrasonic examinations of rivetted boiler drum seams it was necessary to work on some occasions from inside the drums, which were thickly coated with a protective paint. Only when grit blasting had removed the paint could the Ultrasonic test be correctly carried out. Again, the time taken to carry out corrosion surveys on 1500 m of boiler tubes in the combustion chamber was halved when grit blasting was used. To establish the grade of grit to be used it was necessary to carry out in-situ experiments, cleaning surfaces then testing then repeating, until the ultrasonic tester could obtain correct results without spending time checking and local cleaning of suspect.

8.5 Equipment.

8.5.1 Range and Cost.

There are a range of portable multi-purpose pulse echo ultrasonic equipments available. They all have certain basic features but range from small transistorized battery operated types to larger and more complex mains operated types with many refinements, and consequently ten or more controls.

In recent years the ability to measure thickness of plate and pipe from one side and whilst hot has led to the development of simple to operate single purpose equipment which have the minimum of controls and have replaced the C.R.T. with a meter or digital presentation.

A large selection of probes are available including small fingertip types which can be inserted into small apertures, and those which can be used under water or at high temperatures. Prices for ultrasonic thickness gauges range from £400 to £700 and from £450 - £1,000 for equipments which provide defect assessment and thickness gauging facilities. Probes range from £15 to £70 each. A number of probes are required to get the best return for the money spent in the instrument. This number of probes will range from 3 to 30 or more.

8.6.0 Examples of the cost savings arising from the application of ultrasonics are given in Section 12. The running costs are low, modern sets are reliable and maintenance costs are low, whilst service from the manufacturers is good.

<u>FURTHER READING.</u>

1. Ultrasonics, Benson Carlin,
   2nd Edition, 1960
   Mc Graw Hill Book Co. Inc, New York, Toronto, London.

2. Ultrasonic Testing of Materials,
   T & H Krautkramer,
   Ultrasonic Testing of Materials Translation of Second Revised German Edition George Allen and Unwin Limited, London. £7. 10s. 0d.
   Springer Verlag, Berlin, Heidelberg New York.

3. Ultrasonic Methods of Testing Materials,

L. Filipczynski, Z. Pawlowski and J. Wehr,

Butterworth and Co. Ltd, London, 1966.

4. Ultrasonic Testing,

B. Lambert

Technical Report Vol. 1963, 67 - 108

British Engine Boiler and Electrical Insurance Co. Ltd.

5. Ultrasonic Thickness Gauging,

B. Lambert,

Technical Report Vol VI, 1965, p.p. 121-127

British Engine Boiler and Electrical Insurance Co. Ltd.

6. Table Section, 14

lists British Standards for N.D.T. a number of which are solely concerned with ultrasonics.

9.0 Radiography.

9.1 Scope

By the use of light, which is electro-magnetic radiation materials can be examined for surface defects, measurements can be made, and surface features assessed. However, because the majority of materials are opaque to light they cannot be examined by this method for internal defects, but they can be penetrated by electro-magnetic radiation of shorter wave-length than light, such as X and gamma rays which can thus be used to obtain information on internal features in such materials. The application of X and gamma radiation for this purpose, using photographic material as the detection and recording medium is known as radiography. The photographic material may be film, paper on plates. In this article film is used throughout.

Radiography is the production of radiographs, which provide a permanent pictorial record of internal or external features of a material or test object on a piece of photographic film.

The range of objects which can be successfully radiographed to display hidden features ranges from banknotes, plant leaves and minute electronic components to materials of a thickness equivalent to 500 mm (20 inches) of steel.

9.2 Principles

9.2.1 A beam of X or gamma rays passes through a material or a test object and impinges on a sensitized film for a pre-determined exposure period, forming a latent image. The film is then removed and processed by developing, fixing, washing and drying. The processed film showing a negative image is the radiograph which is then scrutinized on an illuminated viewer in a darkened room for interpretation and reporting.

The ability of radiography to show changes in internal or external features of materials or test object depends upon the differential absorption of radiation arising from differences in:-

(a) thickness

(b) density

(c) homogenity

A greater quantity of radiation will pass through a portion of a test object where there is a cavity than will pass through the solid material and this difference will be recorded on the radiograph as a difference in photographic density. The greater the amount of radiation transmitted the darker the radiograph in that area.

9.2.3 Nature and Properties of X and gamma rays.

X and gamma rays are short wavelength electro-magnetic radiations similar in nature to light, television and radio waves.

X and Y rays:-

Travel in straight lines and produce sharp shadows.

Are not refracted (bent) as light is when passing through glass lenses so cannot be focused in this way.

Are not affected by magnetic fields, as the electron beam in a cathode-ray tube, so cannot be focused in this way.

Conform to the Inverse Square law, e.g. If the distance from a source to a detector is doubled the intensity of radiation received will be reduced to one quarter of that at the first position.

Are ionising radiations, that is, are capable of producing ions in a gas, which enables their presence to be detected and the quantity measured.

9.2.4 **Radiographic Film.**

In contrast to photographic film, radiographic film has emulsion, a radiation sensitive layer, on both sides of the flexible transparent support material which forms the base. This double emulsion coating decreases the exposure time and improves the contrast of the image compared with a single emulsion coated film. In addition to the emulsion coatings, radiographic films have two more coatings on each side, a subbing layer to ensure that the emulsion adheres to the base and a top coat to protect the emulsion from pressure damage during handling. In practice the film is used in a light tight cassette or envelope.

To enable consistent radiographs to be produced methods have been developed for specifying certain characteristics of radiographic films, one important one is density, which is expressed in a range of numbers - the darker the film the higher the density number. However if the film is too dense (black) it will not be possible for light to penetrate it during viewing and interpretation. The density range in general industrial radiography is from 1.0 to 3.0 or 4.0.

9.2.5 **Production of X Rays**

Because the density of a particular type of film is proportional to the quantity of X or Y radiation received, and, to cope with a range of materials and thicknesses it is necessary for X ray sources to be controllable in quantity and quality. To understand how this is achieved an insight into the means whereby X rays are generated follows:-

X rays are produced when fast moving electrons are suddenly stopped by collision with a target, (the material of which may be tungsten, cobalt, chromium etc). To produce a controllable beam of X rays for radiography an X ray tube is used. This is a short glass tube closed at the ends, with an electrode sealed in at each end in which a high vacuum exists. A high voltage is applied across the two electrodes, the positive one being called the anode. The negative electrode, the cathode, consists of a coil of tungsten wire which when heated by the passage of an electric current to whist heat gives off electrons. Under the influence of the electric field electrons travel at high speed to the anode where they are stopped by collision with the target and X-rays are generated. Only about 1% electron energy is converted to X-rays so that cooling of the anode is required thus X-ray equipments require oil or water cooling.

The fact that X-rays are produced by an electron beam from a hot cathode enables two controls to be incorporated:-

1) Penetration (Quality) Varying the applied electric potential between anode and cathode will alter the penetration factor of the X-rays. Higher voltages result in the electrons colliding with the target at higher velocities with the production of shorter wavelength more penetrating radiation.

2) Quantity - Regulating the current passing through the hot wire filament by a variable voltage supply will control the temperature and the emission of electrons from it and hence the quantity of X ray radiation produced. The electron beam current can be indicated by a milliampere meter and the duration of the exposure controlled by an electronic clock thus exposures can be stated as mA seconds, or mA minutes, for a given

kilovoltage and material thickness.

X-ray equipments are referred to as 90 kVp, 150 kVp, 400 kVp or 1 MeV etc. The kVp denotes kilo-volt peak value.

The X-ray tube requires a D.C. or rectified A.C. supply although some tubes act as their own rectifier. There are a variety of circuits and arrangements for supplying the high tension and filament currents and mounting the tube etc.

9.2.4 <u>Production of Gamma Rays.</u>

Gamma rays for radiography are not generated as required in equipment designed for that purpose but are continuously emitted from a radio-active piece of material. Certain of these substances such as radium are found in Nature but those used for radiography are produced by an atomic reactor. Thus a small cylinder of iridium or cobalt is made radioactive by leaving it in the reactor for a period of weeks or months. A change in the atomic structure of the material occurs resulting in a radioactive isotope of the parting being formed, the strength of which depends on the activation time and a number of other factors.

<u>Table 2</u> sets out the two isotope sources which are in general use - Iridium 192, Cobalt 60.

Radioactive isotopes are unstable and gradually change their nature. The process may be a long and complicated one but from the radiographic viewpoint the result is that the strength of the source decreases with time, hence sources have to be replaced. The rate of decrease is fixed for each type of isotope, and a measure of the decay of activity is given by the "half life" of the isotope. The "half life" is defined as the time in which the strength of the radioactive source decreases to half its initial value. The half-lives

X-Ray sources

X-ray tube max. voltage peak kVp with lead intensifying screens	Thickness range routine work	Thickness range maximum
[illegible] 100	0–8 mm. (0·3")	12 mm. (½" mm.)
120	0–12 mm. (0·5")	18 mm. (¾ in.)
150 [illegible]	0–20 mm. (0·8")	30 mm. (1¼ in.)
200	0–30 mm. (1·2")	40 mm. (1⅝" in.)
250 [illegible]	0–45 mm. (1·8")	55 mm. (2·0 in.)
[illegible]	100 (4·0 in.)	120 mm. (4·7 in.)

Gamma-ray sources

Source	Energy of Principal Radiation MeV	Half Life	Useful thickness range in steel in millimetres and inches
Thulium 170	0·084	129 days	Thulium is mostly used for alloys.
Iridium 192	0·13–0·615	74 days	16–60 mm (⅝"–2⅜")
Caesium 137	0·667	37 years	15–100 mm. (0·6–4 in.)
Cobalt 60	1·17–1·33	5·3 years	50–150 mm. ([illegible] in.)

Table 3. Gamma-ray & X-ray Sources

of the two isotopes before-mentioned are given in Table 2. Because radio active processes are exponential in character the strength of the source after a period of two half-lives will be reduced to one quarter of the initial value and so on.

Radio isotope sources for radiography can be obtained from National centres in a number of countries. The Radio Chemical Centre of the U.K.A.E.A. Amersham, England, supplies many countries and similar facilities exist in Canada and the U.S.A. - for example.

The energy of the emitted gamma radiation is usually given in units of 1 million electron volts (1 MeV). Table 2 shows that the penetration of the radiation for the two isotopes given is above that of the 400 kV transportable X-ray equipment. This high penetration radiation enables gamma radiography to be carried out on thicker sections without incurring the expense and weight problems of the higher energy X-ray equipments. On the other hand the quantity of radiation obtained from a given radio isotope is generally less than that from an X-ray equipment so that the exposure time for a given material thickness is longer. Gamma ray sources have no controls similar to the milliamp control or the kVp control of X-ray equipments so there is less room for manoeuvre in producing good quality radiographs. However, gamma ray sources have the advantage of being capable of projection through flexible guide tubes into remote or inaccessible areas, where X-ray equipment cannot go, and are often the only method of obtaining a radiograph of plant in-situ. The fact that no electrical supplies are required can also be a useful feature.

9.3 **Applications of Radiography for Maintenance.**

9.3.1 Radiography is the main N.D.T. method for the maintenance of aircraft but in many other industries it is the minor method. One reason is because the thickness of metal which can be penetrated for a stated kVp is dependent on the density of the metal, thus, the light weight alloys used for airframes and fuselage afford good scope for X-rays equipment in the 50 - 250 kVp range, which are relatively light and portable. Applications to aircraft maintenance include:-

(a) Examining aircraft to check on the presence and severity of metal corrosion or damage to skin joints and rivets.

(b) Ditto for fatigue cracking

(c) Monitoring corrosion and crack growth

(d) Searching and debris and checking the run of control systems to ensure they are able to function correctly.

(e) Location of carbon build-up in pipes and monitoring the condition of jet engine flame tubes.

The financial savings achieved by the use of radiography can be high, because the information can be obtained without dismantling components or structures saving manhours and reducing outage time.

9.3.2 **Applications to other plant**

In those industries where the major materials used in plant construction are iron and steel radiography is employed on a more limited scale.

Applications include:-

Castings, Turbine cylinders, Valve bodies, etc.

9.3.3 **Radiographic Techniques.**

9.3.3.1 In cases where an appropriate radiographic technique does not exist it is desirable that a technique be established and put in writing for each application. This is essential when repeat exposures of plant are to be made. Because a radiograph can be produced by one person and then sent for interpretation to a second person who may be kilometres away, it is also essential that the interpretor knows the detail of the radiographic technique employed.

The establishment of a satisfactory technique usually involves a number of experimental exposures, and is best carried out initially in a radiographic laboratory before going to site. To establish confidence in the technique and assist interpretation it is often necessary to dismantle and section the test object and all results from such action should be recorded by photographs and/or drawings.

9.3.3.2 Radiographic Techniques - Examples

Examples of radiographic procedures and techniques are available in a number of British Standards, International Standards Organisation Recommendations and other documents e.g. BS 2910: 1965. General Recommendations for the Radiographic Examination of Fusion Welded Butt Joints in Steel Pipes, BS 2600: 1962. General Recommendations for the Radiographic Examination of Fusion. Welded Butt Joints in Steel. Air Registration Board (United Kingdom) Civil Aircraft Inspection. Procedures Document BL/8-4 illustrates a typical Technique Data Sheet. Basically a Technique Sheet should contain all the information needed for repeat radiography to be carried out under identical conditions with the original.

9.4 Preparation - Safety

9.4.1 To enable an object to be radiographed it is necessary to place the film on one side and the source, lead letters for identification and image quality indicator on the other, thus in general it is necessary for a human being to be able to reach the area where the radiograph is to be positioned. (There are exceptions when gamma guide tubes are used). For in-situ work scaffolding or elevating platforms may be required. The question of the surface particularly of welds, and whether they should be ground flush is a debatable point. B.S. 4080: 1966. N.D.T. of Steel Castings, 8.1 Surface Preparation states - Castings shall be fettled and loose scale and excessive roughness shall be removed. A good "as cast" surface is adequate. In the case of Weldments the question of surface preparation is more critical. BS 2910: 1965 Radiographic examination of Welds - Section 6, Surface Condition states -

"To obtain maximum flaw sensitivity the part of the work to be examined should be smooth and free from irregularities such as weld ripples, grinding or chipping marks. The contour of the weld surface should be smooth and any change of section should be gradual. By agreement between the contracting parties, the weld may be radiographed in the undressed condition".

In practice grinding off the weld overburn can be costly in time and money, so the significant sentence is the first one - unground welds can lower defect sensitivity. Whether the surface is dressed or not a close visual examination of the surfaces is essential, because chips, weld spatter etc. can cause difficulties in interpretation. If the surface is not prepared this should be stated in the Report and any surface markings should be noted.

9.A.2 Safety

Transportable Gamma Source containers and X-ray equipments weigh from 19 kg upwards and attention must be given to provision of ladders, lifting tackle, scaffolding and safe electrical supplies. These are no different from normal safety requirements for site or workshop conditions, but because radiography employs ionising radiations which can affect the human body additional radiographic safety rules must be understood and followed. Radiographic safety has to be considered in relation to the Radiographic Staff, whose exposure to radiation (if any) is monitored by film badges and dosemeters and who have periodic blood counts and medical examinations, and in relation to non-monitored personnel. Where radiography is carried out in a properly constructed laboratory then generally Radiographic Staff only are involved. Where radiography is carried out in workshops where a walled enclosure, using concrete lead plywood panels etc. can be provided, again radiographic Staff are mainly involved, although due attention must be paid to the possibility of scattered radiation reaching workers outside the barrier. When on-site radiography is required, it may be necessary to stop work on adjacent plant leading to a delay. However, this can often be avoided by pre-planning so that the radiography is carried out during a meal break or after day work has finished. For site work it is necessary to erect barriers of rope or other material, warning notices and flashing lights round the object to be radiographed, making a radioactive zone, which must be considered as a sphere particularly in a multistorey building. Regulations state the maximum permissible radiation dose permitted at the barrier, and using a dose-rate meter (monitor) this distance can be readily defined.

As a guide when using a low strength (5 Curie) Ir 192 source the radius of the radiation zone will be 9 metres or less. It is also possible to reduce this if necessary by the use of a lead shielding muff.

There are International and National Regulations governing the storage, transport and operation of gamma ray sources, and the operation of X-ray equipments. (X-ray equipments only emit ionising radiation when electrical supplies are switched on). In the United Kingdom the major documents controlling Industrial Radiography practice are, Radioactive Substances Act 1948, which gives authority for the use of radioactive materials. Radioactive Substances Act 1960. Mainly concerned with accumulation and disposal of radioactive materials and registration of users of same.

Ionising Radiations (Sealed Sources) Regulations Statutory Instrument (S.I.) 1470. Current Edition and a number of Statuatory Instruments covering personnel film badges and records.

Organisations which use radiography must have a trained and responsible person or persons in charge of this work. Where only a small amount of radiography is used it may be preferable to employ one of the N.D.T. contract organisations who provide a world-wide service employing trained personnel.

9.3 Equipment and Costs

9.3.1 Equipment

Gamma or X-ray source, storage, exposure room, film processing room (dark room) viewing room and office for records.

The cost and scope of the building will depend on whether radiography is carried out in the building or in the works or at site. In one case known to the author, consisting of an adequately shielded building with full facilities, including a 5 ton gantry crane the cost was approximately £10,000. The cost of X-ray equipments is approximately £2,[illegible], and gamma source containers £300 and above. However, where all radiography will be carried out in a workshop or a site

It will be possible to start with one gamma source, storage safe, and darkroom for £1,000 approximately. If a 200 kV Tank X-ray set is also purchased this will cost a further

Operating costs have been calculated at approximately £1 per radiograph produced for a production laboratory with a good work load, or 30/- per foot of weld or a ship. The cost on a smaller volume of work may be higher.

9.3.2 **Savings.**

Where radiography is used in aircraft to save downtime and manhours very substantial savings are reported e.g. 230 man-hours on one inspection. Where the object is quality control of repairs to castings and welds, including ensuring defects are removed before repairs start then the financial return is not so straightforward, but with an outage of one week say, due to inadequate repair on a critical component costing anything from £1,000 and £20,000 per week the cost of the radiography is well justified.

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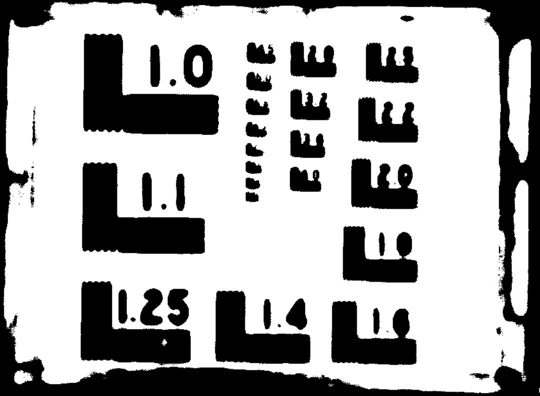


SECTION 10 - EDDY CURRENT & POTENTIAL [illegible]

10. EDDY CURRENT AND POTENTIAL GRADIENT

10.1 Scope

The major applications of eddy current tests is in production where the advantages of contact-less high speed operation enable the tests to be carried out on line. Eddy current tests are limited to detection of defects at or near the surface.

Eddy current tests can be carried out on all materials which are electrical conductors. They are used for crack detection, depth of crack measurement, detection of erosion and corrosion of non ferrous tubes in heat exchangers. Sorting of metals and measurement of conductivity. There are other applications but those listed above are used for plant maintenance.

Potential gradient tests are limited to three applications, thickness measurement, crack depth measurement and for testing the bonding of white metal bearing linings. There are of course well established electrical testing instruments such as the Ductor, which can be used to measure electrical contact resistance but these are outside the scope of this paper.

10.2 Principles

10.2.1 Eddy currents are induced currents which circulate within a piece of metal, generally they follow a circular path if the material is flawless. The name arises from an analogy of eddies in a backwater of a river or stream. In Section 4 para 2.2 reference was made to the fact that whenever an electric current flows through a conductor it sets up a magnetic field at right angles to the direction of current flow. If such a magnetic field is produced by an alternating current flowing in a coil it will also vary in strength; furthermore if a piece of metal is placed in this varying magnetic field eddy currents will be induced in the metal. These eddy currents will in turn produce a varying magnetic field which acts on the coil and produces a change in the excitation current.

Removal of the piece of metal or replacement by other pieces of different electrical conductivity, permeability and geometry can all be detected by a suitable arrangement of coil(s) and electronic circuitry.

10.2.2 <u>Factors affecting Testing</u>

Eddy current testing must take account of the geometry of the object, that is the dimensions, shape and size - Factors in the metal itself, that is, changes in the nature of the metal i.e. ferrous or non-ferrous and specific conduction caused by variations in composition (chemical purity), alloy composition, hardness, work hardening, heat treatment, grain orientation, residual stresses, - nature and type of defects. Factors in eddy current testing over which control can be exercised are as follows:-

10.2.3 <u>Coils</u> - The coil or coils are the means by which the magnetic field is directed to the test object and information on its condition returned. There are three basic types of coil - (a) Encircling Coil, which surrounds the material under test. This is largely used for production inspection and testing. (b) Internal coil, a coil which is surrounded by the material under test. (c) Surface coil - A coil shaped to conform to the geometry of the material under test. Coils b and c are often ina probe and are the types most used for site work.

To provide the primary or exitation field and to detect defects two coils may be used, a primary (excitation) coil and a secondary (detection) coil. However one coil can be successfully used for both purposes which simplifies coil design and makes for a compact assembly.

To assist in distinguishing between changes in the test object which are not significant and those which are significant, the size, shape and number of turns of the coil(s) can be controlled. This enables a coil or probe to be designed which will ignore some aspects while responding to others. For example with a large area probe small defects will be ignored when measuring thickness or conductivity whilst small area probes can be so arranged that they take notice of small defects whilst ignoring slow changes in conductivity or thickness. Shielded probes with a 'window' can examine a limited area of the surface as opposed to the 360° circumferential field of an unshielded probe. Sensitivity to thinning can be controlled by adjusting the ratio of turns on a twin coil probe.

As in magnetic testing it is necessary to consider the relationship between the direction of the applied magnetic field and that of the expected defect. For example in eddy current testing of tubes it is usual to use a solenoid type coil, either encircling or internal, the long axis of which lies along the bore of the tube, this arrangement will detect longitudinal cracks, but not narrow circumferential cracks because they do not distort the eddy current flow pattern as do the longitudinal ones.

The coils themselves are arranged in three ways depending on the test requirements.

(a) Absolute system which measures independently of any external comparison standard.

(b) Comparative system which measures a difference between two separate test pieces.

(c) Differential system (auto-comparator) which compares two adjacent portions of the material under test.

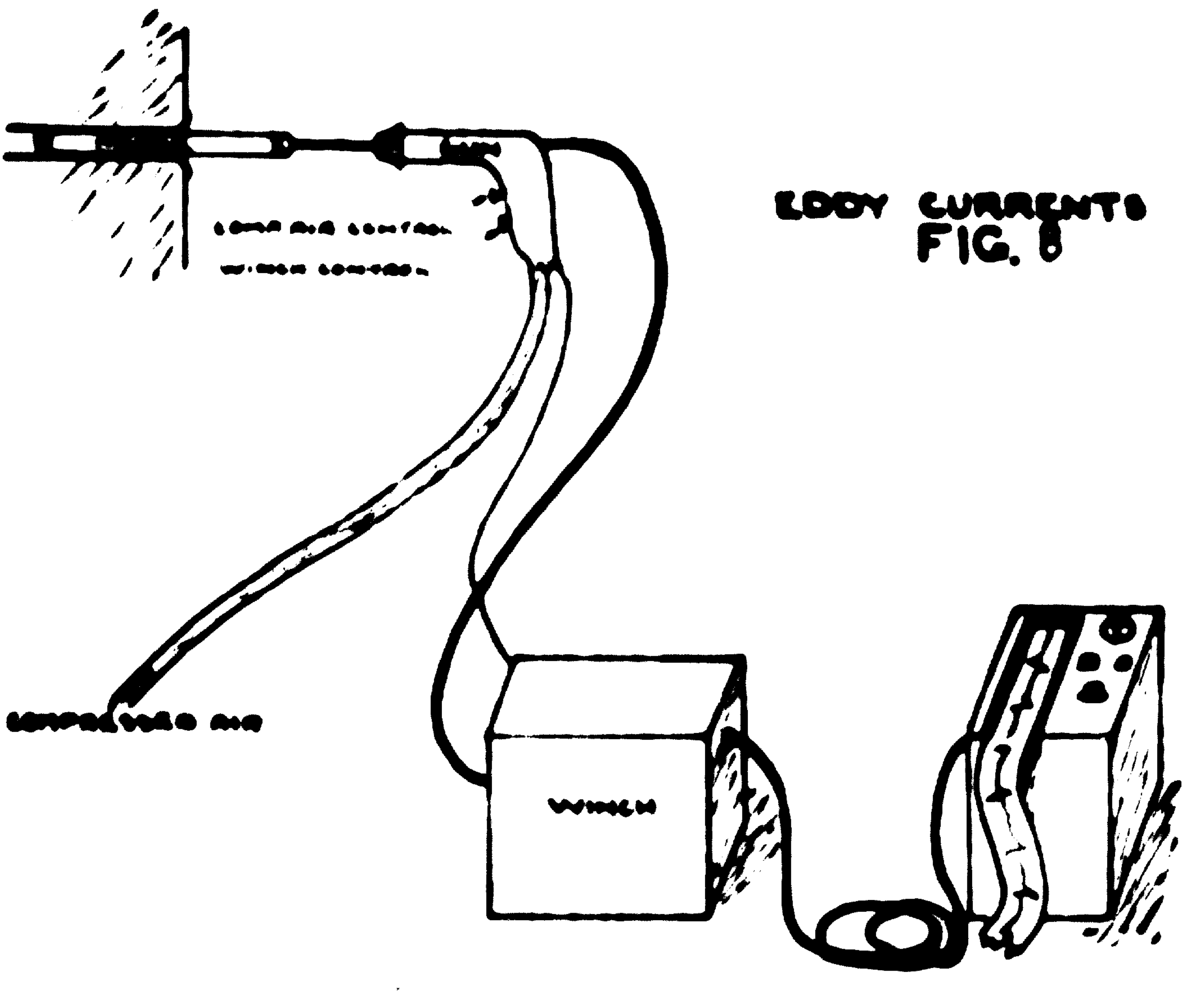
10.2.4 Penetration Depth

Unlike X and gamma radiation or ultrasonic energy, eddy currents have a very limited penetration into metals. The depth of penetration will affect the ability to detect internal defects and it is necessary to control it for specific applications.

Theoretically the eddy current density decreases from the surface in an exponential manner due to the skin-effect; the depth below the surface where the eddy current density has decreased to 37% of the surface density is called the skin depth or penetration depth. There are three factors that control the skin depth - resistivity symbol ρ, the relative permeability, symbol μ and the frequency symbol f, of the applied current and hence magnetic field. The usual formula for skin depth is -

$$\text{Skin depth} = \frac{1}{2\pi}\sqrt{\frac{\rho}{\mu f}}$$

Tables are available based on this formula listing the depth of penetration for various materials at various frequencies. However, these are for one situation and in practise if the tables or formula are



EDDY CURRENTS
FIG. 8

used it is necessary to apply a correction factor based on practical investigations.

10.9.3 Having indicated how the coil(s) system and arrangement and depth of penetration can be controlled a brief description of one type of instrument designed for testing non-ferrous heat exchanger tubes follows.

The instrument consists of a power supply unit, a 1,000 KHz, 1.10 and 100 KHz oscillator, an inductance bridge, a high gain A.C. amplifier, and a phase discriminator connected to a high speed recorder. The oscillator produces an A.C. signal which energises a probe (via a phase shift network) whose twin search coils form two arms of the inductance bridge.

A phase control network for tubes of different resistivities is included. The network is designed for Cupro-nickel, Brass and Copper and with switch at "Various" position, other materials may be tested.

When the probe is inserted into the tube under test, eddy currents are set up, and penetrate the tube. These eddy currents which are dependent on the characteristics of the tube modify the impedance of the probe coils and the bridge has to be balanced for zero output using the inductive and resistive controls.

When changes occur in the metal tube due to corrosion, holes or cracks, an out-of-balance voltage is produced across the bridge. This voltage is then amplified in the high gain A.C. amplifier and passes to the phase discriminator. This discriminator output is applied to output power stage driving a recorder, giving a resultant pen deflection.

When the probe passes through a tube, a defect will effect one coil before the other giving a pen deflection one way and then the other for thinning the pen will be effected by an amount proportional to the thinning.

Other types of instruments differ in the way in which the signals received from the probe coils are analysed but all instruments have the basic features of a probe consisting of coils wound on a core with a protective outer cover, usually stainless steel, connected to the instrument by a cable. An air operated gun for shooting the probe through the tubes and an electronic or air operated winder to pull the probe back, and a chart recorder to provide a record of every tube probed.

10.3 Applications and Procedures

10.3.1 The applications of eddy currents to production for sorting materials, testing a variety of cylindrical, spherical and other shaped components for defects and on-line inspection in tube mills are well established. The applications to plant maintenance are fewer, but are growing, in aircraft maintenance eddy current techniques are used for crack detection and measurement and the assessment of corrosion. On railways the recently developed Amlec instrument is finding wide use, over 60 having been purchased by one country alone.

Eddy current equipments are being used for in-situ materials sorting - see Section 11. and increasingly for the in-situ inspection of non-ferrous heat exchanger tubing, where they are the only practicable technique for the number and extent of tubing involved.

Two applications are discussed by the author (a) Portable eddy current equipments for in-situ testing of non-ferrous heat exchanger tubing. (b) Portable eddy current instruments for surface crack detection and measurement.

Detailed information on the application of the Magnetest equipment to sorting components etc. is given in a recently published book. See further reading for details at end of this Section.

10.3.2 Procedures

Non-ferrous tube testing in condensers, and other heat exchangers by a commercial eddy current equipment specifically designed for this purpose became possible in the United Kingdom in 1952/53 when the Probolog became available following development by the Shell Development Co. California.

The procedure was as follows:-

Before commencing a Probolog job obtain a tube plate diagram and details of the tubes i.e. material, age, nominal wall thickness, diameter and length. In the case of a condenser, if an extensive survey is required, arrange scaffolding for access and for main doors to be open and C.W. culvert openings to be boarded up. A visual survey is made to give a guide as to what the condition the tubes can be expected to be in particularly if there is evidence of considerable blockage of tubes. All tubes can be sighted and blocked tubes noted for attention first after the tubes have been cleaned. It is desirable for the tubes to be washed through and the blocked ones rodded, if the tubes have dried out during a long shut-down period it may be necessary to wet them to reduce probe friction. Select a probe the nearest fit to the tube, as the smallest gap consistent with freedom from jamming is desirable. If there is too large a gap the probe will lie on the bottom of the tube and interpretation would be rendered difficult, consider equal sized defects on the top and bottom of the tube, the magnetic field reaching the top defect will be less than reaching the bottom one and equal reading will not be obtained from equal sized defects.

When the equipment is in position, electrical and air supplies connected and hand lamp at both ends the probing can commence. Start by setting-up the instrument with the probe in a standard tube of 1.5 m length of the same material, wall thickness and internal diameter as those to be tested. The standard tube will have a number of external or internal thinnings and artificial defects in the form of holes or slots.

The instrument is set up on this standard tube with the pen on the centre line of the chart and all control settings recorded. In cases where thickness measurements on a tube bundle are being repeated over an interval of years, a standard tube is essential, but when working on erosion surveys if no standard tube is available a number of tubes are probed and an average setting established.

When a routine has become established the operation of one man shooting the probe through the tube and pulling it back by the winch whilst a second man makes the recording and studies the records as they are produced takes about 1 minute per 6 metre long tube. The standard tube is probed every hour, and at the beginning and end of every chart roll. Allowing for movement of equipment etc. 400 tubes can be probed in a 10 hr. day.

Condenser tubes suffer from several factors which may reduce their useful life: these include high velocity and turbulence in the inlet sections, steam erosion, mud water abrasion and in sea-water cooled condensers marine life such as mussels.

These factors result in pitting, corrosion, holing and local thinning, and it is necessary to relate the type of defects and their significance to the charts produced by the probolog.

One way is to extract a tubes(s) and split it axially then visually inspect, using a hand lens on a binocular microscope: a pit depth measurer and a ball micrometer also assist in determining the depth of pits and variations in wall thickness. However this cannot be called non-destructive, and whilst it is sometimes necessary to resort to such destructive tests to establish N.D.T. interpretation and standards, getting a condenser tube out can be a time consuming and costly job. The use of an endoscope is therefore the first step in interpretation and methods of taking an impression of a pit by use of plasticene or other media.

10.3.2.1 <u>Crack detection and depth measurement</u>

An eddy current instrument the Amlec has been developed by the Ministry of Defence (Navy) specifically for crack detection in ferrous materials for example welds and other objects, without requiring the removal of paint rust or dirt and the work involved in magnetic particle inspection. The equipment which is available commercially comprises a small battery operated transistorised instrument connected to probe by a flexible cable.

The general purpose probe provided with the unit operates at 5 kHz, and scans an area approximately 1 x ½ in. The probe is designed to have a minimum "air gap" of 0.050 in., providing lift-off compensation better than ± 3% of full-scale deflection. In use, the probe is placed upon the surface of the work and then removed whilst adjusting the lift-off control, this repeated until the position of the needle of the instrument becomes essentially independent of the distance of the probe from the work piece. A range of probes are for various types of work are available.

Cracks can be detected from a depth of 0.015 in. upwards by scanning suspect areas with suitable probes, and by observing the deflection of the meter. Indication of actual crack depth in the range 0.015 to 0.50 in., can be obtained to an accuracy of about ± 25%. It is essential that the crack breaks surface, since the instrument measures the surface conductivity of the material.

A second instrument designed for the measurement of cracks and similar type surface defects is the Defectometer 2.154 manufactured by Institute Dr. Forster. This apparatus uses eddy-currents for the measurement of surface defects such as cracks and laps. Depending on the type of probe, crack depths up to 8 mm can be determined. Bore-hole probes for a range of diameters from 4 to 12 mm with two adjustable bore-hole probes for ranges between 12 - 25 mm are available. There are three switched frequency ranges to cover ferro-magnetic, non-ferromagnetic and austenitic metals.

Note:- Another type of instrument for crack depth measurement is dealt with under the potential Gradient Technique later in this same Section.

Both the Amlec and the Defectometer can also be used for a range of other work such as materials sorting.

10.4.0 <u>Safety and Preparation</u>

10.4.1 <u>Safety</u>: No special safety precautions are necessary with the equipments described, provided attention is paid to safety of electrical supplies particularly on wet condenser waterboxes.

10.4.2 <u>Preparation</u>: Some aspects of preparation have been dealt with in preceding text. Generally eddy currents do not require surface grinding, blasting or special cleaning but surfaces should be free from metallic particles, scale and other foreign matter which could give rise to misleading results. A good wire brushing can be used if considered desirable. An exception to the above is when using a Probolog type instrument for condenser tubes, here pre-cleaning by water etc. is necessary.

10.5 Equipment Costs and Saving

10.5.1 Eddy current equipment comes in two forms, multipurpose equipment which by means of plug-in parts such as frequency modules and a variety of probes can cope with a number of applications. The alternative is equipment designed for one specific purpose. Before purchase of any eddy current equipment consultation with a manufacturer is desirable. The range of prices in the U.K. is from approximately £125 for an Amlec instrument to approximately £4000 for the model 70 Probolog with a selection of probes.

10.5.2 Savings: The savings arising from the application of eddy current techniques arise from saving manhours in dismantling, as in aircraft maintenance, and avoiding losses due to unplanned plant outages and reduced efficiency in power stations by providing information on the condition of inaccessible non ferrous heat exchanger.

Further Reading

1) Vol.2. Non destructive Testing Handbook - Edited for ASNT by R.C.McMaster. The Ronald Press Company, New York 1963.

2) Electrical, Magnetic and Visual Methods of Testing Materials J.Blitz, W.G.King and D.G.Rodgers. Butterworths, London 1969 £3.25.

3) Eddy-current testing of Condenser Tubes. J.P.Batin. Non-destructive Testing Vol.3. No.1 Feb. 1970 pgs. 34 - 39.

4) British Standards, see list Section 14.

SECTION 10.A - POTENTIAL GRADIENT

10.A.1 Scope. Potential Gradiant Measurement of crack depth in electrically condutive materials, and measurement of thickness of plates from one side, and testing bonding of white metal lining to base material in bearings.

10.A.2 Principle

The principle on which this method is based is that the electrical resistance between two current prods on the surface of a relatively thin metal plate is inversely proportional to the thickness, with the voltage applied between the prods kept constant for a particular test. In practise two prods are not feasible for a number of reasons and 4 prods or points are required for a workable method. If four in-line electrodes are placed in contact with a metal object and a current 1 amperes is passed between the two outer electrodes, a potential gradient will be produced between them. This potential gradient can be measured by connecting a sensitive galvonometer to the two inner prods.

10.A.3.1 Applications Procedures

For the testing of the bonding of white metal linings to bearings a commercial instrument, the Hoyt Bond Tester, is obtainable from the Hoyt Metal Company of Great Britain Ltd., Deodar Road, Putney, London S.W.15.

Note:- Ultrasonic techniques for bond testing are discussed in Section 8.

10.A.3.2 For the measurement of crack depth by this method, two instruments have been developed by Dr.Karl Deutsch of Germany. These are commercially available as the RMG and RT10 gauges. The RT10 has rechargeable batteries and can be readily taken to plant.

These equipments are used to measure the depth of a crack which has been found by visual or magnetic methods. Whilst crack depth measurements by eddy current techniques are possible, the potential gradient method can deal with deeper cracks, measurements to a depth of 100 mm being quoted.

10.A.3.3 For thickness measurement the author knows of no commercial equipment. The main advantage of this technique being the ability to cope with rusty or dirty surfaces. A number of organisations have constructed and used equipments based on this principle, and measurements of the thickness of plate type and tubular type air heaters have been carried out by the author's colleagues for several years. Information on the design of such equipment is given in the ASNT - Non destructive Testing Handbook. Section 33 Vol.II.

10.A.4 Preparation & Safety

Little surface preparation is required for thickness measurement using hardened steel points to the prods. For crack depth measurement local cleaning of the contact area by emery cloth or other means may be necessary. For the Hoyt Bond Tester the manufacturers suggest that on occasions when the "as-cast" white metal surface has an oxidised skin and may be dirty from contact with the lining mandrel it is preferable to lightly machine the bore before testing.

There are no unusual safety precautions required, where mains electrical supplies are required then attention must be paid to this aspect.

10.A.5 Equipment, Costs and Savings

The cost of the equipments metioned is relatively modest.

As they are robustly constructed, maintenance costs should be low.

Savings

The economic savings from obtaining accurate and reliable information on the depth of a crack, or whether it is a crack or surface marks can be surprisingly high. Often specifications call for rejection of a component if a crack exceeds a stated depth, measurement may mean the difference between rejection and acceptance. Again many plant items can remain in service with cracks provided their depth and extent are known and it is known whether they are progressing - repeat measurements can thus save scrapping plant.

Further Reading ASNT Handbook of N.D.T. Section 33 and papers by Thornton, B.M. listed therein.

11.0 THERMAL AND OTHER METHODS

11.1 SCOPE

11.2 THERMAL METHODS

11.2.1 INFRA-RED

11.2.2 CONTACT

11.3 MATERIALS SORTING

11.0 Thermal and Other Methods

11.1 Scope

The N.D.T. methods for plant maintenance discussed in this paper are those in daily use, in addition there is a class of which only a brief account can be given. Methods under development or not yet in general use. These are thermal methods, comprising Infra red and Thermal comparators and materials sorting equipments.

Development and complexity of N.D.T. is a continuous process, but the methods selected above all have the feature of being applicable to plant in-situ or in the repair shop. The boundaries between N.D.T. and metallurgy, welding, applied physics, mechanical, electrical and electronic engineering and chemistry are often indistinct. Thus N.D.T. methods should not be considered isolation, but should be complemented or complement metallurgical and other tests.

11.2 Thermal Methods

Electromagnetic Radiation with wave lengths longer than red light is called infra-red radiation. It is emitted by hot bodies, such as dry overheated electrical conductors,that are not yet hot enough to be luminous.

11.2.1 Thermovision equipments are now available which can scan an object emitting infra-red radiation and present the information on a cathode ray tube,similar to a television set. A built in facility enables temperature gradients or isotherms to be superimposed on the received picture, enabling temperature to be measured to a close limit. A complete equipment can be mounted on a Land-Rover or in a helicopter for surveillance of electricity supply sub-stations and transmission lines to detect overheated joints and clamps. The resistance of the joints increases due to oxidation, which results in a temperature rise which can lead to failure. The use of this method is now standard practice in at least two countries. Other applications are to detect hot axle boxes on railway locomotives carriages and wagons. Experimental work on detecting corrosion in boiler tubes is also making good progress. The capital cost of infra-red equipments of the thermovision type is approximately £8,000, a cost which can be recovered by organisations such as electricity supply where the outage of transmission line for a day can cost thousands of pounds. For the wider application of infra-red measurement to plant maintenance there are possibilities that lower priced and simpler instruments with lower resolution, will become available.

Reference - Thermography in real-time - It's application to N.D.T.
Leif Bergston and Sven Bertil Borg British Journal of N.D.T.
Vol.10 No.2 June, 1968 pages 54 - 59.

11.2.2 In power station boilers during erection and repairs tubes may become blocked, either completely or partially, by the entry of foreign bodies. When the restriction is severe tube failures can occur, leading to loss of plant availability and money. The Central Electricity Research Laboratories, Leatherhead, England have developed the C.E.R.L. contact flowmeter which can be used to compare the flow of water in boiler tubes thus providing a simple and rapid method for locating blockage or restriction in such tubes.

The basis of the method is that:-

If the tube is blocked either partially or completely, the reduced water flow rate results in a generally reduced heat transfer rate along the tube length. A blocked condition is therefore revealed by heating a small area of the tube at a convenient place and observing the subsequent cooling rate with a simple contact thermocouple instrument.

To use the instrument it is necessary to have access to some spot on the outer surface of the tube through which the water is flowing, thus a circulating water pump must be in action and scaffolding or other access is required. The test is carried out with the boiler cold. Full scale tests have been carried out on large modern boilers and blockages successfully detected. There is therefore a good possibility of this method being adopted as standard practice on new boilers, but experience shows there will be occasions when it will also be useful on existing plant. A patent for this device has been applied for, and a commercial model may become available. For further information on this instrument enquiries should be addressed to:- The author of this paper.

11.3 Materials Sorting

Equipments and methods for sorting mixed materials or components of similar appearance but dissimilar in composition and properties are well established in production. In recent years with the increased use of alloy steels it has become necessary to have ways of identifying materials at site during construction on arrival in the stores, or even in-situ. This means that generally the component cannot be passed through a sorting equipment, nor is it always possible to take a sample, particularly if a large number of components have to be sorted. The Central Electricity Generating Board Quality Control Unit, Production Inspection and Test Branch in conjunction with other users reviewed a number of equipments at a Conference held in London in February 1969. The equipments currently available operate on one of the following principles:-

1) Spectrographic
2) Eddy Current
3) Thermo Electric
4) Isotope Fluorescence Analysers.
5) Chemical, Magnetic, Spark Testing methods.

As is to be expected each type of equipment or method has advantages and disadvantages, there is no cure-all, and choice of an equipment will be governed by factors such as volume of testing, time, access etc. It is therefore suggested that persons wishing to use such instruments should contact the author of this paper.

Further Reading

Infra-Red Radiation

A.Vasko English Translation of Czech edition, published by

Iliffe Books Ltd., 42 Russell Square, London W.C.2.

Sorting Mixed Materials. Chapter 15

Non Destructive Testing. J.F.Hinsley. Macdonald and Evans Ltd.,

London, 1959.

12.0 Selection of Method & Examples of Applications.

12.1 Selection of N.D.T. Method

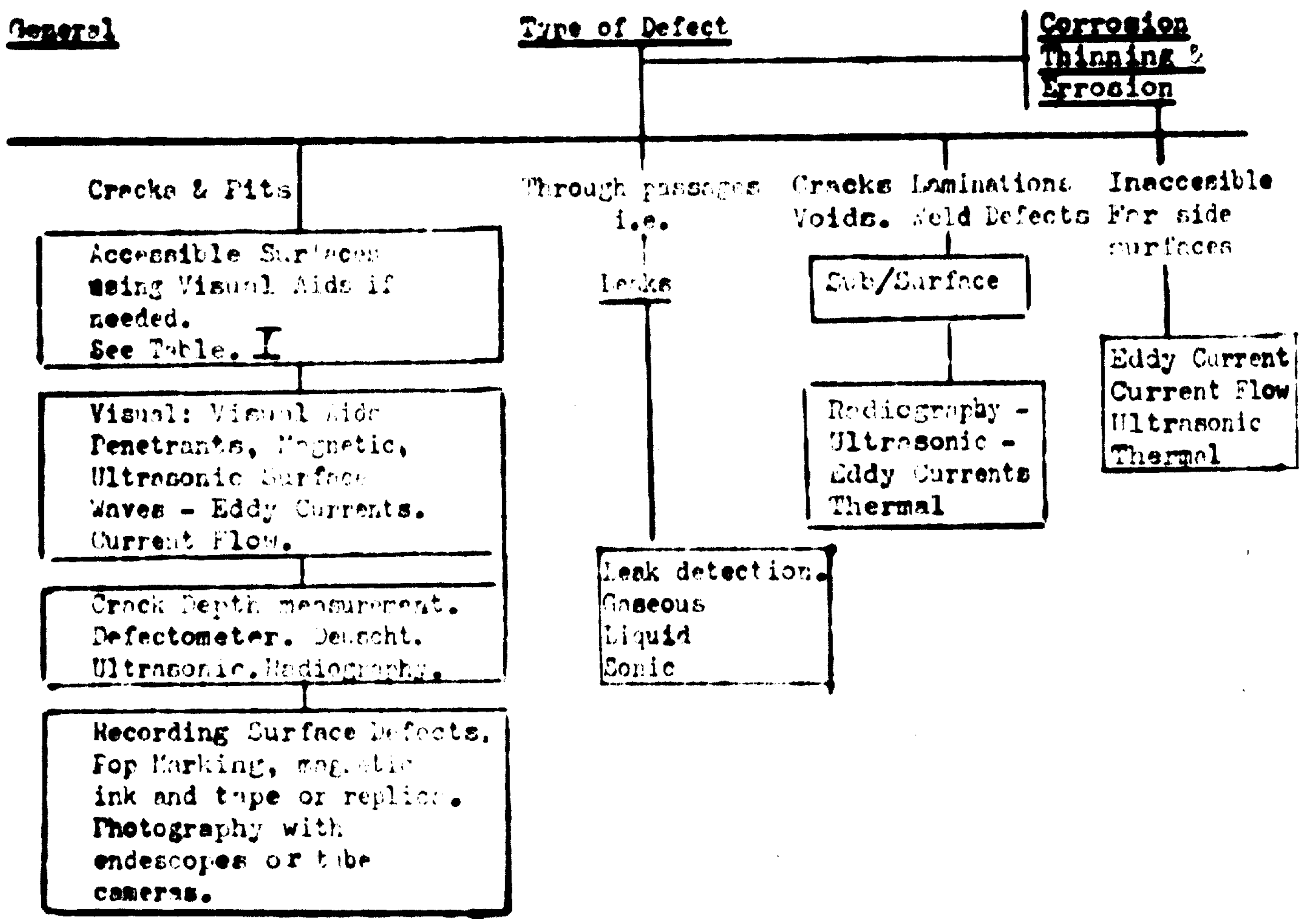


TABLE 4

SELECTION OF N.D.T. METHODS RELATING TO CRACK DETECTION

	PLANT: 1 Ferrous Metals	2 Non Ferrous Metals	3 Fabrications	4 Welds	5 Castings	6 Forgings	TEST: 7 Surface preparation	8 Acid or Etch	9 Visual	10 Penetrant	11 Magnetic	12 Pressure
BS3683: Pt.1: 1963 Glossary of terms used in N.D.T. Part 1 Penetrant Flaw Detection										•		
BS3683: Pt.2: 1963 " " " " " " Part 2 Magnetic Particle Flaw Detection											•	
BS4069: 1966 Specification for Magnetic Flaw Detection Inks & Powders (Supercedes M27)											•	
BS4416: 1969 Method for Penetrant Testing of Welded or Brazed Joints in Metals	•	•		•			•			•		
BS4206: 1967 Methods of Testing Fusion Welds in Copper & Copper Alloys		•		•				•	•			
BS4080: 1966 Methods for N.D.T. of Steel Castings	•				•		•	•	•	•	•	•
BS4124: Pt.2: 1968 Methods for N.D.T. of Steel Forgings. Pt.2. Magnetic particle flaw detection.	•					•	•				•	
BS4124: Pt.3: 1968 " " " " " " Pt.3 Penetrant Flaw detection.	•					•				•		
BS4232: 1967: Specification for Surface Finish of Blast Cleaned Steel for Painting.	•						•					

EXAMPLES OF APPLICATION

Test for: Bond or adhesion

Methods: (a) Ultrasonic

(b) Hoyt Bondmeter

(c) Dye Penetrant Kit

Plant: White metal lined plain bearings/thrust Pads, Brazed Pipe Joints.

Example: Bearing Lining Bond

Ultrasonic: A 10 mm diameter 5 MHz normal, 10/0/5 probe, is scanned over the lining, and any areas of non bond noted. This technique is in effect a thickness measuring one, patches of non-bond reflect the ultrasonic energy giving a "thinning" indication.

<u>Hoyt Bondmeter, (Current Flow Technique)</u>

No special skill required, indication is on a meter.

<u>Red Dye Penetrant</u>

Standard dye penetrant procedure

Where lack of edge bond is suspected, or cracks or porosity in the lining dye penetrant procedure can be used.

Standards: The author knows of no published standards on the permissible amount of non-bond for bearings or brazed pipe joints etc. The following figures are given as a guide.

Desirable to obtain total bonding, or 90% non-bond, to be in scattered small areas away from edges. Edge bond - 100%

Reference: The Hoyt Book on the Lined Bearing, Edited A.A.Adams, Current Edition.

SECTION 13.0 Training & Manuals

19.1 Scope

13.2 Definition of Training

13.3 Need for Training in N.D.T.

13.4 Organisation of Training

13.4.1 Training Officer

13.4.2 Training General

13.4.3 Training Schemes

13.4.3.1 Table - Training and Qualification - NDT Personnel

13.4.3.2 Planning Training

13.4.3.3 Personnel Grades

13.4.3.4 Syllabuses

13.4.3.5 Courses

13.4.3.6 N.D.T. Training Material

13.4.3.7 Manuals & Procedures

13.0 TRAINING AND MANUALS

13.1 Scope

This section provides information on schemes for non-destructive testing personnel qualification in North America, Japan and the United Kingdom. The organisation of Training Courses, the provision of glossaries, standards, reference works, manuals and procedure instructions as aiding the task of training are discussed.

13.2 Definition of Training

13.2.1 In the United Kingdom the need for training as distinct from education has been the subject of much discussion in recent years and this has led to a definition of training as:

"The systematic development of the attitude/knowledge/skill pattern required by an individual in order to perform adequately a given task or job".

Education is defined as:

"Activities which aim at developing the knowledge, moral values and understanding required in all walks of life, rather than knowledge and skill relating to only a limited field of activity". (From Glossary of Training Terms Ministry of Labour H.M.S.O. 4s. [illegible])

In a narrow sense training is the acquisition of a skill in carrying out a task, and education is the acquiring of knowledge. In practice training and education are interwoven and the amount and balance of each in an N.D.T. course are dependent on the level of knowledge and skill required by the person and task for which the course is designed.

13.3 The Need for Training in N.D.T.

The satisfactory and reliable performance of Non-Destructive Testing depends on the Tester having both practical skill and a basic theoretical knowledge of the method or methods and techniques which he employs. Because N.D.T. is a subject which involves many aspects of materials, engineering science and physics, the provision of some form of systematic training is necessary. Expressing these sentiments in another form - There is a 'right' and a 'wrong' way of doing every Non-Destructive Test. In many cases using the wrong way it is possible to show that a test object is defect free. The knowledge, skill and integrity of the Tester are the best safeguard that the right way will be used and any indications interpreted correctly. A Tester who has assimilated a carefully prepared and systematic course or courses of instruction is better equipped to select and use the right way and to appreciate the importance of his choice.

13.4 Organisation of Training

13.4.1 A decision having been reached that an expenditure of effort and money on training N.D.T. personnel will benefit the organisation and the individual the first step is to make a person or persons responsible for organising and supervising a training scheme and programme. Such a person may be a member of the Training Department or N.D.T. staff. Alternatively, in an organisation where N.D.T. is not yet employed a person who has a genuine interest in N.D.T. training and the trainees may be selected.

13.4.2 In general training requires Administrative machinery to deal with the provision of accommodation, finance transport and records, etc. and technical knowledge and experience to establish and conduct tuition and if necessary examinations in the theory, practice and practical aspects od N.D.T. The specialised aspects of training as such are not dealt with in this paper, but information is available in a number of publications and periodicals.

Under the U.K. Industrial Training Act 1964 a comprehensive system of training schemes and facilities has been established, based on having a Training Board for each type of industry. There are now approximately 30 such Training Boards; as a reference source on a systematic approach to training covering a wide range of personnel the author suggests the publications of the:

Engineering Industry Training Board,
140 Tottenham Court Road,
London W1P 9LN.

There are also Institutes and Associations devoted solely to assisting industrial and commercial training and education, one such is the

British Association for Commercial and Industrial Education,
16 Park Cresent,
London W.I. (known as B.A.C.I.E.)

Organisations such as BACIE are a source of information on teaching aids such as films, programmed learning, etc.

In addition to the certification of N.D.T. personnel, Japan and Canada have taken action to ensure organisations providing welding inspection services conform to a known standard. In Japan the Japanese Welding Engineering Society has a Radiographic Testing Committee (RAC). This checks and qualifies the technical capabilities for radiography of the inspection companies. Testing facilities of companies must reach a satisfactory standard and test personnel must consist of at least two supervisors and five technicians who have to be qualified by RAC by examination. This certification is for companies only, not individuals. In Canada the Canadian Standards Association have published a code - Qualification code for welding inspection organisations CSA W178-1966 which sets out standards for qualification of organisations performing welding inspection and the procedures to be followed in maintaining this qualification. The standard is administered by the Canadian Welding Bureau and requirements for certification are set out in some detail. The code establishes categories such as buildings, bridges, ships and pipelines. Standard inspection procedures and test procedures have to be submitted for all work and these must be approved by the Bureau. The test methods will include all forms of N.D.T. used. Personnel are classed as, welding division supervisor, senior welding inspector, junior welding inspector, and test equipment operator.

13.4.3 N.D.T. Training Schemes

13.4.3.1 Table summarises the work which has led to the establishment of N.D.T. personnel qualification and certification schemes in Canada, U.S.A., Japan and the United Kingdom. These schemes are well documented and provide a valuable guide to establishing a training scheme which conforms to a nationally recognised pattern. The scheme produced by the American Society for NDT - Recommended Practice No. SNT-TC-1A provides in 5 slim volumes and 2 appendices the information needed to establish an NDT personnel training and qualification scheme for the modest price of approximately $ 11.00.

13.4.3.2 Planning Training

An approach to planning and organising an NDT personnel training scheme is as follows:

Write a Job Description

Carry out Job Analysis including levels of skill and knowledge and document same.

Personnel Grades, Examinations and Qualifications.

TABLE 6

TRAINING AND QUALIFICATION - N.D.T. PERSONNEL

COUNTRY	GRADE (Top)	GRADE	GRADE	GRADE (Bottom)
Canada One method only. Radiography, covers safety and techniques. Examinations comprising written and practical tests are conducted by the Physical Metallurgy Division of the Mines Branch, Dept. of Energy Mines and Resources on behalf of the C.G.S.B. A certificate is issued to successful candidates. Written examinations are held in many locations in Canada. Practical tests are conducted at a few centres. To date there are approximately 600 Junior and 200 Senior Grade certificated industrial radiographers in Canada.			N.B.: Industrial Radiographers must be certified to work in Canada. Examinations conducted by Canadian Government Staff, as below B. Senior Industrial Radiographer Able to assume full responsibility for a Radiographic laboratory and staff. May be certified in the following categories. (a) Light Alloy Castings and Forgings. (b) Welds and Weldments. (c) Heavy Metal.Castings and forgings. (d) Aircraft structures. Document: Canadian Government Specifications Board and Standard for Certification of Industrial Radiographic Personnel. 48-GP-4. October 1960.	A. Junior Industrial Radiographer Can carry out industrial radiography under supervision, is not responsible for choice of technique or assessment of radiographs.

/Cont'd

TABLE [illegible] - [illegible]ining and Qualification - N.D.T. Personnel (cont.)

COUNTRY	GRADE (Top)	GRADE [illegible]	GRADE [illegible]	GRADE (Bottom)
United States of America 5 methods at present: a. Radiography b. Magnetic Particle c. Ultrasonic d. Penetrant e. Eddy Current Examination procedures established by the Employer. Conducted by Level III N.D.T. person. Examinations comprise written and practical work. The educational level expected of candidates and training course programs are set out in Document SNT-TC-1A. See Pgs. 13A-19A Materials Evaluation Dec. 1969 for article by H. Hovland, describing the philosophy behind this type of employer certification procedure.		N.D.T. Level III Capable of establishing techniques, interpreting specifications and codes, designating the particular test method and techniques to be used and interpreting the results. Have sufficient practical background in applicable materials technology to assist in establishing tests and acceptance criteria when none are otherwise available. It is desirable that he have general familiarity with all other commonly used N.D.T. methods. Shall be responsible for conducting examinations of N.D.T. Level I and II personnel.	N.D.T. Level II Qualified to direct and carry out tests in the method certified. Able to set up and calibrate equipment, read and interpret indications and evaluate them with reference to applicable codes and specifications. Shall be familiar with scope and limitations of the method and be able to apply detailed techniques to products or parts within his limit of qualification. Shall be able to organise and report N.D.T. results.	N.D.T. Level I Must have sufficient training and experience to properly perform the necessary tests. Responsible to N.D.T. Level II or III for proper performance of the tests in the applicable method.
		Documents: SNT-TC-1A N.D.T. Personnel Qualification and Certification Recommended Practise No. SNT-TC-1A published as five separate books, designated supplements each covering one of the five methods. 1966. Set of 5 books $10.00 from the Society for Non-Destructive Testing. 914 Chicago Avenue, Evanston, Illinois, 60202. U.S.A. Appendices 1 and 2 for supplements D and E, general examination question published in 1968. Additional to SNT-TC-1A a set of Programmed Instruction (Ref. Study) Handbooks, comprising 13 volumes are available, price $125.50, supplemented by 5 classroom training (ref. texts) handbooks price $30.50. The complete set of 18 volumes consists of over 4600 pages of training material and costs $156.0 also obtainable from the Soc. for Non-Destructive Testing, U.S.A.		

TABLE - Training and Qualification - N.D.T. Personnel (cont'd)

COUNTRY	GRADE (Top)	GRADE	GRADE	GRADE (Bottom)
Japan Seven methods Y-radiography High energy X-radiography Ultrasonic Magnetic Particle Eddy Current Penetrant Strain Measurement Written and oral examinations are conducted by Japanese Society for Non Destructive Inspection N.D.I. in Tokyo and Osaka. A successful candidate at level 'S' receives a certificate.		Special Grade 'S' N.B.: All industrial radiographers must pass an examination for radiographic safety conducted by Japanese Government Staff. Sufficient knowledge and training of all N.D.T. techniques. Capable of planning and performing N.D. Tests, establishing evaluation criteria and making evaluations. May be entitled certified N.D.T. Inspector.	First Grade Shall have sufficient knowledge and training about the certified N.D.T. Method. Capable of planning and performing N.D. Tests, calibrating equipments reading and evaluating results, interpreting related specifications. Able to establish acceptance criteria and report on N.D. Tests.	Shall have general knowledge and training on equipment and operating procedures for certified N.D.T. method. Qualified to perform tests and operate equipment under direction and guidance of First Grade. Not authorised to designate the particular test method to be used or evaluate results for acceptance.

Document: Education and Qualification of Non-Destructive Testing Personnel in Japan. Y.Tada. Kyowa Electronic Instruments Co. Ltd. Proceedings Fifth International Conference on Non-Destructive Testing. Published by the Queen's Printer. Ottawa, Canada.

TABLE - Training and Qualification - N.D.T. Personnel (Cont'd)

COUNTRY	GRADE (Top)	GRADE	GRADE	GRADE (Bottom)
United Kingdom Certification scheme for Weldment Inspection Personnel - C.S.W.I.P. Two Methods: Ultrasonic.		**One Grade Only** A number of categories for ultrasonic testing of various types of fusion welds in metal thickness from 6 mm and above in ferritic steels.		
Radiographic. The scheme is organised and supervised by a Management Board representative of Industry and Government users. The written and practical examinations are conducted by the Welding Institute at Cambridge on behalf of the Management Board. A certificate of proficiency for categories in each method is issued to successful candidates.		Fusion welded joints in ferrous and non-ferrous wrought and cast materials by X-ray to 400 kV and conventional gamma sources.		
		Industrial Radiologist (Welded Construction) As Grade II plus Application of codes and standards relating to radiographic techniques - Prescribing such procedures if none exist. Planning of records, reports and efficient functioning of equipment and installation.	Industrial Radiographer Grade I (Welds). As Grade II but also possess ability to interpret radiographs and assess quality of welds shown to the requirements of a written standard.	Industrial Radiographer Grade II (Welds). Apply without detailed supervision BS 2600 and 2910. Processing of films and film quality assessment. Prescribing routine weld radiography procedures. Observance safe working practices. Care of equipment and job records.
		C.S.W.I.P. is administered and operated by the Welding Institute, Abington Hall, Cambridge CB1 6AL, England. (a) Documents MB14 Terms of reference and method of working of the Management Board. (b) CSWIP-UST-1-69 Requirements for the Certification of Personnel engaged in the Ultrasonic Testing of Fusion Welded Ferritic Steels in thicknesses of 6 mm and above. (c) Specimen Examination Paper for Phase I - Ultrasonic. (d) Syllabus for Phase I - Ultrasonics. (e) Scale of Charges for Phase I (Ultrasonics) (f) Application forms for Ultrasonic Certification Test. A similar list of documents for Radiographic Phase II are also available.		

TABLE - Training and Qualification - N.D.T. Personnel (Cont'd)

COUNTRY	GRADE (Top)	GRADE	GRADE	GRADE (Bottom)
United Kingdom (Cont'd) Non-destructive testing Society of Great Britain Four groups of methods Radiological Ultrasonic Magnetic Particle and Penetrant Electrical and other recognised methods No written or practical examinations conducted by the Society, but success in appropriate City and Guilds Courses or other approved Courses are accepted. The Society aims to have corporate membership accepted as an N.D.T. qualification.	Fellow Practical requirements Not yet formulate Academic to Degre Standard	Member Practical A level of competence in any one of the four groups of methods such that: "He shall be capable" as set out in ASNT-NDT-TC-1A Document. Academic G.C.E. or 'A' Levels.	Graduate Practical A level of competence in any one of the four groups of methods such that: "He shall be capable" as set out in ASNT-NDT-TC-1A Document. Academic G.C.E. or 'A' Levels.	Affiliate and Student Non-corporate, i.e. non-voting members but associated with, or interested in, N.D.T.

Write Syllabus(es).

Courses.

Training Material.

(a) The Job Description may relate to the ability to perform one specific NDT application, or it may extend to cover the management of an NDT laboratory or Testing Group.

(b) The Job Analysis may be confined to routine or prescribed procedures, or again it may extend to the establishment of techniques, the assessment of defects and consultation on N.D.T.

Some of the factors to be considered in carrying out Job Analysis are the following:

Knowledge of the plant and location and type of defects sought or expected. Ability to select the appropriate N.D.T. method(s), equipment and techniques with an awareness of the limitations of such methods, techniques and equipment. Ability to set up, calibrate and operate correctly the selected equipment. Ability to devise techniques. Ability to distinguish between relevant and non-relevant indications. Ability to record and report test results. Knowledge of appropriate safety codes regulations and practices. Knowledge of appropriate Standards for NDT methods and acceptance where applicable. An understanding of the function of Non-destructive testing in the works organisation in relationship with other departments or sections, for example, metallurgy, welding, maintenance, operations, research etc.

13.4.3.3 Personnel Grades, Examinations and Qualifications

Table contains information on Grades of NDT personnel with levels of knowledge and responsibility. 3 grades appears the general rule and the procedure adopted by the American Society for N.D.T. - Recommended Practice No. SNT-TC-1A, of Level I (bottom) Level II and

Level III (Top) avoids the difficulties which the use of terms such as Technologist, Technician and Operator may cause. When considering personnel for specific training courses it is desirable to review their educational level and if necessary plan to spend a period on revision of subjects such as mathematics, electrical and mechanical engineering principles. The willingness of NDT personnel to attend courses and their availability must also be taken into consideration. Whilst there is at present no clearly defined NDT career structure the place of NDT training as leading to a recognised qualification such as those shown in Table should be clearly understood and stated.

13.4.3.4 Syllabuses

In devising a syllabus for a course we can again turn for guidance to Table where it will be seen that the Canadian Scheme for Radiographers places products into 4 categories. The author of this paper suggests a modification as more suitable for plant maintenance, viz.

(a) Welds and Weldments.

(b) Structures, Tanks, Cranes.

(c) Castings and Forgings.

(d) Pipes, Tubes and Ducting.

For the range of NDT methods for plant maintenance the author extends the number from 5 to 7 as follows:

1. Magnetic
2. Penetrant
3. Visual Aids
4. Leak Tests
5. Ultrasonic (includes Thickness Gauging)
6. Radiographic
7. Eddy Current and Electrical

With the 3 levels of personnel, Level I, Level II and Level III we now have a classification of Plant, Method and Personnel to form a basis for construction of a syllabus. It is important to remember that N.D.T. is a subject which has a strong practical basis so that there should be a balance between theory, practical and practice, i.e. working with test equipment on realistic test specimens.

Examples of syllabi for magnetic, penetrant, ultrasonic, radiographic and eddy methods are provided in the five SPT-TC-14 Supplements. A syllabus for a full time course of study is now available in the City and Guilds of London Institute Course 432. Non-destructive Testing Technicians Course. This requires a minimum of 1000 hours instruction and attendance by pupils, either as a sandwich or part-time day course. City and Guilds of London Institute, 76 Portland Place, London W1. Price below 10/-.

11.4.3.5 <u>Courses</u>

There are alternative methods of providing Courses, one way is to use the internal resources of the training organisation; an alternative is to use external courses as discussed below, or, as is often the case a mixture of internal and external courses are used.

Courses which may vary in scope and depth can be organised on the basis of 15-20 hours (2-3 days); 60-90 hours (2-3 weeks or part time evening or day).

Sandwich. College-Works-College in periods of say 3 months, to a total time of 6, 12, 18 or 24 months.

All courses, with the exception of the Appreciation, Introductory or Review type, should form part of an integrated training scheme, ultimately leading to a recognised qualification. Courses should as far as practicable be based on a modular or building block system and should include an examination and/or test and a marking system. When external courses are used the syllabus should be examined to ensure that they are suitable for the level of personnel attending and as far as practicable conform to an agreed training scheme.

Whilst the organisation of training courses which are limited to simple magnetic, penetrant, visual aids and leak tests are not very expensive, the cost rises steeply when other methods such as ultrasonic, radiographic, etc. are involved. To enable students to obtain the essential familiarity with test equipments, techniques, types of defect and calibration procedures it is necessary to provide ultrasonic equipments in the ratio of 1 equipment per two students, with the cost of each equipment with a range of probes being nearly £1000. For radiography requiring shielding and two or more X-ray and gamma sources the cost is also high. It has been estimated that the cost of equipping an NDT Training Centre to provide a comprehensive range of NDT equipment is £70,000 and above. For this and other reasons, e.g. the fact that in the majority of cases the person who requires training in N.D.T. is an adult who has already learnt one trade or profession to which N.D.T. must be added. There exists in the U.K. a number of organisations providing courses of 1 to 4 weeks duration. Such courses are organised by N.D.T. equipment manufacturers, by Colleges, particularly The College of Technology Wednesbury, Staffordshire which caters for the City and Guilds Course 432, and by the School of Applied N.D.T. at the Welding Institute, Abington Hall, Cambridge.

The cost of sending a student on a SANDT Course of 1 or 2 weeks duration ranges from £45-£65 plus residential accommodation. A reduction of £5-£10 is made for organisations which are members of the Non-destructive Testing Society of Great Britain or the Welding Institute. Information on N.D.T. Courses is listed in the journal - Non-destructive testing, published 6 times per annum by Iliffe Science and Technology Publications Ltd., 32 High Street, Guildford, Surrey, England.

11.4.3.6 <u>N.D.T. Training Material</u>

There exists a good number of documents, books, periodicals and aids to training some of which are listed below.

TABLE 4

	Item	Approx. Price	Reference
1	Glossary of Terms used in N.D.T. British Standard and I.I.W.	5/- per part and above	Section 14.0 Table
2	B.S.I., I.S.O. U.S.A. Standards for NDT Methods, processes and equipment calibration. Many of these documents have details of techniques and can be used as training aids.		Section 14.0
3	N.D.T. Technician Course Syllabus 32, Metallurgical M. [illegible] and other syllabi relevant to N.D.T. education and training.		City and Guilds of London Institute, 76 Portland Place, W1.
4	Recommended Practice No. SNT-TC-1A Guidelines for the Qualification and Certification of Non-destructive Testing Personnel.		The American Society for Non-destructive Testing 914 Chicago Avenue, Evanston, Illinois, 60202, U.S.A.
	Supplement A - Radiographic Testing Method (48 pages)	$2.25	
	Supplement B - Magnetic Particle Method (84 pages)	$2.50	
	Supplement C - Ultrasonic Testing Method (44 pages)	$2.25	
	Supplement D - Liquid Penetrant Method (76 pages)	$2.50	
	Supplement E - Eddy Current Method (56 pages)	$2.25	
	The complete set of Five Books	$10.50	

	Item	Approx. Price	Reference
5	**11 Training Handbooks** **Programmed Instruction (Self Study) Handbooks** PI-4-1 Introduction to Nondestructive Testing (277 pages) PI-4-2 Liquid Penetrant Testing (2[illegible] pages) PI-4-3 Magnetic Particle Testing (410 pages) PI-4-4 Ultrasonic Testing (3 volumes, 903 pages) PI-4-5 Eddy Current Testing (2 volumes, 503 pages) PI-4-6 Radiographic Testing (5 volumes, 1363 pages) OR BUY THE COMPLETE SET PI-4-Set, including all six Programmed Instruction Books (13 volumes) Classroom Training (Ref. Texts) Handbooks) CT-6-2 Liquid Penetrant Testing (128 pages) CT-6-3 Magnetic Particle Testing (142 pages) CT-6-4 Ultrasonic Testing (207 pages) CT-6-5 Eddy Current Testing (201 pages) CT-6-6 Radiographic Testing (225 pages) OR BUY THE COMPLETE SET CT-6-Set, including all five Classroom Training Books These provide a valuable systematic course of self study supported by the more advanced classroom or reference books.	 $10.50 $10.50 $16.50 $34.50 $20.50 $50.50 $125.50 $5.50 $5.50 $8.50 $8.50 $9.50 $30.50	The American Society for Nondestructive Testing, 914 Chicago Avenue, Evanston, Illinois, 60202, U.S.A.
6	NDT Correspondence Course Program. Proposed 15 Lessons for publication by Dec. 1st 1970. Joint organisers - ASNT and ASM (American Society for Metals)	-	Educational Council Reports pg. 27A Materials Evaluation Jan. 1970 Vol. XXVIII No. 1.
7	The Nondestructive Testing Handbook edited by Dr. Robert C. McMaster. 2 vols 1850 pgs. 1,250 illustrations.	$30.50 or $24.50 Members	A.S.N.T.

		Approx. Price	Reference
8	**Reference Radiographs** I.I.W. Collection of 86 Reference Radiographs	320 Swedish Crowns	
9	British Standard 499 Pt. 3, 1966		Section 14.3.3.
10	British Standard 2737:1956	15/-	Section 14.3.3.
11	Radiographs of Welds: This is a small booklet based on the I.I.W. Collection of Reference Radiographs and much lower in price.	12/6	International Institute of Welding
12	Classified Radiographs for Defects in Aluminium Welds	18/-	The Welding Institute
13	A.S.T.M. Series covering Castings in a range of materials, welds, etc.		Section 14.3.1.
14	Atlas of some Steel Casting Flaws as shown by N.D.T.	25/-	Section 14.0 Table
15	MS Ultrasonic Slide Rule	£6.8.0.	The Welding Institute, Cambridge.
16	Exposure Calculation for Gamma Radiography. Anadiographic Slide Rule.		Steel Castings Research and Trade Assn. Sheffield.
17	X-ray demonstration Unit. A table top, shielded unit housing a 60 kV-1 mA X-ray tube, facing a fluorescent screen. Accessories for demonstrations of Fluoroscopy, Ionisation by X-rays. X-ray absorption, Photography of diffraction patterns, Polarisation of X-rays. Compton effect 220 v or 117 v input. 200 Watt.	£330	Educational Systems Ltd., Bristol. St. Lawrence House, 29/31 Broad Street, Bristol [illegible] England.
18	Instructional Films, Filmstrips and Slides		Mullard Ltd., Export Division, Mullard House, Torrington Place, London WC1., England.
	Films		Wells [illegible] Ltd., Letchworth, Herts.
	Films		Central Film Library Government Building, Bromyard Avenue, Acton, London W.3.
19	Information on NDT equipment suppliers and NDT applications, research and literature.		The NDT Centre A.E.R.E., Harwell, Didcot, England.

18.4.3.7 Manuals and Procedures

Well written and illustrated manuals or handbooks and procedure sheets are a powerful training aid both in the classroom and for individuals. The provision of manuals for customers is undertaken by NDT equipment manufacturers, some of whom include information on applications, whilst large organisations where there is a requirement produce manuals and procedure sheets for internal or external circulation. Examples of manuals and procedure sheets which illustrate the form in which such documents are compiled will be included when this paper is issued as a publication following the Symposium.

14.0 STANDARDS & ORGANISATION FOR NON DESTRUCTIVE TESTING

14.1 STANDARDS

14.2 ACCEPTANCE STANDARDS

14.3 REFERENCE RADIOGRAPHS

14.3.1 A.S.T.M.

14.3.2 I.I.W.

14.4.0 INTERNATIONAL AND NATIONAL ORGANISATIONS FOR N.D.T.

14.0 STANDARDS AND ORGANISATION FOR NON-DESTRUCTIVE TESTING

14.1 Standards

The accompanying table sets out a number of British Standards which contain information on N.D.T. Glossaries, methods and procedures also some standards produced by a number of other countries with documents produced by the International Institute of Welding and I.S.O. Further information on this subject is to be found in the publications of the International Organisation for Standardisation I.S.O. and in the catalogue of I.I.W. documents published by the Internatiional Institute of Welding. Also in Materials Evaluation Journal of the American Society for N.D.T. July, 1969. Volume XXVll No.7, page 13A - 18A, under the titel "Commonly used Specifications and Standards for Non-Destructive Testing". The latter is revised and issued annually and includes the addresses of all the organisations supplying Specifications and Standards.

The author regrets his inability to provide more extensive information on N.D.T. Standards than that given. The collection of such documents is a difficult and laborious task, owing to the absence of any single International committee or body to co-ordinate such work. However, in 1969 member countries of the International Organisation for Standardisation, I.S.O. agreed to establish a Technical Committe - TC135 specifically for N.D.T. The plenary meeting of this Committee is planned for the Autumn of 1970 when the terms of reference etc. will be established. The presence of such a Technical Committee can be an important step towards co-ordinating information on the existence of N.D.T.Standards and the many countries where they are used.

14.2 Acceptance Standards

Defining the significance of defects found by N.D.T. is often a difficult task and is a field in which the number of published standards is limited. A number of British Standards wherein reference is made to N.D.T. methods are given in Table.

14.3 Reference Radiographs

14.3.1 Radiography with the radiograph providing a record which is easy to handle, store and transport lends itself readily to the compilation of refrence radiographs which can be used to establish levels of quality for a particular product. The American Society for Testing Materials, A.S.T.M. publish an excellent series of Reference Radiographs covering steel castings in three steps. E.71-64 upto 2" in thickness E.186-65T 2 to 4½" in thickness, E.208-65T 4½ to 12" in thickness with a range of other reference radiographs for, Investment Steel Castings, Aluminium and Magnesium Castings, Tin Bronze Castings, High-Strength Copper Base and Nickel Copper, Alloy Castings, steel welds etc.

The objective in the provision of these radiographs is to provide a source of reference radiographs from which purchases and supplies may, by mutual agreement, select particular radiographs to serve as standards representing minimum acceptability. These reference radiographs by illustrating degrees of severity for different types of defects and thicknesses of material assist the reporting of radiographic examinations and the establishment of quality levels before a job commences.

The cost of a set of these reference radiographs varies from $30 for a set of 31 plates, (5 in x 7 in) in a ring binder - E.71-64 Reference Radiographs for steel castings up to 2 in (50 mm) in thickness, to $150 for a set of 37 plates - E.280-65T - Reference Radiographs for heavy walled (4½ in to 12 inch) Steel Castings. There are considerable reductions in these prices to A.S.T.M. members.

14.3.2 A set of Reference Radiographs in a different category from those of A.S.T.M. are the I.I.W. collection of Reference Radiographs of Welds in steel. This comprises 86 reproductions of radiographs printed on paper or film and mounted in frames. On each frame information is given on the nature and degree of severity of the defects shown, the position of the weld the thickness of the metal, the preparation of the joint and the radiographic characteristics. The text is in French on side of the frame and in English on the other. The approximate cost of a set in a strong box with an insert and to select radiographs with particular feature is for paper, 280 Swedish Crowns, and for film 380 Swedish Crowns. These prices may be lower than the current prices. These radiographs form a valuable teaching or reference aid for N.D.T. and weld inspection personnel. There are other sources of reference radiographs and a collection can be compiled by any organisation for internal use. Two British Standards with illustrations of radiographs containing defects are B.S.499: Part 3: 1966. Welding Terms and Symbols - Terminology of and abbreviations for fusion welding imperfections as revealed by radiography and B.S.2737: 1956. Terminology of defects in castings as revealed by radiography.

14.4.0 National Organisations for N.D.T.

The first international conference on N.D.T. was held at Brussels, Belgium in 1955, the 6th International Conference will be in Hanover, Germany, June 1970. To organise these conferences and maintain contact between nations an International Relations Committee has been established, with representatives from those countries which have a national N.D.T. body e.g. Society, Institute. This committee meets during the International Conference to plan future activities. As each year passes more and more countries establish a Society, Institution or similar body to co-ordinate and foster the growth of N.D.T. in that country. The best known is probably the American Society for N.D.T., A.S.N.T. with members in North America and many other countries, publishing a journal, Materials Evaluation 12 times per annum. In the U.K. the Non Destructive Testing Society of Great Britain is well established and has a growing number of overseas members. Publication of the Society's Journal, is at present 4 times per annum. A third publication which has a large circulation is Defectoscopy, published in Russian of which English translations are available.

There are now a good supply of books available on N.D.T. and workers on this field are characterised by their willingness to exchange information and advise, particularly to newcomers who wish to use N.D.T.

effectively. Equipment manufacturers can also be included in the "helpful" category. N.D.T. equipment suppliers are very close to their customers needs and problems and their personnel often have years of experience in the application of N.D.T., in fact the continuing development of N.D.T. would be impossible without close user equipment manufacturers and suppliers co-operation.

TABLE V

SOME BRITISH STANDARDS RELATING TO N.D.T.

Reference	Title	Remarks
	Glossaries & Terminology	
B.S. 3683	Glossary of terms used in N.D.T.	
Part 1: 1963	Penetrant flaw detection	
Part 11: 1963	Magnetic particle flaw detection	
Part 111: 1964	Radiological flaw detection	
Part IV: 1965	Ultrasonic flaw detection	
Part V: 1965	Eddy-current flaw detection	
B.S. 2737: 1956	Terminology of internal defects in castings as revealed by radiography	
B.S. 2597: 1955	Glossary of terms used in radiology	
B.S. 661: 1955	Glossary of acoustical terms	
B.S. 233: 1953	Glossary of terms used in illumination and photometry	
B.S. 3455: 1962	Glossary of terms used in nuclear science	
B.S. 2951: 1958	Glossary of terms used in high-vacuum technology	
B.S. 499: 1965 Part 111	Welding terms and symbols. Terminology of and abbreviations for fusion welding imperfections as revealed by radiography	Contains illustrations of radiographs show weld defects with a sketch of the weld and the accepted abbreviation

Reference	Title	Remarks
B.S. 3811:1964	Glossary of General terms used in Maintenance Organisation	
B.S. 3889	Methods of N.D.T. of pipes and tubes	
Part 1a:1965	Ultrasonic testing of ferrous pipes	
Part 11a: 1965	Eddy-current testing of ferrous pipes and tubes	
Part 11b: 1966	Eddy-current testing of non-ferrous tubes	
Part 111a: 1965	Penetrant testing of ferrous pipes and tubes	
Part 1Va: 1965	Magnetic particle flaw detection, ferrous pipes and tubes	
B.S. 3923	Methods for Ultrasonic examination of welds	
Part 1: 1968	Manual examination of fusion welded butt joints in ferritic steels.	
Part 11: 1968	Automatic examination of welded seams	
Part 111: 1965	Manual examination of nozzle welds	
B.S. 3451: 1962	Methods of testing fusion welds in aluminium and aluminium alloys, including radiography and dye and fluorescent penetrant methods	
B.S. 4416. 1969	Method for Penetrant Testing of Welded or Brazed Joints in metals	

Reference	Title	Remarks
B.S. 4206: 1967	Methods for testing fusion welds in copper and copper alloys. Metric units.	
B.S. 4080: 1966	Methods for NDT of steel castings	
B.S. 4124	Methods for NDT of steel forgings	
Part 1: 1967	Ultrasonic flaw detection	
Part 11: 1968	Magnetic particle flaw detection	
Part 111: 1968	Penetrant flaw detection	
B.S. 4336	Methods for NDT of plate material.	
Part 1A	Ultrasonic detection of lamina - imperfections in ferrous wrought plate	
B.S. 4408	Recommendations for non destructive.	
	Methods of test for Concrete	
Part 1: 1969	Electromagnetic Cover measuring devices: Metric units.	
Part 2: 1969	Strain gauges for Concrete investigations.	
	Magnetic Methods	
B.S. 4069: 1966	Specification for magnetic flaw detection inks and powders.	
B.S. 4489: 1969	Method for assessing Black Light used in N.D.T.	
	Ultrasonic Methods	
B.S. 2704: 1966	Calibration blocks and recommendations for their use in ultrasonic flaw detection	
B.S. 4331:	Methods for assessing the performance characteristics of Ultrasonic Flaw Detection Equipment	
Part 1: [illegible]	Overall Performance	

Reference	Title	Remarks
	Radiographic Methods	
B.S. 3510: 1962	Specification for symbol for ionising radiation	Corresponds with I.S.O. Recommendation R.361
B.S. 2600: 1962	General recommendations for the radiographic examination of fusion welded butt joints in steel.	Covers 8 individual techniques for X and Gamma ray examination, does not establish radiographic standards of acceptance.
B.S. 2910: 1965	General recommendations for the radiographic examination of fusion welded circumferential butt joints in steel pipes	10 x ray and Gamma ray techniques using three types of film
B.S. 3971: 1966	Specification for image quality indicators for radiography and recommendations for their use.	
B.S. 3490: 1962	Size of industrial x-ray film (including film for crystallography).	
B.S. 3511: 1962	Gamma-radiography sealed sources.	
B.S. 3385: 1961	Specification for direct reading personal dosemeters for x and gamma radiation	
B.S. 3664: 1963	Specification for film badges for personnel monitoring	
B.S. 3890: 1965	General recommendations for the testing, calibration and processing of radiation monitoring films	
B.S. 4031: 1966	X ray protective lead glasses	
B.S. 3783: 1964	X ray lead-rubber protective aprons for personal use.	

Reference	Title	Remarks
B.S. 4094: Part 1: 1966	Data on shielding from ionising radiation shielding from gamma radiation	Metric units
B.S. 4097: 1966	Gamma radiography exposure containers for industrial purposes and their source holders	Metric units
	The price of British Standards ranges from approximately 5/- to £5 but the majority cost less than £1.0s.0d.	
	British Standards are published by the British Standards Institution, 2 Park Street, London W1Y 4AA. United Kingdom and are obtainable in the majority of the countries in the world.	
	I.I.W. Glossaries relating to N.D.T.	
1.	List of terms used in Ultrasonic Testing. In eleven languages with explanations of the terms in English and French 1967. Available through the I.I. Welding . Price approximately £2.	
2.	A Non-destructive Testing Atlas Classification of Defects in Metallic Fusion Welds with explanations by Commissions V and Vl of I.I.W. Document IIS/IIW-340-68 Published in Welding in the World 1969.7.4.	

A selection of some other National Standards relating to N.D.T.

Country	Number	Title
U.S.A. A.S.T.M.	E109-63	Standard method for Dry Powder Magnetic Particle Inspection
U.S.A. A.S.T.M.	E125-63	Standard reference photographs, for magnetic particle indications on ferrous castings.
U.S.A. A.S.T.M.	E138-63	Standard method for wet magnetic particle inspection.
India	IS 1182	General recommendations for radiographic examination of fusion welded joints.
Canada	48-GP-2	Spot radiography of butt welds in ferrous materials.
Czechoslovakia	CSN-05-1305	Classification of weld defects on radiographs.
Germany	DIN.54111	X-ray and Gamma-ray testing of welds on metallic materials.
Hungary	MSZ.4310	Non-destructive testing methods. General. Including dye penetrant and magnetic particle methods; radiographs, types and symbols of weld defects, classification and estimation of weld defects by X-rays and Gamma-rays.
Poland	N-69772	Radiographic determination of weld faults.
Spain	UNE 14011	Grading of welds by X-rays.
Russia	GOST.7512.55	Methods of inspection of welded seams by X-rays and Gamma-rays.
ISO Documents.		
	44 N 244 ISO(WNE)1473X	(Recommended practice for radiographic (inspection of fusion welded butt joints (for steel pipes up to 2 in wall thickness
	44 N 245 ISO(WNE)1475X	(Recommended practice for radiographic (inspection of fusion weldedbutt joints (for steel plates up to 2 in.
	44 N 246 ISO(WNE)1475X	(Radiographic image quality indicators.

TABLE

Application or Product Standards wherein reference is made to N.D.T.

Standard No.	Title	Remarks
B.S. 487: 1963	Part 11-Fusion Welded steel air receiver. Part 11 - Receivers to class 1 requirements.	
B.S. 806: 1967	Specification for ferrous pipe and piping installations for, and in connection with land boilers.	
B.S. 1113: 1969	Specification for water tube steam Generating Plant (inc. Superheaters, reheaters and steel tube economisers).	Includes radiographic Ultrasonic, Magnetic
B.S. 1500A. 1960	Fusion welded pressure vessels for use in chemical petroleum and allied industries. Part 1. Carbon and low alloy steels. Sections 4 and 5 and Appendix A. Part 111 Aluminium. Refers to radiographic examination of welds.	Manufacture, workmanship, inspection and testing refers to radiographic and ultrasonic methods.
B.S. 1515:	Fusion welded pressure vessels (advanced design and construction) for use in chemical, petroleum and allied industries. Part 1. 1965 Carbon and ferritic alloy steels.	Non destructive tests (none except for weld imperfections as revealed by radiographs and pressure tests).
B.S. 1894: 1952	Electrode boilers of riveted, seamless welding and cast iron construction for water heating and steam generating.	
B.S. 2790: 19[illegible]	Steam receivers and generators	

Standard No.	Title	Remarks
B.S. 2633: 1966	Specification for arc-welding of ferritic steel pipe work for carrying fluids.	Reference to B.S. 2910, includes acceptance levels.
B.S. 2645	Test for use in improvement of welders, Part 1.	
B.S. 2654: 1961	Part 11 Site erection, inspection and testing	
B.S. 2790: 1956	Cylindrical land steam boilers of welded construction (other than water tube boilers).	
B.S. 3351: 1961	Piping systems for the Petroleum industry.	Refers to B.S. 2910, includes acceptance levels.
B.S. 3451: 1962	Testing fusion welds in aluminium and aluminium alloys.	
B.S. 3915: 1965	Carbon and low-alloy pressure vessels for primary circuits of nuclear reactors.	Refers to radiographic, ultrasonic examination, crack and leak detection methods.
B.S. 3636: 1963	Methods of proving the gas tightness of vacuum or pressurised plant. Describes 17 methods of proving gas tightness.	Describes 17 methods of proving gas tightness
B.S. 4515:1969	Specification for field welding of carbon steel pipelines metric units.	Includes radiographic, ultrasonic and visual examination, and standards of acceptance. Welder qualification test.

ADDRESSES.

Where an organisation or publisher are mentioned in the text the address is usually included. For ease of reference the following addresses are set out below.

A.S.N.T. The American Society for Nondestructive Testing, Inc. 914 Chicago Avenue, Evanston, Illinois 60202. U.S.A.

N.D.T. Society of Great Britain. The Non-Destructive Testing Society of Great Britain, Chalkwell Park House, 700 London Road, Westcliff-on-Sea, Essex. SS0 9RQ. England.

N.D.T. Centre. The Nondestructive Testing Centre, A.E.R.E., Harwell, Didcot, Berkshire, England.

For information on all aspects of Nondestructive Testing.

British Standards Institution, British Standards House, 2 Park Street, London W1Y 4AA, England.

Complete sets of British Standards are maintained for reference in a large number of countries, and sales agents are also appointed.

I.S.O. International Organisation for Standardisation Central Secretariat, 1. rue de Varembe 1211. Geneva 20. Switzerland.

Copies of I.S.O. Recommendations can be purchased from British Standards Institution for United Kingdom and similar arrangements exist in other I.S.O. member countries.

I.I.W. International Institute of Welding, General Secretariat, 54 Princes Gate, Exhibition Road, London S.W.7, England.

A.R.B. Air Registration Board, Brabazon House,
Redhill, Surrey, England.

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