# Part 4 Non-destructive Examinations

## Leaflet 4-1 Oil and Chalk Processes

### 1 Introduction

1.1 This Leaflet provides guidance and advice on the detection of surface defects, such as cracks and porosity, by processes involving the use of oil and chalk. The principle which the process is based upon, is the absorption by chalk of fluids. A penetrant oil is applied to the surface of the parts to be checked and, after removing the surplus oil, a layer of chalk is applied. Oil entrapped in defects is absorbed by the chalk, the resulting stains indicating their position.

1.2 There are two basic methods of applying the process, i.e. the 'Hot Fluid Process' and the 'Cold Fluid Process'. Of these, the process employing hot oil is the more efficient and should be used wherever possible, but both methods suffer serious limitations, as indicated in paragraph 2. However, some proprietary processes, e.g. the 'Bristol Modified Method of Oil and Chalk Test', which is an adaptation of the hot fluid process, are not subject to such deficiencies. The Bristol Modified Method is considered in more detail in paragraph 5.

1.3 Guidance on the use of penetrant dye and fluorescent ink processes, which have largely superseded the conventional oil and chalk processes, is given in CAAIP Leaflet 4–2. Information on the use of ultrasonic equipment for the detection of flaws is given in CAAIP Leaflet 4–3, and on the radiological examination of aircraft structures in CAAIP Leaflet 4–4. Guidance on magnetic methods of flaw detection is given in CAAIP Leaflet 4–5.

### 2 Limitations of the Processes

2.1 The oil and chalk processes were devised for the detection of surface defects in non-ferrous and some non-metallic materials, but the deficiencies described in the following paragraphs should be considered before deciding upon the suitability of either of the processes for the work in hand. The processes are not considered suitable for the detection of minute flaws or tightly shut cracks.

2.2 The processes are quite effective for such applications as the detection of large cracks in rough castings, but in general, the degree of contrast obtained by oil exudation is very poor and, unless the pre-cleaning and final drying processes are efficiently done, spurious indications of defects may be given.

2.3 Defect indications, at best, will appear only as dark grey stains on a light grey background, and are not sufficiently defined to make the detection of small cracks practicable, particularly when examining parts having dark surfaces, e.g. chromated magnesium alloy parts.

2.4 When the hot oil process is used for parts which are dimensionally large or are of intricate shape, it is often not possible to remove the surplus oil quickly enough to be able to apply the chalk before the parts become cool, thus the object of heating is defeated (see paragraph 3.4). On the other hand, if the drying is not done efficiently, masking of defects may occur due to the spontaneous staining of the chalk in damp areas.

## 3 Hot Fluid Process

3.1 To obtain satisfactory results it is essential that the parts should be thoroughly cleaned before immersion. If the parts have previously been immersed in an acid pickle bath, paint stripper, or some other strong solution, all traces of such solutions must be removed by adequate washing to avoid contamination of the test oil.

3.2 The parts to be examined should be immersed or (if a specified area only is to be examined) partly immersed, in a solution consisting of approximately 28% (by volume) of lard oil in paraffin. The solution should be maintained at a temperature of approximately 80°C, and the period of immersion must be sufficient to allow the parts to attain this temperature. If preferred, solutions consisting of three parts paraffin and one part lubricating oil, or 50% paraffin and 50% spindle oil, may be used.

3.3 After immersion the parts should be dried quickly and thoroughly with a non-fluffy rag; excellent final cleaning can be achieved by the use of unglazed tissue paper.

3.4 The parts should then be placed in the chalk cabinet and a fine layer of dry powdered French chalk should be applied, preferably by a method that will distribute the chalk in a gentle cloud. A paint spray gun with a conical funnel fitted in front of the jet, operated at a pressure of about 0·70 kg/sq cm (10 lb/sq in), will be found suitable for this purpose. The gun should be provided with an efficient water trap. Surplus chalk should be removed by lightly tapping the parts on a block of wood.

**NOTE:** The chalk cabinet should form an enclosed area in which the parts to be examined can be placed. It should have a transparent front and should be fitted with an exhaust fan to remove surplus chalk. The parts can be coated more rapidly if a turntable is used.

3.5 The parts should be inspected for defects when quite cool and it will be found that if any cracks are present, the fluid will have been forced from them as the metal contracted on cooling, causing the chalk to become stained. A gentle air stream from a source pressurised at not more than 0·70 kg/sq cm (10 lb/sq in), if directed on to the surfaces of the parts, may assist in the revelation of defects by removing the adjacent unstained chalk. It is essential that the examination should be made with the aid of a strong light.

## 4 Cold Fluid Process

4.1 As stated in paragraph 1.2, the efficiency of this process is not equal to that of the hot fluid process, and it should be used only where the application of the latter process would not be practicable, e.g. when examining parts of assembled structures or parts too large for immersion.

4.2 The parts should be thoroughly cleaned and then coated with a solution of lard oil and paraffin, or lubricating oil and paraffin, in the proportions recommended in paragraph 3.1. After the surfaces to be examined have been thoroughly coated, all traces of the solution should be removed with a non-fluffy rag, followed by final wiping with unglazed tissue paper. The surface should then be coated with French chalk (paragraph 3.4).

4.3 Any oil entrapped in defects will be drawn out by the absorbent chalk, the resulting stains indicating the position of the defects. It is essential that the examination should be made with the aid of a strong light.

## 5 The Bristol Modified Method

5.1 In this process, finished parts or rough castings are immersed in hot oil, are removed and have the surfaces degreased, and are then sprayed or dusted with dry French chalk.

5.2 The parts to be examined should be immersed or (if a specified area only is to be examined) partly immersed, in a solution consisting of 50% paraffin and 50% spindle oil. The solution must be maintained at a temperature of 70°C and the period of immersion should be sufficient to allow the parts to attain this temperature, one hour usually being sufficient.

5.3 After immersion, the parts should be allowed to stand until all surplus oil has drained off, after which they should be transferred to a degreasing tank containing a solution consisting of the following:

| | | |
|---|---|---|
| Teepol | 5% | by volume |
| Cresylic Acid | 5% | |
| Water | 90% | |

The solution should be maintained at a temperature of between 70°C to 80°C. When the cleansing action deteriorates, additions of Teepol and cresylic acid should be made to restore the above proportions.

**NOTE:** The cresylic acid should comply with the requirements of British Standard 524, Grades A or B.

5.4 The parts should be immersed in the degreasing solution for 3 to 5 minutes and should be agitated throughout this period.

5.5 After degreasing, the parts should be transferred to a tank containing clean hot water, and should be thoroughly swilled for a period of from 3 to 5 minutes, after which they should be allowed to drain.

5.6 When dry, the parts should be coated with a layer of dry French chalk, the equipment described in paragraph 3.3 being suitable for this purpose, except that an air pressure of 4.22 to 5.63 kg/sq cm (60 to 80 lb/sq in) is recommended, after which surplus chalk should be removed by the application of a jet of air at about 1·75 to 2·11 kg/sq cm (25 to 30 lb/sq in) pressure.

5.7 The parts should now be examined for defects, and cracks will be indicated by a thin white line of chalk.

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# Leaflet 4-2 Penetrant Dye Processes

## 1 Introduction

1.1 This Leaflet provides guidance and advice on the penetrant dye processes used for the detection of defects which break the surface of the part, such as cracks, cold shuts, folds, laps and porosity.

1.2 Penetrant dye processes are used mainly for the detection of flaws in non-ferrous and non-magnetic ferrous alloys but may also be used for ferrous parts where magnetic flaw detection techniques are not specified or are not possible. However, in some instances both penetrant dye and magnetic flaw detection techniques may be specified for a particular part (see paragraph 1.6.5). Penetrant dyes may also be used on some non-metallic materials but their use with transparent acrylic-type materials is not recommended, since crazing may result.

1.3 Although the processes are usually marketed under brand names, those used on aircraft parts for which a penetrant process of flaw detection is a mandatory requirement must comply with the requirements of Process Specification DTD 929. It must be ensured that any storage limiting period prescribed by the manufacturer of the process is not exceeded.

1.4 The processes available can be divided into two main groups. One group involves the use of penetrants containing an emulsifying agent (termed water-emulsifiable or water-washable processes) whilst in the other group a dye solvent has to be applied separately after the penetration time (paragraph 4) has elapsed if the surplus dye is to be removed by a water-wash operation. The processes may be further sub-divided insomuch that with some processes the use of a dry developer is recommended whilst with others a wet developer is used. The manufacturers' recommendations and instructions for each individual process must be followed carefully to ensure satisfactory results. Reference should also be made to Leaflet 4–4 Performance Testing of Penetrant Testing Materials, to ensure that the penetrant materials used are in a satisfactory condition.

**NOTE:** An emulsifier is a blending of wetting agents and detergents which enables excess dye to be removed with water and, in the case of wide flaws, assists in preventing the dye seeping out too quickly.

1.5 Basically all the processes consist of applying a red penetrant dye to the surface of the part to be tested, removing after a predetermined time the dye which remains on the surface and then applying a developer, the purpose of which is to draw to the surface any dye that has entered into defects, the resultant stains indicating the positions of the defects.

### 1.6 Penetrant Processes

1.6.1 The selection of the most suitable type of penetrant process e.g. penetrant dye or fluorescent penetrant with or without post-emulsification (see Leaflet 4–3), for any given application must largely be governed by experience, since when used correctly a high degree of efficiency can be obtained with any of the processes. Guidance on some of the factors which should be given consideration is provided in the following paragraphs.

1.6.2 Within a given type of process, the post-emulsification method is generally considered to be the most sensitive and is usually selected for finished machined parts and for the detection of 'tight' defects. However, its use on rougher surfaces (e.g. castings) may be less effective than would be the use of a penetrant containing an emulsifier, since it may pick up the surface texture of the material, thus rendering the detection of actual defects more difficult.

1.6.3 Where large heavy parts are concerned, and particularly where mechanical handling is involved, the use of penetrant dyes may be more practicable than that of fluorescent penetrants, since the necessity of darkening a relatively large area before the examination can be made does not arise.

1.6.4 When making 'in situ' checks on aircraft, the use of penetrant dyes may be more suitable where there is sufficient light but in darker areas a fluorescent process may provide better definition of defects.

**NOTE:** Battery-operated ultra-violet light sources are now available.

1.6.5 With steel castings for example, porosity may be detected more readily by a penetrant process than by a magnetic flaw detection technique (Leaflet 4–7) and for this reason the application of both processes is sometimes specified. If the magnetic flaw detection test precedes the penetrant test, great care will be necessary with the intervening degreasing process to ensure that all traces of the magnetic testing medium are removed, otherwise the subsequent penetrant test may be unsuccessful.

1.7 Some of the materials associated with penetrant testing have low flash points and the appropriate fire precautions should be taken.

## 2 Surface Preparation

2.1 The major reason for the failure of penetrant processes to provide indications of defects is incorrect or inadequate surface cleaning. For example, embedded extraneous matter can seal off cracks, etc., whilst contaminants remaining on the surface can trap the dye and give rise to false indications or, more detrimentally, obscure genuine defects. Thus the surface to be tested must be free from oil, grease, paint, rust, scale, welding flux, carbon deposits, etc., and the method of cleaning should be selected with the intention of removing extraneous matter from within the defects as well as from the surface to permit maximum dye penetration.

2.2 On unmachined steel stampings and forgings it may be necessary to remove rust or scale by sandblasting and to prepare aluminium alloy forgings by light sandblasting. However, the use of such processes must be given careful consideration, since they may result in the filling or 'peening-over' of defects. Generally, unless specified otherwise, aluminium alloy forgings should be prepared by a suitable pickling process (e.g. by one of the methods prescribed in Process Specification DTD 901).

2.3 Magnesium alloy castings should be tested after chromating in order to reduce the risk of corrosion, but the requirements of Process Specification DTD 911, with regard to surface protection, must be taken into account and a suitable sequence devised.

2.4 Where contamination is mainly of an organic nature, degreasing by the trichloroethylene process (unless there are instructions to the contrary) is usually suitable. However, not all types of trichloroethylene are suitable for use with titanium alloys. The cleaning of titanium alloys by methanol should be avoided.

2.5 Where parts have to be tested 'in situ', the use of volatile solvents (e.g. carbon tetrachloride) as cleaning agents should be given consideration. Where paint is present, this should be removed from the surface to be tested prior to cleaning. Subsequent to the test, the surface should be reprotected in the prescribed manner.

**NOTE:** Suitable fire precautions must be taken when flammable materials are used.

2.6 Sufficient time should be allowed after cleaning for drying out, otherwise the efficiency of the penetrant dye may be affected. The time interval allowed for the evaporation of solvents can only be determined by the prevailing conditions of temperature and humidity and the type of solvent used.

## 3 Application of the Dye

3.1 The penetrant dye can be applied to the surface by dipping, spraying or brushing, the method used depending largely on the size, shape and quantity of the parts to be examined. The surface must be dry before the dye is applied. Even the condensation which forms on a cold surface in humid conditions may interfere with dye penetration; in such conditions the part should be warmed to a temperature of about 32°C to 38°C (90°F to 100°F) but temperatures in excess of 60°C (140°F) must be avoided, since these may result in the volatilisation of some of the lighter constituents of the dye.

### 3.2 Dipping Method

3.2.1 Dipping should generally be used where large numbers of small parts are to be examined. The parts must be completely dried before immersion, since apart from affecting penetration, water or solvents will contaminate the dye.

3.2.2 During dipping care must be taken to ensure that the parts are so racked that air pockets are avoided and all surfaces to be examined are completely wetted by the dye.

3.2.3 It is not necessary for the parts to remain submerged in the tank during the penetration time (see paragraph 4) but only for a period sufficient to permit thorough wetting. 'Drag-out' losses can be reduced if the dye is allowed to drain back into the tank during the penetration time.

3.3 **Flooding Method.** The flooding method should generally be used where large areas are to be examined. The dye should be applied with low-pressure spray equipment which will not permit atomisation of the fluid, any surplus dye being allowed to drain back into the tank.

3.4 **Aerosol Can Method.** Penetrant contained in Aerosol type cans is often used for 'in situ' inspections. The best results are obtained when the can is held about 12 inches from the surface under test.

3.5 **Brushing Method.** The brushing method is generally used for individual items and items of complicated shape. A clean soft bristle brush should be used and retained only for this purpose.

## 4 Penetration Time

4.1 The penetration time is the time which has to be allowed for the dye to penetrate effectively into the defects. It is dependent upon a number of factors, such as the characteristics of the process being used, the material from which the part is made, the size and nature of the defects being sought, the processes to which the part has been subjected and the temperatures of the atmosphere, the part and the dye. Clearly the time can be decided only by experience of the particular local conditions but is usually in the range of 5 minutes to 1 hour, the smaller the defect the longer the time necessary.

4.2 Temperatures below 15°C (60°F) will retard the penetrant action of the dye, thus the penetration time should be extended proportionately. Testing in temperatures at or near freezing point should, if possible, be avoided, since in such conditions the performance of the penetrant is considerably reduced.

4.3 Where the effectiveness of the pre-cleaning process cannot be guaranteed or where parts have been sandblasted, the penetration time should be extended but it should be borne in mind that this is no guarantee that defects will, in fact, be revealed in such conditions.

## 5 Removal of Excess Dye

5.1 Any dye remaining on the surfaces of the parts after expiry of the penetration time should be removed as thoroughly as possible but without disturbing the dye which would have found its way into any defects present. Excessive cleaning, however, may result in the dilution of the dye or its complete removal from defects. The method of removal depends on whether a water-washable or post-emulsifiable dye was used and the size and condition of the surface under test.

5.2 **Water-washable Dye.** Water-washable dye should be removed as indicated in the following paragraphs.

a) The dye should be removed from 'in situ' parts with clean rags saturated in water, followed by wiping with clean rags until the surfaces are both dry and free from dye.

b) The dye should be removed from small parts with clean rags saturated in water, followed by drying as recommended in paragraph 5.3.

c) The dye should be removed from large areas or irregularly shaped parts by flushing with an aerated spray of water, followed by drying as recommended in paragraph 5.3.

5.3 **Post-emulsifiable Dye.** Post-emulsifiable dye should be removed from small areas and 'in situ' parts first by wiping with clean rag damped with dye solvent, followed by wiping or blotting with a clean dry rag. The bulk of the dye may be removed from large areas, irregularly-shaped parts and rough-textured surfaces by a quick water wash (allowing this to drain) followed by the application of the dye solvent and a final water wash. The dye solvent should be applied by spraying, swabbing, dipping or brushing, except that brushing should not be used where relatively large defects are suspected. Washing should be followed by thorough drying, as outlined in paragraph 5.4.

5.4 **Surface Drying**

5.4.1 Prior to applying the developer (paragraph 6) it should be ensured that the surfaces of the part under test are completely dry. The following methods of surface drying are recommended which, although slower than the use of, for example, compressed air, are less likely to disturb entrapped dye.

5.4.2 Small areas may be wiped dry but since this may disturb the dye in the wider defects, the use of warm air is preferred.

5.4.3 Hot-air ovens and similar equipment may be used for drying, a temperature of about 54°C (130°F) being suitable; temperatures in excess of 79°C (175°F) must be avoided. The use of lamps for drying is not recommended unless uniform heat application can be guaranteed.

## 6 Application of the Developer

6.1 The developer usually consists of a very fine absorbent white powder which may be applied in

a) the form of a spray, the powder being suspended in a volatile carrier liquid which rapidly evaporates, leaving a white coating on the surface,

b) as a dip with the powder suspended in water or

c) as a dry powder which may be blown on to the component or into which the component may be dipped. The action of the absorbent powder is to draw out the dye from the surface defects, thus indicating their position by the resulting stain.

6.2 Where it is suspected that microscopic defects may be present, great care is necessary to ensure that the developer is applied evenly and very thinly, since a thick layer might conceal completely a defect holding only a minute quantity of dye.

6.3 Where a wet developer is concerned, the best results are obtained when the developer is applied by means of a paint-type spray gun operating at an air pressure not in excess of 1·0554 kg/sq cm (15 lb/sq in). The pressure pot of the spray gun should be equipped with a stirrer to keep the developer agitated and the absorbent particles in suspension. Before pouring the developer into the spray gun it should be well shaken to ensure a thorough distribution of the absorbent particles.

6.4 When requirements are not too exacting, small parts can be dipped into a bath of developer but the action must be performed rapidly to minimise the possibility of the dye being washed out of shallow defects. The bath should be agitated from time to time to ensure that the absorbent particles are kept in uniform suspension. The formation of pools of developer on the parts during draining must be avoided, otherwise the resultant thick coatings may mask defects.

6.5 Due to the usually uneven results obtained, the use of a brush for applying the developer is not recommended.

6.6 If the developer dries with a slightly pinkish hue, this is probably due to faulty cleaning or 'carried over' penetrant in the penetrant remover (see paragraph 7.3) but provided sufficient contrast remains to enable minute defects to be detected, the condition is acceptable.

6.7 Water must not be permitted to enter the developer containers, since its presence will retard considerably the drying rate of the developer.

## 7 Interpretation of Defects

7.1 If defects are present and all stages of the process have been applied correctly, the position of the defects will be indicated by red marks appearing on the whitened surface. The majority of defects are revealed almost immediately the developer dries but additional time (approximately equal to the penetration time (paragraph 4)) should be allowed for 'tight' flaw indications to appear and for flaw patterns to reach their final shape and size (Figure 1).

7.2 By noting and comparing the indications that appear during the first 30 seconds of development with those which exist after about 10 minutes, a more accurate assessment of the characteristics of the defects is possible. For example, the dye exuding from a shallow crack is little more after 10 minutes than after 30 seconds but in the case of a deep narrow crack, considerably more dye is present, causing a much wider indication to develop over a similar period of time. Thus the rate of staining is an indication of the width and depth of the defect, whilst the extent of staining is an indication of its volume.

**Figure 1** Indications given by Defects

7.3 Scattered dots of dye indicate fine porosity or pitting (Figure 1(d)) whilst gross porosity may result in an entire area becoming stained. Where doubt exists as to whether the overall pinkish effect is due to inadequate washing, the process should be repeated, more care being taken particularly during the stage of cleaning off the excess dye.

7.4 Closely spaced dots in a line or curved pattern (Figure 1(c)) usually indicate tight cracks or laps but such patterns are also characteristic of very wide defects from out of which most of the dye has been washed. Wide cracks, lack of fusion in welded parts and other similar defects are indicated by continuous lines as shown in Figures 1(a) and 1(b).

7.5 Examination by means of a powerful magnifying glass is often useful when minute defects are being sought.

7.6 All defects should be suitably marked prior to removing the developer, but crayons should not be used on highly-stressed components subject to heat treatment, since this is known to induce fractures.

## 8 Removal of Developer

Developer can be removed by brushing or by air or water under pressure, but since the surface is then in a condition susceptible to corrosion (where this is applicable) the prescribed protective treatment should be applied with the minimum of delay. It should be noted that the adhesion of paints and resins may be seriously impaired by certain oil-base dyes if thorough cleaning is not ensured.

## 9 Leak Testing with Penetrant Dyes

9.1 On components or assemblies where the main purpose of the test is to locate defects which would result in a fluid leakage (e.g. cracks in pressure vessels) the methods of testing described in the previous paragraphs may not be conclusive. In such cases the inner and outer surfaces should be thoroughly cleaned and degreased, the dye being applied to one surface (usually the inside of pressure vessels) and the developer to the other. After the penetration time (paragraph 4) has elapsed, the surface should be inspected for evidence of staining.

9.2 Where no definite penetration time has been determined then, with a wall thickness of from 1·5 mm (0·0625 in) to 3 mm (0·125 in), the penetration time should be at least three times that which would be allowed for a standard 'one-side-only' test.

9.3 More than one application of the dye is often required and as a general rule an additional application for each 1·5 mm (0·0625 in) to 3 mm (0·125 in) wall thickness is recommended.

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# Leaflet 4-3 Fluorescent Penetrant Processes

## 1 Introduction

1.1 This Leaflet gives guidance on the fluorescent penetrant processes used for the detection of defects in a component, such as cracks, cold shuts, folds, laps and porosity when these break the surface of the component.

1.2 Fluorescent penetrant processes are used mainly for the detection of flaws in non-ferrous and non-magnetic ferrous alloys but may also be used for ferrous parts where magnetic flaw detection techniques are not specified or are not possible. In some instances both fluorescent penetrant and magnetic flaw detection techniques may be specified for a particular part (see paragraph 1.6.4). Fluorescent penetrants may also be used on some non-metallic materials, such as plastics and ceramics, but in each case a suitable process for the particular material must be selected. The processes are not suitable for use on absorbent materials.

1.3 Although the processes are usually marketed under brand names, those used on aircraft parts for which a penetrant process of flaw detection is a mandatory requirement must comply with the requirements of Process Specification DTD 929. It must be ensured that any storage limiting period prescribed by the manufacturer of the process is not exceeded.

1.4 There are two types of fluorescent penetrants, a minor water-based group and a major oil-based group; the manufacturers of the processes usually specify the materials for which each process is suitable. There are variations in the processes which must be taken into account. For example, some types of penetrants contain an emulsifier, whilst in other processes the penetrant and the emulsifier are applied as separate stages. Again in some processes the use of a dry developer is recommended whilst in others a wet developer is used. The manufacturer’s recommendations and instructions for each individual process must be followed carefully to ensure satisfactory results.

**NOTE:** An emulsifier is a blending of wetting agents and detergents which enables excess penetrant to be removed with water.

1.5 Fluorescent penetrant testing is based on the principle that when ultra-violet radiation falls on certain chemical compounds (in this case the penetrant) it is absorbed and its energy is re-emitted as visible light (i.e. the wavelength of the light is changed). Thus, if a suitable chemical is allowed to penetrate into surface cavities, the places where it is trapped and has been drawn to the surface by the developer will be revealed by brilliant greenish-yellow lines or patches (according to the nature of the defect) under the rays of an ultra-violet lamp.

1.6 The selection of the most suitable type of penetrant process (e.g. penetrant dye (Leaflet 4–2) or fluorescent penetrant; with or without post-emulsification) for any given application must largely be governed by experience, since when correctly used a high degree of efficiency can be obtained with any of the processes. Guidance on some of the factors which should be given consideration is provided in the following paragraphs.

1.6.1 Within a given type of process, the post-emulsification method is generally considered to be the most sensitive and is usually selected for finished machined parts and for the detection of 'tight' defects. However, its use on rougher surfaces (e.g. castings) may be less effective than would be the use of a penetrant containing an emulsifier, since it may pick up the surface texture of the material, thus rendering the detection of actual defects more difficult.

1.6.2 Where large, heavy parts are concerned, and particularly where mechanical handling is involved, the use of penetrant dyes may be more practicable than that of fluorescent penetrants, since the necessity of darkening a relatively large area before the examination can be made does not arise.

1.6.3 When making 'in situ' checks on aircraft, the use of penetrant dyes may be more suitable where there is sufficient light but in the darker areas a fluorescent process may provide better definition of defects.

1.6.4 With steel castings, for example, porosity may be detected more readily by a penetrant process than by the magnetic flaw detection techniques (Leaflet 4–5) and for this reason the use of both processes is sometimes specified. If the magnetic flaw detection test precedes the penetrant test, great care will be necessary with the intervening degreasing process to ensure that all traces of the magnetic testing medium are removed, otherwise the subsequent penetrant test may be unsuccessful.

1.7 Some of the materials associated with penetrant testing have low flash points and the appropriate fire precautions should be taken.

1.8 Guidance on dye penetrant processes is given in Leaflet 4–2. Information on the performance testing of penetrant testing materials is given in Leaflet 4–4.

## 2 Surface Preparation

The major reason for the failure of penetrant processes to provide indications of defects is incorrect or inadequate surface cleaning. For example, embedded extraneous matter can seal off cracks, etc., whilst contaminants remaining on the surface can trap the penetrant and give rise to false indications or, more detrimentally, obscure genuine defects. Thus the surface to be tested must be free from oil, grease, paint, rust, scale, welding flux, carbon deposits, etc., and the method of cleaning selected must be capable of removing extraneous matter from within the defects as well as from the surface to permit the maximum penetration.

2.1 With unmachined steel stampings and forgings it may be necessary to remove rust or scale by sandblasting. Aluminium alloy forgings may also need light sandblasting. However, the use of such processes must be given careful consideration, since they may result in the filling or 'peening-over' of defects. Generally, unless specified otherwise, aluminium alloy forgings should be prepared by a suitable pickling process (e.g. by one of the methods prescribed in Process Specification DTD 901).

2.2 Magnesium alloy castings should be tested after chromating in order to reduce the risk of corrosion, but the requirements of Process Specification DTD 911, with regard to surface protection, must be taken into account and a suitable sequence devised.

2.3 Where contamination is mainly of an organic nature, degreasing by the trichloroethylene process (unless there are instructions to the contrary) is usually suitable. However, not all types of trichloroethylene are suitable for use with titanium alloys. The cleaning of titanium alloys by methanol should be avoided.

2.4 Where parts have to be tested 'in situ', the use of volatile solvents (e.g. carbon tetrachloride) as cleaning agents should be given consideration. Where paint is present this should be removed from the surface to be tested prior to cleaning. Subsequent to the test, the surface should be reprotected in the prescribed manner.

**NOTE:** Suitable fire precautions must be taken where flammable materials are used.

2.5 Sufficient time should be allowed after cleaning for drying-out, otherwise the efficiency of the penetrant may be affected. The time interval allowed for the evaporation of solvents can only be determined by the prevailing conditions of temperature and humidity and the type of solvent used.

## 3 Application of the Penetrant Process (without Post Emulsification)

3.1 **Application of Penetrant**. The penetrant can be applied to the surface by dipping, spraying or brushing, the method used depending largely on the size, shape, and quantity of the parts to be examined. The surface must be dry before the penetrant is applied. Even the condensation which forms on a cold surface in humid conditions may interfere with penetration; in such conditions the part should be warmed, preferably within the temperature range of 21°C (70°F) to 32°C (90°F).

3.1.1 **Dipping Method**. Dipping should generally be used where large numbers of small parts are to be examined. The parts must be completely dried before immersion, since apart from affecting penetration, water or solvents will contaminate the penetrant.

a) During dipping care must be taken to ensure that the parts are so racked that air pockets are avoided and all surfaces to be examined are completely wetted by the penetrant.

b) The parts should be dipped for a few seconds and allowed to drain, care being taken to ensure that the solution is able to drain away from any pockets or cavities in the parts. If there is a tendency for the penetrant to dry on the surfaces the parts should be redipped.

3.1.2 **Flooding Method**. The flooding method should generally be used where large areas are to be examined. The penetrant should be applied with low-pressure spray equipment which will not permit atomisation of the fluid, care being taken to ensure that the penetrant completely covers the surface and remains wet. On no account should the penetrant be allowed to dry during the penetration period (paragraph 3.2).

3.1.3 **Aerosol Method**. Penetrant contained in aerosol-type cans is often used for 'in situ' inspections. The best results are obtained when the can is held about 30 cm (12 in) from the surface under test.

3.1.4 **Brushing Method**. The brushing method is generally used for individual items and items of complicated shape. A soft clean bristle brush should be used and retained only for this purpose. On no account should the penetrant be allowed to dry during the penetration period.

3.2 **Penetration Time**. The penetration time is the time which has to be allowed for the penetrant to enter effectively into defects and usually a period of up to 10 minutes is sufficient for the larger type defects, but longer times may be necessary where minute defects are being sought. (See Table 1).

3.2.1 Typical penetration times are given in Table 1 but these may vary according to the temperature and process used. The manufacturer’s recommendations must always be followed where these differ from the figures given.

3.2.2 Where the effectiveness of the pre-cleaning process cannot be guaranteed or where parts have been sandblasted, the penetration time should be extended but it should be borne in mind that this is no guarantee that defects will, in fact, be revealed in such conditions.

**Table 1**

| Material | Nature of Defect | Penetration Time (Minutes) |
|---|---|---|
| Sheets and Extrusions | Heat treatment cracks, grinding cracks and fatigue cracks. | 15 |
| Forgings | Laps, Cracks. | 30 |
| Castings | a) Shrinkage, cracks and porosity.<br>b) Cold Shuts. | 3-10<br>20 |
| Welds | a) Cracks, porosity.<br>b) Included flux. | 20<br>1 |
| Plastics | Cracks, crazing. | 1–5 |

3.3 **Removal of Excess Penetrant.** Excess penetrant should be removed by spraying with running water at a mains pressure of about 2·11 kg/sq cm (30 lb/sq in) or by the use of an air/water gun. In the case of self-emulsifying penetrants, it may be necessary with some surfaces to use a detergent solution, supplied by the manufacturer, prior to spraying the developer. It is most important to ensure that the rinsing operation is completely effective, otherwise traces of the residual penetrant may remain on the surface and interfere with the subsequent diagnosis of defects.

3.3.1 After rinsing, the surfaces of the component should be quickly inspected by means of ultra-violet light to ascertain the efficiency of the rinse. If any general fluorescence is still evident the rinsing operation should be repeated.

3.3.2 If a wet developer is to be used, the surfaces need not be dried but drying is essential if a dry developer is to be used. On large parts the excess water can be blown off with clean, dry, oil-free air but when parts are of convenient size, drying in a recirculating hot-air drier is recommended. Excessive time in the drier should be avoided, as the penetrant will slowly evaporate.

3.4 **Application of the Developer.** The developer usually consists of a very fine white powder which may be applied in

a) the form of a spray, the powder being suspended in a volatile liquid carrier,

b) as a dip with the powder suspended in water or

c) as a dry powder which may be blown on to the component or into which the component may be dipped. The action of the absorbent powder is to draw out the dye from the surface defects, thus indicating their position by the resultant yellowish-green stain when viewed under ultra-violet light.

3.4.1 Where it is suspected that microscopic defects may be present, great care is necessary to ensure that the developer is applied evenly and very thinly, since a thick layer might completely conceal a defect holding only a minute quantity of dye.

3.4.2 Where a wet developer is concerned, the best results are obtained when the developer is applied by means of a paint-type spray gun operating at an air pressure not in excess of 1·05 kg/sq cm (15 lb/sq in). The pressure pot of the gun should be equipped with a stirrer to keep the developer agitated and the absorbent particles in suspension. Before pouring the developer into the spray-gun it should be well shaken to ensure thorough distribution of the absorbent particles.

3.4.3 When requirements are not too exacting, small parts can be dipped into a bath of developer but the action must be performed rapidly to minimise the possibility of the penetrant being washed out of shallow defects. The bath should be agitated from time to time to ensure that the absorbent particles are kept in uniform suspension in the solvent. The formation of pools of developer on the parts during draining must be avoided, otherwise the resultant thick coatings may mask defects.

3.4.4 Due to the usually uneven results obtained, the use of a brush for applying the developer is not recommended.

3.4.5 After the developer has been applied, the parts should be allowed to stand for at least 15 minutes and should then be examined in a darkened room, using ultra-violet light. Where doubt exists as to the validity of an indication, the part should be left for at least 2 hours and then re-examined. If viewing periods are to exceed 30 minutes, the use of special viewing goggles is recommended to reduce the risk of eyestrain and headaches.

**NOTE:** Portable lamps specially manufactured for fluorescent viewing are available.

## 4 Application of the Penetrant Process (with Post Emulsification)

In principle the process is similar to that described in the previous paragraph, except for the addition of the emulsification step. However, the separate application of penetrant and emulsifier does introduce additional factors which must be taken into account and these are described below.

4.1 After the parts have been dipped in the penetrant, the drain-off period should not be less than 15 minutes and not more than 2 hours. If the period is less than 15 minutes, dilution of the emulsifier by the penetrant may occur and penetration of contaminated defects may not be complete. If the period exceeds 2 hours, partial drying of the penetrant may occur, resulting in exceptionally long emulsification times. Once an optimum draining period has been determined for a particular part, it should be adhered to within ± 20%, since this period directly influences the process and effects of emulisification.

4.2 The parts should be dipped into the emulsifier (the length of time the emulsifier is allowed on the parts being somewhat critical), and should be held to the minimum time necessary to give a good water wash, since this will result in the highest sensitivity. It should be determined by experience for each type of part and finish and then strictly adhered to.

4.3 An average emulsification time is about 2 minutes, but may vary between 30 seconds to 5 minutes, according to the surface condition of the part.

4.4 After removal of the emulsifier, the part should be dried, treated in the dry developer and then inspected for defects.

## 5 Interpretation of Indications

If defects are present and all stages of the process have been applied correctly, they will be indicated by brilliant greenish-yellow marks on the surface of the part; some may appear immediately as the developer dries but others may take longer to develop. The characteristics of the markings, such as the rapidity with which they develop and their final shape and size, provide an indication as to the nature of the defect revealed (see Figure 1).

5.1 The rate of staining is an indication of the width and depth of the defect, whilst the extent of staining is an indication of its volume. A wide shallow defect is revealed almost instantly but narrow deep defects may take some time to display the final pattern.

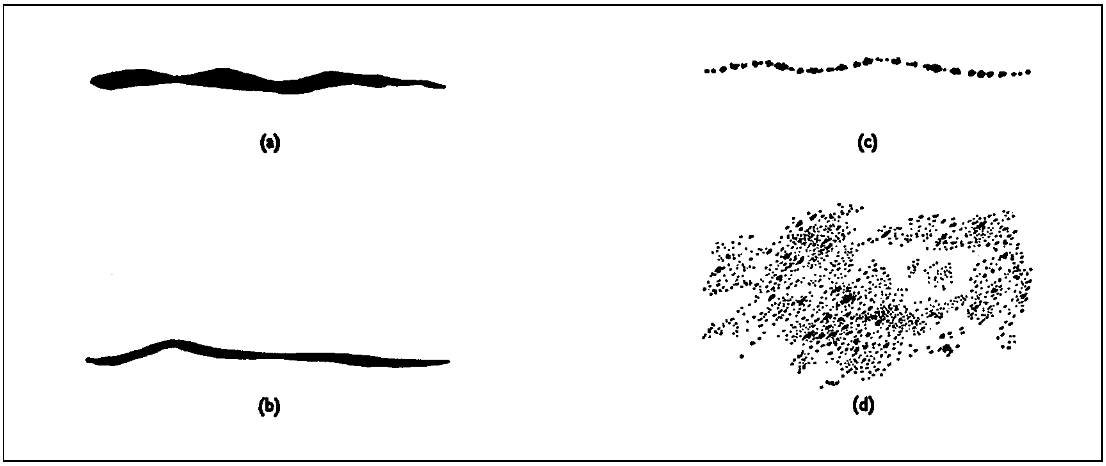

**Figure 1** Indications Given by Defects

5.2 Scattered dots indicate fine porosity or pitting (Figure 1 (d)), whilst gross porosity may result in an entire area becoming stained.

5.3 Closely spaced dots, in a line or curved pattern (Figure 1 (c)), usually indicate tight cracks or laps but such patterns are also characteristic of very wide defects from out of which most of the penetrant has been washed. Wide cracks, lack of fusion in welded parts and other similar defects are indicated by continuous lines as shown in Figures 1 (a) and 1 (b).

5.4 All defects should be suitably marked prior to removal of the developer, but crayons should not be used on highly-stressed components subject to heat treatment, since this is known to induce fractures.

## 6 Removal of Developer

Developer should be removed by washing with water spray or by dipping the component in an aqueous solution of 2% chromic acid. Since the surface is then in a condition susceptible to corrosion (where this is applicable) the prescribed protective treatment should be applied without delay.

# Leaflet 4-4 Performance Testing of Penetrant Testing Materials

## 1 Introduction

1.1 This Leaflet provides guidance on tests devised to show whether materials used for the penetrant inspection processes described in Leaflet 4–2 Penetrant Dye Processes, and Leaflet 4–6 Fluorescent Penetrant Processes, are in a satisfactory condition for further use.

1.2 The tests described in this Leaflet (there are other equally satisfactory methods) consist of comparing the performance of materials in use with samples of unused materials which are known to be in a condition as received from the manufacturer. The tests should be carried out at regular intervals as specified by the manufacturers and should also be made if it is suspected that the materials may have become contaminated.

1.3 In order to provide for the tests, a one-pint sample of all new batches of penetrants and emulsifiers should be taken and stored in airtight glass containers, protected from extremes of temperature and direct sunlight, and suitably identified to show the batch of materials to which they belong.

1.4 A metallic specimen containing cracks the location of which are known is necessary to enable the comparison to be made between samples. The preparation of a suitable test piece is described in paragraph 2.

## 2 The Test Piece

2.1 The most suitable type of specimen is the 'demountable' type test piece which can be dismantled between tests for cleaning but a suitable alternative is an aluminium alloy block, as illustrated in Figure 1, containing known fine defects.

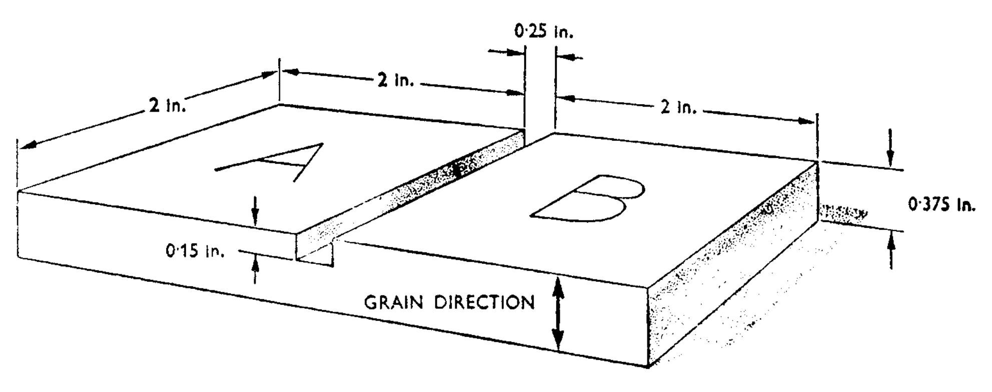

**Figure 1** Test Piece

2.2 The test piece should be cut from 2024 rolled aluminium plate to the dimensions and in the grain direction shown in Figure 1. All excessive markings should be removed from the working face and the test piece cracked by heat-treating in the following manner.

2.3 The test piece should be heated over an open flame so controlled that a temperature of 525°C (977°F) is reached in not less than 4 minutes, after which the test piece should be quenched in cold water and then heated gently over a flame to ensure that it is completely dry.

2.4 A slot of the dimensions given in Figure 1 should be made in the working face and the two 2 inch square surfaces thus obtained should be identified by lightly etching the surface with suitable symbols, e.g. 'A' and 'B'.

2.5 A record of the surface markings of the test piece should be made for subsequent reference in the following manner. The penetrant process should be applied to the test piece by hand under ideal conditions and using materials of a known standard and of the same type as those for which the test piece will be used. After allowing the defect indications to develop for a period of 15 minutes, the test piece should be photographed. Finally the test piece should be cleaned by the method described in paragraph 4.

## 3 Use of Test Piece

3.1 A test piece prepared for use with dye penetrants must not be used for testing fluorescent penetrants and vice versa. In this way the risk of contamination, which would give a false indication of the quality of the material being tested, is considerably reduced.

3.2 The test piece should be used by dipping surface 'A' into a sample of unused material and surface 'B' into a sample of the material under test. The test piece should then be allowed to drain for not less than 20 minutes, care being taken to ensure that the penetrants cannot mix.

3.3 After draining, both halves of the test piece should be washed simultaneously by the normal process method (see Leaflets 4–2 or 4–6, as applicable), notice being taken of the ease with which each half is cleaned. The test piece should then be dried and developed by the normal process method and allowed to stand for 15 minutes.

**NOTE:** Where the recommendations given above would not be suitable for a particular process, the general principle should be followed but adapted as necessary.

3.4 The two halves of the test piece should be compared one with the other and with the record of the initial test for the following:

a) Vividness of indications;

b) Definition of indications;

c) Extent to which very fine defects are revealed;

d) Ability to retain indications in wider cracks;

e) Background contamination.

3.5 After making the comparisons described above it should be possible to arrive at one of the following conclusions.

a) Both halves of the test piece compare favourably with each other and with the record of the initial test, it can be concluded that the material under test and the process used are satisfactory.

b) If the half of the test piece treated with unused material is comparable with the record of the initial test but the half treated with used material is not, this suggests that the used penetrant has become contaminated or has otherwise deteriorated and should be discarded.

c) If both halves of the test piece compare favourably one with the other but not with the record of the initial test, this suggests that the whole or some part of the process is at fault and should be investigated. However, the possibility of the test piece having become contaminated should not be overlooked. Possible faults with the process include incorrect temperatures, excessive washing and incorrect development techniques.

## 4 Restoration of Test Piece

4.1 On completion of each test the test piece should be thoroughly cleaned to remove all traces of contamination.

4.2 After cleaning the test piece should be stored in an airtight container in a mixture of 50% trichloroethylene and 50% toluene until required for further use.

4.3 It should be borne in mind that the useful life of the test piece depends entirely on the effectiveness of the restoration process.

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# Leaflet 4-5 Ultrasonic Flaw Detection and Thickness Measurement

## 1 Introduction

1.1 The methods of crack detection dealt with in Leaflets 4–1, 4–2 and 4–3, are of considerable value for finding surface defects but are unable to reveal the presence of internal flaws which are distant from the surface. This Leaflet gives general guidance on the application and scope of ultrasonic sound waves for detecting surface and internal flaws in materials and parts and for the measurement of thickness.

1.2 Ultrasonic testing is not a complete substitute for other methods of flaw detection and should generally be regarded as complementary to them. It should be considered an extension to efficient inspection but should not be regarded as a foolproof method without considered trials and its indiscriminate use could be uneconomical and misleading. There are instances however, particularly in aircraft applications, where ultrasonic testing is the only satisfactory method, e.g. when a distant defect lies parallel with the only available surface of a component. The degree of skill and experience required to use ultrasonic apparatus and to interpret the indications obtained, varies with the complexity of the parts to be examined, the type of equipment available and the acceptance standards specified. Operators should be properly trained and qualified on the equipment in use.

1.3 Cavities, inclusions and cracks in cast metal prior to fabrication by extrusion, rolling, forging, etc., can be found by ultrasonic techniques and automatic scanning devices are often used during the manufacturing process. Large steel or aluminium forgings, components welded by gas, arc or flash butt methods and a variety of parts such as turbine discs, propeller blades and wing spar booms may all be examined at various stages during manufacture. Ultrasonic methods can also be used for finding fatigue cracks and other defects arising from operating conditions, during the periodic inspection of airframe and engine parts.

1.4 Thickness measurement by ultrasonic methods has some aircraft applications. It provides a satisfactory means of measuring the skin thickness of hollow propeller or turbine blades and for checking tubular members or sheet metal assemblies. Delamination of bonded assemblies can also be checked by similar methods.

## 2 Sound Waves

2.1 Ultrasound describes sound at a pitch too high to be detected by the human ear. The frequencies used in ultrasonic testing are normally within the range 500 kHz to 10 MHz.

2.2 **Sound Energy.** Sound is energy produced by a vibrating body, the energy being transferred through a medium by the wave-like motion of the particles making up that medium. The frequency of the waves is the same as that of the vibrating body and the wavelength is dependent upon the speed of sound in the particular material. This is illustrated in Figure 1, the 'y' axis representing the distance of a vibrating particle from its mean position and the 'x' axis its distance from the sound source. The time taken for the sound to travel one wavelength ($\lambda$) is the same as the time taken for the vibrating body to execute one complete cycle.

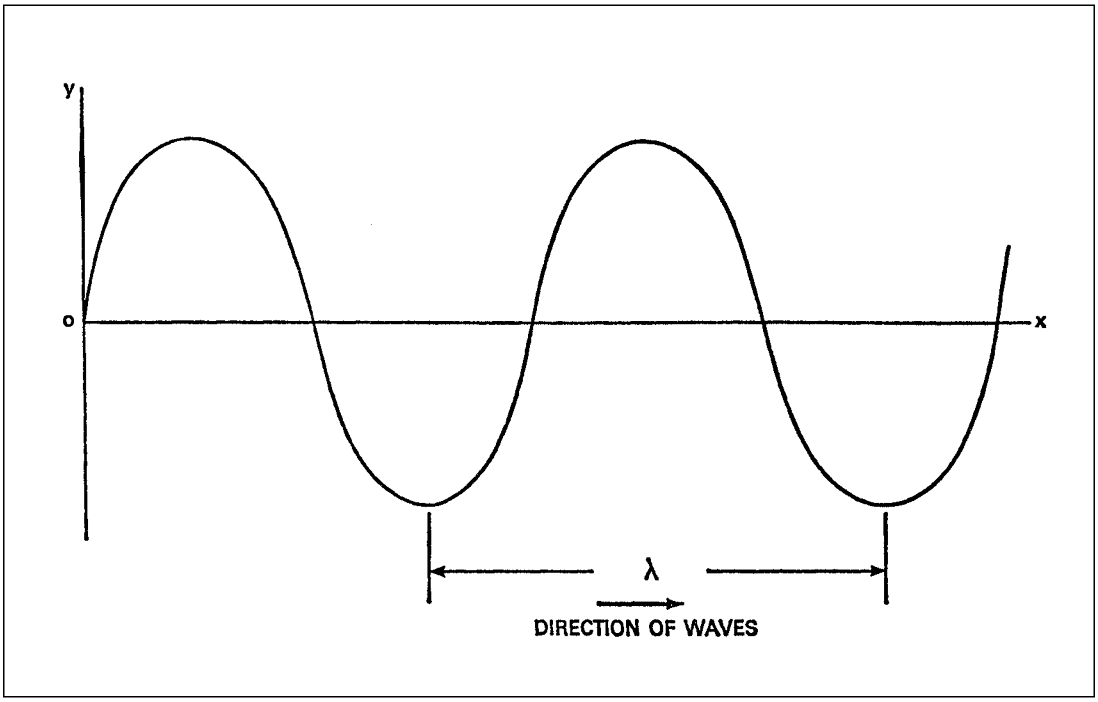


**Figure 1** Form of Sound Waves

2.3 **Wave Types.** Three main types of waves may be generated. The vibrations in **Longitudinal** (compression) waves are in the same direction as the sound motion and the vibrations in **Transverse** (shear) waves are perpendicular to the sound motion. Waves generated along the surface of a material, known as Surface waves, have an eliptical motion. Any of these types of waves may be generated in solids but only longitudinal waves can normally be generated in liquids or gasses. Other types of waves exist and are sometimes used in ultrasonic testing (e.g. Lamb Waves, which are vibrational waves capable of propogation in thin sheet material).

2.4 **Speed of Sound.** The speed of sound through any particular material depends on the density and elastic constants of that material. Transverse waves travel at approximately half the speed of **Longitudinal** waves and surface waves at approximately 90% of the speed of **Transverse** waves.

2.5 **Beam Characteristics.** When sound waves are generated by a flat disc vibrating at ultrasonic frequencies the beam of sound is initially parallel and then, at a distance from the disc related to its diameter and the sound frequency, spreads out and loses intensity, the spread increasing as frequency and disc diameter are reduced. Within the near (parallel) zone variations in sound intensity occur and absorption results in a loss of energy with increased distance from the source. A material with a large grain structure or holes associated with porosity absorbs more energy than one with a fine grain structure but, since absorption is also a function of frequency, by decreasing the frequency absorption is also reduced.

2.6 **Mode Conversion.** When a beam of sound is directed at the boundary between two solid materials at an angle other than normal to the interface, both reflection and refraction occur as shown in Figure 2. If material 'A' is a liquid, as in ultrasonic testing, only longitudinal waves will be reflected. Adjustment of angle 'a' will enable any of the main types of waves to be injected into material 'B'. Unfortunately mode conversion also produces unwanted reflections from the surface of a component which, due to the different speeds of the various types of waves, may give confusing results.

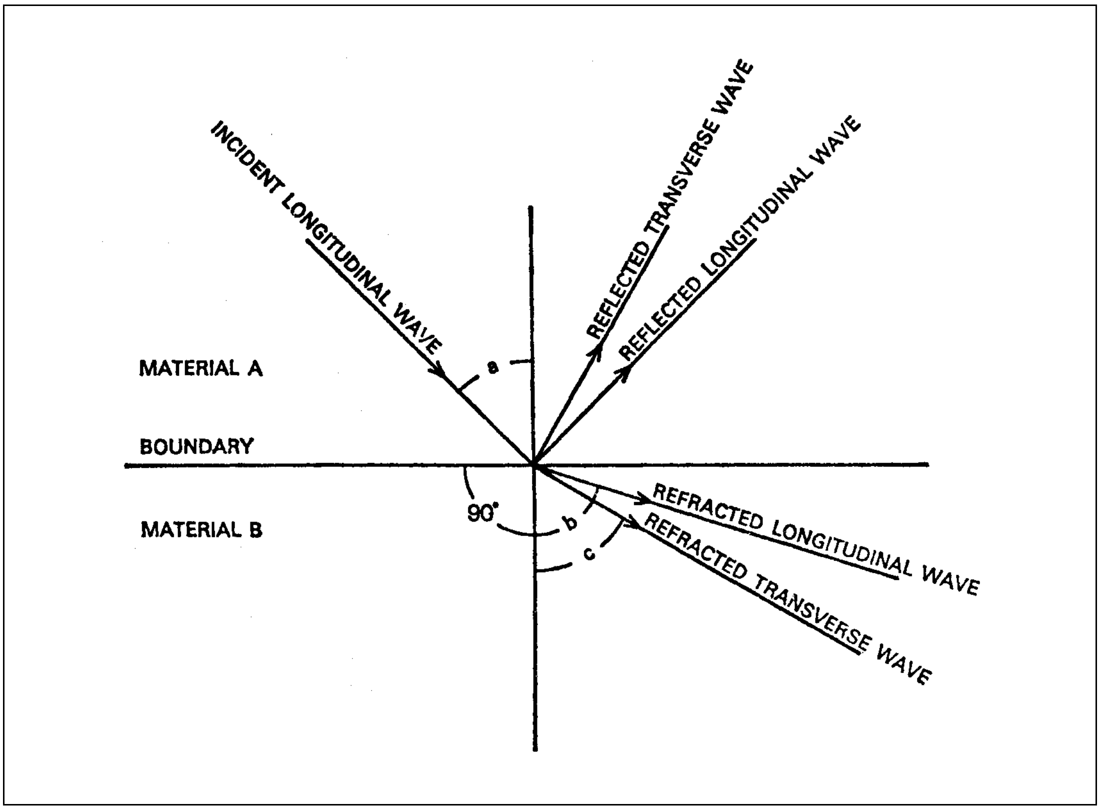


**Figure 2** Mode Conversion

## 3 Generation and Detection of Sound Waves

3.1 The sound waves used in ultrasonic testing are produced and detected by means of an electro-mechanical transducer, i.e. a device which converts electrical energy into mechanical energy and vice versa. The properties of the materials used in the manufacture of transducers are discussed in the following paragraphs.

### 3.2 Piezoelectric Effect

3.2.1 If a mechanical stress is applied in a specified direction to certain natural crystals such as quartz, an electrical field is produced in which the voltage is proportional to the magnitude of the stress. Similarly, if a voltage is applied between the crystal faces a proportional mechanical stress is produced in the crystal. By applying an electrical potential to the faces of an X-cut quartz crystal (i.e. a crystal cut in the form of a disc whose faces are normal to one of the 'X' axes) a vibration is produced, the frequency of which depends on the thickness of the crystal. Conversely, when such a crystal is caused to vibrate under the influence of a sound beam an alternating current is produced between the crystal faces.

3.2.2 A similar effect is produced in all electrically insulating materials and certain ceramic materials such as barium titanate are particularly sensitive in this respect. Transducers made from these materials consist of a large number of tiny crystals fused together and are permanently polarised during manufacture so as to vibrate in one plane only.

3.2.3 Piezoelectric crystals lose their activity when heated above a particular temperature and this may be a severe limitation for certain uses.

3.3 **Crystal Frequencies.** To achieve maximum efficiency crystals must be operated at their natural frequency (determined by their dimensions and elastic properties).

Transducers used in ultrasonic testing are generally used in this way when searching for cracks but for resonance testing different methods are used (see paragraph 4.4).

3.4 **Acoustic Coupling.** The amount of energy transferred across a boundary between two materials depends on the Characteristic Impedance of each material, which may be taken as the product of the density and the speed of sound in each material. Good coupling will be provided when the Characteristic Impedance of the two media are closely matched and the capability of ultrasonic flaw detection depends on these factors. The coupling between metal and air is extremely poor and it follows that if any air is present between a probe and the material being tested very little energy will be transferred across the interface. For this reason a liquid couplant such as water, oil or grease is normally used in ultrasonic testing.

3.5 **Reflection.** If an ultrasonic beam is injected into a material it will continue through that material until it strikes a surface and will then either pass through the interface or be reflected, depending on the factors outlined above. If the beam strikes a discontinuity, crack or void in the material the reflection may be picked up by a suitably placed transducer, the amount of reflected energy depending on the nature of the defect and its orientation. Most of the energy striking an external surface or void will be reflected but in cases such as bolt holes or bushes which have been well lubricated very little reflection may occur.

3.6 **Probes.** A probe consists of a transducer mounted in a damping material and connected electrically to the test set. For any particular application it may be necessary to use a probe of a particular design so that a sound beam is injected into the material at an angle normal to the expected defect. The required angle of the incident beam is achieved by mounting the transducer on a suitably shaped plastic block. Similar blocks are also used for injecting sound waves into a material with a uniformly shaped surface such as a tube. In certain applications a wheel probe, consisting of a transducer mounted inside an oil-filled plastic tyre, has been found suitable for high speed automatic scanning.

### 3.7 Display

3.7.1 The most usual method of displaying the information obtained in ultrasonic testing is by means of a cathode ray oscilloscope. A pulsed transmission technique is normally used and is described below; other methods are described in subsequent paragraphs.

3.7.2 In the cathode ray oscilloscope (Figure 3), a triggering device causes both the pulse generator and time base control to operate simultaneously. The time base control (connected to the 'X' plates of the oscilloscope) deflects the trace produced by a beam of electrons, so that the trace moves across the screen from left to right in synchronisation with the ultrasonic pulse transmissions. Vibration of the transducer results in an electrical signal at the 'Y' plates of the oscilloscope, which deflects the electron beam in the form of a peak (A) in the time base. Any returning echo acts on the receiving transducer to produce a second peak (B), the distance of the flaw from the surface being represented by half the distance between A and B. This distance can be calculated from knowledge of the speed of sound in the particular material and the time base scale. The time base scale is usually variable and provision is often made for the attachment of a graticule scale to the oscilloscope screen so that direct measurements may be taken.

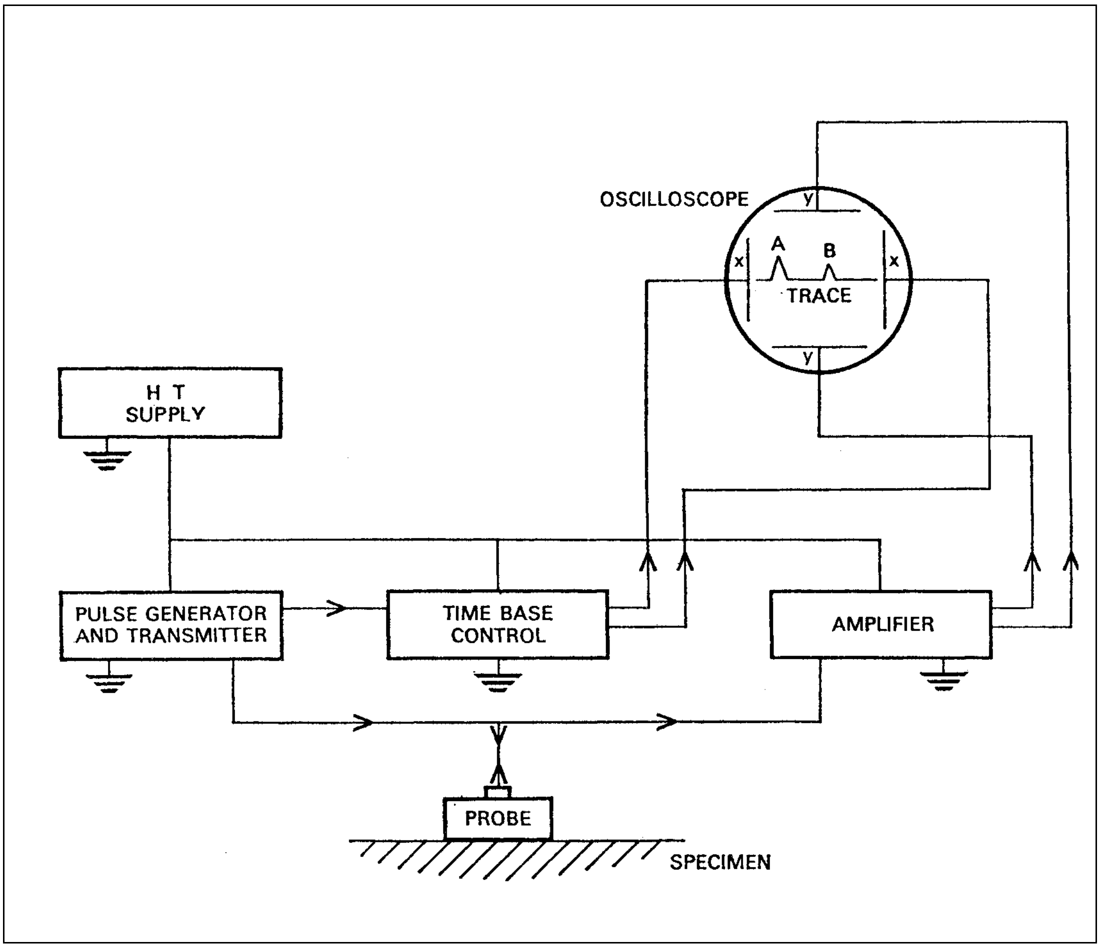


**Figure 3** Simple Block Diagram of Ultrasonic Set

3.7.3 Transducer crystals are usually damped to reduce the length of the pulse, but a layer (known as the 'dead zone') is left immediately below the surface of the test material in which defects parallel to the surface can only be examined from an opposite face. Increasing the ultrasonic frequency would reduce the depth of this layer but would also result in high absorption and might not be suitable for certain materials.

3.7.4 The pulse repetition frequency is extremely rapid to ensure a good trace on the oscilloscope, but must not be so quick that sound energy is still reflecting within the specimen when the next pulse is initiated.

3.7.5 The presentation described above is known as 'A scan' but the information may also be displayed in the form of a side elevation (B scan) or a plan view (C scan), the latter usually being used in automatically produced paper read-out form from a normal A scan oscilloscope.

## 4 Methods of Operation

4.1 **Transmission Method**. If a transmitting and a receiving probe are placed on opposite sides of a specimen (Figure 4), sound waves will be transmitted directly through the material and picked up by the receiving probe. If a flaw in the material interrupts the sound beam, a loss of signal will result and the second peak on the time base will disappear. Longitudinal wave probes are normally used for transmission scanning but angled probes may also be used when only one surface is accessible (Figure 5).

### 4.2 Pulse-echo Method

4.2.1 This method relies on reflections from a defect being detected by the receiving probe and either a single transceiver probe or separate transmitting and receiving probes may be used (Figure 6).

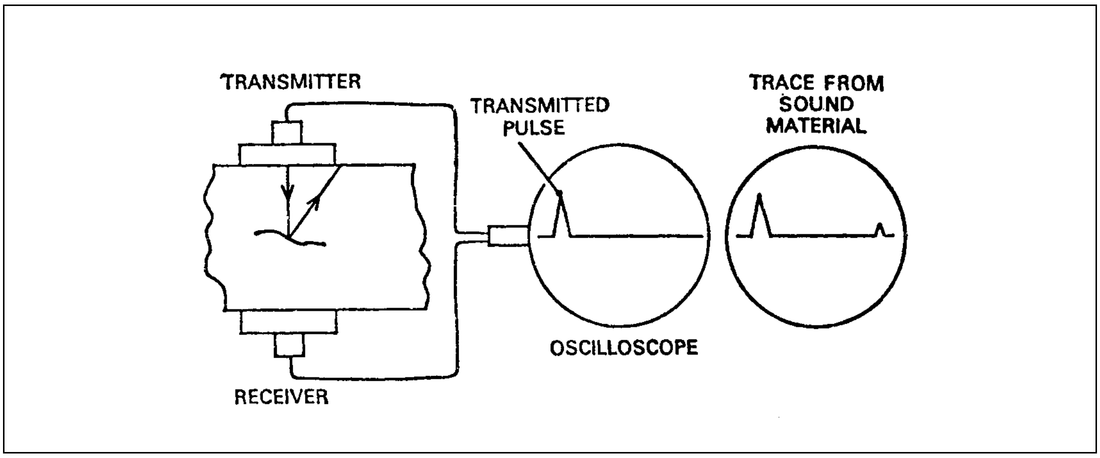


**Figure 4** Normal Transmission Technique

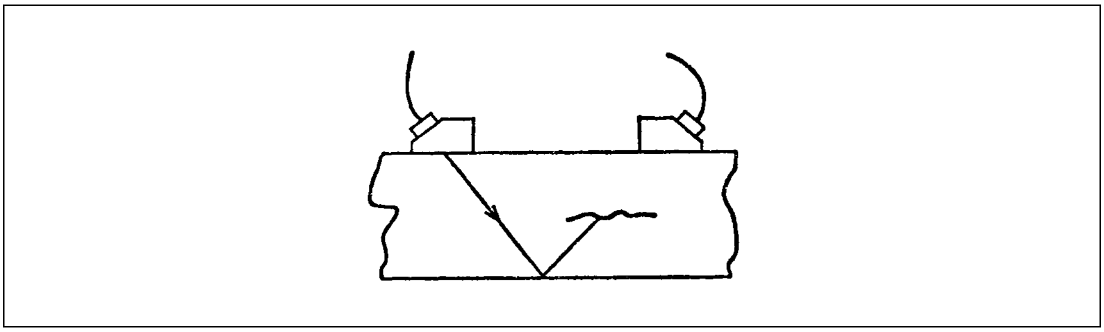


**Figure 5** Alternative Transmission Technique

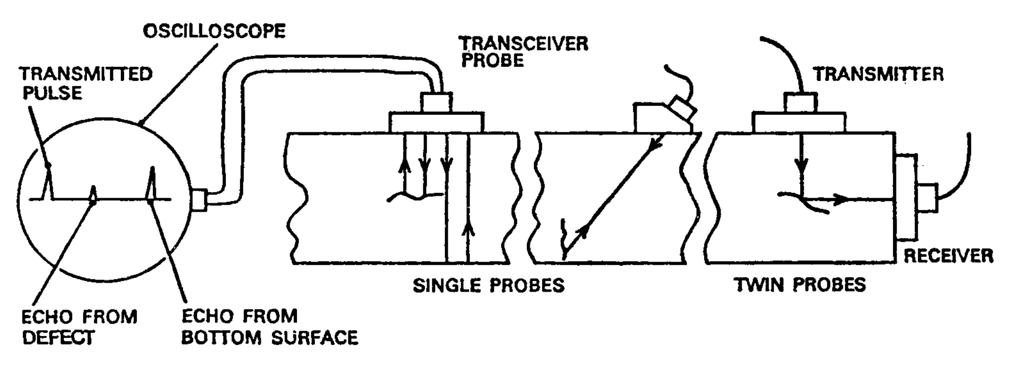


**Figure 6** Pulse-echo Techniques

4.2.2 Pulse-echo methods are also used for finding cracks at right angles to a surface. An angled probe is used to inject surface waves into a material, the waves following the surface contour and reflecting back to the probe from any discontinuity (Figure 7).

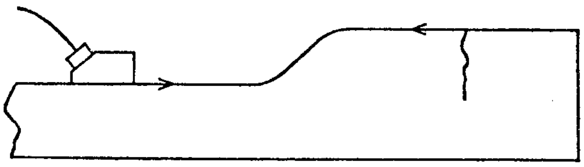


**Figure 7** Surface Wave Testing

4.3 **Immersion Testing**. The technique of holding a probe in contact with the specimen is known as 'contact scanning', but there is also an important method of inspection known as 'immersion scanning', in which the specimen is immersed in a tank of water and a waterproof probe placed in the water, above the specimen (Figure 8). Pulse-echo techniques are normally used but transmission techniques would also be possible.

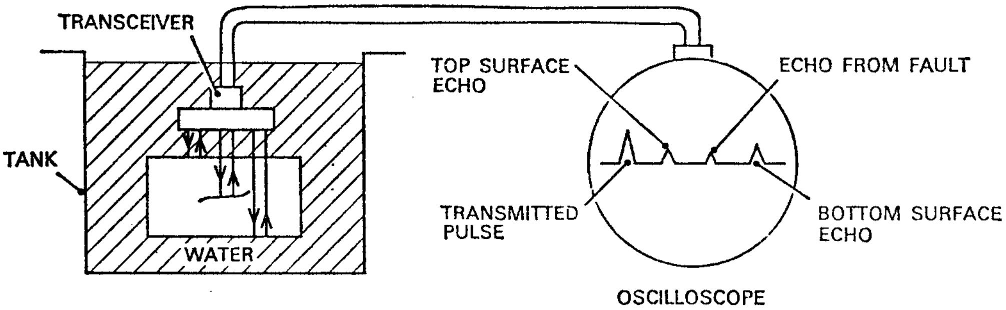


**Figure 8** Immersion Testing

4.3.1 Pulses of ultrasound are emitted by the probe and pass through the water into the specimen. The top and bottom surfaces of the specimen are shown on the oscilloscope, together with indication from the transmitted pulse and any flaws within the material.

4.3.2 The distance between the probe and specimen must be selected so that confusing repeat echoes are avoided and can also be set to avoid use of the near zone in examining the specimen.

4.3.3 The trace produced by a fault-free specimen will normally produce three peaks, the space between the second and third, i.e. the depth of the specimen, being the only part of interest during inspection. The time base is usually delayed and its scale expanded, so that indications of defects are more easily seen.

4.3.4 Immersion scanning lends itself to automation and is frequently used for the inspection of parts of simple shape. Parts of complicated geometric shape present difficulties in that expensive electronic circuits would be required to differentiate between surface reflections and internal flaws.

4.4 **Resonance Technique.** If a sheet or plate specimen is caused to vibrate in the direction of its thickness, resonance will occur if the thickness is equal to exactly half the wavelength of the inducing vibrations. By using a quartz transducer to vary the frequency of the vibrations, resonance is produced in the specimen and this frequency is displayed to indicate the thickness. A laminar type of defect, or loss of bonding, can also be detected by resonance methods providing that the separation is dry.

### 4.5 General Considerations

4.5.1 A number of factors must be considered before making an ultrasonic inspection and special techniques may have to be developed for a particular situation.

4.5.2 **Surface Conditions.** There are various surface conditions, such as rust, scale, loose paint etc., which will prevent inspection by ultrasonic methods and these must be removed. The rough surfaces such as are found on cast billets may present difficulties, but the use of grease as a couplant may be effective, or, alternatively, the immersion technique may be used. The shape of the specimen should also be considered so that slipper blocks may be made to provide the best acoustic contact.

4.5.3 **Sensitivity.** With too great a sensitivity, porosity and large grain size will hide flaws in a material by producing numerous peaks on an oscilloscope. It is important, therefore, that the sensitivity of the test equipment be adjusted so that unimportant features can be disregarded. The amplitude of reflections depends mainly on the size of the flaw and if the maximum acceptable size of defect were specified, then any reflection producing peaks higher than this would be known to be unacceptable.

a) For longitudinal wave scans the acceptable size of defect is related to a flat bottomed hole of a particular diameter. Test blocks are used in which holes of various sizes are drilled and oscilloscope sensitivity is adjusted to give a peak of, say, 2.54 centimetres (1 inch) in height on the reflection from the hole of specified size. Blocks with holes drilled to different distances from the surface may be required to check the effect of attenuation on peak height. During test, defects producing peaks lower than 2.54 centimetres (1 inch) can then be ignored.

b) For transverse wave scanning the acceptable size of defect is related to a hole or saw cut made in a block of the same material and thickness as that to be inspected.

c) Notwithstanding the sensitivity setting of the oscilloscope, some defects, such as cracks, may extend over a considerable distance and therefore be unacceptable. These would be recognised by a constant peak as the probe was moved in the direction of the crack.

d) A special test piece has been designed by the International Institute of Welding and may be used for checking ultrasonic equipment in respect of both longitudinal and transverse waves; oscilloscope scale and resolution can also be verified.

**NOTE:** Most ultrasonic test sets are now fitted with an attenuator. This is a device which applies calibrated attenuation to the received signal, enabling received signal strength to be measured, in decibels, relative to the signal from a reference standard.

4.5.4 **Choice of Frequency.** Both absorption and diffraction of sound waves are a function of the frequency used. For any particular test it is necessary to take into account the size and position of possible defects, the nature of the material and the distances to be scanned. With a coarse grained material a low frequency must be used, especially in large specimens, but with a fine grained material a higher frequency may be used, with a consequent increase in sensitivity.

4.5.5 **Type of Defect.** When preparing a technique for the inspection of a particular item, knowledge of the type of defect which can be expected is of great assistance. For example, if a casting has a known tendency to crack at a particular position during service, sketches can be provided showing the oscilloscope patterns obtained from both sound and faulty castings; inspectors will then not be misled by spurious reflections due to the shape of the castings.

## 5 Practical Applications

### 5.1 Testing Ingots, Billets and Heavy Forgings

5.1.1 Large blocks of metal of simple shape are particularly suited to testing by ultrasonic methods, provided that a suitable technique and frequency are used.

5.1.2 Rectangular blocks can be checked by systematically scanning three faces with a longitudinal wave probe. Because it is difficult to detect flaws which are close to the surface it may be advisable to scan all faces, but this will not be necessary if surface material is to be subsequently machined off.

5.1.3 Certain cast ingots may have such a coarse grain structure that the ultrasonic beam is scattered to a degree which renders flaw detection difficult or even impossible. If echo techniques prove to be unsuitable, the transmission method should be tried, but if this also is impracticable, it may be necessary to delay the inspection until rolling or forging have been carried out.

5.1.4 Inability to obtain satisfactory results can often be traced to poor acoustic coupling, a difficulty which can be overcome by use of the immersion technique.

5.1.5 It is common practice in industry to use automated ultrasonic techniques on billets, pipes and other similar products. A water jet, passing through a jacket within which the transducer is mounted, acts as the coupling agent and electronic alarms trigger marking systems which record the position of a defect. An automated immersion technique is also sometimes used on finished size thin wall tubes, using Lamb waves for flaw detection.

### 5.2 Testing Welded Joints

5.2.1 Most types of welds in thick materials can be inspected by ultrasonic methods, but thin sheet metal welds are more satisfactorily checked by the use of X-rays (Leaflet 4–6). It is good practice to obtain a separate specimen in the same material and to drill holes (as shown in Figure 9) which will indicate if it is possible to detect flaws at these positions. Experience has shown that this is not possible with all types of material and welding techniques.

5.2.2 Butt welds made by gas or arc welding methods can be checked by using an angled probe which injects transverse waves towards the weld line. If flaws are present in the weld, the beam will be reflected back to the probe. Experience in the application of scanning methods has made it possible to identify most types of welding defects, although it is not always easy to determine the acceptability of the weld from this information. When doubt exists, the information derived from the ultrasonic test should be correlated with other methods of testing, such as radiography.

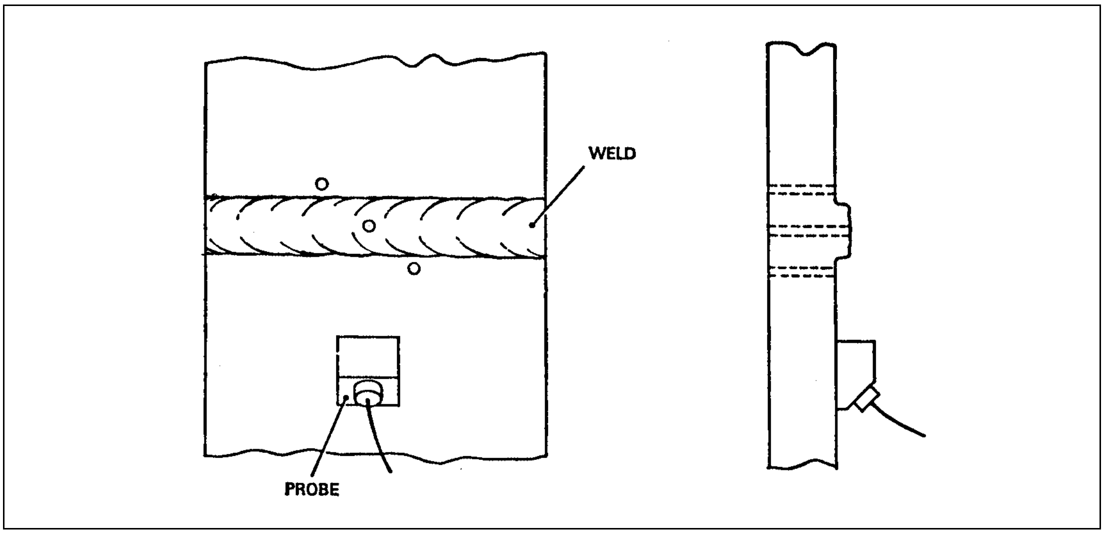


**Figure 9** Test Holes in Weld Sample

5.2.3 Special techniques are required for testing flash butt welds, since they contain no filler metal and flaws are normally in the plane of the weld. One method of testing is to position two probes as shown in Figure 10. Scanning is carried out by moving both probes simultaneously in opposite directions so that any flaws are detected by the receiver probe. The probes may, in some instances, be positioned on the same side and certain specimens are best scanned by fixing the probes in a jig to ensure correct alignment. To determine the best method for inspecting a particular weld, all these methods should be tried until the most consistent results are obtained.

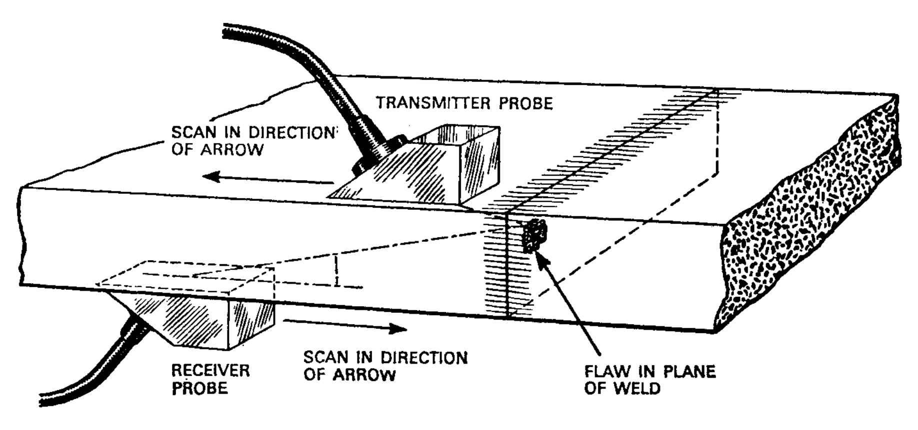


**Figure 10** Scanning Method for Finding Flaws in Flash Butt Welds

### 5.3 Thickness Measurement

5.3.1 **Pulse-echo Method.** By the choice of suitable probes and the selection of appropriate test frequencies, several types of flaw detectors can be used for measuring thickness, but the accuracy of most is limited when dealing with material of the thin gauges used in aircraft manufacture. Their main application is therefore, the measurement of thick material during machining and manufacturing operations, particularly when the parts concerned would have to be removed from jigs or machines in order to measure them by physical methods. Vertical probes are normally used and may be either the transceiver type or a probe combining separate transmitting and receiving crystals.

5.3.2 **Resonance Method.** This method is suitable for the measurement of new aircraft skin, structure and tubing and is normally only used during aircraft manufacture. A quartz crystal is excited by means of a valve oscillator, at a frequency well below the fundamental resonant frequency of the crystal and held in contact with the specimen. This causes the specimen to vibrate in its thickness direction and the frequency of the sound wave is increased until the specimen resonates. An increase in the amplitude of the vibrations results, with a corresponding increase in crystal voltage. If the crystal frequency is further increased, resonance recurs (i.e. at the next harmonic) and the fundamental frequency of the material and hence its thickness, can be determined. Resonances may be shown on a suitably calibrated oscilloscope screen but more simple methods such as a voltmeter reading or an audible note in earphones are often used.

**NOTE:** The thickness is equal to an exact number of half-wavelengths, which can be calculated from the speed of sound in the material and the fundamental resonance frequency.

### 5.4 Detection of Lamination

5.4.1 There are several ways of checking materials for internal laminations and similar methods may also be used to determine the integrity of bonded structures. The pulse-echo technique may be used on plate over 1·27 cm (½ inch) thick but it is unsuitable for thinner sections.

5.4.2 **Transmission Method.** If a transmitting and a receiving probe are held in alignment on opposite sides of a specimen, any lamination inside the specimen will interfere with the transmission of the ultrasonic waves and will be shown by a reduction in received signal strength. However, because of the need to have access to both sides of the specimen, this method has limited application in aircraft work.

5.4.3 **Resonance Method.** It has been explained that resonance occurs at one of the natural frequencies of the material, the thickness being related to an exact number of half-wavelengths of the ultrasonic beam. If a material is laminated, or the bond between two layers is defective, resonance will occur at a different frequency and will result in a change in the shape of the oscilloscope trace. Special test sets have been developed for the inspection of bonded structures and techniques have been established from which it can be determined whether a bond is satisfactory or not when the bond is dry.

5.4.4 **Multiple Echo Method.** The time base and sensitivity of an ultrasonic set can be adjusted to give a number of boundary reflections. With a set adjusted in this way, any laminations present in a specimen being scanned will show up as a sudden increase in the number of reflections, e.g. if the specimen is laminated at its centre, the number of peaks on the oscilloscope screen will be doubled.

5.4.5 **'Lamb' Wave Method.** Laminations near to the surface of a metal plate are very difficult to detect. However, Lamb waves may be generated in plate which approximates, in thickness, to one wavelength of the sound beam and any lamination will result in a change in the screen display. The angle of the probe is very important and varies with the thickness of the lamination; it is necessary, therefore, to scan with a variable angle probe.

## 6 Techniques for Aircraft Parts

6.1 Ultrasonic testing is widely used on parts removed from aircraft, but is also applicable to the examination of parts in situ where other types of inspection would require extensive disassembly. Techniques are established to ensure consistent results and these are written into the appropriate manuals.

6.2 Aircraft structural parts which can be checked by ultrasonic methods include large forgings, wheels, engine bearers, axles etc. Before these parts are installed in aircraft, or at times when they are removed during overhaul, the immersion method of testing will often give good results. Large tanks and automatic testing equipment are not necessary for examining parts of manageable proportions; such parts can be submerged in water in a convenient container, the probe being mounted in a fixture to ensure that the required beam angle is maintained. However, certain parts, such as wheels, lend themselves to automated methods and some aircraft operators have found these to be worthwhile; their use also permits an electronic record of each inspection to be kept. The essential requirement for any test is a standard of reference and this may be provided by using an identical part of known condition as a specimen. As a check on sensitivity, defects can be introduced in the reference specimen, by drilling small holes or by spark erosion, at positions where defects are likely to occur. Reflections introduced by these artificial defects can be compared with the traces obtained from a part under test.

6.3 The chief value of ultrasonic examination in situ, is that defects and in some individual cases corrosion, can be found in areas not accessible for visual examination. Provided that one smooth surface is accessible to the ultrasonic probe, most forgings, castings and extrusions can be satisfactorily inspected. On some aircraft, spar boom and some similar structural members require periodic examination for fatigue cracks, but the areas of suspected weakness may not be accessible for examination by visual or dye-penetrant methods. Ultrasonic testing gives quick results on those defects which lend themselves to this form of testing, i.e., the defect is normal to the directed beam. In this instance radiographic techniques would be quite unsuitable.

6.4 When carrying out ultrasonic tests in situ, the surface to be scanned by the probe should be thoroughly cleaned and covered with oil or grease to provide good acoustic contact. If parts are removed for testing, then water may be used as a couplant, but the parts should be thoroughly dried before being put into storage or service.

# Leaflet 4-6 Radiological Examination of Aircraft Structures

## 1 Introduction

1.1 This Leaflet gives guidance on the operation of radiological testing apparatus and the establishment of satisfactory inspection techniques.

1.2 The use of radiography in accordance with an approved technique will often facilitate the inspection of structures during manufacture, overhaul and maintenance and can be used for the examination of structures which would otherwise be inaccessible. A number of airframe and engine manufacturers and aircraft operators, have devised techniques for particular inspections. These are written into the appropriate Maintenance Manuals and Maintenance Schedules or included in a separate Non-destructive Testing (NDT) Manual. General information on radiographic techniques is included in British Standard (BS) M34.

1.3 Radiographic methods may also be used to advantage where normal physical methods of measurement are difficult or impractical. It has been shown, for example, that it is extremely difficult to detect eccentricity in items with long bored or counterbored holes and that wall thickness in these cases can be accurately determined by means of a radiograph. Where this type of measurement is considered necessary the appropriate technique should be quoted on drawings or inspection instructions.

1.4 Radiography should be considered as an extension to efficient inspection and is sometimes of value in providing a second opinion where inconclusive results have been obtained by other methods. It should not be regarded as a foolproof method of inspection without considered trials and its indiscriminate use would be both uneconomical and misleading.

1.5 The misuse of radiographic equipment could result in the release of physically harmful radiations and it is therefore extremely important that operators should be properly trained and aware of the regulations concerned with safety. The provision of adequate protection is not dealt with in this Leaflet; it is emphasised however, that the operating procedures and conditions set out in 'The Radioactive Substances Act (1960)' and the 'Ionising Radiations (Sealed Sources) Regulations No.808 (1969)' must be observed at all times when radiography is used for aircraft inspection.

1.6 The importance of proper training is also evident in the interpretation of radiographs. Incorrect conclusions could result in the clearance of unsafe structures or components or, conversely, the scrapping of expensive items which are really sound.

## 2 Sources of Radiation

2.1 There are two forms of electro-magnetic radiations which can be used in radiography, namely X-ray and gamma rays. The main difference between the two is in the method of propagation. The radiations are of very short wavelength (0·001 Å to 2Å) and are capable of penetrating solids, the rays passing through a specimen being used to expose a sensitised film. X-rays also cause the fluorescence of certain chemicals and this reaction is sometimes used to produce an image on a phosphor screen; this technique is known as fluoroscopy.

## 2.2 X-Rays

2.2.1 This particular form of electro-magnetic radiation is produced when electrons, travelling at high speed, collide with matter in any form.

2.2.2 The basic requirements for the production of X-rays are a source of electrons, a means of accelerating the electrons to high speed and a target to emit the X-rays. A typical circuit of an X-ray set is shown in Figure 1. The X-ray tube is an evacuated chamber in which the electrons are derived from a filament, set in a focussing cup and heated to incandescence by a low voltage current; electrons are released and form a 'space charge' around the filament. When a high potential is applied, electrons accelerate from the filament (the cathode) to the anode and strike the target, which then emits X-rays.

2.2.3 Only approximately 1% of the electron energy is converted into X-rays the rest being changed into heat and light. For this reason the anode consists of a substantial block of copper, in which the target is set and is often cooled by the circulation of liquid. The target is made from tungsten to resist the high temperatures produced by the electrons at the focal spot.

2.2.4 X-rays are emitted in all directions from the target but the tube is normally shielded so that a beam is emitted in the shape of a 40$^{\circ}$ cone. However, some X-ray tubes are designed to emit different shaped beams for particular uses.

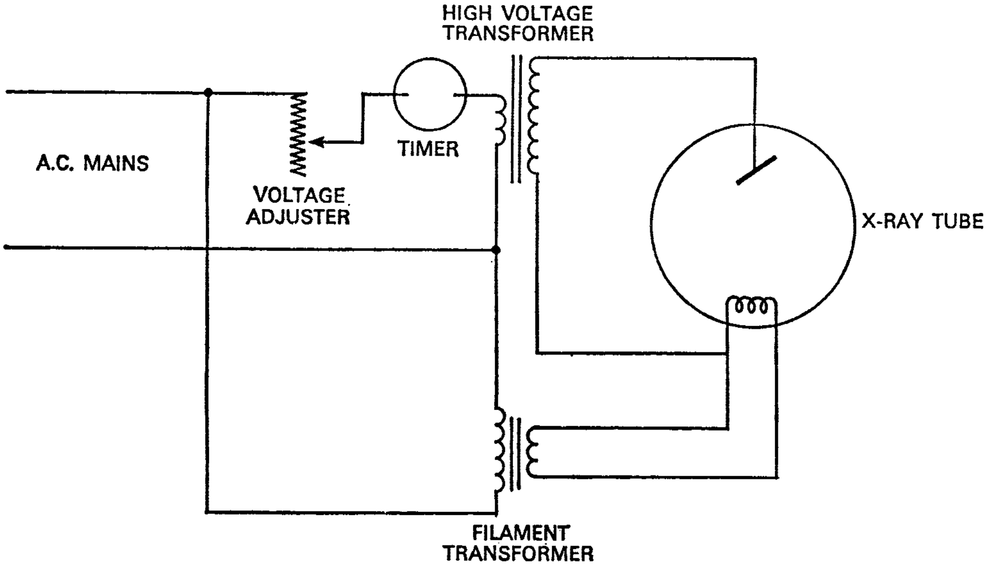


**Figure 1** Typical Circuit of an X-ray Set

2.2.5 The electrical supply to an X-ray tube is normally from the a.c. mains through a transformer and, since electrons can only flow from the cathode to the anode, a pulsed tube current results. Some X-ray sets use complex electrical circuits to produce a constant potential in the tube, but they are generally very expensive and unsuitable for the type of portable equipment which is generally used on aircraft. The wavelength of the X-rays is inversely proportional to the voltage applied and the X-rays produced will vary in wavelength down to a minimum value determined by the peak voltage. This is known as a 'continuous spectrum' and is a characteristic of all X-ray tubes. The penetrating power of X-rays increases as the wavelength decreases and high voltages are therefore used when radiographs of dense materials, such as steel, are required.

2.2.6 **Penetrating Power.** Although penetrating power is related to the voltage of the X-ray tube, it is often indicated by the 'half value layer' (HVL) of the beam. This represents the thickness of a given material (usually aluminium or copper) which will reduce the intensity of the beam to half its original value. This method is not completely accurate however, since the longer wavelengths, being less penetrating, are removed first and quality of the beam is changed. If additional filtration (i.e. thicker aluminium or copper sheets) is provided it will be seen that the HVL increases progressively until a constant beam quality is obtained.

2.2.7 **Types of Equipment.** X-ray equipment is normally graded according to the voltage range over which it is designed to operate. The portable sets used in aircraft work normally cover voltages between 10 kV and 250 kV, but no single set will cover this whole range. Tubes designed for high voltages possess inherent filtration properties, which, combined with space charge effects, will preclude the emission of an effective X-ray beam at low voltages. Typical ranges covered by portable sets are 10 kV to 100 kV and 100 kV to 250 kV.

### 2.3 Gamma Rays

2.3.1 Electro-magnetic radiations resulting from the disintegration of radioactive materials are known as gamma rays. The isotopes now used in radiography are artificially produced and emit rays of similar wavelength to those produced in X-ray tubes. Gamma radiation is not in the same form as X-rays however and consists of one or more discrete wavelengths in what is known as a 'line spectrum'. The relative intensities of each wavelength are always the same for a particular material. The four most commonly used isotopes are Cobalt 60, Iridium 192, Caesium 137 and Thulium 170.

2.3.2 **Radioactive Decay.** Radioactive elements, whether natural or artificial, are subject to a specific rate of decay i.e. a reduction in strength of the radioactivity. This decay is measured in terms of the time over which half the original activity is lost and is called the 'half life' of the material. The half life of radioactive materials varies considerably, for example, Aluminium 28 has a half life of 2.27 minutes whereas Uranium 238 has a half life of $4.5 \times 10^9$ years. Radioactive materials can be used for radiography through several half life periods provided that an adequate working strength remains and some are capable of re-irradiation in an atomic pile.

2.3.3 **Penetrating Power.** It is customary to express the penetrating power of gamma rays in terms of the voltage which would be required to generate X-rays of similar penetrating power. The unit used, the mega electron volt (MeV), represents the energy required to accelerate an electron through 1 000 000 volts. The energy emitted by Caesium 137 is 0·66 MeV and this is equivalent in penetrating power to the X-rays generated at 660 kV by an X-ray set. Due to the differences in the radiation spectra of the two sources, however, gamma ray sources, which do not generally emit the longer wavelengths, have a mean penetrating power somewhat higher than X-rays.

2.3.4 **Gamma Ray Sources.** Radiographic gamma ray sources consist of a circular disc or cylinder of radioactive material encased in a sealed aluminium or stainless steel capsule. The capsule is kept in a container which acts as a storage safe and may also be used as a support during exposure. The container is made of a material, such as lead or depleted (non-radioactive) uranium, which will substantially reduce the emission of gamma rays. High intensity sources are kept in bulky, heavily shielded containers, exposure being achieved by positioning the source opposite a restricting aperture in the container. Some users employ an exposure head connected to the container by guide tubes, the isotope being positioned and controlled by a remote control device. Since gamma rays cannot be turned off, strict regulations have been devised to safeguard both operators and general public during the transportation and use of radioactive sources.

## 3 Photographic Aspects

### 3.1 X-ray Film

3.1.1 The films used in radiography are very similar to those used in photography except that the emulsion covers both sides of the flexible transparent base. The emulsion is sensitive to X-rays, gamma rays and light and when exposed to those radiations a change takes place in its physical structure. When treated with a developer, a chemical reaction results in the formation of black metallic silver; it is this silver which, comprises the image. Handling of the undeveloped film is normally carried out in a 'dark room' which is illuminated by subdued yellow light.

3.1.2 Film is supplied in two classes, depending on whether fluorescent intensifying screens are to be used or not. Within these classes, film is available in a wide range of speeds and grain sizes.

3.1.3 Where the high clarity of a normal film is unnecessary, for instance when searching for debris or checking for correct assembly of a component, certain types of photographic paper can be used, with a consequent saving in cost.

3.1.4 Film is normally prepared for exposure by placing in a cassette which may be either rigid or flexible, or in a light-proof envelope. For many applications film is also prepared in roll form, an example of which would be the film used for taking radiographs of a complete fuselage former. An X-ray tube which emits a 360° beam is located in the centre of the fuselage and a roll of film placed to encircle the fuselage.

### 3.2 Intensifying Screens

3.2.1 It is sometimes necessary to take a radiograph of a thick or dense material, necessitating a very long exposure time. This time may be reduced by converting the energy of the X-rays or gamma rays into another form of energy to which the film emulsion is more sensitive.

3.2.2 Phosphor coated screens (known as 'salt' screens) will fluoresce in the presence of X-rays and if in contact with the X-ray film, will supplement the image formed by X-rays during exposure. The disadvantage of this arrangement is that the screen imparts a grainy appearance to the film and detracts from image sharpness. 'Screen' type film must be used in conjunction with fluorescent intensifying screens.

3.2.3 Metal foil screens are usually made of lead and assist the normal X-ray exposure by producing photo-electrons in the presence of X-rays. This intensifying effect is only evident at potentials above 120 kV, but since the lead screens also reduce scattered radiation and are not granular in manufacture, they are always used in radiography carried out at energies above this value.

3.2.4 It is essential that both types of screen are held in close contact with the film (on both sides), as any gap will result in a spread of light (or photo-electrons) and produce a blurred or fogged image. Absolute cleanliness of the screen is also essential, since any dust or grease between the film and screen will be reproduced on the radiograph.

### 3.3 Sensitivity

3.3.1 The darkness of a radiograph depends on the quantity of radiation penetrating the specimen; the thicker the specimen, the lighter will be the image. Defects such as a crack or gas hole will show up as dark areas on the radiograph, since they will give less resistance to the rays. However, the ability to recognise a defect will depend on its size and the quality of the radiograph. The sensitivity of the radiograph is normally measured by an image quality indicator (IQI), also known as a penetrameter (Figure 2), but this should not be used as a means of calculating the smallest size of defect which may be detected. The shape of the defect and the plane in which it lies are most important; if a crack runs in a plane normal to the X-ray beam it will probably not be detected and this must be taken into account when establishing a technique for a particular inspection.

3.3.2 Ideally IQIs should be made of the same material as the radiographic subject, but in practice mild steel is suitable for all steel specimens, pure aluminium is suitable for all aluminium alloys and copper is suitable for most bronzes and brasses. The IQI should be placed on the upper surfaces of the area undergoing radiography, i.e. nearest to the beam source, so that it will appear on the radiograph. The thickness of the last detectable step (or wire) should be ascertained and expressed as a percentage of the specimen thickness.

3.3.3 It will be appreciated that the difference in the sizes of the steps or wires in the IQIs shown in Figure 2 must be very small for use with aircraft structures. In fact, although the use of IQIs is essential with thick specimens, the very nature of aircraft structures, comprising skins, ribs, stringers, paint, sealant, etc., is an adequate form of IQI for most radiographic needs.

3.3.4 The step-wedge IQI (Figure 2(a)), consists of a number of steps ranging in thickness from 0·005 in to 0·1 in or greater as required. Each step contains a number of holes, varying in size according to the step thickness and these are used both for identification of the step and as an indication of image sharpness.

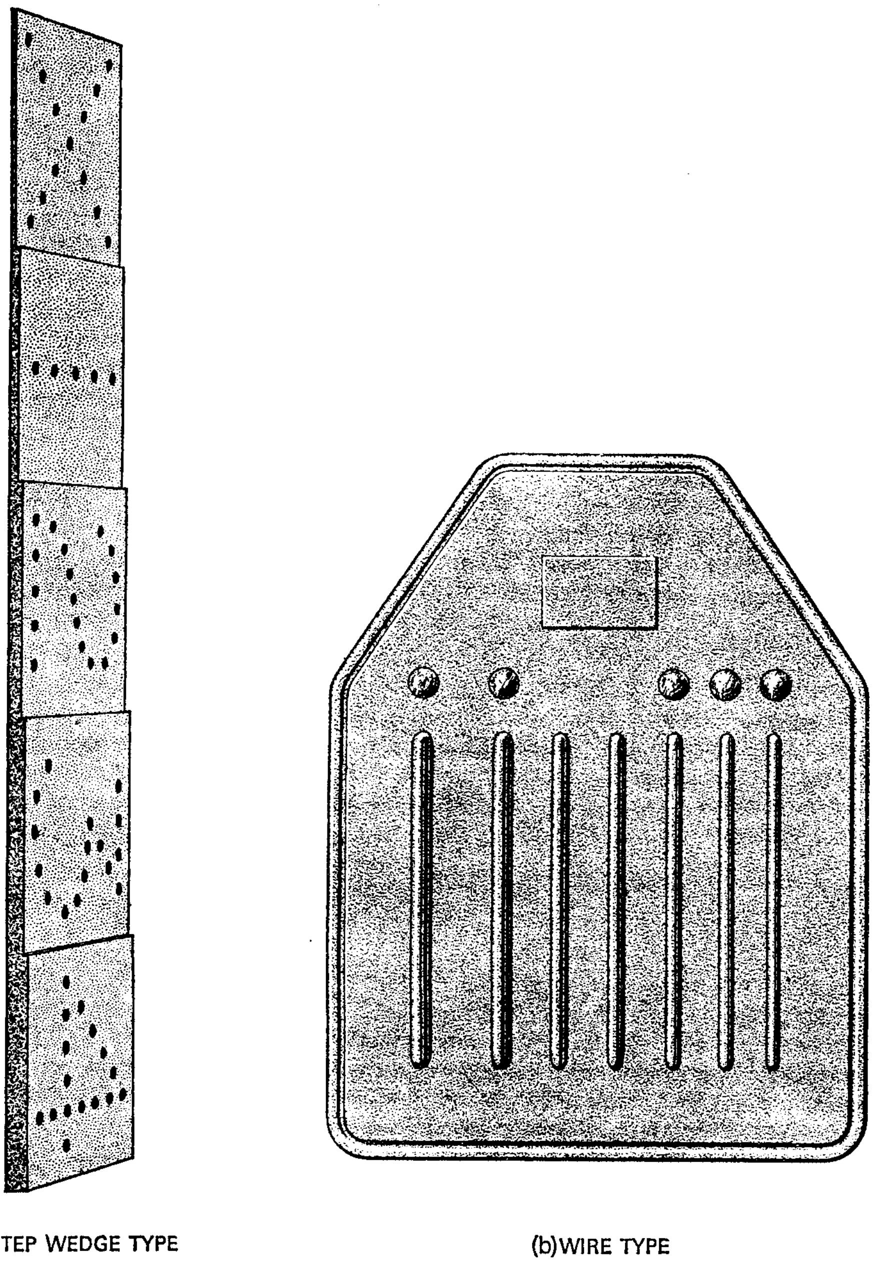
3.3.5 The wire IQI (Figure 2(b)), consists of a series of short lengths of wire in graduated diameters, embedded in thin rubber or plastic sheet. This type of IQI is sensitive to both sharpness and contrast, particularly in the smaller sizes.

3.3.6 Variations of the standard IQI are sometimes used for special purposes, e.g., when searching for fatigue cracks an IQI containing a typical defect could be used (Figure 3). The IQI is placed on the surface of the member being examined and, provided that the simulated defect is clearly visible on the radiograph, it can be assumed that any other crack of similar size and orientation would also be visible.

### 3.4 Geometric Considerations

3.4.1 The sharpness of a radiographic image is influenced by the film characteristics and by geometric effects, which, since they are to a large extent under the control of the radiographer, are very important. The factors involved are the size of the radiation source, the distance between the source and the film and the distance between the specimen and the film; these factors are illustrated in Figure 4.

3.4.2 It is generally accepted that a radiographic image viewed by the naked eye will appear to be sharp if the blurring of edges does not exceed 0·025 centimetres (0·01 inches). The blurring, or sharpness, is caused by the finite size of the radiation source and this is quoted in the specification for the equipment concerned or can be found by experiment. From Figure 4 it can be seen that the closer the film is to the specimen then the sharper will be the image. However, practical considerations may prevent contact between the film and specimen and in this case acceptable sharpness can only be obtained by increasing the source-to-film distance. Alternatively, better coverage of a large or irregularly shaped part may be achieved by taking several radiographs from different angles, thus keeping the object-to-film distance to a minimum.


(a) STEP WEDGE TYPE

(b) WIRE TYPE

**Figure 2** Standard Image Quality Indicators

3.5 **Exposure Conditions**

3.5.1 The quantity of radiation affecting an area of specified size varies inversely as the square of the distance from the source; if the source-to-film distance is increased the exposure time must be increased accordingly. The ideal situation would obtain where the cone of radiation just covered the film area.

3.5.2 The required exposure conditions could be obtained by the use of exposure charts and calculations dependent on film characteristics. However, since a number of variables exist, it is more usual to establish a technique from knowledge of the structure involved, study of the aircraft manufacturing drawings and systematic trial and error methods. Once the geometric considerations have been determined, a series of radiographs is usually taken, systematically varying the voltage, exposure time and occasionally the tube current or type of film, until an acceptable radiograph is produced. A double film technique is often used to reduce the number of exposures required. The lowest useable kilovoltage gives the highest contrast thus making recorded defects more distinct.

### 3.6 Filtration

3.6.1 When a beam of radiation passes through a material, some passes directly through (the primary radiation) and some is scattered by collision with the atoms making up the material (the scattered radiation). The primary radiation is the true image forming energy, but the scattered radiation results in a fogging effect on the film, reducing contrast and impairing definition. While scattered radiation is always present, its effects can be reduced by the use of metallic screens, masks or backing.

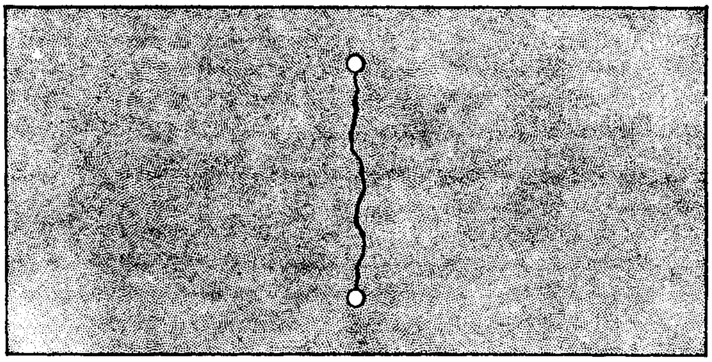


**Figure 3** IQI Simulating a Defect

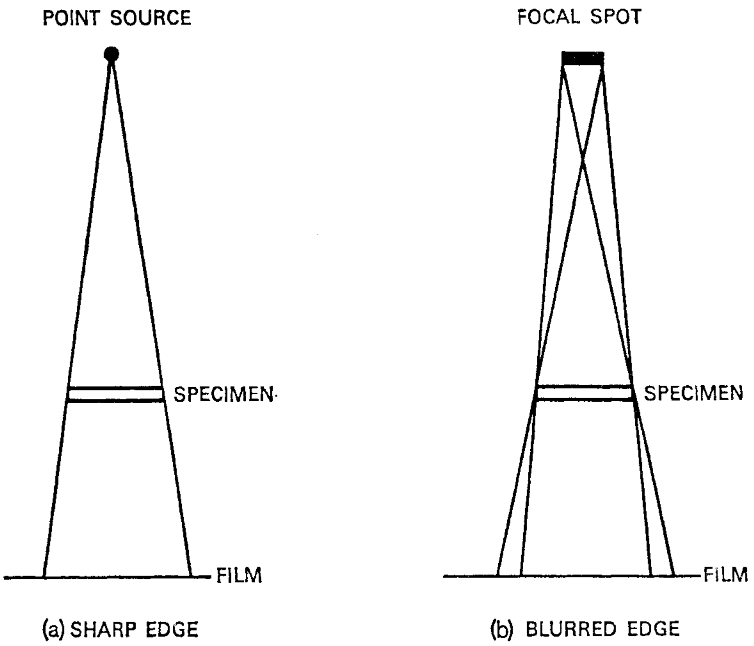


**Figure 4** Geometric Unsharpness

3.6.2 **Primary Beam Filtration.** X-rays consist of a wide band of wavelengths, the shorter of which are the image forming radiations. The longer wavelengths have little penetrating power but are a significant source of scattered radiation and can normally be eliminated from the X-ray beam by placing a metal filter close to the X-ray source.

The thickness of the filter is important since it affects the total material to be penetrated and it is usually found by experiment; a copper filter 0·1 mm thick would normally be used with a 100 kV to 200 kV set.

3.6.3 **Scatter Within the Specimen.** Some scattered radiation is generated within the specimen, particularly when it consists of a box-like structure, or dense material. This may be reduced by placing a filter, similar to that used for the primary beam, immediately above the film. Particular care is necessary to ensure that this filter is clean, since any dirt will show up on the radiograph. In the case of light alloy structures a limitation of 2 minutes exposure time will usually eliminate such scatter.

3.6.4 **Masks and Backing.** Scattered radiation can be produced from any point within the area of coverage of the radiation beam and will, therefore, be produced by structure situated beside or behind the film. This radiation is reduced by placing lead sheets adjacent to the film and specimen, immediately at the back of the film and in permanent radiographic rooms, by covering the floor and table with lead. With irregularly shaped specimens an opaque paste mask is sometimes used.

## 4 Radiographic Techniques

4.1 The establishment of completely reliable techniques of examination is essential if confidence is to be placed in the resulting radiographs. It may be necessary to prove their effectiveness initially by dismantling the particular structure to ensure that no defects exist which have not been revealed in the radiographs and to determine that the radiographs have been correctly interpreted.

4.2 The factors outlined in paragraph 3 should be taken into account in evolving a satisfactory radiographic technique and a record should be kept of the conditions under which the technique was established. A typical Radiographic Technique sheet, as recommended in British Standard M34, is reproduced in Figure 5. This sheet should be given a number for identification purposes and should also include, in the 'Notes' section, such details as items which must be removed (including fuel from the fuel tanks, radiation sensitive items, sealant or paint, etc.), any jacking or trestling necessary and measurements from which the film, X-ray set or isotope may be positioned. A simple isometric drawing may also assist identification of an area under examination and the inclusion of photographs or drawings showing potentially defective items should also be considered.

4.3 It may often be necessary to penetrate a widely varying range of thicknesses and, if only a single radiograph is taken, this may result in the appearance of greatly contrasting light and dark areas, making accurate interpretation almost impossible. In such circumstances the simultaneous exposure of two or three films without intervening wrapping in a common cassette or envelope may be employed; if the films and exposure time are carefully selected, each different thickness will be shown at a suitable density on one of the radiographs. The use of a lead screen separating two films is sometimes useful in achieving satisfactory radiographs of different material thicknesses and also gives greater flexibility in the selection of a film pack.

## 5 Gamma Rays in Aircraft Radiology

5.1 In general it may be considered that the majority of radiographs of aircraft structures are taken with an X-ray set. This is due to the unsharpness and lack of contrast normally obtained with gamma sources and the gradual decrease in radiated energy. However, there are occasions when a gamma source is used, mainly due to lack of space or access for X-ray equipment.

**Figure 5** Typical Radiographic Technique Sheet

(Company name and address)

| | | | |
|---|---|---|---|
| Set used: | RADIOGRAPHIC TECHNIQUE SHEET | Sheet..........<br>of.........sheets | Technique sheet No. |
| Type of radiation:<br>Source size: | Description | | Part No. |
| Film processing: | Purpose of inspection:<br>Area to be inspected:<br>Acceptance standard: | | Material and specification |
| Preparation: | Associated documents | Prepared by: | Date: |
| | BS M.34 | Approved by: | Date: |

| Exposure details | | | | | | Filters | | Screens | *U*g | Film | Size and pattern | Radiograph No. | Figure reference |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Aspect or position | Angle of beam to film | s.f.d | kV | mA | Time | on tube | on film | | | | | | |
| | | | | | | | | | | | | | |

NOTES:

5.2 **Application.** By the use of guide tubes or handling rods attached to containers, it is often possible to place isotopes in positions which would be completely inaccessible to X-ray equipment. An example of this is where an internal portion of a structure is to be examined, there being no means of access for the X-ray equipment and the complexity of the structure precluding the taking of X-ray pictures from the outside. Provided it is possible to place the film in position, the isotope can be inserted through a convenient aperture and a direct radiograph of the particular area may be obtained.

5.3 Isotopes are also often used for the examination of internal features of turbine engines, such as the main rotor shaft and provision of access points is sometimes included in the engine design.

5.4 **Isotopes.** The types of isotope used will be determined by the thickness of the subject, the source-to-film distance and the source output in terms of exposure time.

## 6 Fluoroscopy

6.1 The luminescent property of phosphors enables them to transform X-rays into visible light. The effect is most pronounced with low energy X-rays, normal gamma ray sources are therefore unsuitable, being of too short a wavelength.

6.2 X-rays are passed through the specimen and impinge on a phosphor coated screen which emits light in proportion to the intensity of the X-radiations falling on it. A positive image is formed on the screen, showing internal details of the specimen in a similar manner to a radiograph.

6.3 Viewing cabinets are so manufactured that the observer is protected from harmful radiations. Where low energy radiations are used the phosphor screen is viewed directly through a lead glass window but when high energy X-rays are necessary it is usual for an angled mirror to be interposed so that the screen is viewed at an angle to the primary X-ray beam.

6.4 Due to the coarse grain of the phosphor screen and the poor geometric sharpness resulting from the need to place the screen close to the X-ray source, fluoroscopic images are greatly inferior to those produced by radiographs; for this reason fluoroscopy is seldom used in aircraft work. However, one big advantage of fluoroscopy is that there is no film to be developed and the method is suitable for checking the correct assembly of components or inspecting for debris in aircraft. In general engineering fluoroscopy is also used in conjunction with image intensifiers, for the examination of welded tube and other simple structures.

## 7 Viewing Conditions

7.1 In order to recognise all the indications available on a good radiograph, it is essential that suitable viewing conditions are provided.

7.2 Ideally, radiographs should be examined in a room set aside for this purpose and situated away from distracting conditions such as a high noise level. The room should be capable of being darkened but, during viewing, should have a low intensity background light which does not reflect on the film.

7.3 The viewing of radiographs requires a good deal of concentration. It is recommended that continuous viewing periods should not exceed 90 minutes and should be followed by a period of at least 30 minutes doing associated work away from the viewing area.

7.4 The radiograph itself should be placed on a special viewing box where it can be illuminated from the back, preferably by diffused lighting. Any light appearing round the edge of the radiograph should be masked off since it would tend to dazzle the viewer, possibly resulting in fine defects in the denser parts of the radiograph being overlooked. Controllable shutters are usually provided on the viewing box for this purpose. In addition, the masking of light areas of the radiograph while viewing dark areas will increase the apparent contrast of the image. Where the radiograph has areas of widely differing density the provision of a dimming control may assist the viewing of very light areas.

7.5 In some instances it may be advisable to make use of a magnifying glass for the examination of fine detail, but a glass with high magnification should not be used.

## 8 Interpretation of Radiographs

8.1 The accurate interpretation of the defects indicated on a radiograph is a matter which requires considerable skill and experience and, if the maximum benefits are to be obtained from radiography it is essential that the viewer should have an intimate knowledge of the aircraft structure. Without such knowledge it would be possible to overlook faults which would be obvious to an engineer, e.g. distorted or missing parts. Interpretation of radiographs can be considerably simplified if radiographs of a sound structure are available as standards, for comparison with radiographs on which defects are recorded. For simple structures an isometric drawing of the area might be suitable. Some of the indications obtained on radiographs are described in the following paragraphs.

### 8.2 Castings and Welds

8.2.1 Metallurgical defects in castings and welds generally produce characteristic patterns which may be recognised by an experienced viewer. Porosity, for example, will reduce the amount of material through which the X-rays or gamma rays must pass and result in dark spots in the film, whereas segregated constituents of alloys, or inclusions, may be light or dark, depending on their relative density.

8.2.2 Cracks in welds may be difficult to detect and knowledge of the defects associated with the particular type of weld is essential. The angle at which the radiograph is taken is of particular importance, since defects in a plane normal to the radiation beam would not result in any significant change of density in the emulsion. Surface blemishes produced by welding are recorded on the radiograph and produce a complex image liable to misinterpretation.

### 8.3 Corrosion

8.3.1 The detection of corrosion is invariably difficult, the difficulties often being aggravated by the presence of paint, jointing compound and surfaces fouling which, by their radiographic density, may compensate for the deficiency of material caused by corrosion or give rise to a suspicion of corrosion which does not exist. However, corrosion normally has an irregular and possibly 'fuzzy' outline, while compounds will usually have a regular and sharply defined one. Intergranular corrosion may not be detectable by radiography until it has reached an advanced state and affects the metal surface.

8.3.2 Under laboratory conditions, where scattered radiation can be effectively reduced and ideal exposure conditions obtained, it is possible to detect very small cavities. However, when radiographs of an aircraft structure are being taken, ideal conditions will not normally exist and the size of detectable cavities may be much larger. For example, fuel tank sealant is particularly dense and it is doubtful if pitting less than 10% to 15% of the total thickness, including the sealant, would be revealed.

8.3.3 A corrosion pit giving rise to a sudden change of thickness in a given specimen is more readily visible on a radiograph than a pit of the same depth in the form of a saucer-shaped depression. This is due to the fact that a sudden change in the density level on the radiograph is more easily seen than a gradual merging of two areas of different density.

8.3.4 A further difficulty in the detection of corrosion is that the corrosion products often adhere to the surface and the difference in density might be so slight as to be undetectable. In some instances the build up of corrosion products can be detected when the radiograph is taken at an oblique angle to the surface of the metal.

8.3.5 In aircraft structures, stress corrosion often has a characteristic appearance, showing up as lines of spots on the radiograph. With experience this condition can be identified from similar indications caused by debris or poor developing.

8.3.6 Corrosion can sometimes be detected where successive radiographs, taken over a period of time by an identical technique in each instance, reveal a gradual change in density in a particular area.

### 8.4 Cracks

8.4.1 There is a tendency to regard cracks as straight gaps perpendicular to the working surface, but this is not invariably so. Unless appropriate techniques have been used in taking the radiographs, it is possible for fairly large 'dog-leg' cracks particularly in the thicker sections, to remain undetected.

8.4.2 Stress cracks around rivets in aircraft structures often have a characteristic appearance, running along a line of rivets in a series of arcs. In certain circumstances the edge of the jointing compound used during wet assembly of rivets can give the appearance of hair line cracks of this type, but masking down to a very small area will reveal the true nature of the indication.

8.4.3 When cracks are being sought on the tension side of a wing it is sometimes possible to open up the cracks by applying a tension load, normally by jacking. This will result in a more positive indication on the radiograph.

8.4.4 While cracks will normally appear as a darker line on the radiograph, instances may occur when a lighter line is present. This may result from a part, such as a stringer, being cracked right across and overlapping at the point of fracture, thus presenting a thicker section for the rays to penetrate.

8.4.5 Many radiographs of structure bear evidence of what appears to be structural cracking but, when such areas are examined physically, the cracks have been found not in the structure but in the sealing or jointing compound used in the area. Such conditions may occur inside integral fuel tanks, but with experience it is possible to distinguish between the two types of cracks by reason of their distinctive shape. Some sealants are very opaque to X-rays and may completely hide a defect.

8.5 **Leaded Fuel.** It is often necessary to take radiographs where the primary beam of radiation passes through a fuel tank (e.g. the lower surface of a wing containing integral fuel tanks). Since lead offers considerable resistance to the penetration of X-rays and gamma rays, the presence of even the small percentage of lead contained in most aviation gasolines will restrict the quantity of radiation reaching the film. It is imperative, therefore, that the fuel tanks should be completely drained before the film is exposed. Pools of fuel left in the tanks may also give misleading indications on the radiograph. Less difficulty is experienced with kerosene but some scatter does occur and may impair the quality of the radiograph.

## 9 Glossary of Terms Used in Radiography

The following terms and abbreviations are used in radiological non-destructive testing and are taken from a complete list contained in British Standard 3683, Part 3.

| | |
|---|---|
| Ångstrom unit (Å) | Unit of measurement of the wavelength of X-rays and gamma rays. 1Å = $10^{-8}$ cm. |
| Anode | The positive electrode of an X-ray tube which carries the target from which the X-rays are emitted. |
| Cathode | The negative electrode of an X-ray tube. |
| Casette (or cassette) | A light-tight container for holding radiographic film, paper or plates during exposure. Screens may or may not be included. |
| Contrast | The relative brightness of two adjacent areas on an illuminated radiograph. |
| Definition | The sharpness of image details on a radiograph. |
| Density | The degree of blackening of a radiograph. |
| Focus-to-film | The distance from the focal spot of an X-ray distance (ffd) tube to a film set up for exposure. |
| Gamma ($\gamma$) rays | Electromagnetic radiation emitted by radioactive substances during their spontaneous disintegration. |
| Grain size | The average size of the silver halide particles in a photographic emulsion. |
| Image Intensifier | A device used to give a brighter image than that produced by X-rays alone upon a fluorescent screen. |
| Isotopes | Atoms of a particular element which have the same chemical properties and atomic number, but a different mass number from those normally present in the element. |
| Penumbra (Ug) | Blurring at the edges of a radiographic image due to the radiation source being of finite dimensions. |
| Quality | The penetrating power of a beam of radiation. |
| Radiograph | The photographic image produced by a beam of radiation after passing through a material. |
| Resolution | The smallest distance between recognisable images on a film or screen. |
| Source-to-film distance (sfd) | The distance from the source of primary radiation to a film set up for exposure (i.e. ffd related to gamma source). |
| Tube current | The current passing between the cathode and the anode during the operation of an X-ray tube. |

| | |
|---|---|
| Tube head | A type of X-ray shield which, in addition to the X-ray tube, may contain part of the high voltage generator. |
| Unsharpness | Image blurring caused by the penumbra, by movement, by grain size, or by light, electron or X-ray scatter. |
| X-rays | Electromagnetic radiation resulting from the loss of energy of charged particles (i.e. electrons). |

# Leaflet 4-7 Magnetic Flaw Detection

## 1 Introduction

1.1 This Leaflet provides guidance and advice on the detection of surface and sub-surface defects in ferro-magnetic materials by magnetic processes. The procedures recommended in this Leaflet are complementary to British Standard (BS) 6072 and should not be taken as overriding the techniques of examination prescribed by the manufacturer of a particular component, either in drawings or in approved manuals.

1.2 Magnetic flaw detection tests are applied to many steel parts at the manufacturing, fabrication and final inspection stages. The process is normally applied to all Class 1 aircraft parts manufactured from ferro-magnetic materials and to any other parts where the designer or inspection authority considers it to be necessary.

**NOTE:** A Class 1 part is defined as a part, the failure of which, in flight or ground manoeuvres, would be likely to cause catastrophic structural collapse, loss of control, power unit failure, injury to occupants, unintentional operation of, or inability to operate, essential services or equipment.

1.3 The methods of magnetising in general use are the magnetic flow and the current flow processes, which are described in paragraph 3. By choosing the most suitable process, or combination of processes, for a particular component, both surface and subcutaneous defects may be revealed.

1.4 Great care must be taken when establishing a technique of examination suitable for a particular component, in order to ensure that consistent results are obtained. Operators of magnetic flaw detection equipment should be thoroughly trained in its use and experienced in interpreting technique requirements and the indications obtained from a test.

## 2 The Principle of Magnetic Flaw Detection

2.1 If a component is subjected to a magnetic flux, any discontinuity in the material will distort the magnetic field and cause local leakage fields at the surface. Particles of magnetic material applied to the surface of the magnetised component will be attracted to the flux leakage areas and reveal the presence of the discontinuity.

2.2 The sensitivity of magnetic flaw detection depends largely on the orientation of the defect in relation to the magnetic flux and is highest when the defect is at 90° to the flux path. Sensitivity is considerably reduced when the angle between the defect and the flux path is less than 45°, so that two tests are normally required with each component, the flux path in the first test being at 90° to the flux path in the second test. Components of complex shape may require tests in several different directions.

2.3 A component may be magnetised either by passing a current through it, or by placing it in the magnetic circuit of a permanent magnet or electromagnet. The required strength of the applied magnetic field varies considerably and depends largely on the size and shape of the component and on the magnetic characteristics of the material from which it is made.

2.4 The magnetic particles used to reveal defects are either in the form of a dry powder, or suspended in a suitable liquid. They may be applied by spray, pouring, or immersion, depending on the type of component. Magnetic flaw detection 'inks' complying with BS 4069 are used in aircraft work and consist of finely divided black or red magnetic oxides of low coercivity (i.e. they will not retain the magnetism induced during testing), suspended in a liquid (normally kerosene). Pigments may be added to provide a contrast with the surface of the specimen. Black inks are suitable for use on bright, machined components, but red inks may be more suitable for unmachined parts or, alternatively, a thin coat of white paint or strippable lacquer may be added to the component before carrying out the test.

2.5 If magnetic inks are left standing for long periods the solid particles settle at the bottom of the container and form a sediment which may be difficult to redisperse. If the machine does not have pump agitation, frequent manual agitation must be provided during tests to ensure satisfactory inking of the specimens. The solids concentration in inks manufactured to BS 4069 should be 0·8% to 3·2% by volume, but with fluorescent inks the solids content is approximately one tenth of these values. Methods of determining the solids content of magnetic inks are detailed in BS 4069. Magnetic ink should be discarded if it becomes diluted by solvents or contaminated with oil or any foreign substance likely to reduce its effectiveness as a detecting medium.

2.6 Fluorescent inks are also widely used and are often specified where high sensitivity is required. Inspection of a component to which fluorescent ink has been applied, should be carried out under black light.

## 3 Methods of Magnetisation

### 3.1 Current Flow Method

3.1.1 If an electric current is passed through a conductor, a magnetic flux is induced, both within the conductor and in the surrounding atmosphere, in a series of concentric circles at 90° to the direction of current flow. With steady current, the strength of the internal magnetic flux is greatest at the surface of the conductor and decreases uniformly to zero at the centre, but with alternating current both the current and magnetic flux are confined to a thin layer at the surface, because of the effects of induction. Magnetisation at the surface can be greater with alternating current than with direct current, but direct current has the advantage of greater depth of penetration. In practice, machines are often designed so that alternating or rectified current can be applied to a specimen, to make use of the advantages of each method.

3.1.2 Current flow machines normally provide a sustained current through the specimen, ink being applied while current flows. The specimen is usually clamped between contact pads on a static machine, but portable units are available in which the contacts take the form of hand-held prods and these are often used for checking components which are difficult to mount in a static machine. Good electrical contact is essential and the contacts are usually provided with copper gauze pads, sufficient pressure being used to prevent arcing between the pads and the specimens. Because of the dangers of burning and possible subsequent fatigue cracking, the use of prods is often prohibited on finished parts, especially those of high tensile steel.

3.1.3 A variation of current flow magnetisation is the 'impulse' method, which employs either direct or alternating current in the form of a short impulse (generally less than one second). Difficulty may be experienced in satisfactorily inking the specimen while current is flowing and the specimen may be immersed in a bath of magnetic ink. Alternatively, with some materials, remanent magnetism may be sufficiently strong to provide defect indications when ink is applied after current has ceased to flow. The alternating current impulse method is not often used, due to the difficulty of interrupting the current at a point in the hysteresis loop which will leave the specimen adequately magnetised.

3.1.4 For testing purposes it is usual to apply a sufficiently heavy current to give a satisfactory magnetic flux in the specimen and to use a low voltage to safeguard the operator. As a rough guide to the basic current setting to use, most steels can be satisfactorily tested using an alternating current of 500 A rms per inch diameter or, for specimens of irregular shape, 150 A rms per inch of periphery. Some steels, e.g. nickel-chrome steels, may require a higher magnetising force due to their low permeability. Current values for irregular shaped components should be decided by fixing an artificial defect to the area required, applying ink and varying current value until a satisfactory indication is obtained.

**NOTE:** The effective current value with regard to magnetisation is the peak value. Ammeters do not usually record the peak value however and testing techniques must state whether the current values specified are rms (root mean square) or peak. It is normally assumed that an ammeter reading rms is fitted to an a.c. machine and an ammeter reading mean current is fitted to a rectified a.c. or constant potential d.c. machine. Current values producing a magnetic flux equivalent to that produced by 500 A rms, a.c., with these types of ammeter fitted, are:

| | |
|---|---|
| d.c. | – 710 A |
| half-wave rectified a.c. | – 225 A |
| full-wave rectified a.c. | – 450 A |

If a peak-reading ammeter is fitted to an a.c. machine, the current value should be the same as for d.c. (i.e. 710 A). In cases where the wave form is unknown, the relationship between peak and average values must be determined empirically and the current adjusted accordingly.

3.1.5 The passage of a heavy current will have a heating effect on the specimen, particularly when direct current is used. This could cause burning in specimens such as thin tubes and possibly have an adverse effect on any heat treatment previously applied. The duration of each test should, therefore, be limited to as short a time as possible, consistent with satisfactory inking of the specimen.

### 3.2 Induction Methods

3.2.1 In all induction methods, the magnetic field external to the current-carrying element is used to induce a magnetic flux in the specimen.

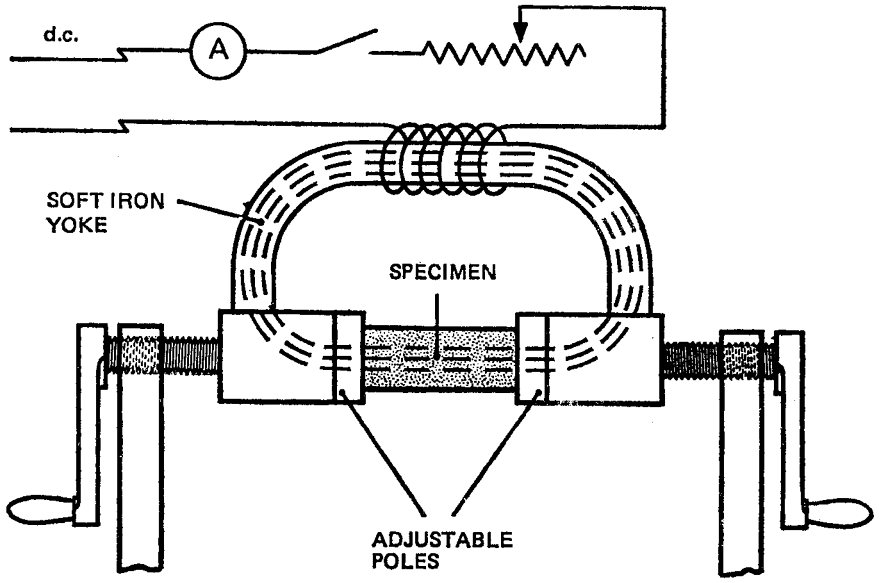


**Figure 1** Magnetic Flow Machine

3.2.2 **Magnetic Flow Method.** Figure 1 shows the arrangement of a typical magnetic flow machine, the specimen being clamped between adjustable poles in the magnetic circuit of a powerful electromagnet. Good contact between the poles and specimen is essential, otherwise a marked lowering of the field strength will result. Laminated pole pieces are often used to ensure that good contact is maintained with specimens of curved or irregular shape and in some portable equipments which employ a permanent magnet, contact is obtained through a number of spring-loaded pins.

a) The magnetising force required to carry out a test using a magnetic flux machine, will depend on the length, cross-section and permeability of the yoke, the number of turns of the windings and the magnetic characteristics of the test piece. No set current value would be suitable with all machines and tests should be conducted to ascertain the current value which will ensure magnetisation just below the saturation level. Saturation is indicated by a heavy build-up of magnetic ink at the ends of the specimen, or an overall coating on its surface. In all tests the cross-sectional area of the pole pieces should be greater than that of the specimen, but the maximum cross-sectional area which can be tested will normally be stated in the operating instructions for a particular machine.

b) To ensure that the strength of the magnetic flux in a specimen is sufficient to reveal defects during a test, it is common practice to employ portable flux indicators. These may take the form of thin steel discs containing natural cracks, which, when attached to the surface of a specimen during a test, will give an indication of flux strength and also, with some indicators, the flux direction.

c) With many machines it is easy to over-magnetise, particularly when carrying out tests on small specimens. If the machine does not have controls for adjusting the energising current, a reduction in magnetic flux can be achieved by inserting non-magnetic material between the pole pieces and the specimen.

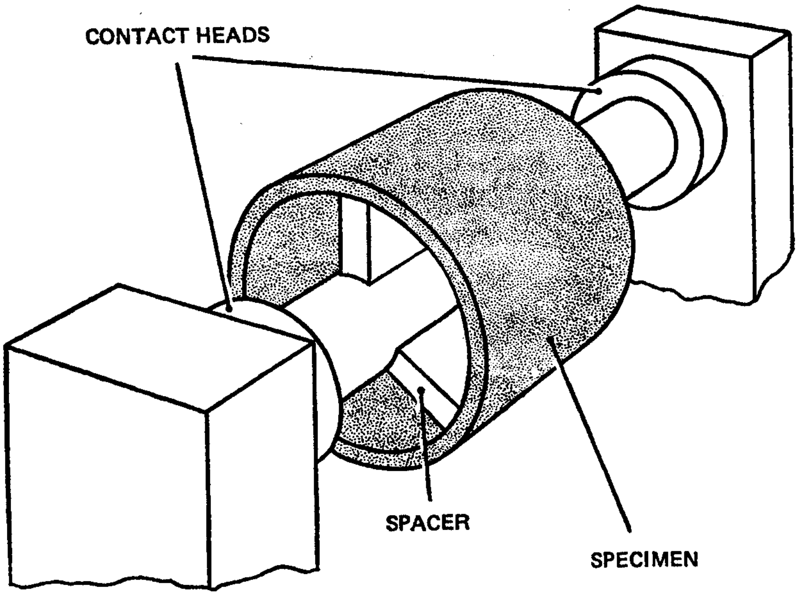


**Figure 2** Threading Bar Method

d) Magnetic flow machines are generally designed to operate with direct current, the magnetising coil containing a large number of turns of wire and carrying a current of a few amps only. This type of coil would be unsuitable for use with alternating current, since the coil would have too much inductance. If it is required to use alternating current for magnetic flow tests, the coil must be replaced by one having a few turns and carrying a heavy current.

3.2.3 **Threading Bar Method.** This method is used for testing rings and tubes and is illustrated in Figure 2. A current flow machine is used and a conductor connected between the contact heads of the machine. Current flowing through the conductor induces a magnetic flux in the specimen at 90° to the direction of current flow; this flux may be used to reveal defects in line with the axis on the specimen. Best results are obtained when the air gap is smallest, i.e. the conductor is only slightly smaller than the internal diameter of the specimen, but a larger air gap is often necessary in order to permit examination of the interior surface.

a) A symmetrical flux may be obtained in the specimen by inserting non-conducting spacers between the conductor and the specimen, but this is not essential except to prevent burning should the conductor overheat. If the shape of the item undergoing test precludes the use of a straight conductor, a heavy flexible cable may be used.

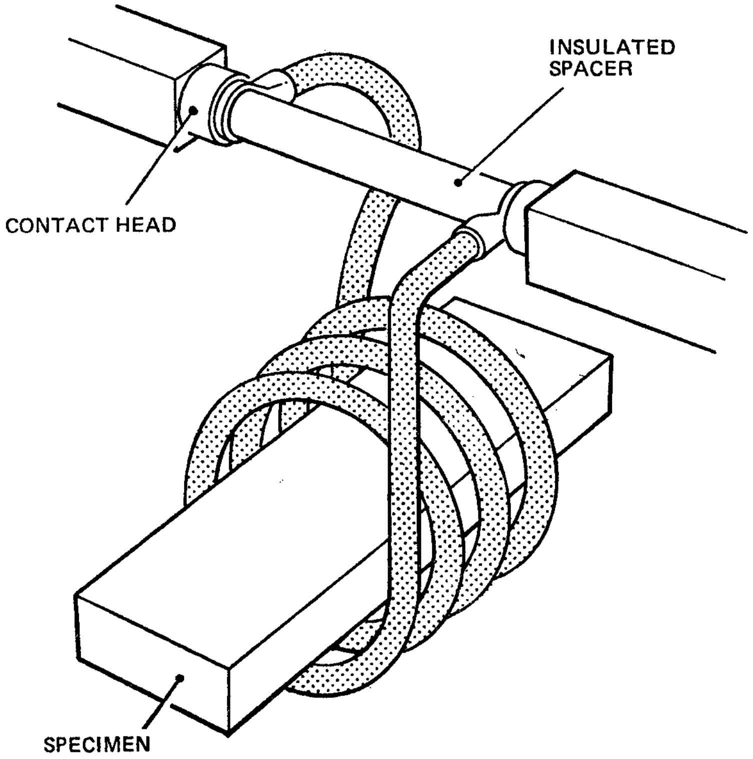


**Figure 3** Magnetising Coil Method

b) The basic current setting should be determined from the length of the flux path, i.e. the outside periphery of the specimen, 100 to 200 amps per inch being a satisfactory basic setting for most steel specimens. The current required is unaffected by the length of the specimen, except that if the specimen is very long the resistance of the conductor may limit the available current.

3.2.4 **Magnetising Coil Method.** A current flow machine is also used for the magnetising coil method. An insulated heavy gauge copper wire or strip is connected between the contact heads of the machine as shown in Figure 3 and formed into a coil; a.c. coils have 2½ to 4 turns and d.c. coils 6 to 10 turns, the space between turns being less than the cross-sectional diameter of the wire in order to minimise flux leakage. The magnetic lines of force resulting from passing current through the coil, will induce a magnetic flux in the specimen, in the direction of the coil axis.

a) Components of simple shape may be placed within the coil during a test, but satisfactory magnetisation will only be obtained within the length of the coil. Difficulty may be experienced with short components, due to the de-magnetising effect resulting from the close proximity of the free poles (i.e. the ends of the specimen) and it is often advisable to complete the magnetic circuit using a yoke manufactured from mild steel, or extend the effective length of the component with end blocks.

b) When components of complicated shape are being tested, it is difficult to estimate the strength and direction of the magnetic flux in all parts of the specimen during a single test. It is often preferable to make several tests with the coil located at several positions within or around the specimen, inspecting only those parts adjacent to the coil at each position.

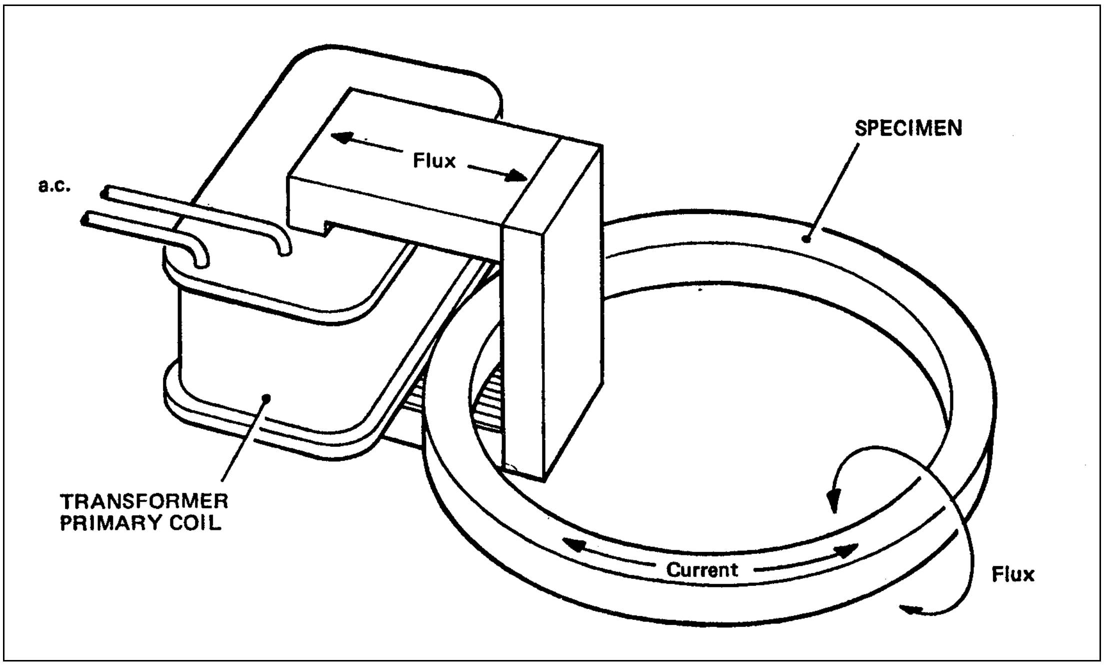


**Figure 4** Induced Current Flow Method

c) As with the magnetic flow method, the current required depends on a number of factors, including the relative diameters of the specimen and coil and the length/diameter ratio of the specimen. BS M35 gives a formula for calculating the current required under specified conditions, but the most suitable values are generally obtained by experiment and by selecting a current which gives a field strength just less than that required to saturate the material.

3.2.5 **Induced Current Flow Method.** Figure 4 shows the coil arrangements for this method, in which current is induced to flow through the specimen by the action of the primary coil of a transformer. The induced current itself provides a magnetic field within the specimen, which may be used for detecting defects lying mainly in a longitudinal direction. This method is often used on ring specimens of large diameter.

## 4 Testing Procedures

4.1 Techniques of testing by magnetic methods are established after preliminary tests have shown that defects can be consistently revealed in similar parts to those under test. When carrying out routine tests in accordance with a specified technique, each instruction must be carefully followed in order to obtain satisfactory results. The full test procedure consists of degreasing, magnetising, application of magnetic ink or powder and interpretation of indications, this process being repeated for each test specified on the technique sheet and concluding with final demagnetising and cleaning. The use of a hand lens of low magnification is normally specified for the examination of defects.

### 4.2 General Considerations

4.2.1 Before carrying out a test the equipment should be checked to ensure that it is functioning properly. The technique sheet (see paragraph 5) will usually specify the capacity of the machine required for a test and stipulate the type of magnetic ink or powder to use. An initial test, using a specimen containing known defects, may be carried out to verify that these defects can be revealed. Alternatively, in the absence of a cracked specimen a test may be carried out using a 'portable crack' taped to the surface of the specimen. This often consists of a thin strip of material in which a crack has been artificially induced and may be used as a guide for acceptance or rejection of the specimen under test. Equipment is usually checked with standard test pieces.

4.2.2 Good lighting is essential for examining the specimen. Good daylight provides the best illumination for normal inks, but fluorescent lighting, free from highlights and of correct intensity, is a suitable substitute. When using fluorescent inks, black light is essential and daylight should, as far as possible, be excluded from the viewing area; efficiency of the black light source should be checked periodically (BS 4489).

4.2.3 Adequate bench space should be provided adjacent to the testing machine and, where the nature of the work permits, should be away from noisy or otherwise distracting locations.

4.2.4 When specimens are tested in batches and set aside in a magnetised condition for subsequent examination, they should not be permitted to come into contact with one another, or with any other magnetic material, such as steel-topped benches or steel brackets, until the examination has been completed. If specimens do come into contact with other magnetised objects a local dis-arrangement of the magnetic field may occur, giving an effect similar to that obtained with a real defect.

### 4.3 Selection of Method

4.3.1 In cases where a technique of examination has not been specified, tests must be made to ensure that defects in the specimen can be satisfactorily revealed.

4.3.2 Factors to be considered are the size and shape of the specimen and the capacity of the machines available. Changes of cross-section in a component will result in variations in the intensity of magnetisation through the component, requiring several tests using different current settings at each change of cross-section. The shape of a component may also modify the distribution of magnetic flux and result in misleading indications in the ink pattern. Examples of difficult specimens are toothed gears, turbine blades with fir tree roots and threaded components, where over-magnetisation may result in build-up of iron oxide at the extremities and cause defects to be hidden. This type of component may often be examined using a remanent magnetism technique, a d.c. supply being used with fluorescent ink; the part should be gently swilled in paraffin after application of the ink to clear the background, but retain any defect indications.

4.3.3 Since the majority of specimens must be tested for longitudinal and transverse defects, both current flow and magnetic flow tests are normally required; both tests may be carried out on a single universal machine.

4.3.4 Table 1 gives guidance on the most suitable methods of testing materials of various simple shapes; components of complicated shape may require special techniques. Tests using flux detectors and portable cracks will usually permit a satisfactory technique to be established however and great difficulty is not often experienced.

**Table 1**

| Specimen | Suitable Test Methods |
|---|---|
| Bar | Current flow for longitudinal defects.<br>Magnetic flow for transverse defects. |
| Tube | Magnetising coil for tranverse defects.<br>Threading bar for longitudinal defects.<br>Magnetic flow for transverse defects.<br>Current flow for longitudinal defects.<br>Magnetising coil for tranverse defects. |
| Ring | Threading bar for defects in line with ring axis, and radial defects.<br>Current flow or induced current flow for circumferential defects. |
| Plate | Current flow or current flow using prods for both longitudinal and transverse defects. |
| Disc | Current flow or current flow using prods, with the disc rotated 90° between successive tests. |
| Sphere | Current flow or current flow using prods, sphere being rotated to reveal any defects.<br>Magnetic flow or magnetising coil may also be used if flux path is extended using steel extension pieces. |

## 4.4 Preparation

4.4.1 Specimens should be free from dirt, grease or scale, since these may hide defects and contaminate the magnetic ink. Scale may usually be removed by abrasive blasting or approved chemical methods and trichloroethylene or other suitable solvents are normally used for degreasing when the parts are being tested away from their assembled positions. Trichloroethylene should not be used for cleaning parts in situ, due to the health hazard. Unless otherwise specified, magnetic particle inspection should not be performed with coatings in place which could prevent the detection of surface breaking defects in the ferromagnetic substrate. Such coatings include paint or chrome plate thicker than 0·003", or ferromagnetic coatings such as electroplated nickel thicker than 0·001".

**NOTE:** The fluorescent properties of certain magnetic inks may be diminished by chemical reaction with acids. When acid pickling is used as a cleaning process, care is necessary to ensure that all traces of acid are washed off.

4.4.2 Preparation of the specimen should also include de-magnetisation. Magnetisation may have been induced by working, by machining in a magnetic chuck, or by lying adjacent to magnetised components or material. In the case of raw material, magnetisation may be removed by heating to a temperature above the Curie point for the material, but generally, for finished parts, it must be removed as detailed in paragraph 4.8.

4.4.3 Apertures such as oilways and deep tapered holes, which do not form part of the area to be examined, should be plugged to prevent the intrusion of ink, which may be difficult to remove.

4.5 **Magnetisation.** Components of simple shape will normally require magnetising in two directions, by a selection of the methods described in paragraph 3, so that defects of any orientation will be revealed. Components of complicated shape may require further magnetisation in selected areas to ensure complete coverage. A component should normally be demagnetised between each test, to remove the effects of residual magnetism, which could cause spurious indications.

4.6 **Inking.** Except where remanent magnetism is used to reveal defects (paragraph 3.1.3), magnetic ink should be applied gently, immediately before and during the period of magnetisation. With a.c. machines the magnetic flux should be applied for at least 3 seconds to allow time for the ink to build up at defects, but d.c. machines are often fitted with a time switch which limits the application of flux to between 1/2 and 1 second. When the immersion method is used, extreme care is necessary during removal of the specimen from the bath, in order to avoid disturbing the magnetic ink and any indications of defects which it may show.

### 4.7 Interpretation of Indications

4.7.1 Particles of magnetic ink are attracted to flux leakage fields and these may occur at defects, brazed joints, the heat affected zone in welds, or sudden changes of section. The presence of a sudden build-up of ink on a specimen is not therefore, necessarily an indication of a crack, inclusion or similar discontinuity and experience is essential in interpreting the indications produced by a test.

4.7.2 Cracks are revealed as sharply defined lines on the surface of the specimen, the magnetic particles often building up into a ridge which stands proud of the surface.

4.7.3 Subcutaneous defects such as may occur during manufacture of the material, will be more blurred than surface cracks. Non-metallic inclusions are often revealed by a diffuse clustering of magnetic particles, but may sometimes give an indication which is as sharply defined as a crack.

4.7.4 Grinding cracks are usually readily identified and consist of a pattern of irregular lines over the affected area, or, on small radius bends or teeth, they may appear as short parallel lines.

4.7.5 Tool marks may give an indication similar to cracks, but the bottom of a tool mark can usually be seen with the aid of a hand lens with approximately 5x magnification, whereas cracks are usually deep and narrow.

4.7.6 Localised magnetic flux resulting from ineffective demagnetisation, or careless handling after a specimen has been magnetised, may give indications known as magnetic writing. Careful demagnetising and retesting will show whether the magnetic writing is spurious, or an indication of a real defect.

4.7.7 Excessive magnetisation causes furring and magnetic particles tend to follow the grain flow, giving the appearance of clusters of inclusions. The remedy is to reduce magnetisation when testing areas of reduced cross-section.

4.7.8 Changes in permeability within a specimen, such as may occur at welds, may give misleading indications. Magnetic detection methods may not be suitable in these instances and radiography may have to be used.

### 4.8 Recording of Defects

4.8.1 Defects are normally marked with grease pencil or paint for future reference, but it may be necessary, for record purposes, to preserve the indications obtained in a test, either on the specimen or as a separate permanent record.

4.8.2 If the magnetic ink has an oil based carrier, the specimen should be drained and dried or, alternatively, another test may be carried out using an ink containing a volatile carrier fluid. If dry powder is used no preparation is necessary.

4.8.3 In cases where the specimen is to be retained, it should be gently sprayed with quick-drying lacquer or covered with a transparent adhesive film, care being taken not to disturb the surface indications.

4.8.4 If a separate permanent record is to be retained the specimen may be photographed, or one of the following actions taken:

a) The indications may be covered with a transparent adhesive tape, which may then be peeled off and applied to a paper or card of suitably contrasting colour, to show the defects.

b) A strippable adhesive coating may be gently sprayed on to the surface of the specimen. When carefully removed, this coating will retain the indications of defects and these may be viewed on the surface which was in contact with the specimen.

c) The specimen may be heated and dipped in a thermosetting plastic powder material. When cured and stripped off, this material may be viewed as in b) above.

### 4.9 Demagnetisation

4.9.1 There are a number of reasons why specimens should be demagnetised before, during or after magnetic particle testing. These include the effects of magnetic writing (see paragraph 4.7.6), the difficulty which would be experienced in any subsequent machining operation due to the adherence of swarf, bearing wear due to the adherence of fine metallic particles and interference with the aircraft magnetic compasses. A specimen should, therefore, be demagnetised before starting tests, between tests which involve a change in flux direction and after tests have been completed.

4.9.2 The most commonly used demagnetiser is an aperture type of coil carrying an alternating current. The specimen should be placed inside the energised coil and withdrawn a distance of at least 1½ metres (5 feet) along the coil’s axis with the current switched on, or may be placed inside the coil and the current gradually reduced to zero. Ideally, the coil should be just large enough to accept the specimen.

4.9.3 If a demagnetising coil is not available the crack detecting machine may be used. Alternating current from the machine may be passed through two or three turns of heavy cable, which may be used in the same way as a demagnetising coil. Alternatively, a suitably equipped direct current electromagnet machine may be used, the specimen being placed between the poles and the current being gradually reversed and reduced simultaneously to zero.

4.9.4 For demagnetising parts in situ an alternating current yoke is normally used. This consists of a coil wound on a laminated yoke, which is used in a stroking action on the specimen. The strokes should always be in the same direction along the specimen and the yoke should be moved away in a circle on the return stroke.

4.9.5 After demagnetising, the specimen should be removed from the vicinity of the demagnetising coil, the testing machine, or any other magnetised material.

### 4.10 Tests for Demagnetisation of Parts

4.10.1 Any components which are manufactured from steel and liable to affect the aircraft compass, should be demagnetised and a test for remanent magnetism carried out before assembly in the aircraft. The standard test for remanent magnetism in aircraft parts is the deflection of a magnetic compass needle under controlled conditions, but an alternative method, such as the use of a flux meter, may be permitted and suitable limits prescribed.

4.10.2 The test consists of placing a suitable magnetic compass in a position away from all stray magnetic influences and slowly rotating the component at a position along the east/west axis of the compass. The distance of the component from the compass should be specified for the test and should be the same as the distance from the aircraft compass to the installed component. Deflection of the compass needle by more than 1° will require the component to be demagnetised again and the test to be repeated.

4.11 **Final Cleaning.** When a component has been accepted following a magnetic detection test, all traces of detecting ink, contrast paint or temporary marking should be removed. Wiping or washing in solvent, or immersion in an approved degreasing agent are the methods normally used. During cleaning, any plugs or blanks fitted during the preparation for the test, should be removed. A temporary rust protective should be applied after cleaning and the part should be identified in accordance with the appropriate drawing, to indicate that magnetic flaw detection has been satisfactorily carried out.

## 5 Technique Sheets

5.1 A technique sheet is a document detailing all the magnetising operations to be performed when inspecting a particular component by the magnetic particle method. It may be accompanied by an illustration of the component and by instructions applicable to all magnetic particle tests, such as the methods of cleaning and demagnetising to be used.

5.2 A technique sheet should show all the relevant details for each magnetising operation, including type of equipment, strength and form of current, acceptance standard, contact areas, positions of flux detectors, type of coil, size of threading bar and test pattern, as appropriate to the particular test. It is recommended that the symbols used in BS M35 should be used on all technique sheets and, where appropriate, on related drawings or sketches.

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# Leaflet 4-8 Eddy Current Methods

## 1 Introduction

1.1 This Leaflet provides guidance and advice on the eddy current equipment for detecting cracks, corrosion or heat damage in aircraft structures and also shows how the method can be used for the measurement of coating thickness or for sorting materials. Elementary theory of eddy currents is also included to show the variables which are being measured and to indicate the interpretation of results which may be necessary for a particular application. Nothing in this Leaflet should be taken as overriding the information supplied by aircraft or engine manufacturers.

1.2 Eddy current methods can detect a large number of physical or chemical changes in a material and the selection of the required parameter presents the equipment manufacturer with many problems; interpretation of the test indications would be very difficult if undesired parameters were not reduced or nullified. Conversely, equipment set up for a particular purpose is comparatively easy to use when indications are compared with a 'standard' or known defect. Eddy current equipment is normally built to perform only certain types of tests, these falling broadly into the categories of flaw detection, conductivity measurement and thickness measurement.

1.3 The main advantages of the use of eddy current methods are that they do not normally require extensive preparation of the surface or removal of the part to be tested, do not interfere with other work being carried out on the aircraft and with surface defects, offer improved sensitivity over other non-destructive techniques. Small portable sets are battery powered and can easily be used in comparatively inaccessible places in aircraft structures.

1.4 Eddy current testing may be subject to certain difficulties, including depth of penetration and the effects of surface coatings and unseen changes in the geometry of the material under test. In addition the results of a test can only be related to the size of signal received and are not necessarily an indication of the size of defect. Techniques are established after trials have shown a method which gives consistent results.

1.5 In aircraft work, eddy current testing is usually of the comparative type, a reference piece or standard in similar material containing an artificial defect, being used to compare indications from the part under test.

## 2 Principles of Operation

2.1 Eddy currents are induced in an electrically conducting material when the material is subjected to a changing magnetic field and normally flow parallel to the surface of the material (see Figure 1). In eddy current testing, a coil is supplied with alternating current and held in contact with (or in close proximity to) the test specimen. The alternating magnetic field produced around the coil induces an alternating eddy current in the specimen and the eddy current itself produces an alternating magnetic field which opposes and modifies the original coil field. The resultant magnetic field is the source of information which can be analysed to reveal the presence of flaws in the test specimen.

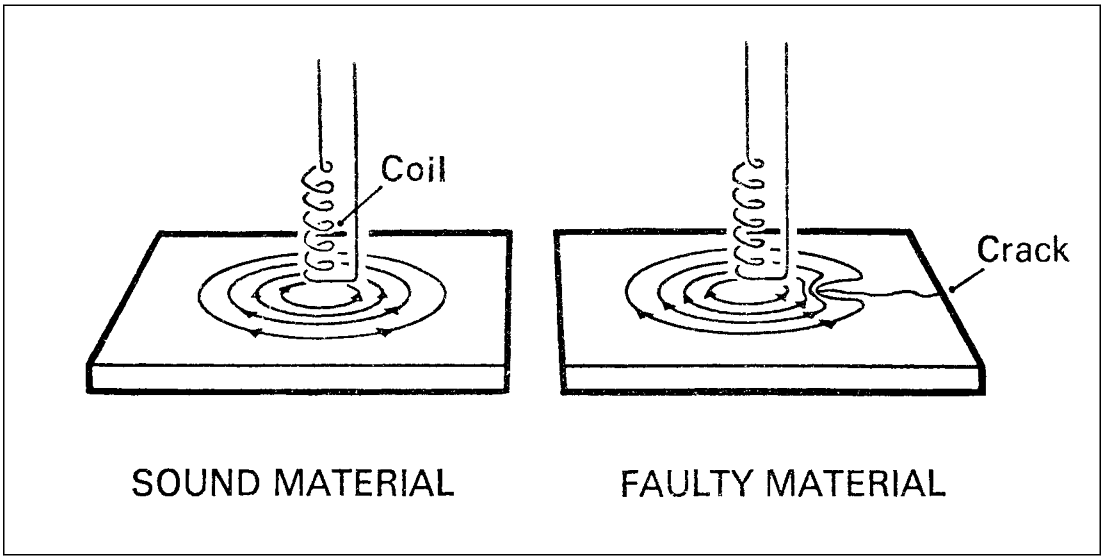

**Figure 1** Eddy Current Flow

2.2 **Permeability.** This quality is a measure of the ease with which a material will conduct magnetic lines of force and decides the density of flux which can be induced in that material. Permeability is a function of magnetising force and flux density; air and non-magnetic materials have, for testing purposes, a permeability ($\mu$) of 1, while ferromagnetic materials have a permeability greater than 1. Permeability is not constant in magnetic materials and varies with the magnetising force (coil current). Eddy currents are induced by flux changes in a material and are directly related to flux density; as permeability increases so the strength of eddy currents increases. Non-magnetic materials do not generate additional flux densities, but magnetic materials produce high flux densities which can mask all other measurements. During tests on ferromagnetic materials, that is materials with a permeability greater than 1, these effects can be suppressed or made constant by saturation with high d.c. or a.c. fields which, in effect, restore the permeability to 1.

2.3 **Conductivity.** Conductivity ($\sigma$) is a measure of the ability of electrons to flow through a material and is one of the main variables in eddy current testing. Each material has a unique value of conductivity and this fact enables changes in chemistry, heat treatment, hardness or homogeneity to be detected simply by comparing the conductivity with a specimen of known properties; increased conductivity gives increased eddy currents (although depth of penetration decreases). Conductivity is measured in either of two ways; it can be compared to a specific grade of high purity copper known as the International Annealed Copper Standard (IACS), which is considered as 100%, or it can be measured in metres per ohm millimetre$^2$. ($58\ \mathrm{m}/\Omega\,\mathrm{mm}^2 = 100\%$ IACS).

2.4 **Effects of Specimen on Test Coil.** A probe coil placed on the surface of a specimen will possess a particular value of impedance which can be found by measuring the voltage across the coil. The voltages due to resistance and reactance can also be separated and if required, displayed on a cathode ray tube. Any change in conductivity, permeability or dimensions (d) of the specimen will, through the eddy current field, alter the coil's impedance, either in magnitude or phase and depending on the parameter sought, can be indicated on a meter or cathode ray tube display. Changes affecting apparent conductivity, e.g. a crack, will be 90° out of phase with changes affecting permeability or dimensions under certain test conditions.

2.5 **Geometry.** The size and shape of the test specimen may distort the primary magnetic field and mask defects in the affected area (see Figure 2). The effects of geometry can be overcome by probe design, equipment calibration, frequency selection, or the use of jigs to maintain the probe in a particular relationship to the material surface, but must often be taken into account when conducting tests.

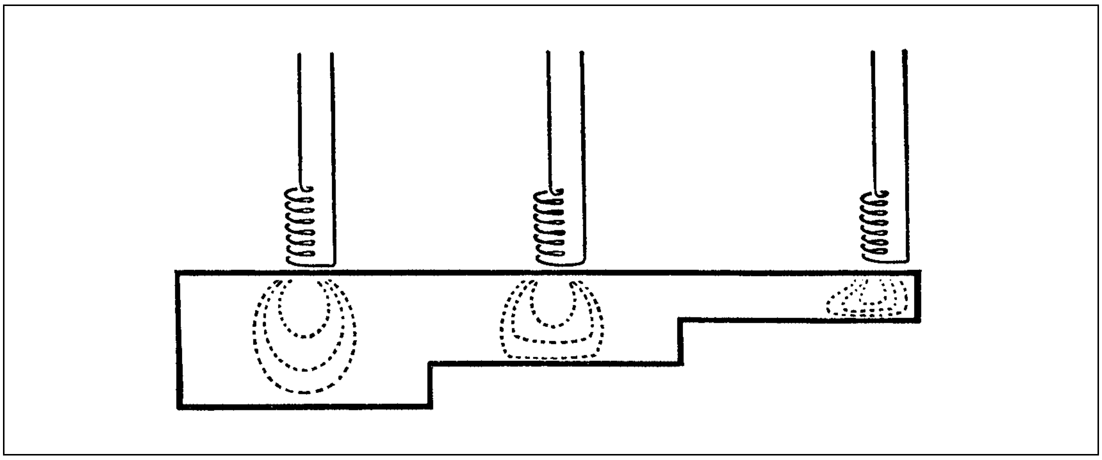

**Figure 2** Geometric Effects on Primary Magnetic Field

2.6 **Penetration.** Eddy currents are strongest at the surface of a material and weaken with depth. This effect becomes more pronounced with increased frequency (f) of the alternating magnetic field and is known as 'skin effect'. Increases in permeability (μ) and conductivity$(\sigma)$ in a material also decrease penetration depth. In practice the depth of penetration (P) of eddy currents is related to a depth where the current is reduced to 1/e (approximately 37%) of the surface current and may be calculated from the formula, $P \approx \frac{500}{\sqrt{f\sigma\mu}}$ where P is in mm and $\sigma$ is in $m/\Omega\,mm^2$.

2.7 **Effects of Frequency**

2.7.1 Any particular material possesses what is known as a characteristic frequency ($f_g$), which depends on its conductivity, permeability and dimensions. A practical use of the characteristic frequency is that samples of different materials tested at the same $f/f_g$ ratio will give similar indications for similar defects. Actual test frequency is selected to obtain the best results from a particular test and depends on the type of defect sought, the depth of penetration required and the geometry of the specimen. When it is necessary to determine the phase of a signal, the frequency should be within the range where phase angle is greatest. When testing for conductivity only, to check hardness, heat treatment, etc., some penetration is required so a low frequency would be used, but when testing for surface cracks greater sensitivity would be obtained at a higher frequency.

2.7.2 In aircraft work testing is often concerned with thin sheet structure in aluminium alloy and test frequencies between 5 kHz and 4 MHz are used, depending on the defect sought. However, frequencies as low as 50 Hz are used for checking material properties in ferromagnetic materials.

2.8 **Lift-off.** This may be defined as the change in impedance of a coil when the coil is moved away from the surface of the specimen. This produces a large indication on the test equipment. In some equipment the lift-off effect is nullified by applying a compensating current to the probe circuit, thus enabling rapid testing without the need for special jigs, but in other equipment the lift-off effect is analysed to measure for example, the thickness of a non-conducting coating. This effect, when applied to encircling coils and bar specimens, is known as 'fill factor'.

## 3 Coil Arrangements

3.1 A number of different coil arrangements may be used in eddy current testing and some of the more common are discussed below. The types shown in Figures 3, 4 and 5 are not generally used during aircraft maintenance operations, but are widely used by material and component manufacturers.

3.2 **Single Primary Coil.** Figure 3 shows the simplest arrangement. If a sound specimen is placed in the coil the impedance of the coil is modified and if a faulty specimen is placed in the coil the impedance is modified to a different degree.

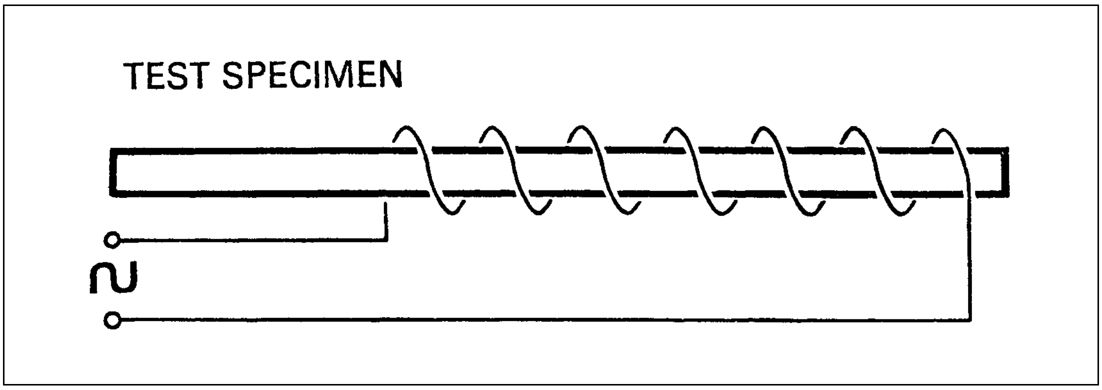

**Figure 3** Single Primary Coil System

3.3 **Comparative Coil System.** Figure 4 shows a coil arrangement which has two arms, one containing a flawless reference piece and the other the test specimen. Since the two sets of coils are identical any fault in the test piece will result in a voltage across AB.

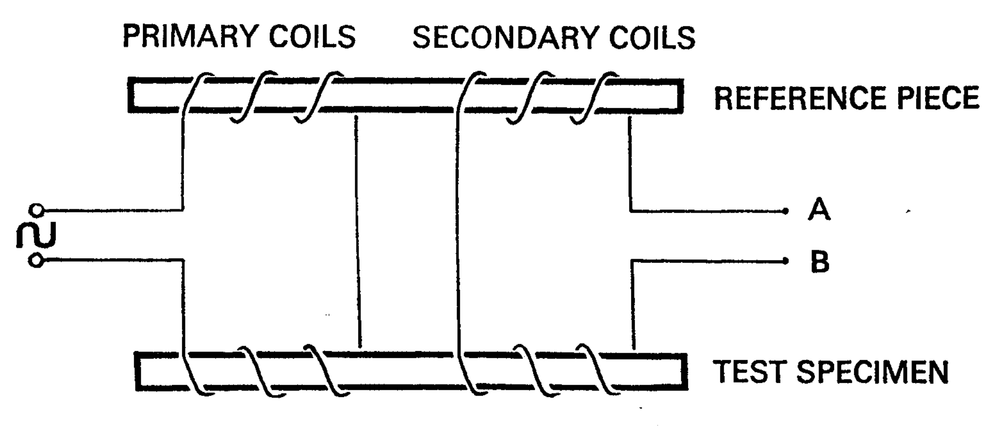

**Figure 4** Comparative Coil System

3.4 **Differential Coil System.** Figure 5 shows a coil arrangement which is also a comparison method, but in this case adjacent portions of the test specimen are compared with each other. The coil windings are, in effect, identical to the comparative coil system shown in Figure 4.

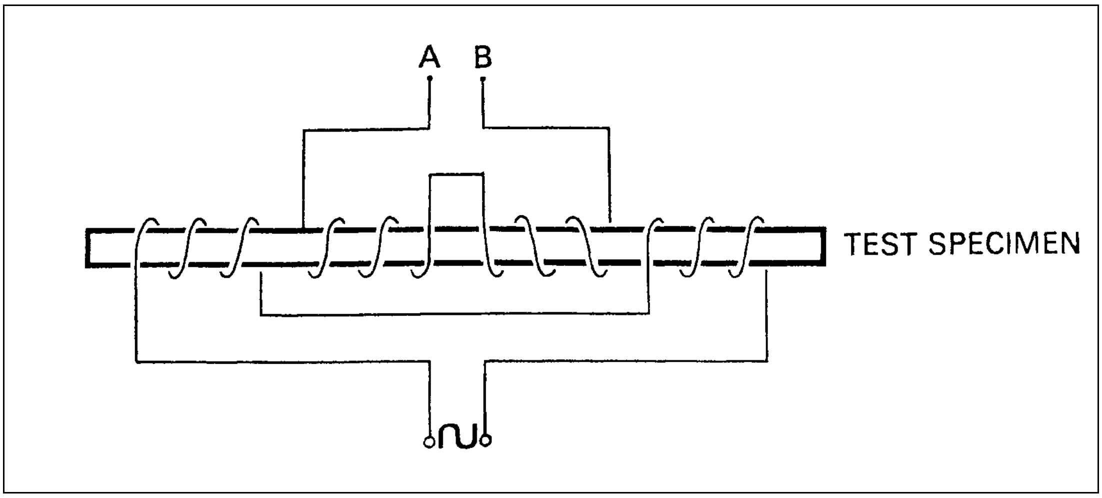

**Figure 5** Differential Coil System

3.5 **Surface Coils.** In aircraft work a single coil is generally used, with the axis of the coil normal to the surface being tested (Figure 6). A ferrite core is used to increase sensitivity to small defects and the arrangement is used for detecting cracks in flat surfaces, curved surfaces or holes, by mounting the coil within a specially shaped probe. Impedance changes obtained during a test are compared with those obtained from a defective part or a reference piece.

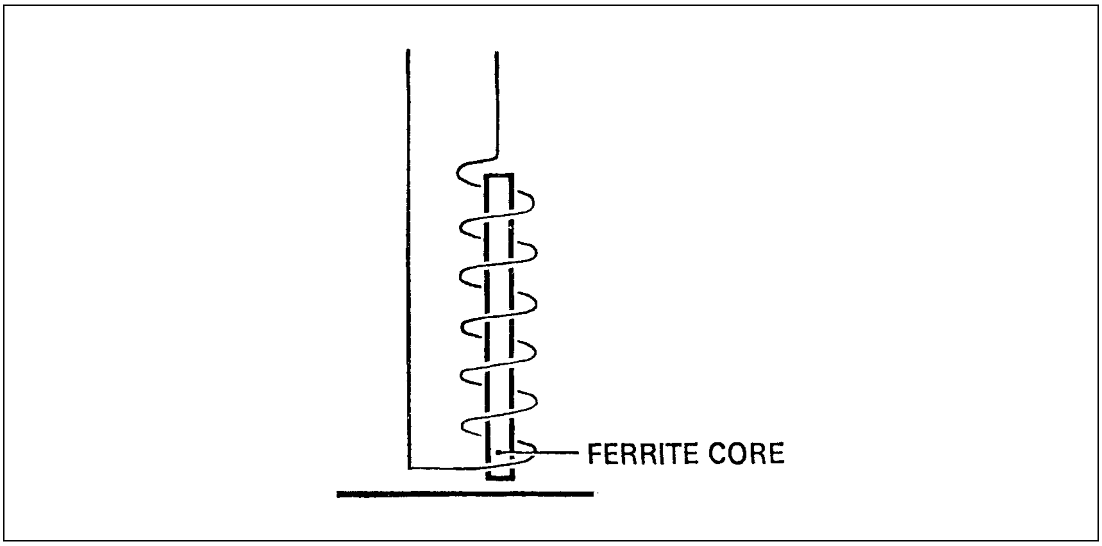

**Figure 6** Surface Coil

## 4 Types of Circuits

4.1 **Bridge Circuits.** Figure 7 shows a bridge circuit, one arm of which consists of two adjustable controls and a coil and the other arm comprises the reference and test coils. The bridge is balanced initially (meter zeroed by adjustment of the variable resistor and inductor) with the probe located on a flawless specimen. In use, any alteration in the impedance of the probe coil (due to faults in the test piece, or to lift-off) will unbalance the bridge and result in a deflection of the meter needle.

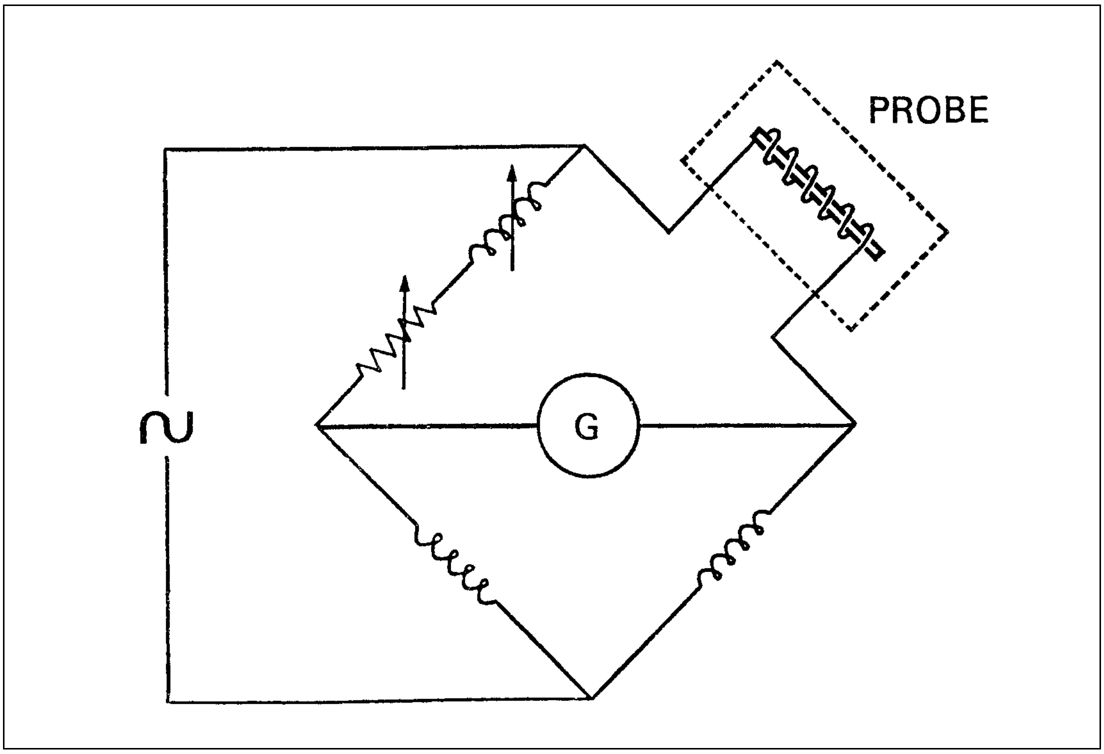

**Figure 7** Bridge Circuit

### 4.2 Resonant Circuits

4.2.1 The capacitance of a coil is usually small in relation to its inductance. However, if a capacitor is connected in the same circuit as a coil, since inductive reactance increases with frequency and capacitive reactance decreases with frequency, a condition will occur, at some frequency, when the effects are equal and opposite. This condition is known as resonance and the circuit then behaves as if it contained only resistance, resulting in a large change in current flow.

4.2.2 Figure 8 shows a typical eddy current circuit which operates on the resonance principle. The probe is a parallel tuned circuit connected to the grid of an oscillator and determines the frequency at which the circuit oscillates. If the flux density (and hence the impedance) of the probe coil is altered (e.g. by placing the probe on a metallic object) the oscillator frequency changes. Consequently, the frequency developed in the anode tuned circuit is no longer the frequency at which that circuit is tuned. This results in a change of impedance, which is recorded on the meter through the secondary windings of the anode coil.

4.2.3 Operation of the circuit shown in Figure 8 is dependent upon adjustment of the controls to suppress lift-off. With the probe located on the test specimen the anode circuit is tuned to a frequency in sympathy with the probe circuit by adjustment of the variable capacitor (i.e. the lift-off control) until the meter reads zero. If the probe is now removed from the specimen a change in impedance will again occur and result in deflection of the meter needle; this deflection can be counteracted by adjustment of the set-zero and lift-off controls. Further adjustment of these two controls will enable a zero meter reading to be obtained with the probe on or off the specimen. Any change in the specimen (e.g. a defect) will result in a change in the impedance of the probe coil and a deflection of the meter needle, regardless of the presence of, for example, a paint film of uneven thickness.

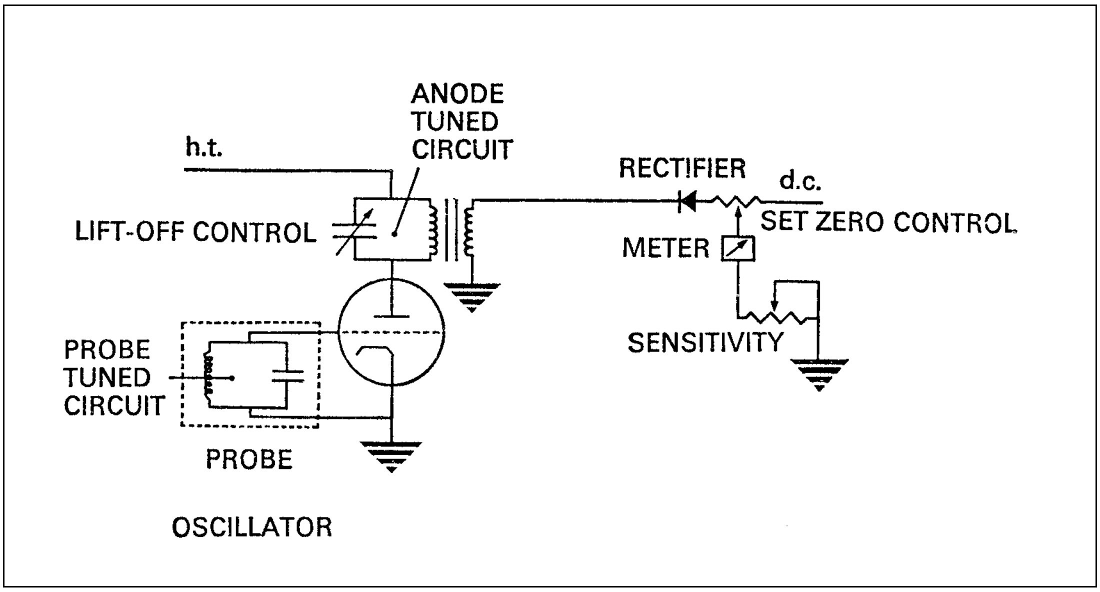

**Figure 8** Typical Tuned Circuit

4.2.4 A different type of resonant circuit is shown in Figure 9. The probe coil and capacitor in this case being connected in series. Lift-off is suppressed by the addition of a compensating voltage to the measurement voltage.

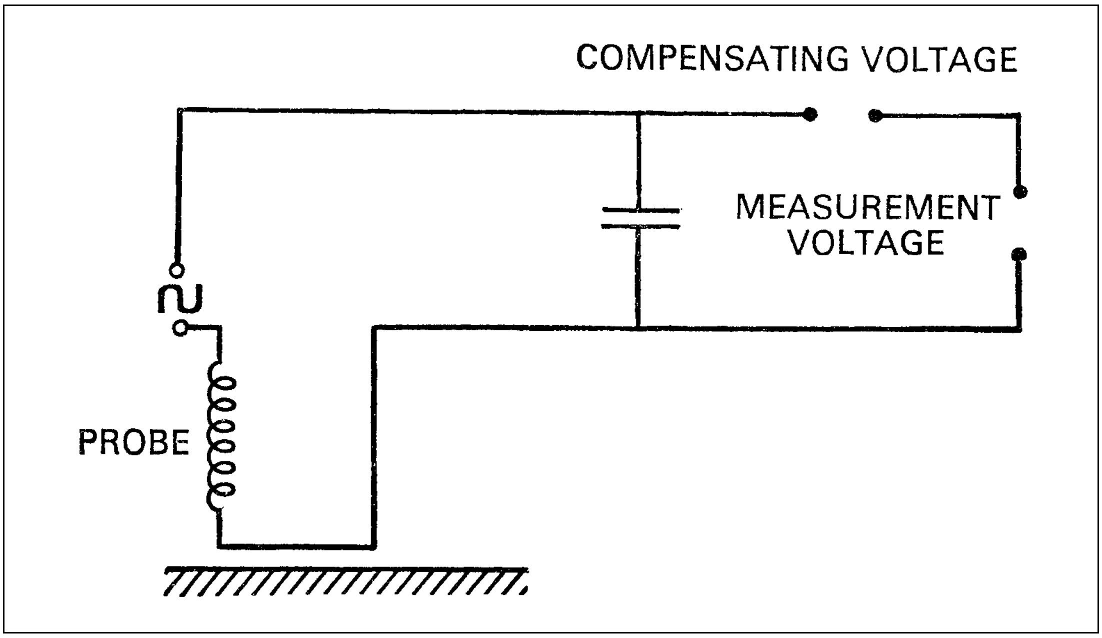

**Figure 9** Series Resonant Circuit

## 5 Phase Analysis

5.1 Where one of the parameters affecting impedance is required and all others can be assumed to be constant, the measurement of total impedance changes will satisfactorily reveal the presence of a defect or change in the unknown parameter, provided that a suitable reference piece is used for comparison. However, in many cases it is necessary to separate the reactive and resistive components of impedance in order to detect a particular type of defect and more sophisticated equipment becomes necessary.

5.2 Figure 10 shows the oscilloscope trace of a signal containing two voltages, $V_1$ and $V_2$, which are representative of the signal which could be obtained from eddy current equipment under certain test conditions. While the voltages are of the same frequency they can be seen to start at different points of the time scale, the difference resulting from the effects of reactance and being known as a phase change. Eddy current testing based on the use of phase changes is known as phase analysis.

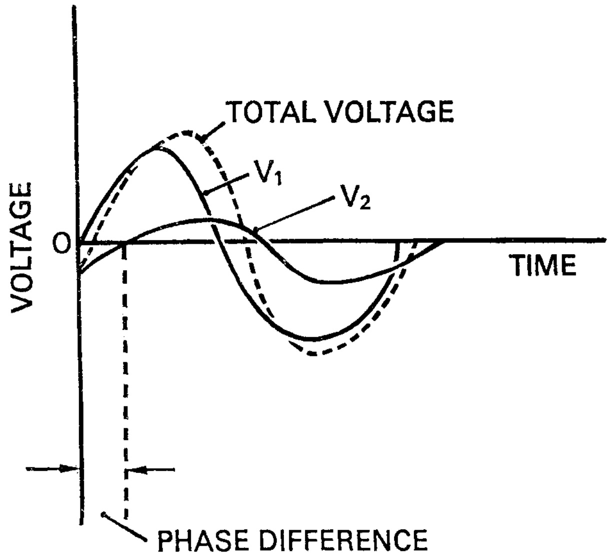

**Figure 10** Phase Difference

5.3 One method of suppressing the unwanted components of the measurement voltage (i.e. probe coil voltage) and presenting only the parameter required, is to include a phase sensing device in the circuit. This operates on the principle that only those components which are in phase with a reference voltage are passed to the meter. Figure 11 shows a typical phase sensing circuit in which the measurement voltage is applied to one diagonal of a bridge and a reference voltage to the other. The rectifiers act as switches which pass current during one half of each cycle of the reference voltage only, but no reference current flows through the meter due to the symmetry of the bridge circuit. The measurement voltage is applied to the meter during those periods when the rectifiers are conducting and by varying the phase of the reference voltage, unwanted components of the measurement voltage can be eliminated.

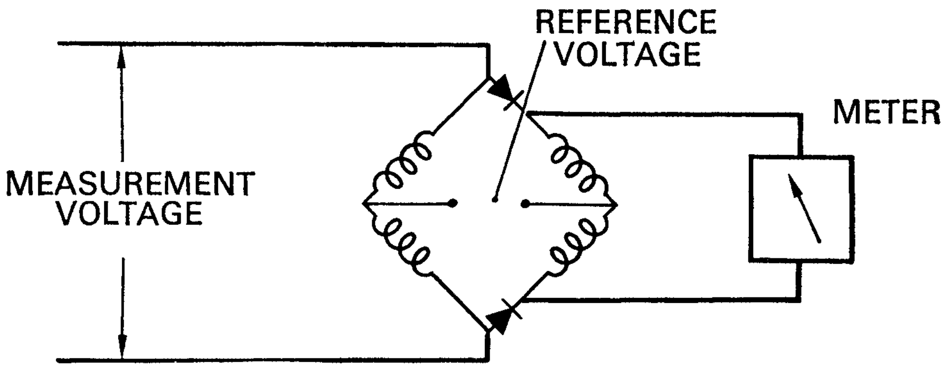

**Figure 11** Phase-sensing Circuit

### 5.4 Displays

5.4.1 The resistive and reactive components of the measurement voltage ($V_1$ and $V_2$ respectively) can also be separated, fed to separate plates of a cathode ray tube (CRT) and presented as a two-dimensional display on the screen. By suitable phase controls the vertical and horizontal components can be made to represent, for example, conductivity variations and dimensional variations respectively. The most common types of display are the vector point, ellipse and linear time base.

5.4.2 **Vector Point.** A spot is projected on to the screen of the CRT, representing the end of the impedance vector (Z) (Figure 12) and is adjusted to the centre of the screen when the test piece has the same properties as the reference specimen. Any anomaly in the test piece will result in movement of the spot, the direction of movement being an indication of the cause of the anomaly. If more than one variable is present, since the position of the spot indicates direction and magnitude, the cause can often be determined by vector analysis.

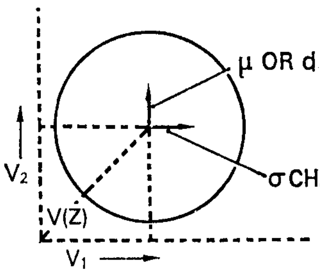

**Figure 12** Vector Point

5.4.3 **Ellipse Method.** A comparative coil arrangement is also used in this method. In the balanced condition a horizontal line is shown on the screen of the CRT whilst an unbalanced condition can be shown in either of two ways. One variable can be displayed by a change in the angle of the line and a second variable by the formation of an ellipse (Figure 13). By analysing the position and shape of the ellipse both variables can be evaluated.

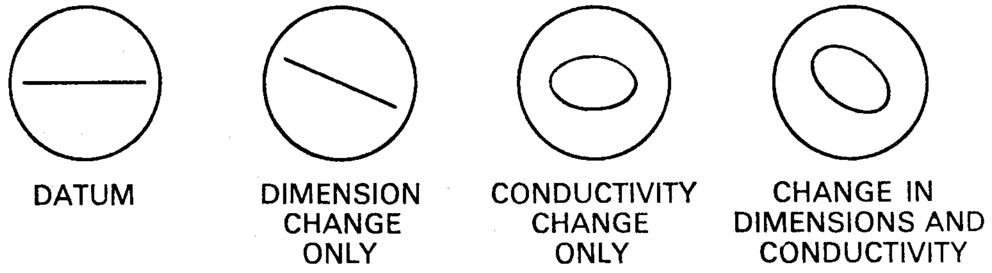

**Figure 13** Ellipse Method

5.4.4 **Linear Time Base.** A spot moving across the screen at a constant rate can be adjusted to show the wave-form of the voltage from a comparative coil system. A change in impedance will alter the wave-form and either of the components of impedance can be measured by adjustment of the phase shift controls. To assist in measuring any changes, the screen is often fitted with a slotted cursor (Figure 14).

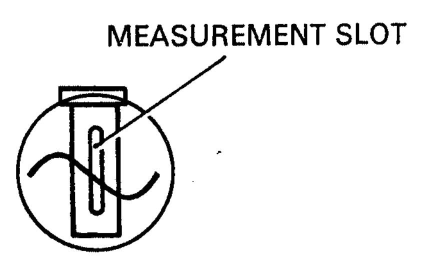

**Figure 14** Linear Time Base

## 6 Probes

6.1 Unlike ultrasonic probes, the probes used in eddy current testing, because they are connected to the material by a magnetic field, do not require a coupling fluid and no surface preparation is necessary other than the removal of any surface condition which would hinder free movement of the probe. Coils are also normally wound on a ferrite core and this has the effect of concentrating the magnetic field and increasing sensitivity to small defects. Coils are often protected by enclosures in a plastics case, but the ferrite core is often left unprotected when required by particular test conditions. To maintain the coils in close proximity to the work it is often necessary to design a probe for one particular use only; some of the probes commonly used in aircraft work are discussed in 6.2, 6.3 and 6.4.

6.2 **Surface Probes.** Figure 15 shows two typical surface probes. (A) could be used for detecting surface cracks and would be connected to a resonant circuit type of test set, whereas (B) could be used for coating thickness measurement or conductivity tests and would be connected in a bridge circuit type of test set. In the case of (A) a simple jig may be necessary to prevent spurious indications due to inadvertent probe angulation.

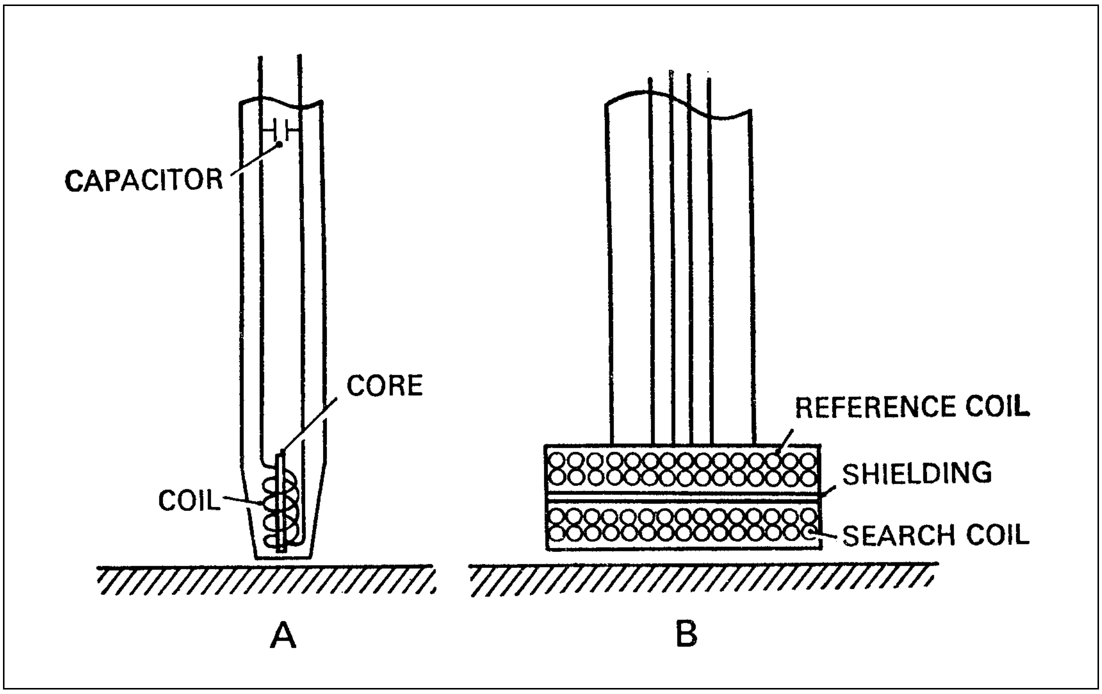

**Figure 15** Surface Probes

### 6.3 Hole Probes

6.3.1 Hole probes used during material manufacture would normally consist of a coil, the axis of which would be coincident with the axis of the tube under test, but in aircraft work a hole probe is normally located with the coil diametrically across the hole to achieve greater sensitivity. This type of probe is therefore a surface probe used for testing the surface of a hole. Figure 16 shows a typical hole probe of the latter type, the main use for which would be the detection of radial cracks round fastener holes.

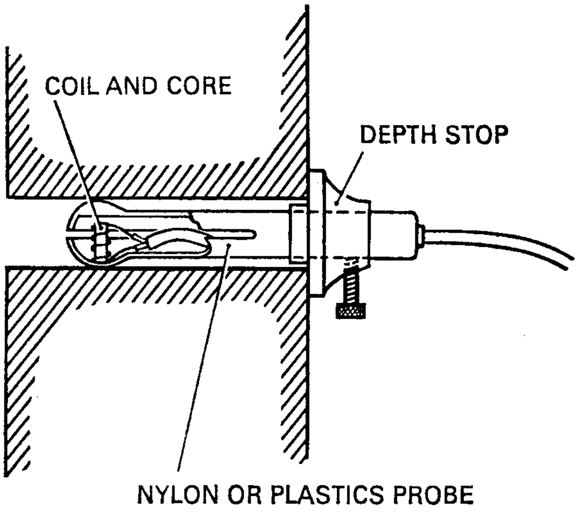

**Figure 16** Hole Probe

6.3.2 The actual position of a crack can be determined by using an offset coil as illustrated, or by shielding one end of the coil.

6.4 **Special Probes.** Probes may be designed to suit any application, the object being to present a coil at a particular position on a component, so that information can be obtained from changes in the coil's impedance. Examples of the use of special probes would be for the detection of cracks in wheel bead seats, turbine engine compressor or turbine blades and each of these probes could be connected to a single test set of suitable frequency and complexity. Probes are also designed with a view to eliminating the need for disassembly when carrying out routine maintenance operations.

## 7 Reference Pieces

7.1 In order to calibrate the equipment, standard reference pieces, manufactured from a material similar to that being tested, are necessary. These pieces should contain defects of known size and shape, so that the change in coil impedance against a known defect could be used as an acceptance limit.

7.2 A typical reference piece for surface crack tests would contain, for example, three cuts of different depths, the depth being marked adjacent to each cut and the block being marked with the material specification. The test acceptance level could then be related to a signal of the same amplitude as that obtained on a specified cut in the block.

7.3 Reference pieces are usually small in size and can be taken to the test location so that quick cross-reference can be made between the reference piece and the test specimen.

**NOTE:** Since the manufacture of a reference piece involves the removal of metal (by saw cut or spark erosion), the phase and magnitude of the impedance changes will not be identical with those obtained from a natural crack of similar depth. For this reason, actual defective aircraft components are sometimes used to give comparative readings.

## 8 Typical Applications of Eddy Currents

8.1 The eddy current equipment used in many material manufacturing processes is very sophisticated and completely automatic. Bar, tube and wire materials are normally passed through encircling coils of suitable size and defects are both displayed on a cathode ray tube and recorded by tape or memory store. Audible warning, marking and defective component rejection systems, actuated by the defect signal, are also often included. A recent innovation is the use of rotating probes through which bar material can be passed, the advantage of this method being an increase in the sensitivity to surface cracks. In aircraft maintenance work, however, eddy current equipment is usually restricted to conductivity tests and crack detection, mainly by the use of surface probes. Sophisticated equipment such as that described above is not normally required and equipment is usually portable and battery operated. The following paragraphs describe typical eddy current applications.

### 8.2 Checking Fastener Holes for Cracks

8.2.1 A suitable equipment for testing holes would be a simple impedance test set (i.e. not including phase analysing circuits) with lift-off control and the probe would be similar to that shown in Figure 16, adjusted to be a snug fit in the hole. The reference piece should be of similar material to that being tested and should contain holes of the same size as the probe with natural cracks or artificial notches at various depths in the hole to simulate cracks of maximum acceptable size.

8.2.2 The following procedure should be used when carrying out a test:

a) Clean loose paint, dirt, burrs, etc. from inside and around the holes being checked.

b) Calibrate instrument and adjust for lift-off in accordance with the manufacturer’s instructions.

c) Insert probe in hole in reference piece and adjust depth stop to obtain maximum needle deflection from a selected notch or crack. Adjust sensitivity to give the specified scale deflection from the crack.

d) Insert probe in hole in test specimen and slowly rotate, noting and marking any holes producing needle deflections greater than that from the reference piece. Re-check probe in reference piece frequently.

**NOTE:** Any ovality in hole diameter will give a meter deflection which can be confused with the signal from a crack. Generally the indication from ovality shows a much slower change than that from a crack as the probe is rotated.

e) Repeat c) and d) at incremental depths to cover the hole surface completely.

f) Ream out marked holes as recommended by aircraft manufacturer and repeat test with an appropriate sized probe and reference piece hole.

### 8.3 Checking Heat Damaged Skin

8.3.1 The conductivity of aluminium alloy sheet will increase with exposure to elevated temperatures up to approximately 500°C and above this temperature obvious signs of damage such as melted or charred metal become apparent. Tests conducted on the surrounding material will show the extent of the area in which the metal is below strength requirements and must be replaced.

8.3.2 The acceptable range of conductivity readings depends on the type of material and its heat treatment condition and these readings may be stipulated in the appropriate Maintenance Manual. As a rough guide, the conductivity of unclad 7075–T6 material is 31% to 35% IACS, but the important reading in relation to heat damage is the change in conductivity between sound and defective material.

8.3.3 A conductivity meter should be used for this test and this will normally be an impedance change instrument, with a meter and separate scale graduated in percentage IACS. This equipment is supplied with a surface probe and two test samples, one of high purity copper (with high conductivity) and the other a material of low conductivity, for calibration purposes.

8.3.4 The following procedure should be followed when carrying out the test:

a) Thoroughly clean area to be inspected.

b) Calibrate instrument in accordance with the manufacturer’s instructions.

c) Place probe on sound skin of similar material and thickness and remote from the heat affected zone and adjust scale until meter is zeroed. Compare this reading with the expected conductivity.

d) Check conductivity all round the affected area, noting any meter deflection and marking the skin accordingly. By this means a demarcation line can be drawn round the damaged area and material removed up to this line.

### 8.4 Detection of Corrosion

8.4.1 Corrosion on hidden surfaces can be detected by eddy current methods using phase sensitive equipment. If a reading at the normal thickness of a sheet material can be taken, since corrosion reduces the thickness of a sheet, when the probe is over a corroded area a different reading will be obtained. The equipment can be set up by noting the readings obtained from a sound material of, say, 90% of the thickness of the test specimen and a rough estimation of the volume of corrosion beneath the probe can be obtained during a test.

8.4.2 Equipment is available which is specially designed for thickness measurement having a meter graduated in appropriate units, but any equipment operating at a frequency which would give a penetration depth at least equal to the sheet thickness could be used to give an indication of the presence of corrosion. Equipment designed for detecting surface cracks and operating at very high frequency would be unsuitable.

8.4.3 Care is necessary when checking for corrosion to ensure that underlying structure (stringers, frames, etc.), chemically contoured areas and loose debris, do not cause misinterpretation of results.

8.5 **Material Sorting.** Provided that a known sample is available, eddy current equipment can be used to ensure that a batch of materials is correctly identified, or that a component is made from the correct material. Simple impedance equipment could be used for coarse sorting, but in order to differentiate between materials closely related in composition, equipment with phase sensing circuits is necessary. By placing the known sample in an encircling coil the characteristic trace of that material can be displayed on an oscilloscope and unknown samples accepted or rejected by comparison.

8.6 **Coating Thickness Measurement.** The thickness of conducting or non-conducting coatings on ferrous or non-ferrous bases can be measured using basic eddy current methods; although measurement becomes difficult where the conductivity of the coating and base metal are similar. It is possible to utilise crack detection equipment for measuring thick coatings, by comparing the readings obtained from the test specimen with the lift-off effect obtained when the probe is placed on slips of non-conducting material (e.g. mica) of known thickness. When measuring very thin coatings however (i.e. less than 0·12 mm (0·005 inch)), it is recommended that equipment designed specially for coating thickness measurement should be used.

## 9 Reference Material

9.1 Further information on eddy current theory and operating principles may be obtained from the following publications:

### Standards

| | |
|---|---|
| BS 3683 | Terms Used in Non-destructive Testing.<br>Part 5, Eddy Current Flaw Detection. |
| BS 3889 | Methods for Non-destructive Testing of Pipes and Tubes.<br>Part 2A, Eddy Current Testing of Ferrous Pipes and Tubes.<br>Part 2B, Eddy Current Testing of Non-ferrous Tubes. |

### Text Books

*Non-destructive Testing Handbook Vol.II*, 1963, by Robert C. McMaster.
(The Ronald Press Co.)

*Non-destructive Testing*, 1968, by William E. Schall.
(Machinery Publishers Ltd. London)

*Non-destructive Testing No. CT-6-5*, 1967,
(General Dynamics, Convair Division)

*Electromagnetic Testing Handbook H54*, 1965,
(Office of Assistant Secretary of Defense, Washington.)

# Leaflet 4-9 Endoscope Inspections

## 1 Introduction

1.1 This Leaflet provides guidance and advice on the use of endoscope inspection equipment (also known as boroscope, introscope or fibrescope equipment, depending on the type and the manufacturer) for the assessment of engine serviceability, both on a routine basis and for the investigation of developed defects. Although endoscope inspections are utilised in other areas, the information in this Leaflet is intended primarily for the inspection of gas turbine engines; it is not related to any particular engine and should, therefore, be read in conjunction with the relevant Maintenance Manuals and approved Maintenance Schedules, which should also be consulted for specific damage and time limits.

1.2 Endoscope equipment permits the inspection of gas turbine engine parts which would otherwise be inaccessible with the engine installed and in service. Early gas turbine engines had poor provision of ports for this type of inspection, apart from the igniter plug and burner holes, but engine manufacturers now tend to provide improved facilities for endoscope inspection of the rotating and combustion sections of the engine. Other large engine components may also have limited facilities, as do some airframe air-conditioning turbine units, etc.

1.3 Engineers should be conversant with the techniques of endoscope inspection to enable them to use the equipment as an effective inspection and diagnostic tool and as part of normal inspection procedures. This form of use will result in a more effective assessment being made of damage caused by an in-service incident such as a bird strike or foreign object ingestion.

## 2 Endoscope Equipment

2.1 Manufacturers of endoscopes tend to market the complete range of units required and it is unusual to be able to interchange parts of one system with those of another. The following general description of the equipment is not related to any particular manufacturer and should be read in conjunction with the appropriate manufacturer’s technical instructions or service manual.

### 2.2 The Probe

2.2.1 The probe is an optical instrument which performs two functions:

a) it relays and directs a beam of light for illumination and

b) it displays a focused and undistorted image at the eye-piece.

Probes differ in that some have an integral light source, while others rely on a remote 'light box'; another version has a small bulb at the tip of the probe to provide the illumination. In addition, facilities for adjusting the focus and magnification may be incorporated.

2.2.2 The probe shaft usually consists of concentric tubes, the inner one of which is the view tube, while the outer one provides a separate light path for the illumination beam. This beam is carried through an annular 'fibre optic bundle' to the tip where the necessary change in direction is made through prisms. The image is modified throughout its travel through the view tube by a series of lenses and may also be changed in direction by the same method.

2.2.3 At the tip, the prisms are protected by windows which prevent dust, grit or direct contact harming the optical clarity of the image. If the probe is of the non-adjustable type, the angle of view at the tip will be marked and there are the following four variations:

a) Straight View, where the centre of the field of view is parallel to the probe shaft.

b) Lateral View, where the centre of the field of view is at right-angles to the probe shaft.

c) Oblique View, where the centre of the field of view is at an oblique angle to the probe shaft.

d) Retro View, where the centre of the field of view is at an acute angle to the probe shaft, resulting in an amount of doubled-back view.

2.2.4 The field of view is designed to give a fairly useful amount of visible area and magnification at the kind of distances required in the internal inspection of a gas turbine engine. The eye-piece makes the final adjustment to the image before visual perception and provision is usually made here to indicate the relative direction of view with respect to the engineer. An array of inscribed lines, called a graticule, is sometimes provided to indicate, under specific conditions of use, a measurement of distance useful for damage assessment. Accessories can enable a still camera to be used to provide a permanent record of defects, etc. and television and video equipment can be used for applications where direct access to the probe would be uncomfortable or unsafe.

2.2.5 Flexible endoscopes (Figure 1) rely on fibre optic bundles to transmit an image in the same way as the illumination beam is transmitted along the rigid probes. However, for the transmission of an image, the relationship of each fibre to all of its neighbours must be the same at the eye-piece as at the probe tip. The image bundle and the illumination bundle are concentric with each other, with the image bundle forming the central core. The flexible probe tips are usually changeable and are of less elaborate manufacture, allowing the tip to be shorter, thus not having a cumbersome non-flexible end to restrict use in a confined space.

2.2.6 Migration of fluids by capillary action along the bundles between the individual fibres is prevented by the application of a transparent resin to the bundle ends. Compression, twisting and kinking of the fibre optic bundles is prevented by fitting the bundles in a flexible conduit, normally of spiral or 'armadillo' manufacture, which will restrict the manipulation of the probe to within the capabilities of the bundles.

2.3 **The Light Source.** Most endoscope equipment now in use utilises a separate and remote light source to illuminate the view area. This normally takes the form of a self-contained 'light box' containing the lamps, transformers, switchgear and cooling fans to provide a high-intensity beam. This beam is focused upon an adaptor in the box to which the fibre optic light bundle from the probe is connected. Quartz/halogen or quartz/iodine lamps provide the source of light, which may be varied in intensity to suit both the application and personal preference. Mains power supplies are normally used although some equipment can be arranged to allow typical aircraft voltages and frequencies to provide the system with power.

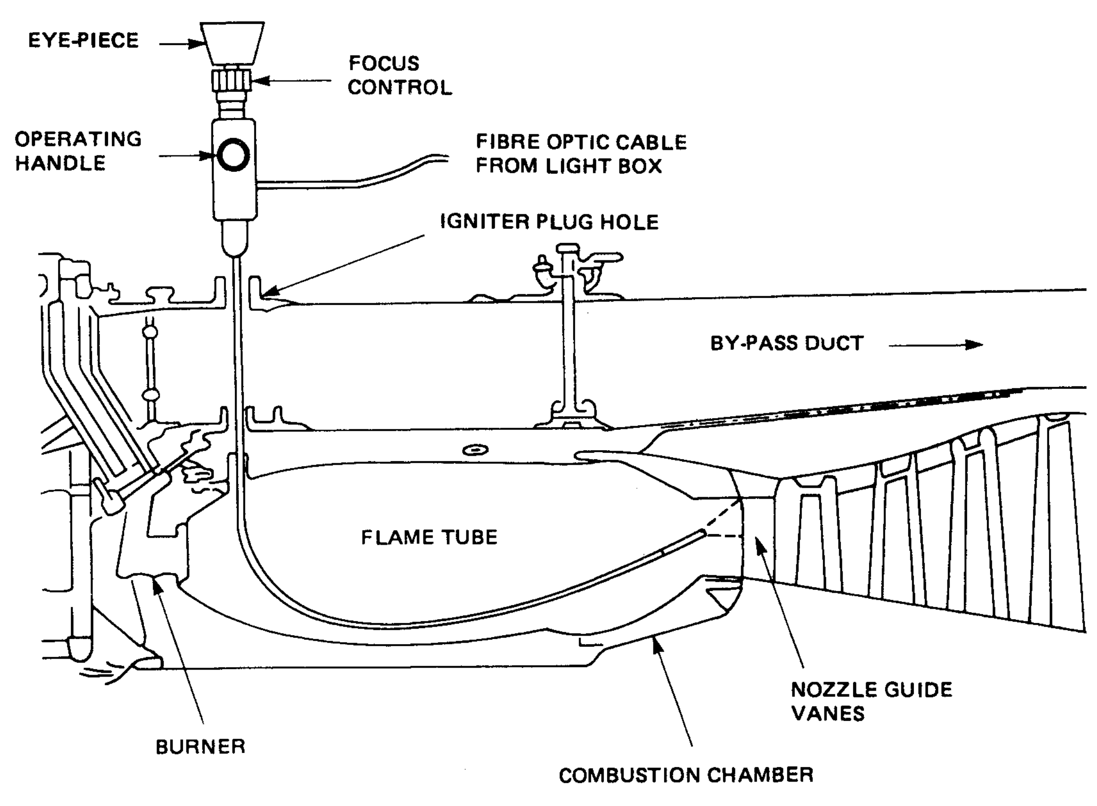

**Figure 1** Flexible Endoscope Inspection Equipment

## 3 Preparations

3.1 **Precautions.** Consideration must be given to the potential hazards involved in the inspection of gas turbine engines while under ramp or first-line maintenance conditions and special precautions should be taken because of the engineer's pre-occupation at the engine. A dangerous situation could occur in the event of the inadvertent operation of a starting system, ignition system, thrust reverser system or any mechanical or electrical controls; these systems should therefore be inhibited.

3.2 Other factors to be considered when inspecting engines under these conditions include:

a) Dissipation of residual heat;

b) Effect of windmilling;

c) Endoscope equipment contamination;

d) Electrical potential difference between the probe/light source and the aircraft structure;

e) Fuel and oil leakage.

### 3.3 Access

3.3.1 Engines designed for endoscope inspections have access ports fitted with blanking plugs at various points in the casings and the areas visible through these parts are detailed in the relevant Maintenance Manual. However, if specific access is not provided, a general knowledge of the layout of the engine together with the access provided by the removal of igniter plugs, temperature probes, pressure sensing lines, compressor bleed valves and other air off-takes enables useful condition assessments to be made. Forward view endoscopes can also be used to view through the air intake of an axial flow compressor or, to a more limited degree, through the turbine, the latter being restricted because of the greater curvature of nozzle guide vanes.

3.3.2 Access-port blanking plugs are subject to high temperatures and high rates of temperature change. This has the effect over a period of time of 'pinching' the blanking plugs to a higher torque than was applied at assembly. During removal, therefore, care must be taken to select a spanner which is a good fit on the plug and which will provide adequate leverage. Plugs which are fitted into blind holes in engine casings invariably have thread inserts and these, under high torque removal stresses, can become extracted with the plug and will require replacement.

3.3.3 The 'pinching' effect can be overcome to a certain extent by applying an anti-seize compound when fitting the blanking plugs. Manufacturers usually recommend the application of a graphite-based release agent which forms a dry film on the threads. Alternatively, a paste with metal or metal oxide content is applied. Neither paste nor dry film should be applied unless it can be established which of the compounds had been used previously, as any mixing will result in the formation of a hard-setting compound.

**NOTE:** In consideration of this 'pinching' effect, the initial torque settings for the blanking plugs must be those recommended in the relevant Maintenance Manual.

3.4 **Orientation.** Familiarity with the layout of an engine and experience in the use of endoscope equipment enables an engineer to recognise the area being viewed and the extent of inspection possible through a given access port.

**NOTE:** Parts frequently appear larger when viewed through an endoscope and damage can seem more extensive than it really is. Familiarisation with the size (height and width) of the item being viewed is therefore essential and ideally a spare part should be available to be held in the hand and viewed with and without an endoscope probe to ensure the item is correctly assessed.

3.5 Non-rotating assemblies cause few problems because major components such as burners and stators provide points of reference. Damage reporting on non-rotating components requires that burners, flame tubes, etc., be numbered to a standard form and that areas and components are named. An inspection report can then identify areas of damage by stating:

a) Access port used;

b) Direction of view;

c) Area or component inspected (by name and/or number);

d) Dimensions of and type of damage.

3.6 Components of rotating assemblies need to be identified for the same reasons. At overhaul, marks may be applied to the convex surface of turbine blades, together with the balance details normally applied, to number the blades consecutively around the disc. This procedure will enable positions to be fixed for the parts of the whole spool connected to that turbine. For instance, if HP turbine blades are numbered, HP compressor blades can be identified by stating:

a) Compressor access port used;

b) Direction of view;

c) Details of damage;

d) Turbine access port used;

e) The turbine blade number visible at the centre of the field of view.

3.7 The number of blades in a particular compressor or turbine stage should be known and the blades counted while viewing to ensure that all blades in the stage are checked. When viewing large blades, such as early compressor stages, it will be necessary to make two or three passes to cover the complete blade length, i.e. view the outer third of the aerofoil, mid span section and inner third adjacent to the inner platform.

### 3.8 Inspection

3.8.1 If damage is found on a rotating assembly which has no consecutive numbering of blades, point reference must be established by using an externally or internally recognisable point on the rotating assembly. Again, access ports must be stated and consecutive blades must be counted to locate the point of damage.

3.8.2 For ease of inspection, the HP shaft can be rotated (at a suitable speed to permit a satisfactory inspection) by an air-driven motor through the high-speed gearbox on engines with a drive facility; otherwise, hand-turning may be accomplished by using either a redundant component drive coupling or a standard socket fitting in the gearbox. Air-driven motor systems in general use have hand or foot controls to vary direction and speed; this is an advantage over using the hand-turning method which requires one person to turn the shaft while another performs the inspection.

3.8.3 LP shafts must be turned by hand and to rotate an Intermediate Pressure shaft in a three-spool engine, without a gearbox, a locally-made tool may be required to turn the shaft through the IP intake.

## 4 Inspections

4.1 One of the reasons for the increased use of endoscopes is the high cost involved in engine changes, either due to suspected internal damage or because of a Maintenance Schedule based on a “Hard Time Life” philosophy. It is therefore, an advantage to allow the engines to remain in service until defects are revealed via performance analysis, oil analysis, endoscope inspection, or by repetitive monitoring of allowable damage.

4.2 **Scheduled Inspections.** Scheduled inspections are the regular ones which are carried out as part of an approved Maintenance Schedule. The frequency of such inspections is dependent upon either engine cycles or flight time and need not be concurrent with the aircraft’s scheduled checks. The combustion section and the turbine blades are the primary concern during these inspections, due to the high stresses and temperatures encountered during service. All defects should be recorded, normally on a chart specific to the engine type, which after completion constitutes a record of any deterioration taking place within that particular engine. An assessment can then be made as to whether the engine may be allowed to continue in service until the next scheduled inspection, or that it may only continue in service subject to more frequent checks.

4.3 **Special Inspections.** Occasionally, experience gained by frequent endoscope inspections, in-service failures or inspection during overhaul highlights the development of particular defects which can be monitored using endoscopes while the engine continues in service. Normally only one or two access ports need be disturbed because it is only the area detailed by the special inspection which needs assessing. This again enables the engine either to continue in service or to be monitored even more frequently.

**NOTE:** Engines are often removed after scheduled or special inspections to prevent a primarily minor defect causing secondary damage, possibly leading to engine failure.

4.4 **Non-scheduled Inspections.** Endoscopes can be used to great effect when it is necessary to assess the damage caused by foreign object ingestion or engine surge, diagnose the cause of developed defects and provide a means of establishing engine serviceability following excursions beyond the normal turbine temperatures or maximum power limits. Together with other basic visual techniques of inspection, the use of endoscopes may, under certain circumstances, provide the necessary evidence to permit an aircraft to fly back to base for repair when it would otherwise require an immediate engine change.

4.5 **Final Inspection.** On completion of an endoscope inspection, it is essential that all access plugs are refitted correctly and securely. Failure to do so could cause a gas leak and result in a fire warning, shut-down and turn-back or in some cases cause a failure due to blade flutter or loss of cooling air. Access panels must also be correctly refitted.

## 5 Application

5.1 Components normally inspected with an endoscope, such as compressors, combustion sections and turbines, are subject to different types of damage and defects; therefore, actual limits and the specific forms of defects can only be found in the relevant Maintenance Manual.

### 5.2 Compressors

5.2.1 Endoscope inspections after such occurrences as foreign object damage (FOD), bird strikes or surge, must be systematic, not confined to single stages and always preceded by a comprehensive external visual examination. In addition to the endoscope ports provided, it may be possible to use bleed valve apertures and air-sensing probe points to inspect the compressor.

5.2.2 The most common form of damage to compressors is FOD. Centrifugal compressors have proved to be fairly damage-resistant but axial compressors are not so resistant to FOD and are also subject to surge damage. Inspection of axial compressors and their blades should, therefore, always include a search for evidence of FOD in all its manifestations - nicks, dents, scratches and the cracks which these defects may produce.

5.2.3 Surge damage may be in the form of trailing edge cracks at the blade root, rubbing marks on the blade platform or blade shroud, with perhaps damage to the spacer plates between the blades. Interference between tips or shrouds and the casing can occur during surge and may bend blade tips, cause cracks, etc. Interference between rotors and stators (clanging) is a more serious defect because of the likelihood of substantial deformation. Engine manufacturers normally know the type of damage which may be caused to their engines during surge and the Maintenance Manual may, therefore, indicate which particular stage or stages need to be inspected and which defects are particularly indicative of surge damage.

5.2.4 Grime and oil deposits may form on the compressor blades over a period of time. Excessive oil deposits are usually an indication of front bearing oil leakage or general wear in the engine. Where engines are operated in sandy conditions, dust tends to stick on the rear of the compressor if there are oil deposits present and such engines could benefit from compressor washing procedures.

5.2.5 Compressor blades which have mid-span shrouds (or clappered blades) are sometimes subject to wear at the point where the end of each shroud abuts its neighbour. On 1st stage LP or fan blades this wear is recognised and can be measured by taking up the total free play of the whole stage, by moving half the blades clockwise about their mounting pins and the other half anti-clockwise; this leaves a gap between one pair of blades which represents total shroud wear. Of course, this procedure will not be suitable for other than fans or 1st and maybe 2nd, stage LP blades. Inspection of mid-span shroud wear through an endoscope is confined to a close and clear view of abutting shrouds. Shrouds which are wearing may be recognised by:

a) Metallic streaking from the join;

b) A wavy, uneven join line;

c) Hammering (which is where the abutting faces deform, like chisel shafts under the effects of frequent hammer blows).

5.2.6 Whatever damage is found on compressor blades, its position on the blade will determine its seriousness. It is usual for the inner one-third of the blade to be classified as a 'no damage allowable' area, as are the areas on each side of mid-span shrouds.

### 5.3 Combustion Section

5.3.1 High temperature is the reason for most combustion section defects. Burning, cracking, distortion and erosion of nozzle guide vanes (NGVs) are typical. The combustion section may be inspected with an endoscope either through the designated access ports or through the igniter plug holes or burner apertures. The components visible depend, of course, upon engine design and the position of the access ports, but the flame tubes or liners, burner flares and swirlers, tube interconnectors and the NGV leading edges are normally inspectable.

**NOTE:** In the combustion section, all defects must be assessed on the basis of the likelihood of the defect causing a breakaway of material. This could lead to greater damage occurring in the turbine.

5.3.2 **Burners.** The burners protrude into the forward face of the flame tube/liner through an aperture which is usually flared; this is sometimes called the burner flare. The burner must be concentric with this flare otherwise a loose flare or burner should be suspected. In an annular combustion chamber, the burners and flares are separated by blank segments and these must be secure.

5.3.3 The burners may develop carbon deposits, which can be in the form of an irregularly-shaped protuberance from the burner face. In some engines this has a detrimental effect on starting, but when it breaks off it rarely causes any damage because it is usually soft. Hard carbon, however, can block the burner spray nozzle but does not grow large enough to cause break-off damage.

5.3.4 Swirlers (or swirl vanes) should be inspected for security and missing elements. All components should be inspected for cracks.

5.3.5 **Flame Tubes/Liners.** Flame tubes (or, in annular combustion chambers, the liners) contain the flame by directing air through holes or slots to the centre of the tube. The whole surface of the tube is peppered with cooling holes of varying sizes arranged in a regular pattern and these are usually the starting points for cracks and sometimes determine the limits of cracks. For instance, the Maintenance Manual may state that axial cracks which extend rearward beyond the third row of cooling holes are unacceptable. The allowable limits for cracks can depend on both their position and length. To assess their length through an endoscope must at times be a matter of estimation. The engineer should, however, be aware of the general dimensions of the component being inspected (these are sometimes stated in the Maintenance Manual, otherwise familiarity with the components is required); from this a near estimate can be made of crack length. The flame tubes should be inspected for cracks and other damage as follows:

a) **Cracks.** These start at holes or edges and may stop when they reach another hole or edge. Circumferential cracks can be more serious than axial cracks as they can result in pieces breaking off under the effect of airflow and flame impingement. Cracks around dilution chutes (scoops or nozzles into the airstream) are usually considered to be serious, since any distortion of the chute may create hot-spots which will accelerate deterioration and may cause torching of the flame onto the air casing.

b) **Distortion.** Usually, defined limits give the allowable amount of distortion into the airstream and the length of cracks associated with it. The manufacture of a flame tube normally includes sections which overlap each other; these overlaps allow cooling air to flow near the surface of the tube. The sections are joined by a 'wigglestrip' (corrugated spacer) which allows air to flow through the overlap. The wigglestrips should be inspected for security because the welds can fail, causing distortion of the strips into the airstream of the tube. Limits for this damage are measured in numbers of adjacent or total wigglestrip pitches affected.

c) **Burning and Hot Streaking.** The high temperature materials used for the flame tubes/liners sometimes change colour quite dramatically with heat, so coloured areas alone may not indicate serious burning. Burning is caused by the flame approaching the tube/liner and is recognised by the texture of the surface; this becomes rough and pitted and a reduction of wall thickness is noticeable. Streaks of metallic particles sparkle under the high intensity light of the endoscope and are recognised this way. Edges of lips and overlaps are susceptible to burning and erosion. Burn limits depend upon position and area.

d) **Holes.** These can be caused in three ways:

   i) pieces breaking off,

   ii) cracks allowing a section of metal to be lifted off and

   iii) burning through.

   Holes in a flame tube/liner need not be a reason to reject an engine. However, the turbine should be inspected if the hole was caused other than by burning through. Carbon deposits produced at the burner can sometimes be mistaken for holes as the carbon is an intense black; the angle of view of the suspected hole should be changed if any doubt exists. If the suspected hole is a carbon deposit no detail of the edge of the 'hole' will be visible, neither will any detail through the 'hole'.

e) **Nicks and Dents.** Inspection should be extended to the NGVs if this damage is found because these are evidence of broken-off particles or FOD.

5.3.6 **Nozzle Guide Vanes.** The NGVs are subject to very high thermal and mechanical stresses and only the newest of engines do not show physical signs of this when inspected through an endoscope. If viewed from the igniter plug holes, the leading edges and some concave surfaces only will be visible. Access ports are required elsewhere to view the whole surface of NGVs as they are highly cambered. Rows of cooling-air holes are visible on most NGVs and these may be used to identify areas of the vane. Damage can be as follows:

a) **Discoloration.** Slight discoloration is nearly always present and is not necessarily a defect. Heavy discoloration, however, is associated with burning.

b) **Cracks.** These are allowable to a limited extent but if associated with lifting of the surface from the original contour they are not acceptable. Cracks are either axial (from leading edge to trailing edge) or radial (vertical) and their allowable length will depend on their direction; those which converge or are in convex surfaces may well necessitate engine rejection.

c) **Burning and/or Erosion.** Erosion, although caused separately from burning, is usually found in the same areas as burning and is subject to the same limits. Erosion is the product of abrasion and looks like burning without the discoloration; that is, roughness and pitting with a noticeable reduction in skin thickness. Burning and erosion are most common on NGV leading edges and concave surfaces. They may penetrate the outer skin and are sometimes allowable, but again subject to position and size of area affected.

d) **Dents and Nicks.** These are caused by FOD and further inspections should be carried out if they are found.

e) **Tearing.** Tearing can occur in trailing edges and is allowable only within defined limits.

### 5.4 Turbine Section

5.4.1 Access for the endoscope inspection of turbine blades is either through the ports provided or sometimes through the igniter plug holes using a flexible endoscope (flexiscope). For this, a holding tool can be made which is fed through the igniter plug hole and fixed. The flexiscope is then inserted and the holding tool guides the tip through the NGVs to view the blades. Methods of identifying blades are explained in paragraph 3.6.

**NOTE:** When viewing the aerofoil surface of a turbine blade, the end of the probe is located between the blades and must be withdrawn prior to engine rotation to avoid damaging the probe and blades.

5.4.2 Turbine blades are subject to the same types of damage and defects as NGVs. The limits for such damage are, however, more stringent. Blades can have some leading edge damage and cracking but still remain in service; trailing edge cracks, however, can propagate quite quickly due to tearing forces imposed by centrifugal force and the twist of the blade and these cracks are not normally allowable. Dents on aerofoil surfaces of hollow turbine blades can initiate cracks on the cooling-air passage wall inside the aerofoil section which can propagate to form quite large internal cracks before breaking through and becoming visible.

5.4.3 Deposits can form on most internal parts of gas turbine engines. When airborne sand is ingested it usually accumulates on the NGV and turbine blade leading edges. It has a sandy colour and becomes baked on by the combustion process and is not easily removed even at engine overhaul. It can cover some cooling holes but does not usually cover significant NGV or turbine blade defects. Its effect on inspections is therefore minimal, but its overall effect is to shorten engine life.

### 5.5 Record of Damage

5.5.1 When damage is found it must be recorded in the engine records. This is the case whether the inspection was routine or a special one. Increases in crack length, for instance, can then be assessed over a period of time, thus giving time to arrange for repairs or removal. Some operators have introduced inspection sheets for use when carrying out routine and special endoscope inspections. The sheets detail the preparation work necessary before inspection and also include drawings which depict blades or flame tubes; engineers then mark in observed defects and identify the drawings accordingly. These representations of the internal state of each engine then form part of the engine's records and can be used in future assessments of damage and the growth of existing damage. Photographic records may also be kept, using a still camera or video tape recording.

5.5.2 The Maintenance Manual will sometimes define a defect as acceptable for a finite number of flying hours or cycles. Engineers should, therefore, ensure that additional entries are made in log books and/or technical logs to limit engine operation to the periods allowed. If, however, inspection reveals that different defects exist which are related, each with a finite allowable number of flying hours, the engineer should consider certifying such defects as allowable only for a shorter time than the most restrictive of the allowances given.

# Leaflet 4-10 Design and Production Personnel Certification for Non-Destructive Testing of Aircraft, Engines, Components and Materials

**(Content previously issued as Airworthiness Notice No. 94 and GR No. 23)**

## 1 General

1.1 This Leaflet advises means of compliance acceptable to the UK CAA for the qualification of Non-Destructive Testing (NDT) personnel involved in design or production under BCAR and/or Part 21 requirements, which shall be in accordance with European Standards EN473 (NOTE 1) or EN4179 (NOTE 2), and the Approved Organisation's written practice/procedures for the authorisation of NDT personnel.

1.2 This Leaflet reflects the introduction of EASA requirements and details the changes that have resulted from the establishment of a UK National Aerospace NDT Board (UK NANDTB). The Leaflet clarifies CAA policy relating to the acceptability of central (EN473) and organisation-based (EN4179) schemes for the qualification of NDT personnel in accordance with European NDT personnel requirements, and is intended to recognise the competence of Level 3 qualified personnel.

1.3 The term NDT is used throughout this Leaflet to include, but not be limited to, liquid penetrant, magnetic particle, eddy current, ultrasonic, radiographic and other recognised methods as identified in the above referenced standards and shall be applicable to all NDT methods used by Approved Organisations. Other methods and their associated procedures will be subject to acceptance by the CAA under the applicable airworthiness approval standard (Part 21 or BCAR), following technical consultation with the National Aerospace NDT Board as necessary. Definitions of other key terms used throughout this Leaflet are contained in paragraph 9.

**NOTE 1:** EN473 - General Principle for Qualification and Certification of NDT Personnel.

**NOTE 2:** EN4179 - Qualification and approval of personnel for non-destructive testing. Version prEN4179:2003 (P3) is currently recognised by the CAA and is expected to be followed, and is referred to hereafter as EN4179.

**NOTE 3:** Except where stated, all references to Standards are to be taken as referring to the latest issue and are available from the British Standards Institute, 389 Chiswick High Road, London, W4 4AL.

**NOTE 4:** Details relating to UK NANDTB Policies can be found on its website: www.bindt.org/Mk1Site/NANDTBhome.html

## 2 Procedures for the Qualification of NDT Personnel

2.1 All Approved Design and Production Organisations involved in any aspect of NDT shall develop and maintain procedures for the qualification and authorisation of their NDT personnel in accordance with either EN473 for a central Personnel Certification scheme (see paragraph 2.3) or EN4179 for an organisation-based Personnel Certification scheme. In either case, the organisation's procedures and/or written practice as defined by EN4179 shall be approved by the Nominated Level 3 (see paragraph 3) and cross-referenced in the appropriate Exposition/Handbook.

2.2 Where an Organisation elects to use EN4179, then the training and examination procedures/written practice must be under the control of the UK NANDTB. The Board has declared that BINDT accreditation is an acceptable means to demonstrate such control (www.bindt.org/Mk1Site/NANDTBhome.html).

2.3 Where an Organisation elects to use EN473, then the training and examination procedures/written practice must be sent to the UK CAA Team Leader for that Organisation following approval by the Nominated Level 3.

2.4 Within the UK, the CAA currently recognises the national scheme for Personnel Certification in Non-Destructive Testing (PCN) administered by the British Institute of Non-Destructive Testing as meeting the requirements of EN473 for central certification.

2.5 CAA Approved Design and Production Organisations operating in accordance with the previous CAP 747 - Mandatory Requirements for Airworthiness, Generic Requirement (GR) No. 23 have until 28th September 2007 to comply with this Leaflet.

## 3 Nominated Level 3

3.1 Organisations shall nominate in writing using an EASA Form 4 (for Part 21) or Form AD458 (for BCAR), supported with evidence of independent qualification, an individual responsible to the Chief Executive/Accountable Manager, for the technical supervision of NDT. This individual will hold NDT Qualification at NDT Level 3 in the appropriate Industry Sector and will be referred to as the Nominated Level 3. This position shall be identified within the Organisation's Exposition/Handbook, and any change in this position advised to the CAA.

3.2 The CAA recognises the following independent qualifications as appropriate for the position of Nominated Level 3:

- PCN/GEN Appendix A
- PCN/AERO
- ASNT Level III
- ACCP Level III (Aerospace)

Such an individual must also demonstrate evidence of specific knowledge and experience appropriate to the Organisation's scope of work. Guidance on the expected level of knowledge is contained in Paragraph 3 of Appendix 1 to this Leaflet.

3.3 Where the Nominated Level 3 is not qualified in all methods used by the Organisation, then personnel necessary to provide coverage shall be identified in the Exposition/Handbook and shall hold NDT Level 3 certification under those schemes detailed in 3.2 above.

3.4 The CAA may accept persons external to the Organisation as the Nominated Level 3, provided written agreement exists between the individual and the Organisation setting out the individual's responsibilities within the Organisation.

## 4 Inspections and Certification of Inspections

4.1 NDT inspections shall be carried out by personnel approved in accordance with the Organisation's written practice. Where NDT procedures are specified by the organisation responsible for the design and/or manufacture of the aircraft, material, structure or component, then these must be used, except where change is permitted and authorised as defined in paragraph 5 of this Leaflet. Where non-mandatory inspections are to be undertaken, for which the responsible design/manufacturing organisation has not specified NDT procedures, then the NDT method, technique, procedure and instruction shall be prepared in accordance with paragraph 5 and approved by a Level 3 holder qualified in the applicable method.

4.2 Normally, certification of inspections will be made by authorised persons who hold Level 2 or Level 3 authorisations. However, where an inspection task is determined by the Nominated Level 3 to have clearly defined acceptability and rejection criteria requiring no interpretation, then certification may be carried out by an authorised Level 1, as detailed within the written practice.

4.3 Where a Level 3 is required to carry out and certify an NDT inspection then this person must either hold current Level 2 certification in those methods, or alternatively be able to provide evidence that they have successfully completed an appropriate Level 2 practical examination and maintained continuity in the application of practical testing as defined in the referenced standards and detailed in the written practice before the issuance of an authorisation.

## 5 NDT Techniques and Instructions and their Approval

5.1 NDT techniques, procedures and instructions, published and specified by the Type Certificate holder in NDT Manuals, Service Bulletins, Approved Drawings etc. constitute airworthiness data.

5.2 Where the airworthiness data published by the Type Certificate holder permits changes (e.g. selection of equipment model, probe type etc.) then such changes must be authorised in writing by a Level 3 qualified in the appropriate method.

5.3 Any other change to the Type Certificate Holder's airworthiness data requires the written agreement of the Type Certificate holder responsible for the design of the product/structure before such a change is implemented.

5.4 NDT Instructions prepared by a Level 2 holder shall be approved by a Level 3 holder qualified in the applicable method.

5.5 The procedure for the control of all NDT techniques, procedures and instructions, including their preparation and authorisation within any CAA Approved Organisation, shall be detailed in the Organisation's Exposition/Handbook.

## 6 Control of Suppliers and Sub-contractors

Design and Production Organisations utilising suppliers and sub-contractors where NDT processes are employed shall detail within their written practice how the Organisation ensures that training and approval of NDT personnel in such suppliers or sub-contractors is controlled. Organisations are referred to Part 21A.139 b)1) and GM No. 2 to 21A.139(a) and to BCAR A8-1 Appendix 2 'Surveillance of Sub-Contractors' as appropriate.

## 7 Other Means of Compliance

For Design and Production Organisations outside the EU that the CAA conducts oversight of either as Competent Authority for the UK or on behalf of EASA, the CAA may consider local national qualifications alternative to EN473 and EN4179 provided that they are demonstrated to be equivalent, have the approval of the local airworthiness regulating authority, and the CAA is satisfied that no degradation of airworthiness standards is likely to occur as a result of the acceptance of such alternative arrangements. Details of the qualification standard shall be made available for review by the CAA.

## 8 National Aerospace NDT Board (UK NANDTB)

8.1 The UK NANDTB was established in October 2004. Full details of the UK NANDTB Policy can be found on the following website: www.bindt.org/Mk1Site/NANDTBhome.html. Some of the responsibilities of the board are as follows:

a) Control and to support the implementation of employer-based NDT personnel standards;

b) Formulate necessary qualification policy framework;

c) Maintain an overview of the implementation of its policy; and approve the methods and levels of any charges in connection thereof;

d) Have the authority to set up working groups and committees, establish their terms of reference, and set out the procedures whereby they report to the Board; and

e) To advise industry and regulatory authorities on emerging new methods not listed in paragraph 1.3.

8.2 The Board will also provide a mechanism for maintaining an overview of EN 4179 PCN/AERO scheme aerospace qualification examinations.

## 9 Definitions

**Authorisation (of NDT procedures)**: The act of signifying approval of NDT procedures by a Nominated Level 3.

**Authorisation (of NDT personnel)**: A written statement issued by a Nominated Level 3 based on the individual's competence as specified within the certificate.

**Certificate**: Document issued under either EN473 or EN4179 indicating that adequate confidence is provided that the named person is competent to perform specified non-destructive testing.

**Industry Sector**: A particular section of industry or technology where specialized NDT practices are used requiring specific product-related knowledge, skill, equipment or training. An industrial sector may be interpreted to mean a product (welds, castings, etc.) or an industry (aerospace, petrochemical, etc.)

**National Aerospace NDT Board**: An independent organisation representing a nation's aerospace industry chartered by the participating prime organisations and recognised by the national regulatory authorities to provide or support NDT qualification services and examination in accordance with EN4179.

**NDT Instruction**: A written description of the precise steps to be followed in testing to an established standard, code, specification or NDT procedure.

**NDT Method**: Discipline applying a physical principle in Non-Destructive Testing (e.g. ultrasonic method).

**NDT Procedure**: A written description of all essential parameters and precautions to be observed when applying an NDT technique to a specific test, following an established standard, code or specification.

**NDT Technique**: A specific way of utilising an NDT method (e.g. ultrasonic immersion technique).

**Nominated Level 3**: An independently certified Level 3 certificate holder responsible to the Chief Executive or Accountable Manager for the airworthiness aspects of NDT work undertaken by that Organisation.

**Qualification**: The proven ability of NDT personnel to meet the requirements of a given specification in terms of physical requirements, training, knowledge and experience necessary to perform the applicable NDT method.

**Qualification Examination**: An examination administered by an independent certifying body (e.g. PCN), or by a body authorised within the employer's EN4179 compliant written practice, which demonstrates the general, specific and practical knowledge of the candidate.

**Type Certificate**: For the purposes of this Leaflet, Type Certificate includes Type Certificates, Supplementary Type Certificates, Repairs or Minor Design Changes and European Technical Standard Order (ETSO) Authorisations as defined in Part 21.

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# Appendix 1

## 1 The Role of the Nominated Level 3

The Nominated Level 3 is responsible to the Chief Executive/Accountable Manager for the technical supervision of NDT within the Organisation. Whether the Nominated Level 3 is an employee or contracted from outside, the Organisation needs to:

a) Propose the Nominated Level 3 to the CAA by means of an AD458 (for BCAR approvals) or an EASA Form 4 (for Part 21 approvals) and identify the Nominated Level 3 in the Exposition/Handbook. As a nominated individual, the Nominated Level 3 must be provided with the necessary co-operation (access to facilities, company procedures, training records, audits and inspection reports etc.) to allow that person to carry out their function under the CAA Approval.

b) Identify the Terms of Reference (either within the Exposition or by reference to a separate document) for the Nominated Level 3 to discharge their responsibilities. As a minimum, the Nominated Level 3 will need to:

   i) Identify any additional centrally certified Level 3 personnel necessary for coverage when the Nominated Level 3 is not qualified in all NDT methods used by the Organisation.

   ii) Identify any additional Level 3 personnel necessary to provide adequate day-to-day coverage depending on the size/facilities of the approved Organisation.

   iii) Approve the Organisation's NDT procedures and written practice for the Training and Certification of NDT personnel as meeting CAAIP Leaflet 4-10 and EN473/EN4179 as appropriate.

   iv) Review the written practice on a regular[1] basis to ensure that any changes in the regulations, applicable standards and the Organisation itself are reflected.

   v) Ensure that NDT procedures are reviewed on a regular[1] basis.

   vi) Ensure that regular[1] technical audits (both system and product) are carried out by appropriately qualified personnel in order to ensure the continued standard of NDT work carried out in that Organisation.

## 2 Oversight of Technical Supervision

2.1 Where an Organisation uses its internal expertise and resources to operate and maintain an EN4179-based scheme, then this remains acceptable under this Leaflet. However, with the establishment of the UK National Aerospace NDT Board it is expected that examinations should be conducted by personnel or organisations under the control of such a Board. Organisations are given a transition period until 28 September 2007 to seek accreditation of their internal written practice or qualification procedure to the UK NANDTB.

2.2 An Organisation may also issue an NDT certification authorisation to personnel qualified in accordance with Paragraph 1.4 of this Leaflet (BINDT PCN scheme) subject to the Nominated Level 3 person determining and detailing in the Organisation's written practice or qualification procedure whether any additional

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[1] It is recommended that these activities take place on at least an annual basis. Review should also take place after significant amendment to applicable standards/specifications.

specific job training and/or examination is required covering the products to be tested and the NDT process and equipment used by the organisation.

2.3 Where an Organisation decides to employ an external agency to provide EN4179 support, then that agency must be subject to audit under the contracting Organisation's documented quality system to ensure that compliance with this Leaflet is demonstrated. Where an external agency is approved under the BINDT Outside Agency Scheme, then the contracting Organisation may take due regard of this when planning audit activity. In these circumstances the training and qualification scheme is also expected to be under the control of the NANDTB.

2.4 Where an Organisation does not possess the internal resource or technical competence to carry out such an audit, then personnel training and examinations will need to be carried out by a BINDT approved Outside Agency.

**NOTE:** The above is only required for training and qualification examinations, not for continuation/awareness and development training.

2.5 NDT Personnel Certification does not relieve an Organisation of its responsibility to authorise staff to carry out work. Such Authorisations are to be given by approved personnel within an Organisation in accordance with the Organisation's Quality Procedures and be subject to audit.

2.6 In all cases the Organisation's procedures for the training, examination and certification of NDT personnel should be subject to independent QA audit as required by BCAR and Part 21.

## 3 Guidance on Specific Knowledge and Experience

3.1 The purpose of provision of the AD458/EASA Form 4 is to allow the CAA to make an individual assessment of the suitability of the Nominated Level 3 to provide technical supervision to the particular Organisation. This will continue to be the case; however, the following general guidance is provided:

3.2 For those Organisations involved in the provision of products such as raw material, basic castings, forgings, extrusions, machined components etc., specific aerospace experience and sector scheme qualification is not generally necessary where the technology is not specific to aerospace.

**NOTE:** In the case of products intended for critical applications (such as high energy rotating components), the responsible Type Design Organisation may require aerospace experience and sector scheme qualification.

3.3 Where an Organisation produces fabricated assemblies where the airworthiness of aircraft may be directly affected, knowledge of aerospace methods of construction, joining technology etc. may be necessary depending on the particular work being undertaken. Appropriate aerospace experience and sector scheme qualification may be required.

3.4 In the case of Organisations involved in the manufacture of stressed or load-bearing aircraft structure, knowledge of aerospace methods of construction, joining technology, in-service flaws and regulatory requirements is required. Specific aerospace experience and sector scheme qualification is expected.

## 4 EN4179 Developments - PR EN4179 P3 (February 2003)

4.1 The recent work to harmonise EN4179/NAS410 did not address all of the CAA concerns regarding the standard. Organisations revising their written practices to comply with the revised standard need to ensure that they remain in compliance with CAA policy as defined in this Leaflet. The PR EN4179 P3 paragraph references given below are to assist in identifying areas of interest to the CAA:

1.1 There is a distinction between Certification of Personnel as a result of training/ examination and Certification of Inspections as used in BCAR/ Part 21. Once Personnel Certification is in place, an Organisation must authorise a person in accordance with its procedures so that person can carry out and certify NDT inspections.

4.1 Written practices developed by sub-contractors must be approved by the controlling Approved Organisation.

4.5.2 A "responsible" Level 3 under EN4179 must be independently certified to be acceptable to CAA as a Nominated Level 3 under this Leaflet.

5.1 Requirements for Qualification.

The EN4179 requirements for the levels of qualification of NDT personnel do not satisfy CAA policy on levels of certifying personnel, specifically:

Level 1 - EN4179 permits trainees to obtain work experience under the "guidance" of a Level 1. CAA accepts a Level 1 observing in order to record work experience, but guidance should be provided by a Level 2/3.

Level 1 - It is a long-standing CAA position that a Level 1 in not allowed to interpret results. Only where there are clear accept/reject criteria requiring no interpretation may a Level 1 certify components.

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