BL/8-3

Issue 2.
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BASIC
NON-DESTRUCTIVE EXAMINATIONS

ULTRASONIC FLAW DETECTION AND THICKNESS MEASUREMENT

1 INTRODUCTION The methods of crack detection dealt with in Leaflets **BL/8-1** and **BL/8-2** 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.

1.1 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.

1.2 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.

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

2.1 **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 (λ) is the same as the time taken for the vibrating body to execute one complete cycle.

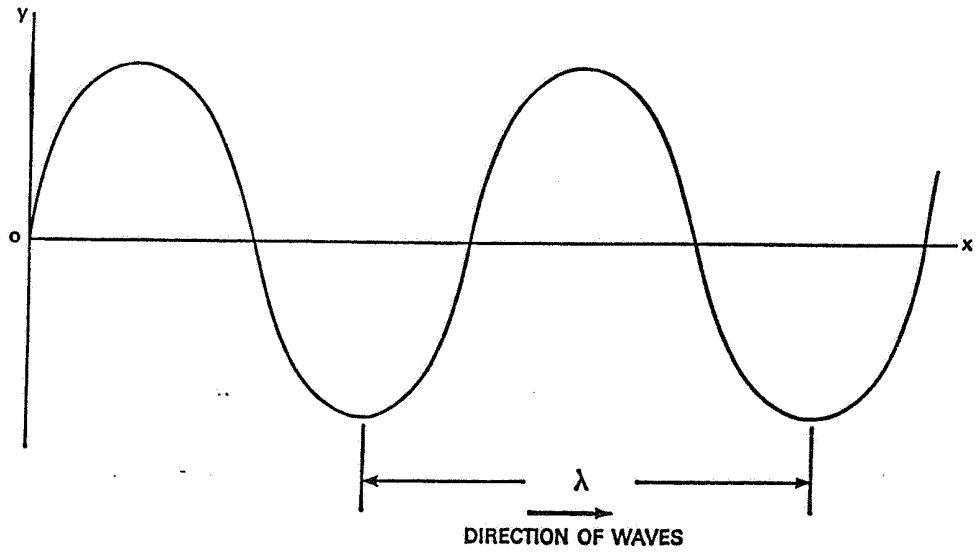

Figure 1 FORM OF SOUND WAVES

2.2 **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).

2.3 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 per cent of the speed of transverse waves.

2.4 **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.

2.5 **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.

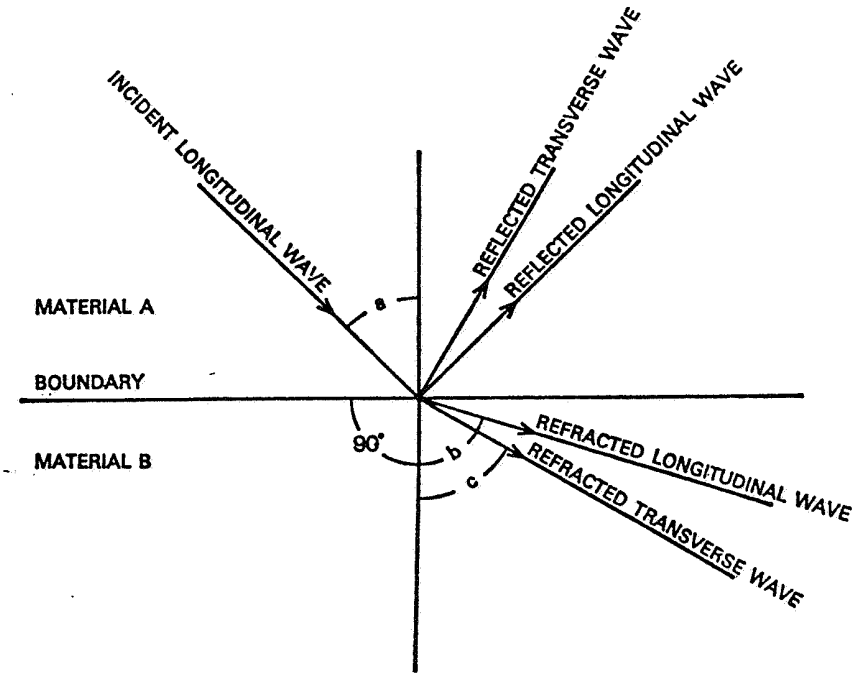

Figure 2 MODE CONVERSION

3 GENERATION AND DETECTION OF SOUND WAVES 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.

3.1 **Piezoelectric Effect.** 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.

3.1.1 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.

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

3.2 **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).

3.3 **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.

3.4 **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.

3.5 **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.

3.6 **Display.** 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.

3.6.1 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.

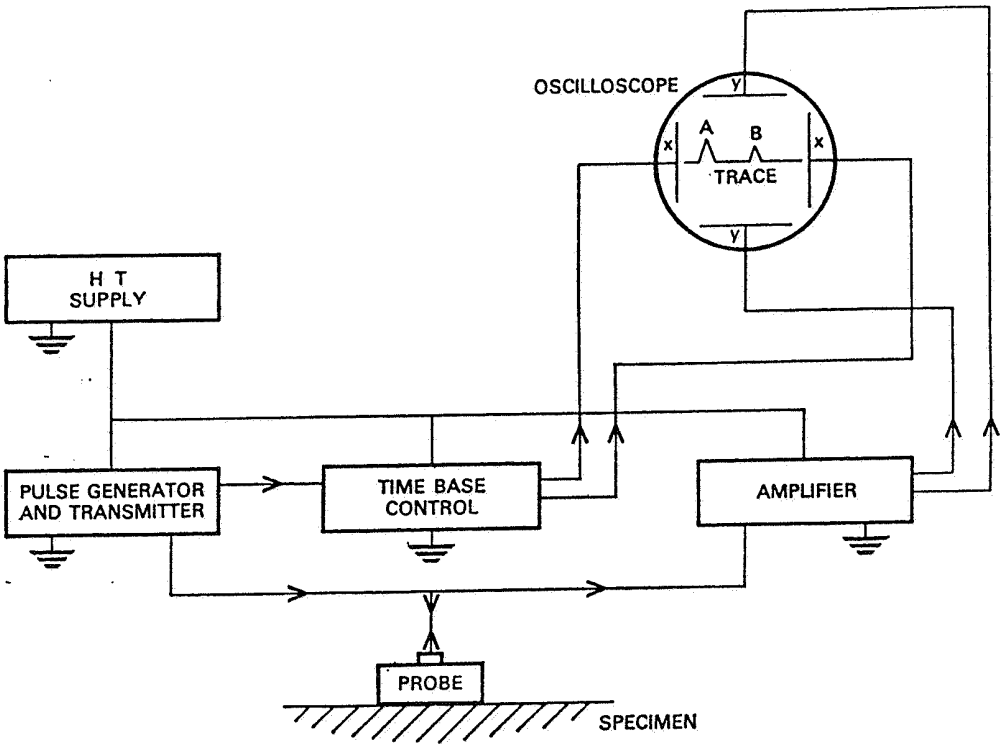

Figure 3 SIMPLE BLOCK DIAGRAM OF ULTRASONIC SET

3.6.2 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.

3.6.3 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.

3.6.4 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.** 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).

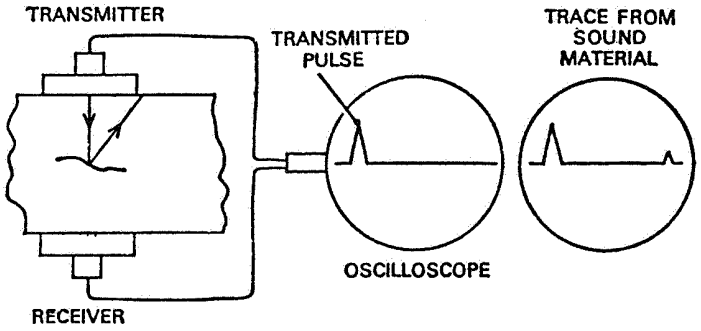

Figure 4 NORMAL TRANSMISSION TECHNIQUE

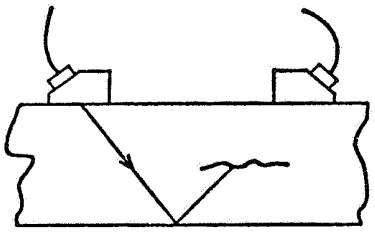

Figure 5 ALTERNATIVE TRANSMISSION TECHNIQUE

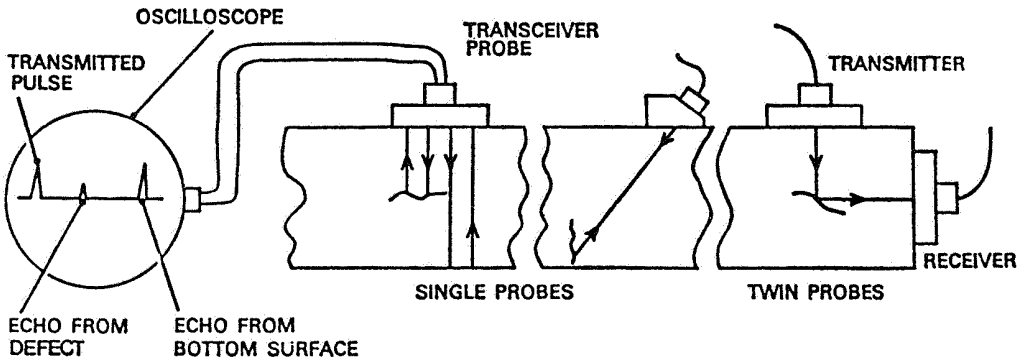

Figure 6 PULSE-ECHO TECHNIQUES

4.2.1 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).

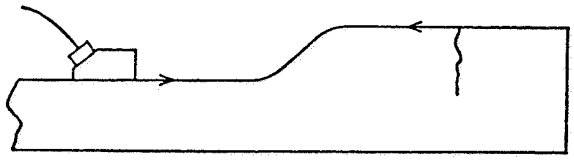

Figure 7 SURFACE WAVE TESTING

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.

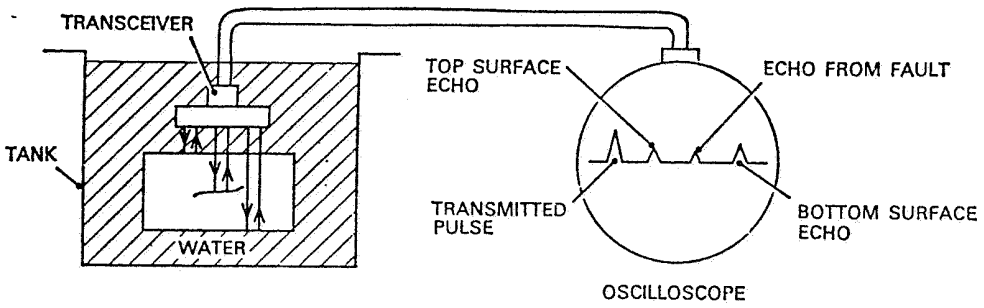

Figure 8 IMMERSION TESTING

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

4.5.1 **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.

4.5.2 **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.

(i) 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, one 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 one inch can then be ignored.

(ii) 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.

(iii) 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.

(iv) 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.

4.5.3 **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.

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

5.1.1 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.

5.1.2 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.

5.1.3 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.

5.1.4 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.** 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 **BL/8-4**). 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.

5.2.1 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.

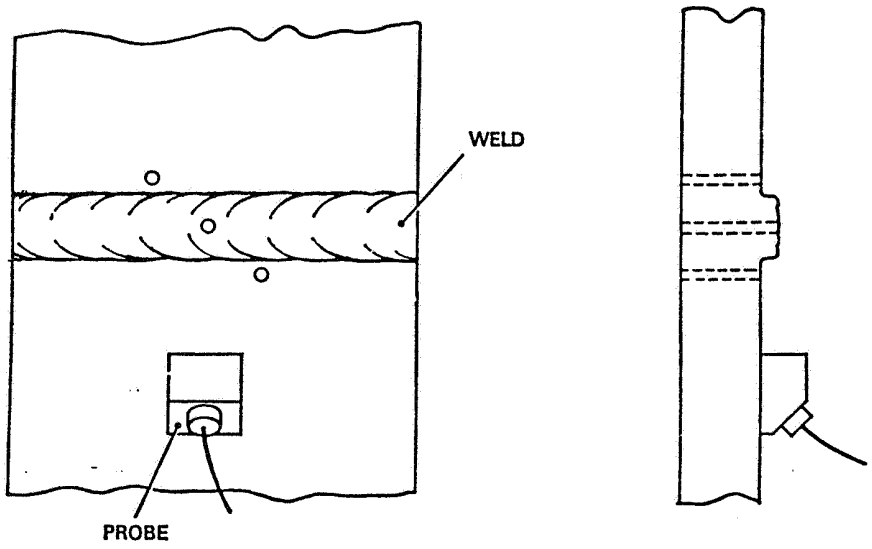

Figure 9 TEST HOLES IN WELD SAMPLE

5.2.2 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.

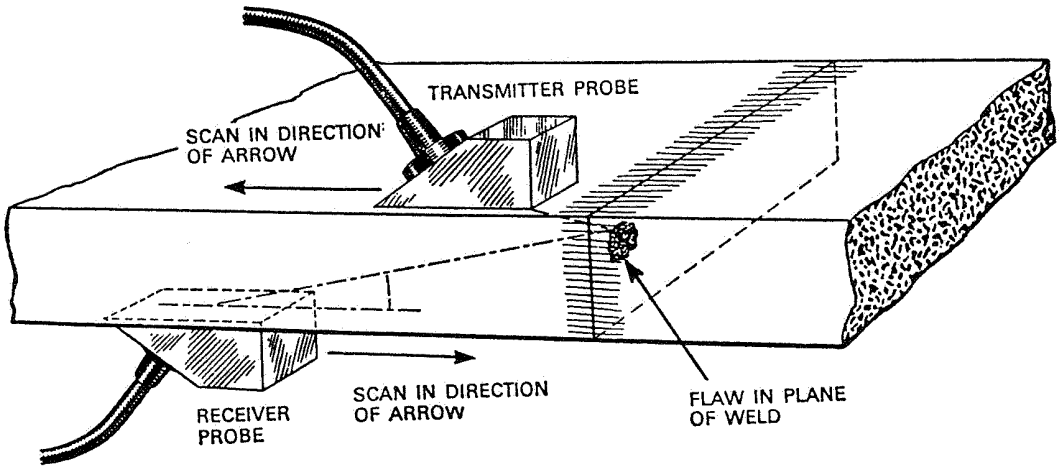

Figure 10 SCANNING METHOD FOR FINDING FLAWS IN FLASH BUTT WELDS

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 construction. Their main application is, therefore, to 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-wave lengths, which can be calculated from the speed of sound in the material and the fundamental resonance frequency.

5.4 **Detection of Lamination.** 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 $\frac{1}{2}$ inch thick but it is unsuitable for thinner sections.

5.4.1 **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.

5.4.2 **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.

5.4.3 **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.

5.4.4 **'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 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.

6.1 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.

6.2 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 booms 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.

6.3 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.

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BASIC
NON-DESTRUCTIVE EXAMINATIONS
RADIOLOGICAL EXAMINATION OF AIRCRAFT STRUCTURES

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

1.1 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, and these are written into the appropriate Maintenance Manuals and Maintenance Schedules or included in a separate Non-destructive Testing (N.D.T.) Manual. General information on radiographic techniques is included in British Standard (BS) M34.

1.2 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.

1.3 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.

1.4 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.

1.5 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 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.

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

2.1.1 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.

2.1.2 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.

2.1.3 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° cone. However, some X-ray tubes are designed to emit different shaped beams for particular uses.

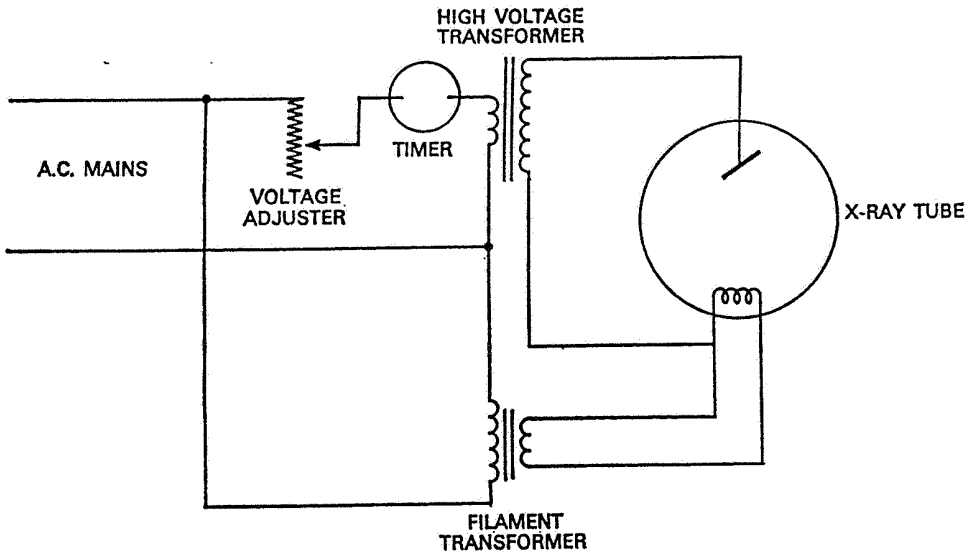


Figure 1 TYPICAL CIRCUIT OF AN X-RAY SET

2.1.4 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.

2.1.5 **Penetrating Power.** Although penetrating power is related to the voltage of the X-ray tube, it is often indicated by the 'half value layer' (H.V.L.) 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 the quality of the beam is changed. If additional filtration (i.e. thicker aluminium or copper sheets) is provided it will be seen that the H.V.L. increases progressively until a constant beam quality is obtained.

2.1.6 **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 10kV and 250kV, 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 10kV to 100kV and 100kV to 250kV.

2.2 **Gamma Rays.** Electromagnetic 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.

2.2.1 **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 $4{\cdot}5 \times 10^9$ 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.

2.2.2 **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 660kV 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.

2.2.3 **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 trays. 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.** 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.

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

3.1.2 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.

3.1.3 Film is normally prepared for exposure by placing in a casette, 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.** 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.

3.2.1 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.

3.2.2 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 120kV, but since the lead screens also reduce scattered radiation and are not granular in construction, they are always used in radiography carried out at energies above this value.

3.2.3 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.** 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 (I.Q.I.), 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.

3.3.1 Ideally I.Q.Is 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 I.Q.I. 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.

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

3.3.3 The step-wedge I.Q.I. (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.

3.3.4 The wire I.Q.I. (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 I.Q.I. is sensitive to both sharpness and contrast, particularly in the smaller sizes.

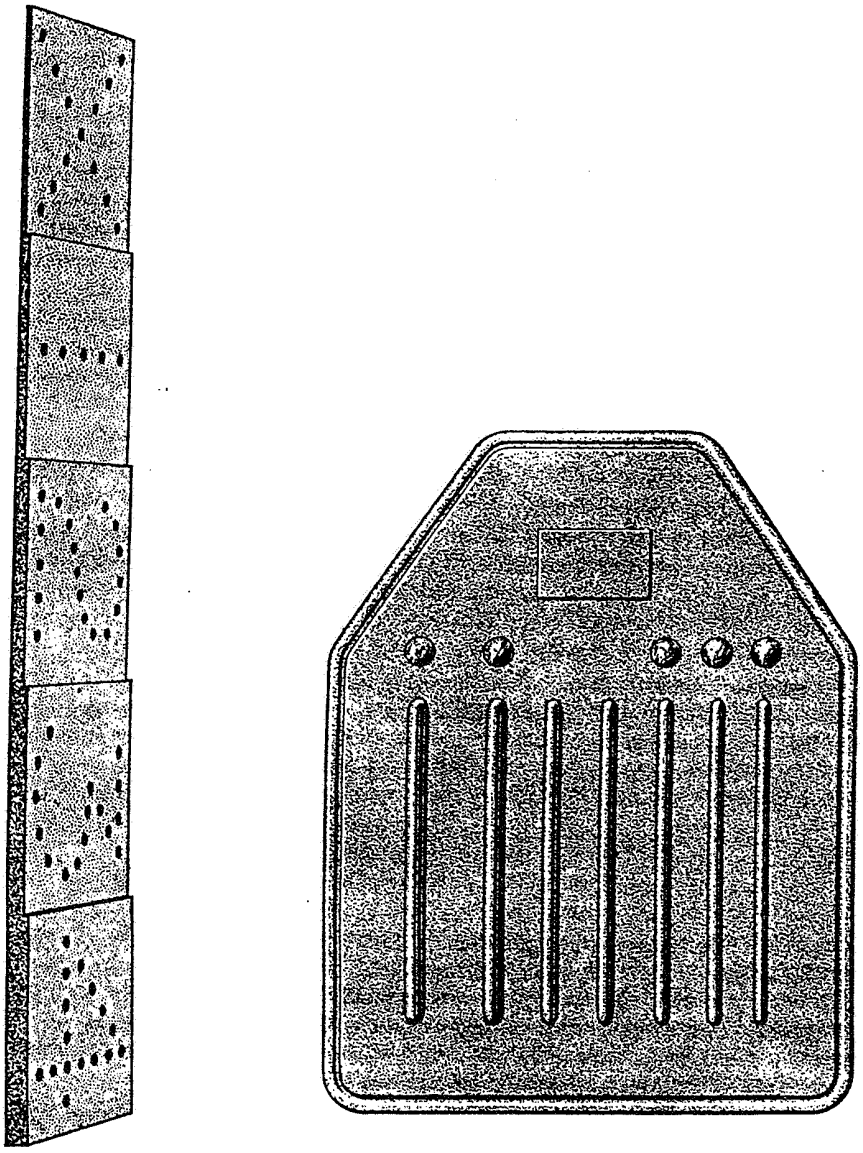
3.3.5 Variations of the standard I.Q.I. are sometimes used for special purposes, e.g., when searching for fatigue cracks an I.Q.I. containing a typical defect could be used (Figure 3). The I.Q.I. is placed on the surface of the member being examined and, provided that the simulated defect is clearly 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.** 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.

3.4.1 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 0·01 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.

3.5 **Exposure Conditions.** 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.

3.5.1 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.



(a) STEP WEDGE TYPE (b) WIRE TYPE

Figure 2 STANDARD IMAGE QUALITY INDICATORS

3.6 **Filtration.** 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.

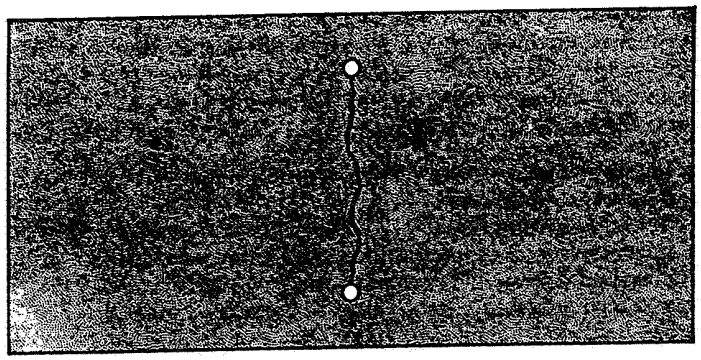


Figure 3 I.Q.I. SIMULATING A DEFECT

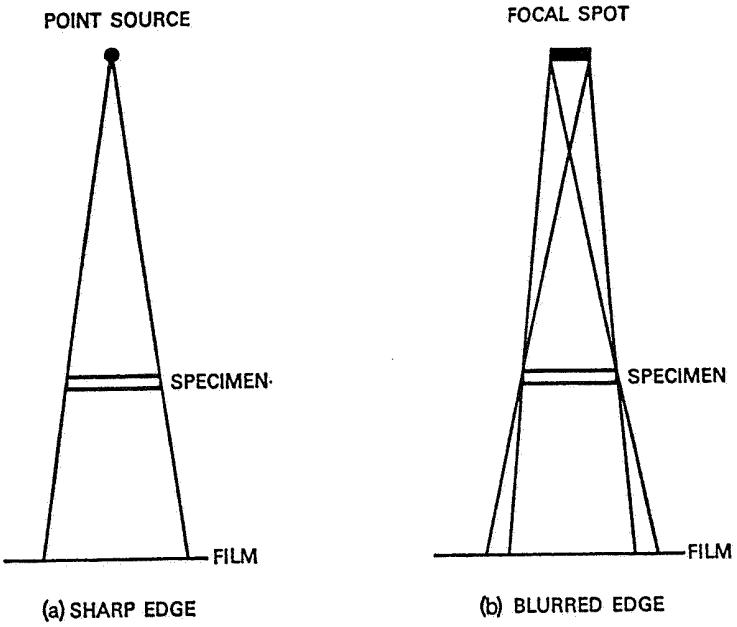


Figure 4 GEOMETRIC UNSHARPNESS

3.6.1 **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 100kV to 200kV set.

3.6.2 **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.

3.6.3 **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 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.

4.1 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.

4.2 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 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.

5.1 **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.

(Company name and address)													
Set used: Type of radiation: Source size:	RADIOGRAPHIC TECHNIQUE SHEET										Sheet ..... of ..... sheets	Technique sheet No.	
	Description											Part No.	
Film processing: Preparation:	Purpose of inspection: Area to be inspected: Acceptance standard:											Material and specification	
	Associated documents: BS M.34							Prepared by:				Date:	
								Approved by:				Date:	
Exposure details						Filters		Screens	*Ug*	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:													

Figure 5 TYPICAL RADIOGRAPHIC TECHNIQUE SHEET

5.2 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.

5.3 **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 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.

6.1 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.

6.2 Viewing cabinets are so constructed 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.

6.3 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 and other simple structures.

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

7.1 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.

7.2 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.

7.3 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 provide 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.

7.4 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 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 on isometric drawing of the area might be suitable. Some of the indications obtained on radiographs are described in the following paragraphs.

8.1 **Castings and Welds.** 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.

8.1.1 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.

8.2 **Corrosion.** 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.

8.2.1 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 per cent of the total thickness, including the sealant, would be revealed.

8.2.2 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.

8.2.3 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.

8.2.4 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.

8.2.5 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.

8.3 **Cracks.** 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.

8.3.1 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.

8.3.2 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.

8.3.3 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.

8.3.4 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.

8.4 **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. $1 Å = 10^{-8}$ 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 distance (f.f.d.)	The distance from the focal spot of an X-ray tube to a film set up for exposure.
Gamma (γ) 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 (s.f.d.)	The distance from the source of primary radiation to a film set up for exposure (i.e., f.f.d. 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).

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BASIC NON-DESTRUCTIVE EXAMINATIONS

MAGNETIC FLAW DETECTION

1 INTRODUCTION This Leaflet gives guidance 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) M35, 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.

1.1 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.

1.2 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.

1.3 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 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.

2.1 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.

2.2 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.

2.3 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.

2.3.1 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.

2.3.2 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.** 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.

3.1.1 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.

3.1.2 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.

3.1.3 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.

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

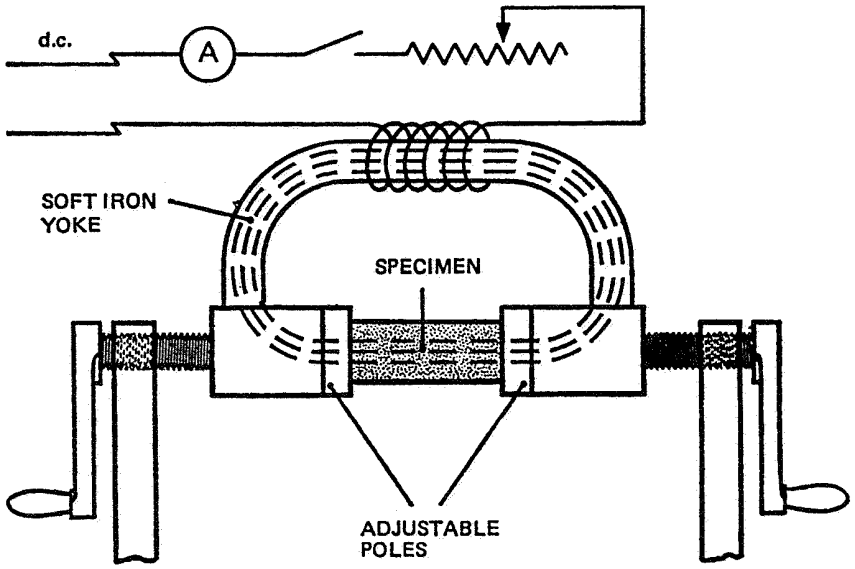

Figure 1 MAGNETIC FLOW MACHINE

3.2.1 **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.

(i) 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.

(ii) 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.

(iii) 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.

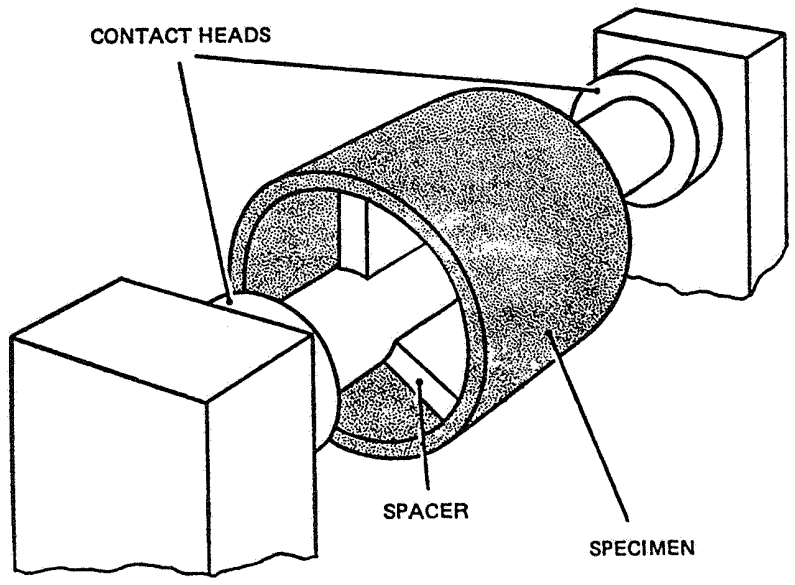

Figure 2 THREADING BAR METHOD

(iv) 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.

3.2.2 **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.

(i) 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.

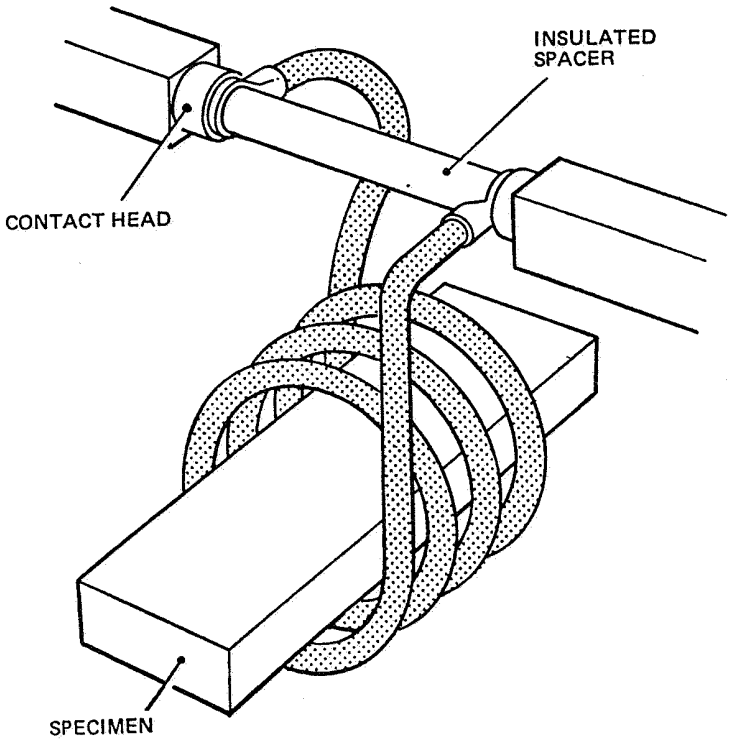

Figure 3 MAGNETISING COIL METHOD

(ii) 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.

3.2.3 **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.

(i) 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.

(ii) 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.

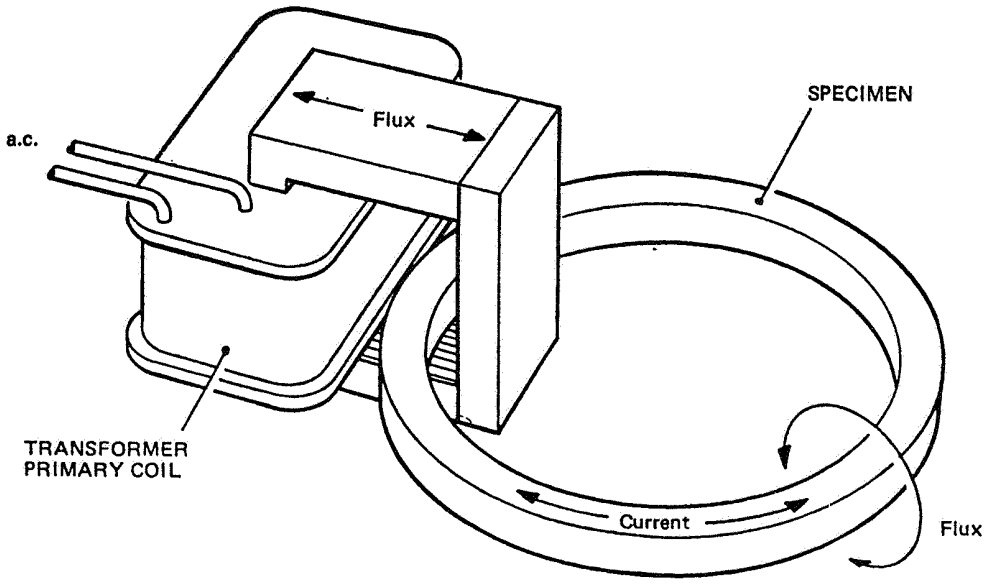

Figure 4 INDUCED CURRENT FLOW METHOD

(iii) 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.

3.2.4 **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 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.

4.1 **General Considerations.** 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.

4.1.1 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).

4.1.2 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.

4.1.3 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.

4.2 **Selection of Method.** 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.

4.2.1 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.

4.2.2 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.

4.2.3 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. Magnetic flow for transverse defects. Magnetising coil for transverse defects.
Tube	Threading bar for longitudinal defects. Magnetic flow for transverse defects. Current flow for longitudinal defects. Magnetising coil for transverse defects.
Ring	Threading bar for defects in line with ring axis, and radial defects. 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. Magnetic flow or magnetising coil may also be used if flux path is extended using steel extension pieces.

4.3 **Preparation.** 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. It is not usually necessary to remove paint or plating except to provide good electrical contact for the current flow process.

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.

4.3.1 Preparation of the specimen should also include demagnetisation. 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.

4.3.2 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.

4.4 **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.

4.5 **Inking.** Except where remanent magnetism is used to reveal defects (paragraph 3.1.2), 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 three 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 $\frac{1}{2}$ 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.

4.6 **Interpretation of Indications.** 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.

4.6.1 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.

4.6.2 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.

4.6.3 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.

4.6.4 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.

4.6.5 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.

4.6.6 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.

4.6.7 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.

4.7 **Recording of Defects.** 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.

4.7.1 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.

4.7.2 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.

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

(i) 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 constrasting colour, to show the defects.

(ii) 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.

(iii) 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 (ii) above.

4.8 **Demagnetisation.** 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 4.6.5), 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.

4.8.1 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.

4.8.2 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.

4.8.3 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.

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

4.9 **Tests for Demagnetisation of Parts.** 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.

4.9.1 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.

4.10 **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 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.

5.1 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.

BL/8-7

Issue 1.

15th April, 1965.

BASIC

NON-DESTRUCTIVE EXAMINATION

FLUORESCENT PENETRANT PROCESSES

1 INTRODUCTION 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.

1.1 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 1.5.4). 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.

1.2 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.

1.3 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.

1.4 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.

1.5 The selection of the most suitable type of penetrant process (e.g. penetrant dye (Leaflet BL/8-2) 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.

1.5.1 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.

1.5.2 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.

1.5.3 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.

1.5.4 With steel castings, for example, porosity may be detected more readily by a penetrant-process than by the magnetic flaw detection techniques (Leaflet **BL/8-5**) 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.

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

1.7 Guidance on dye penetrant processes is given in Leaflet **BL/8-2.** Information on the performance testing of penetrant testing materials is given in Leaflet **BL/10-9**.

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

and further guidance on this and other aspects of trichloroethylene cleaning is given in Leaflet **BL/6-8.** 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 70°F. to 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.

(i) 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.

(ii) 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 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 ten 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	(i) Shrinkage, cracks and porosity. (ii) Cold Shuts.	3—10 20
Welds	(i) Cracks, porosity. (ii) Included flux.	20 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 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 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 two 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 per cent, since this period directly influences the process and effects of emulsification.

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 per cent 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.

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BASIC

NON-DESTRUCTIVE EXAMINATIONS

EDDY CURRENT METHODS

1 INTRODUCTION This Leaflet gives guidance on the use of 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 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.

1.1 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.

1.2 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.

1.3 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.

1.4 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 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 (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.

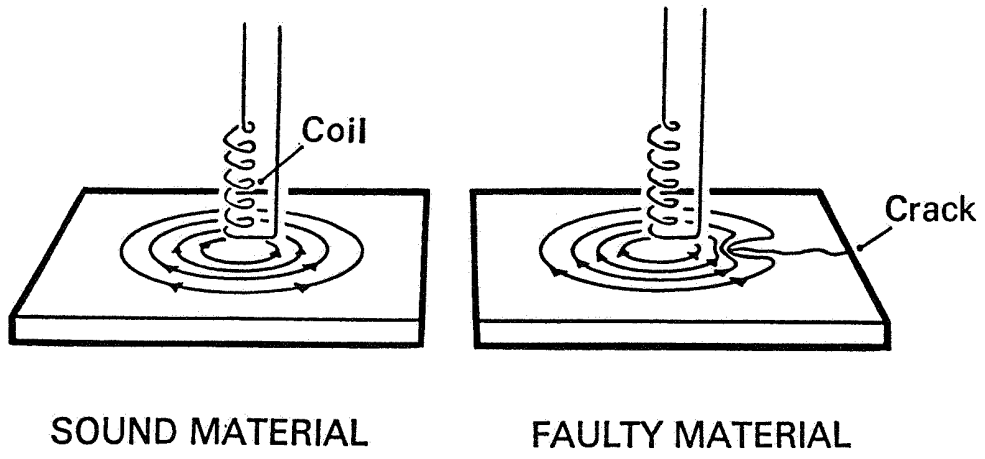

Figure 1 EDDY CURRENT FLOW

2.1 **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 (μ) 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.

2.2 **Conductivity.** Conductivity (σ) 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. ($58\ m/\Omega mm^2 = 100\%$ IACS).

2.3 **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.

2.4 **Geometry.** The size and shape of the test specimen may distort the primary magnetic field and mask defects in the affected area (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.

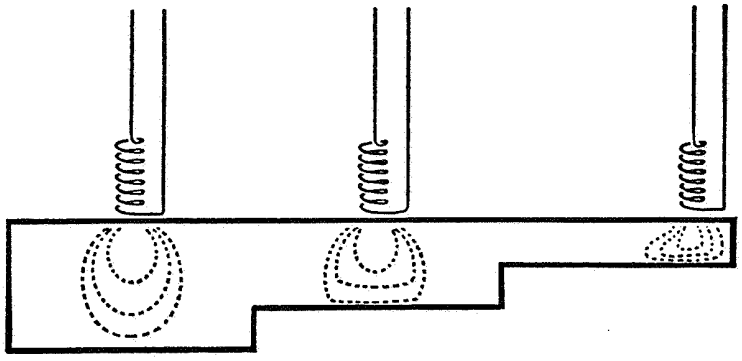

Figure 2 GEOMETRIC EFFECTS ON PRIMARY MAGNETIC FIELD

2.5 **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 (σ) 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 σ is in m/Ωmm^2.

2.6 **Effects of Frequency.** 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.

2.6.1 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.

2.7 **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 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.

3.1 **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.

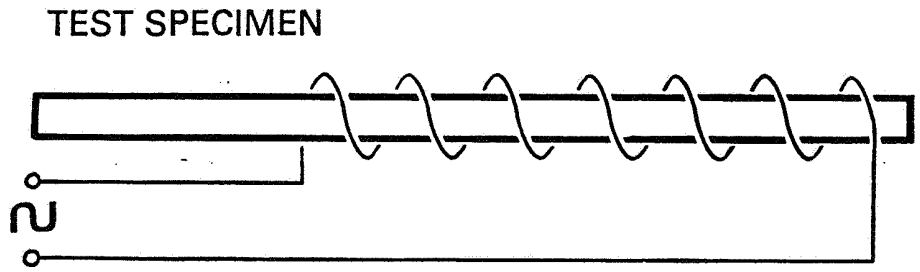

Figure 3 SINGLE PRIMARY COIL SYSTEM

3.2 **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.

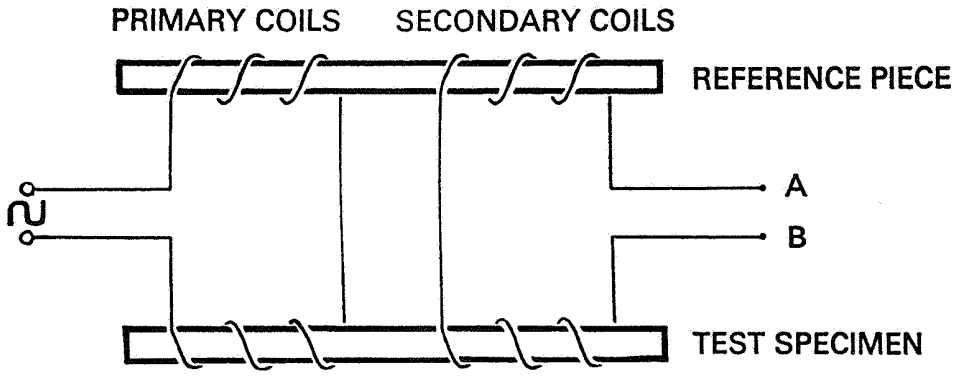

Figure 4 COMPARATIVE COIL SYSTEM

3.3 **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.

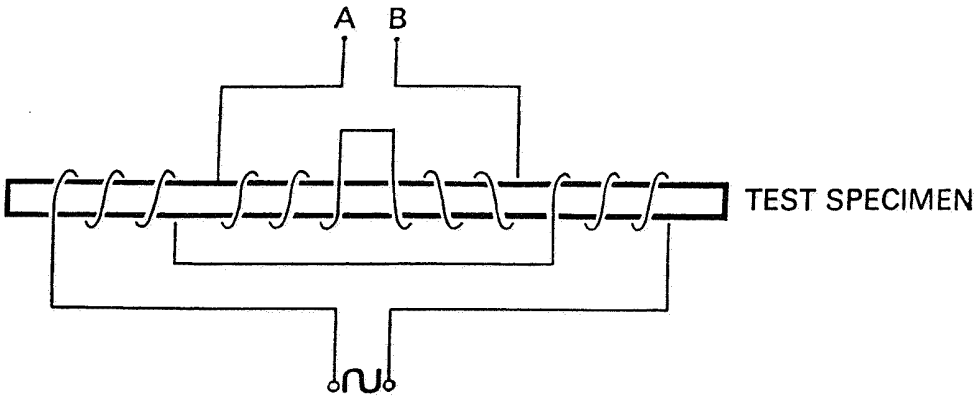

Figure 5 DIFFERENTIAL COIL SYSTEM

3.4 **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.

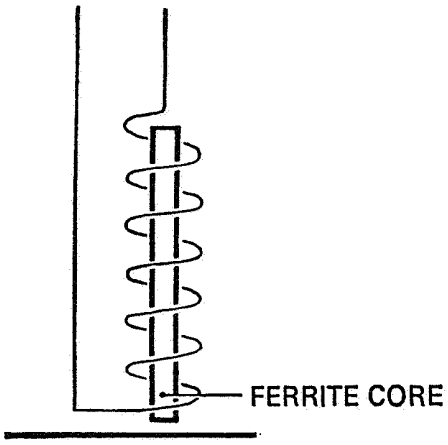

Figure 6 SURFACE COIL

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.

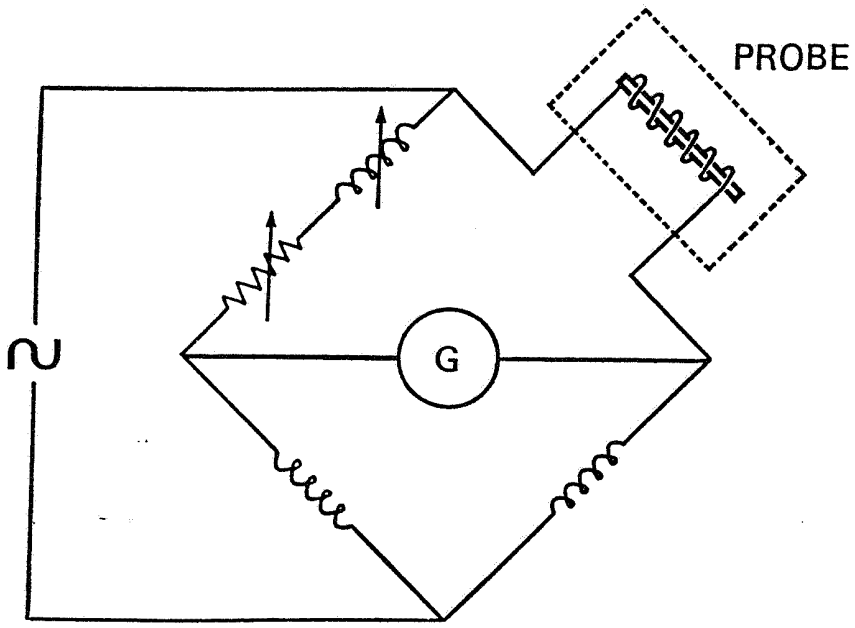

Figure 7 BRIDGE CIRCUIT

4.2 **Resonant Circuits.** 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.

4.2.1 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.

4.2.2 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.

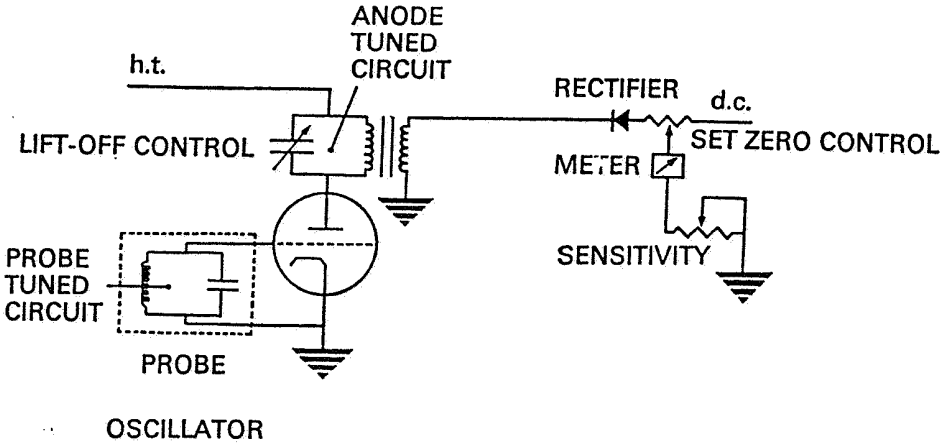

Figure 8 TYPICAL TUNED CIRCUIT

4.2.3 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.

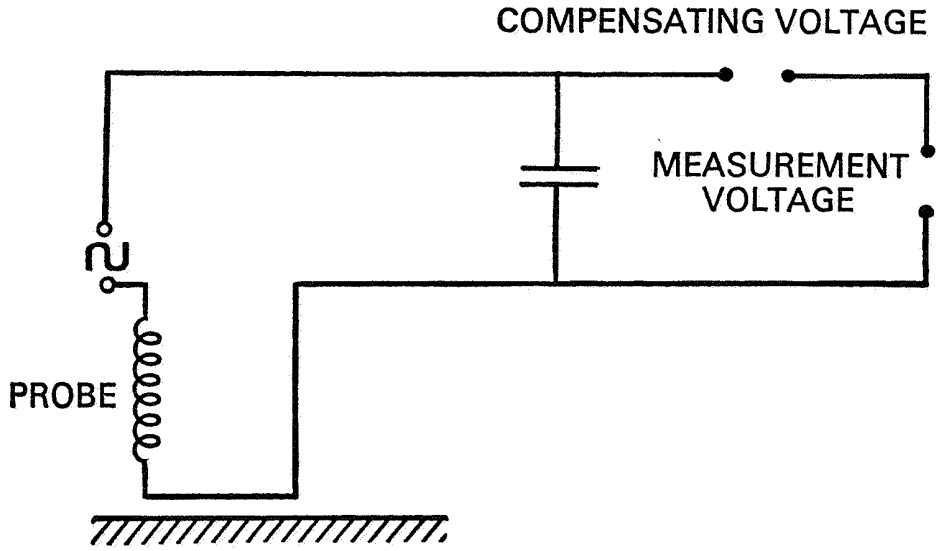

Figure 9 SERIES RESONANT CIRCUIT

5 PHASE ANALYSIS 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.

5.1 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.

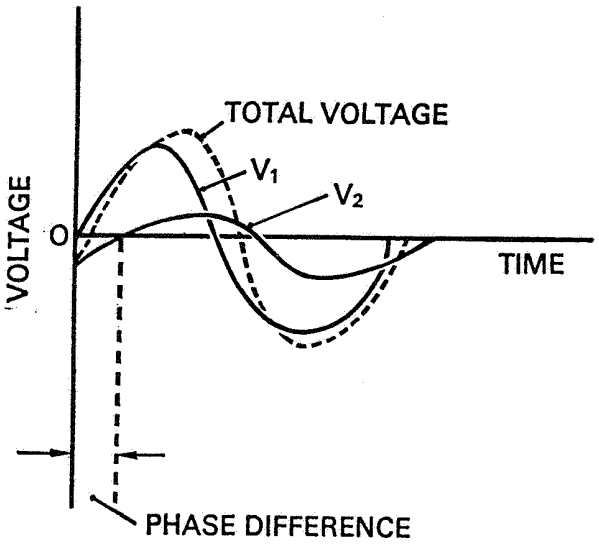

Figure 10 PHASE DIFFERENCE

5.2 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.

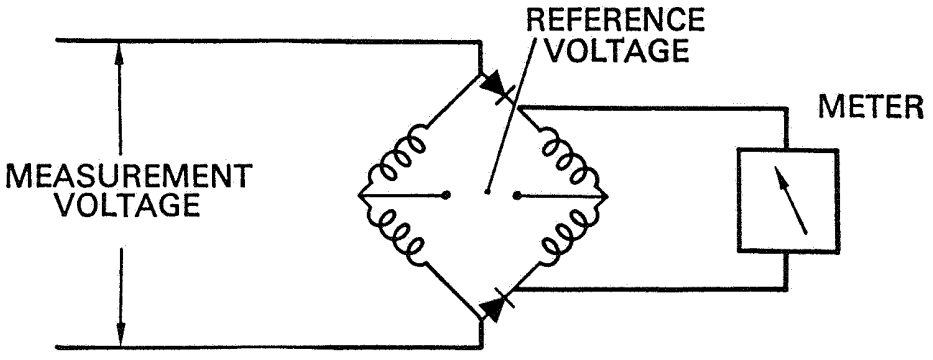

Figure 11 PHASE-SENSING CIRCUIT

5.3 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.

5.3.1 **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.

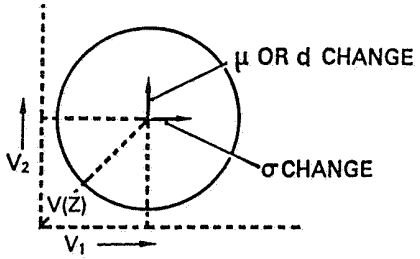

Figure 12 VECTOR POINT

5.3.2 **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.

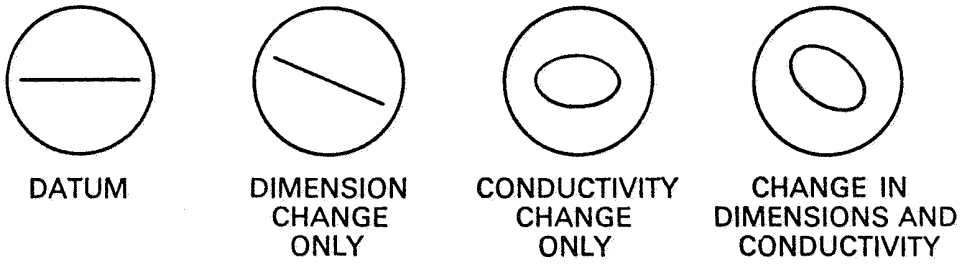

Figure 13 ELLIPSE METHOD

5.3.3 **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).

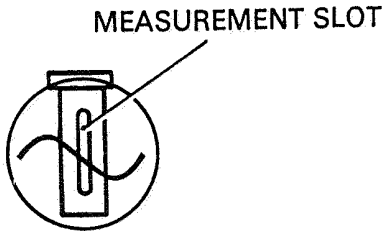

Figure 14 LINEAR TIME BASE

6 PROBES 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 6.1, 6.2, and 6.3.

6.1 **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.

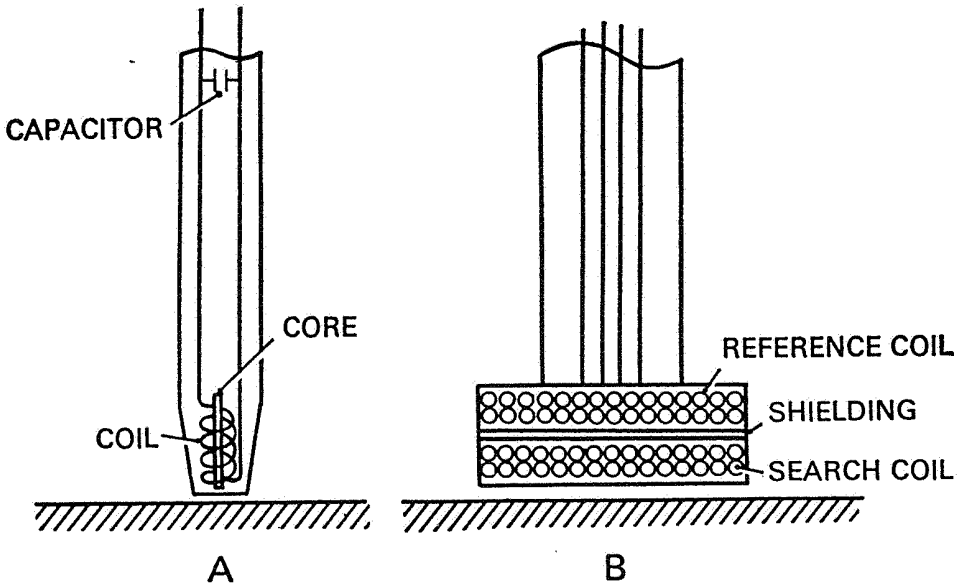

Figure 15 SURFACE PROBES

6.2 **Hole Probes.** 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.

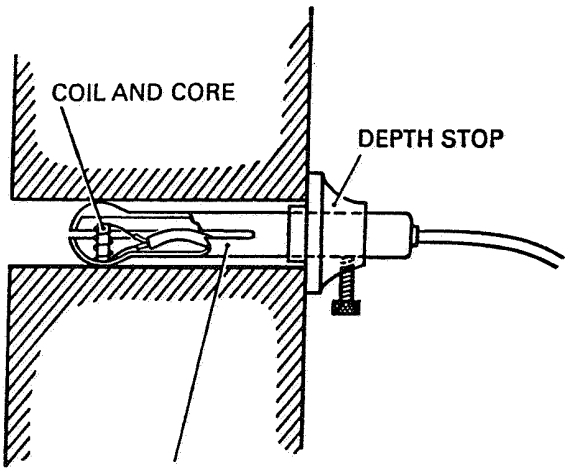

Figure 16 HOLE PROBE

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

6.3 **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 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.

7.1 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.

7.2 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 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.

8.1 **Checking Fastener Holes for Cracks.** 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.

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

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

(ii) Calibrate instrument and adjust for lift-off in accordance with the manufacturer's instructions.

(iii) 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.

(iv) 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.

(v) Repeat (iii) and (iv) at incremental depths to cover the hole surface completely.

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

8.2 **Checking Heat Damaged Skin.** 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.

8.2.1 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.

8.2.2 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.

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

(i) Thoroughly clean area to be inspected.

(ii) Calibrate instrument in accordance with the manufacturer's instructions.

(iii) 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.

(iv) 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.

8.3 **Detection of Corrosion.** 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.

8.3.1 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.

8.3.2 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.

8.4 **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.

8.5 **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 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.
Part 5, Eddy Current Flaw Detection.

BS 3889 Methods for Non-destructive Testing of Pipes and Tubes.
Part 2A, Eddy Current Testing of Ferrous Pipes and Tubes.
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.)

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BASIC

NON-DESTRUCTIVE EXAMINATIONS

ENDOSCOPE INSPECTIONS

1 INTRODUCTION This leaflet gives guidance 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.

1.1 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.

1.2 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 Manufacturers of endoscopes tend to market the complete range of units required and it is, therefore, 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.

2.1 **The Probe.** 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.

2.1.1 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.

2.1.2 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.

2.1.3 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.

2.1.4 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 construction, allowing the tip to be shorter, thus not having a cumbersome non-flexible end to restrict use in a confined space.

2.1.5 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' construction, which will restrict the manipulation of the probe to within the capabilities of the bundles.

2.2 **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.

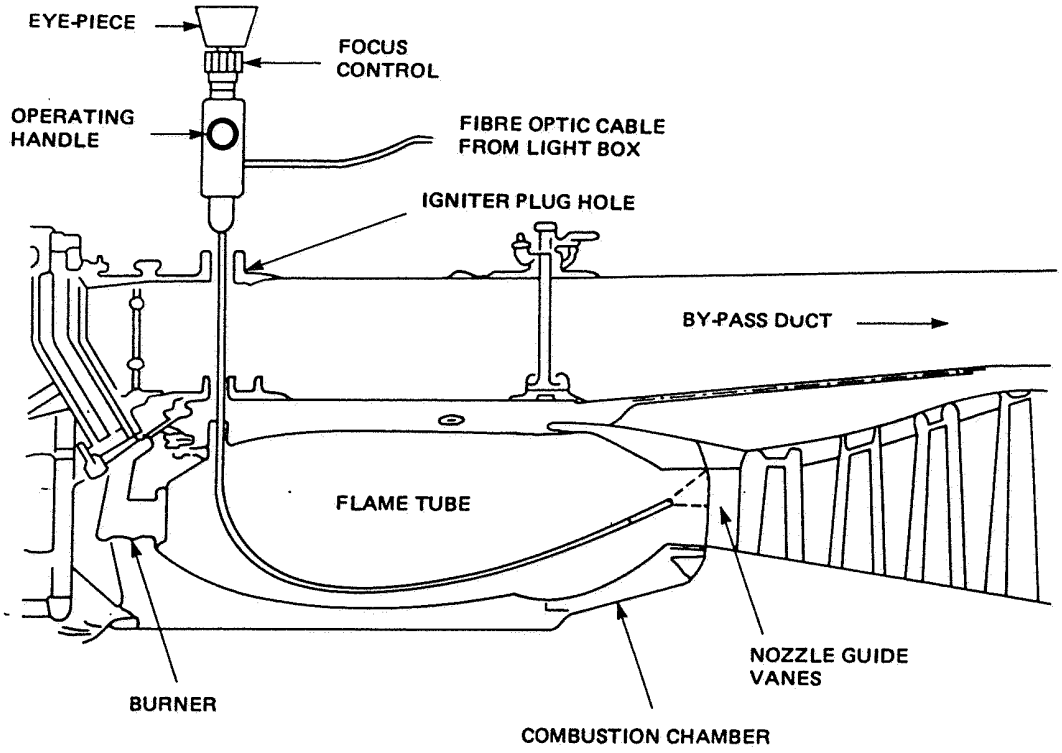

Figure 1 FLEXIBLE ENDOSCOPE INSPECTION EQUIPMENT

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.** 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.

3.3.1 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.

3.3.2 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 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.

3.8.1 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.

3.8.2 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 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.

4.1 **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.

4.2 **Special Inspections.** Occasionally, experience gained by frequent endoscope inspections, in-service failures or inspection during overhaul highlights the develop-

ment 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.

4.3 **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.

4.4 **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 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.

5.1 **Compressors.** 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.

5.1.1 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.

5.1.2 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.

5.1.3 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.

5.1.4 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).

5.1.5 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.

5.2 **Combustion Section.** 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.

5.2.1 **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.

5.2.2 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.

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

5.2.4 **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 construction 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.

5.2.5 **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.

5.3 **Turbine Section.** 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.

5.3.1 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.

5.3.2 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.

5.4 **Record of Damage.** 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.

5.4.1 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.

BL/9-1

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BASIC HEAT-TREATMENT

WROUGHT ALUMINIUM ALLOYS

1 INTRODUCTION This leaflet gives guidance on the heat-treatment of wrought aluminium alloys. The recommendations apply only to those alloys which require solution treatment or precipitation treatment ; they do not refer to the non-heat-treatable alloys which achieve their strength through cold work.

1.1 Aluminium alloys of widely varying compositions and strengths are used in aircraft structures, and they each attain their optimum properties by a specific heat-treatment process. The process may consist of solution treatment followed by natural ageing, or solution treatment followed by precipitation treatment.

1.2 Except in special circumstances, e.g. when a drawing specifies a particular procedure, or when a special process for a specific batch is covered by endorsement of the Approved Certificate, the heat-treatment procedure prescribed in the relevant specification must be followed.

NOTE : The relevant specification may, in some instances, be a specification prepared by the aircraft constructor.

1.3 Heat-treatment is sometimes necessary to soften materials for manipulation purposes, and this is done either by annealing or by solution treatment, depending on the extent of the proposed manipulation. When material has been annealed, it is essential that its specified properties should subsequently be restored by the application of the full recommended heat-treatment process. Solution treatment of artificially aged alloys must be followed by precipitation treatment.

1.4 When it is foreseen that extensive manipulation will be necessary materials are sometimes ordered in the annealed or "as-manufactured" condition. Great care must be taken to ensure that such material is correctly heat-treated after fabrication.

1.5 If any delay is envisaged between the various operations of the heat-treatment process, e.g. between solution treatment and precipitation treatment, the material should be treated with a temporary protective to prevent the possibility of a corrosive attack.

2 SOAKING TIME The soaking time is the period during which the material is held at the required temperature, and is considered to commence when the temperature of the load (or charge) has reached the specified minimum. The time required to reach this condition will depend on the nature of the load and its spacing in the bath or furnace, but the aim should be to bring the load to the soaking temperature as quickly as possible. Typical soaking times for materials in various forms are given in Tables 1, 2 and 3, but actual times can only be determined by experience of the particular plant.

3 LIMITATION OF HEAT-TREATMENT Clad sheet should not be heat-treated more than three times, since the corrosion resisting properties of the material may be reduced due to diffusion through the cladding of copper from the core.

4 ANNEALING This process softens the material for manipulation purposes and consists of heating the material to a temperature some 100 to 200°C below that specified for solution treatment. The soaking period is followed by cooling in air at room temperature.

4.1 When materials, other than clad alloys, are required in a particularly soft condition, a "super-anneal" can be given. This consists of soaking the material at 400-425°C for at least one hour, followed by slow cooling at about 15°C per hour down to 320°C and finally cooling in air. In general, longer soaking times and slower cooling rates result in greater softening, but in no circumstances should materials be heat-treated by an unauthorised process.

4.2 Some age hardening will take place after the material has been annealed, and it is recommended that all severe manipulation should be completed within 24 hours of annealing.

4.3 Table 1 indicates typical soaking times for annealing wrought aluminium alloy forgings, bars and extrusions. The soaking time for sheet material of all thicknesses is usually about one hour.

4.4 Special care is necessary in the storage of material in the annealed condition to prevent the possibility of distortion.

TABLE 1

HEAT-TREATABLE WROUGHT ALUMINIUM ALLOYS FORGINGS, BARS AND EXTRUSIONS

Size	*Time*
Bar up to ½ in. diameter	1 hour
Forgings up to 3 lb. and bar up to 1½ in. diameter	1½ hours
Forgings up to 1½ in. max. section and bars up to 4 in. diameter	2—4 hours
Forgings up to 4 in. max. section and bars up to 8 in. diameter	4—8 hours
Large complex forgings	8 hours

5 SOLUTION TREATMENT For materials finally required in the naturally aged condition, the primary purpose of solution treatment is to alter the structure of the material so that an improvement of strength will occur during the ageing process. A similar situation exists for materials finally required in the precipitated condition.

5.1 The process consists of heating the material to a prescribed temperature (with the object of taking the alloying elements into solution) maintaining it at that temperature for a suitable period, and then immediately quenching it, usually into cold water, but sometimes, to reduce quenching stresses, into hot or even boiling water.

5.2 Solution treatment at a temperature lower than the specified minimum, or a delay in quenching, can result in the material having reduced mechanical properties. Conversely, treatment at a temperature in excess of the specified maximum is likely to cause burning or overheating, producing an impairment of the mechanical properties which cannot be restored by re-heat-treatment, resulting in the scrapping of the material. Guidance on the temperature control of heat treatment plants is given in paragraph 14.

5.3 Prolonged holding of clad alloys at solution treatment temperatures will affect the material in a manner similar to that described in paragraph 3.

5.4 When material is manipulated in the solution-treated condition, it is desirable that cold bending and similar work should be completed as soon as possible, but in any case within two hours of quenching. In instances where manipulation processes would exceed this period, the material should be annealed as described in paragraph 4.

5.5 **Solution Treatment of Sheet Metal.** Sheet material is usually solution treated in a salt bath, but a gas or electrically-heated muffle furnace of the fan-assisted, air circulation type is also suitable. Table 2 lists typical soaking times for sheet material of various thicknesses.

TABLE 2

Gauge	*Time*
26 S.W.G.	8 to 12 minutes
24 S.W.G.	11 to 15 minutes
22 S.W.G.	12 to 18 minutes
20 S.W.G.	14 to 20 minutes
18 S.W.G.	17 to 23 minutes
16 S.W.G.	20 to 26 minutes
14 S.W.G.	24 to 30 minutes
12 S.W.G.	30 to 36 minutes
10 S.W.G.	34 to 42 minutes
8 S.W.G.	43 to 49 minutes
3—6 S.W.G.	50 to 60 minutes

5.5.1 The requirements of British Standard L72, together with its allied standards L70, L71 and L73, are specific regarding the temperature range for solution treatment, and this governs treatment both by the material manufacturer and the user. However, experience has shown that the effects of the solution treatment of sheets in large batches, as practised by the material manufacturer, and the re-solution-treatment of the same material as individual pieces, or in small batches, by the user, may differ considerably. For example, the material manufacturer may use a temperature at the upper limit without difficulty, yet the same material solution-treated in small quantities at a similar temperature, may give rise to cracking troubles.

5.5.2 When re-solution-treatment of the material in small batches is necessary, it is recommended that a temperature towards the lower end of the temperature range should be used.

5.5.3 When material, and particularly thin sheet, is moved from the solution treatment plant to the quenchant, it is essential that it should be handled smoothly and carefully. Rough handling at this stage can in itself give rise to cracking troubles, irrespective of the heat treatment temperature.

5.6 **Solution Treatment of Bars, Extrusions and Forgings.** The solution treatment temperatures of some of the alloys used for such sections and components are critical, in particular L65, where even a short period in excess of the permitted maximum can be detrimental. Typical soaking times for bars, extrusions and forgings are given in Table 3.

TABLE 3

HEAT-TREATABLE WROUGHT ALUMINIUM ALLOYS
FORGINGS, BARS AND EXTRUSIONS

Size	*Time*
Bar up to ½ in. diameter	1 hour
Forgings up to 3 lb. and bar up to 1½ in. diameter	2 hours
Forgings up to 1½ in. max. section and bars up to 4 in. diameter	4 hours
Forgings up to 4 in. max. section and bars up to 8 in. diameter	6 hours
Large complex forgings	8 hours

5.7 **Rivets.** The procedure applicable to the solution treatment of rivets is given in Leaflet **AL/7-5.**

6 QUENCHING On completion of the soaking period, the material should be quenched in water with as little delay as possible. To ensure correct cooling, the material should be left in the quenching tank until its temperature is the same as that of the quenchant. Where cold water quenchant is used, the temperature of the quenchant should not be allowed to rise above 20°C, and 30°C is regarded as an absolute maximum ; to ensure this, the quenching tank should contain an adequate quantity of water, preferably with provision for a continuous flow of fresh water.

6.1 The most critical problems in regard to solution treatment are concerned with quenching, particularly when treating dimensionally large extrusions and forgings. Parts manufactured of high strength aluminium alloys may be cracked by the high stresses induced by rapid quenching, as may also some parts manufactured of medium strength alloys.

6.2 When hot components are quenched, the outer layers are cooled more rapidly than the centre, so that they tend to shrink and may be compelled to yield plastically. As heat is conducted away from the centre, the inner material also endeavours to shrink, and thus becomes stressed in tension. This usually induces compressive stresses in the outer layers so that the final locked-up stress system is tri-axial tension at the interior and bi-axial compression just below the surface.

6.3 In view of the undesirability of such stress systems, parts are sometimes quenched into hot or even boiling water to slow the cooling rate, with the object of reducing

the level of internal stress. However, it should be emphasised that an increase in quenchant temperature usually results in a reduction in the mechanical properties of the material and in some instances, a reduction in the resistance to corrosion.

6.4 When chromium bearing DTD.683 is quenched into boiling water, the presence of the chromium has the effect of making the material more sensitive to a slow rate of cooling, resulting in a loss of tensile strength proportional to the percentage of chromium. However, this may be considered preferable to the presence of a high residual stress system.

6.5 Residual stress, as mentioned in paragraph 6.2, in parts of constant cross-section, such as certain forgings, extrusions and rolled plate, can often be effectively reduced by stretching the material so that it sustains a plastic deformation of between 1-2 per cent, but this process can seldom be applied by the aircraft constructor, since components of constant cross-section are infrequently used. Stretching should be completed as soon as possible after solution treatment, or the available elongation of the material will be reduced.

6.6 There are advantages to be derived from machining components in the annealed condition to within a few thousandths of an inch of the final dimensions, since the adoption of this procedure, in conjunction with hot water quenching, reduces the risk of cracking induced by internal stress. The parts should not be machined to final dimensions, since small dimensional changes may occur during heat treatment. In some instances it may be more practicable to machine to within $\frac{1}{8}$ in. or so of final size, any small or intermediate size forgings which are in the fully heat-treated condition, and then to re-solution-treat, using a hot water quenchant.

6.7 If material is solution-treated after anodising, the presence of the anodic film may cause a more rapid rate of cooling than would occur if the material was not anodised. This practice is not recommended, since greater distortion or, if distortion cannot occur, a higher residual stress system, would result.

6.8 **Correction of Distortion.** Apart from the introduction of an internal stress system quenching may also cause distortion which, if unacceptable, must be corrected as soon as possible after heat treatment, because the process of ageing commences immediately after solution treatment. It is recognised that the correction of distortion is often difficult and, in some instances, may leave high local stresses in the material; it is essential therefore that such work should not be carried out without the prior knowledge of the design department.

6.9 **Quenching Extrusions and Forgings.** Such components should normally be quenched vertically to minimise the risk of distortion and, with tapered extrusions, the thickest end should, where possible, be entered into the quenchant first. However, where vertical furnaces are used, it is often impracticable to suspend the extrusion from the thinnest end, since this may introduce undesirable dimensional changes during heat treatment, and suspension from the thick end must be employed.

6.10 **Quenching Hollow Sections, Tubes, and Components of Complex Shape.** Great care should be taken when quenching such items after salt bath treatment, since entrapped molten salt solution may be ejected violently from one end as the other is plunged into the quenchant. In addition, trapping of the quenchant, either as water or steam, may reduce cooling rates and locally affect the mechanical properties of the material.

6.11 **Final Cleaning.** When material has been solution treated in a salt bath, it should be washed immediately after quenching to remove all traces of the corrosive salt deposits. Washing should be done in a bath other than that used for quenching, unless the latter is large by comparison with the load quenched and is fed with a continuous supply of fresh water. Forgings are usually cleaned with sawdust, or with water and detergents.

7 AGEING The natural ageing of aluminium alloys occurs at room temperature, and has the effect of bringing about a change in the mechanical properties of the material, e.g. increase in strength and hardness. The Al/Zn/Mg alloys show natural ageing curves very different from those of the Al/Cu alloys, since hardening continues to take place over several years, whereas the Al/Cu alloys are fully aged in a few days. For alloys to be used in the naturally aged condition, the specifications always quote the minimum period which must elapse before the material is suitable for use and reference should be made to these in all instances.

8 PRECIPITATION TREATMENT With some high strength alloys, the specified properties are secured by precipitation treatment. The process is usually effected in a furnace, but salt baths containing solutions having a sufficiently low melting point may also be used.

8.1 The process consists of heating the material within the prescribed ranges of time and temperature, and then cooling it slowly in air or, more rarely, in water. No attempt should be made to accelerate the ageing of material for which no precipitation procedure is prescribed in the specification.

8.2 With alloys of the Al/Zn/Mg type, the mechanical properties of the material are improved if precipitation treatment follows solution treatment within two hours. However, if this is not possible it should be noted that the properties of some high strength alloys are adversely affected if the precipitation treatment is delayed for a period of some months after the solution treatment has been carried out. It is essential that the precipitation process should be carefully controlled if the full mechanical properties of the material are to be obtained.

9 REFRIGERATION Natural ageing can be suspended by storing the material at a sub-normal temperature, immediately after solution treatment, in a refrigerator or cold storage plant maintained within a temperature range of —15°C to —20°C, or 0°C to —5°C.

9.1 When the former temperature range is used, the maximum storage period is limited to 150 hours, and with the latter range to 45 hours.

9.2 Any manipulation which may be necessary must be performed within two hours of removal from the refrigeration plant, since natural ageing occurs somewhat quicker after refrigeration. After this time, re-heat-treatment will be necessary, as will also be the case on expiry of the maximum storage period, but the limitations given in paragraph 3 regarding the number of times the clad alloys should be re-treated must be borne in mind.

9.3 When material is to be dried before refrigeration, this should be done as quickly as possible and the drying temperature should not exceed 60°C.

10 STOVE ENAMELLING The precipitation mechanism of artificial ageing after natural ageing produces an initial drop in strength, followed by a marked rise, and eventually a further drop. The aim in artificial ageing is to achieve the maximum properties, and the time has to be selected to obtain this.

10.1 Stove enamelling has the effect of commencing the precipitation process, but the temperature and time are normally such as to take the mechanism only to the stage where the drop in properties occur.

10.2 Some recovery of mechanical properties may occur over a period after completing the stoving process, but this cannot be relied upon to restore to the specified values any material which fails to give these values immediately after stoving.

10.3 Only low temperature stoving enamels, complying with specification DTD.235, should be used with alloys which have been solution treated, and it is recommended that a temperature of 125°C should not be exceeded.

11 BATH LOADING Prior to solution treatment, the material should be cleansed free of dirt, oil, grease, paint, etc., otherwise local overheating may occur, causing blistering or partial melting of the metal. The trichlorethylene process detailed in Leaflet **BL/6-8** is suitable for this purpose. Where water has been used in conjunction with chemical cleaners, care must be taken to ensure that the material is perfectly dry before immersion into the solution bath to prevent the possibility of a violent reaction.

11.1 The bath should not be overloaded nor should the free circulation of the solution be restricted. To reduce distortion to a minimum, all material, including tubes and light sections, should be suspended in the bath as nearly vertical as possible, but with strip material, it is preferable that this should be rolled before treatment and subsequently straightened.

11.2 It is essential that the whole of the material should be immersed ; treatment in part is not permitted in any circumstances. The material must not be allowed to touch the sides or bottom of the bath.

11.3 Small articles may conveniently be treated in perforated containers which permit the free circulation of the solution.

12 SALT BATH OPERATION AND MAINTENANCE A suitable mixture for salt bath operation consists of 90 per cent nitrate of soda and 10 per cent sodium nitrite, but other compositions are sometimes used.

12.1 **Storage of Salts.** Nitrate of soda is usually supplied in jute bags and sodium nitrite in metal drums. The salts should be stored in a dry, cool room, care being taken to ensure that they are not placed near sources of heat (such as steam pipes) or near electrical wiring. The salts, when mixed with any combustible matter, are easily ignited and it is essential that naked lights should not be permitted in the store.

12.2 **Starting Up the Bath.** Dry salts only should be used and these should be well mixed, in the correct proportions, ensuring that no combustible matter is introduced into the mix. The salts should be melted slowly, and when the required temperature is reached, the grids or perforated liner should be placed in the bath.

12.3 **Operating the Bath.** Precautions should be taken to prevent the accumulation of foreign matter, such as metal pieces, sludge and scale in the bath, since this may lead to the formation of local "hot-spots" which, in addition to overheating certain parts of the load, may result in a serious explosion.

12.3.1 The mixture should be topped up from time to time to replace that lost by "drag-out" and at monthly intervals a sample of the mixture should be taken for analysis of the nitrite content, which should not be allowed to fall below 8 per cent.

12.3.2 When the bath is loaded, the temperature of the load lags behind that of the bath, the extent and duration of the difference depending largely on the mass of the load in relation to the size of the bath. Although typical soaking times are given in Tables 1-3, actual treatment times can only be determined by experience of a particular plant.

12.3.3 Information on temperature control is given in paragraph 14.

12.4 **Shutting Down the Bath.** When shutting down the bath, it is preferable to reduce the temperature to 300-350°C, rather than to cut off the heat altogether and let the mixture solidify. The subsequent re-heat of a solidified mixture may overstress the container and there is a possibility that the expansion of the liquid under the solid crust may cause a mishap.

12.5 **General.** Water should never be used to extinguish fires in the neighbourhood of heat-treatment baths where molten salt mixtures are used. The fires should be extinguished by the use of dry sand.

13 AIR FURNACES When an air furnace is used for solution treatment, it is essential that the material should be properly cleaned and dried before treatment. Every effort should be made to exclude water vapour from the furnace, since its presence may cause the surface of the material to blister.

13.1 Furnaces should be large enough to preclude the necessity of placing the material in the cool zone near the door and the material should be stacked in such a way that the circulation of the air is unrestricted.

13.2 Instances have occurred where material has been overheated by direct radiation from the walls of the furnace, although pyrometer readings were within the permitted tolerance. Care must be taken to prevent this possibility by the use of suitable shields to protect the material from excessive radiation, or by improving the rate of heat transfer through the material to keep the temperature of the whole mass uniform.

14 TEMPERATURE CONTROL The degree of temperature uniformity of a furnace or salt bath should be thoroughly investigated before either is put into operation. This should be done by taking readings in as many different positions as may be necessary to prove that the whole of the effective space is at a uniform temperature. It is preferable that the suitability of the plant should be finally confirmed by cut-up tests on large samples treated in the plant.

14.1 Where a grid is used in a salt bath to prevent the material touching the sides or bottom of the bath, the pyrometer couple, or couples, should be placed within it and not between it and the sides of the bath.

14.2 The temperature of the plant should be registered by one or more pyrometers, one of which must be of a recording type. A record must be kept showing the times at which the treatment of each batch began and ended, so that, by comparison between this and the pyrometer chart, the thermal conditions relating to the part or material can be subsequently ascertained.

14.3 The accuracy of the temperature control equipment must be checked regularly and the results recorded for reference purposes. Normally it is sufficient to check pyrometers once monthly, but where temperature limitations are critical, a weekly check should be made.

14.4 Since there are several types of pyrometers in use, each varying slightly from the other, it is not possible to detail the necessary checks for accuracy, therefore the instrument manufacturers' instructions should be carefully followed in each instance. Every effort should be made to reproduce normal working conditions whilst the checks are being made.

14.5 The thermo-couple wiring should be checked periodically for soundness of insulation and connections, and for cleanliness and corrosion.

14.6 A portable "standard-couple" should be kept for checking purposes and this should be used in conjunction with a proprietary indicator supplied by the pyrometer manufacturer. In some plant the cold junction is compensated electrically, but where direct reading instruments are used, the setting should be checked at least once daily.

15 CONTROL TESTING Although every care might be taken in the control of the heat-treatment process, it cannot be guaranteed that the finally heat-treated parts will automatically comply with the requirements of the specifications, therefore some mechanical testing is necessary to ascertain the actual properties obtained. For this purpose a system of control sampling, such as that outlined in the following paragraphs, should be used. This procedure does not apply to forgings or stampings, for which the test procedures contained in the relevant material specifications must be followed.

15.1 The control test samples should, where possible, be prepared from material of the same batch as that to be heat-treated, and in instances where the characteristics of the material are not well known, this is essential. It is common practice to cut the control samples from the sheet or extrusion after full heat-treatment rather than before. The samples of sheet or strip material should be prepared as prescribed in British Standard L100, Section 1, Paragraph 5.4. Where the plant is used only for intermittent treatment of batches, a control sample should be treated with each batch, but where the plant is in continuous use, two samples per day are sufficient.

15.2 If prepared before heat treatment, the control samples should be wired to the material which they represent, and should be heat-treated and quenched with it. After ageing, the control samples should be hardness-tested and the sample showing the lowest hardness number in each batch should be subjected to tensile testing.

15.3 When materials are to be precipitation treated, the samples should follow through the complete heat-treatment sequence with the parts they represent, and should be tested on completion of the process. A system for recording the results of the tests must be maintained.

15.4 It should be noted that control testing is not intended primarily as a method of sentencing heat-treated parts, but as a means of verifying that the heat-treatment operation has been carried out with consistent correctness. An isolated failure of a control test sample to give the specified test values requires immediate investigation into the application of the heat-treatment process. Where recurrent failures are experienced, or where investigation made as a result of an isolated failure gives cause for anxiety, the matter should be investigated immediately. Further treatment should be suspended until the fault has been ascertained and rectified, and consideration should be given to the suitability of the parts heat-treated with the batch in question.

16 IDENTIFICATION OF HEAT-TREATMENT CONDITIONS Immediately after the material has been heat-treated, it should be marked with the appropriate symbol denoting the treatment to which it has been subjected, since serious risk would attend the use of materials in one heat-treatment condition which were thought to be in a different condition.

16.1 There are two identification systems in general use, i.e. that recommended in British Standards 1470 to 1477 and that recommended by the Ministry of Supply in SP4089. Both systems are acceptable to the Board and details of both are given below.

16.2 **Identification System Recommended in British Standards 1470 to 1477.**

O	Material in the annealed condition.
M	Material in the "as-manufactured" condition, e.g. as rolled, as extruded, straight and/or drawn to size, or as forged, without subsequent heat treatment of any kind.
OD	Material which has been annealed and lightly drawn (at present applicable only to rivet, bolt and screw stock).
T	Material which has been solution-treated and requires no precipitation treatment.
W	Material which has been solution-treated and will respond effectively to precipitation treatment.
WP	Material which has been solution-treated and precipitation-treated.
WD	Material which has been drawn after solution treatment (at present only applicable to wire).
P	Material which has been precipitation-treated only.

16.3 **Identification System Recommended in SP4089.**

A	Material and parts which have been annealed.
N	Material and parts which have been solution-treated and which do not require precipitation treatment.
W	Material and parts which have been solution-treated and which require subsequent precipitation treatment.
WP	Material and parts which have been solution-treated and precipitation treated.

16.4 **General.** The symbol must be applied in the manner prescribed in the appropriate drawing.

BASIC

TESTING OF MATERIALS AND CHEMICAL SOLUTIONS

MEASUREMENT OF pH VALUES

1 INTRODUCTION This leaflet gives guidance on the methods used for determining the pH values of industrial chemical solutions, but should not be taken as overriding existing methods where these are producing satisfactory results.

1.1 The term "pH value" is a mathematical expression used to represent the intensity of degree of active or alkalinity of a solution. It is the negative of the logarithm to base 10 of the hydrogen ion concentration, and is expressed as $pH = -Log_{10}(H+)$. The principle upon which the measurement of pH values is based is described in paragraph 2.

1.2 In this leaflet, the application of pH measurement only to the processes used for the surface treatment of metals is considered, e.g. cadmium plating, nickel plating and chromating. For pickling acids and strongly alkaline solutions, the determination of pH values is seldom worthwhile, since sufficient indication of their efficiency can be obtained by routine titration methods.

1.3 Prior to the introduction of pH measuring equipment for such purposes, the acidity of chemical solutions was generally tested by indicators, such as litmus paper, which changes to red in acid solutions and blue in alkaline solutions ; the results of such tests were expressed in vague terms such as "strongly acid" or "faintly alkaline". However, since the degree of acidity or alkalinity of a solution has an important influence on the quality of the surface treatment, the need for more precise measurement was generally recognised. Suitable methods, such as the colorimetric process and the electrometric process, are described in this leaflet.

1.4 Guidance on anodising is given in Leaflet **BL/7-1,** on cadmium plating in Leaflet **BL/7-2** and on chromating in Leaflet **BL/7-3.**

1.5 For those not familiar with the terminology used in this leaflet, a glossary of terms not explained in the text is given in paragraph 6.

2 THE PRINCIPLE OF pH VALUES When an acid or an alkali is dissolved in water, the resultant solution is capable of conducting an electric current. This is due to the fact that all or part of the acid or alkali splits up (or "dissociates") into positively and negatively charged particles, termed "ions", which move about freely in the solution.

2.1 Acids dissociate into positive hydrogen ions (H+) and negative non-metallic ions, whilst alkalis dissociate into negative hydroxyl ions (OH—) and positive metallic ions. It is the presence of hydrogen ions or hydroxyl ions which causes the characteristic properties of acids and alkalis respectively, thus the more hydrogen ions there are present, the more acid the solution becomes, and the more hydroxyl ions there are present, the more alkaline the solution becomes.

2.2 In simple terms, pH measurement is merely the measurement of the concentration of hydrogen ions in a solution to determine precisely where the solution lies in the acid/alkaline scale, i.e. the pH scale.

2.3 The pH scale, for practical purposes, extends from 0 to 14 pH units, the acid region being from 0 to 7 pH units and the alkaline region from 7 to 14 pH units. In the above scale, 0 pH units is the most acid state, and 14 pH units the most alkaline state. Neutrality is 7 pH units, and this is the value of pure water, which contains hydrogen ions and hydroxyl ions in equal proportions.

2.4 The notation of the pH scale is based on the hydrogen ion concentration (expressed in gram-ions) in one litre of solution, thus water with a hydrogen ion concentration of 0·0000001, or 10^{-7}, gram-ions per litre is described more simply as having a pH value of 7. A strong acid solution with a hydrogen ion concentration of 0·1, or 10^{-1}, gram-ions per litre has a pH value of 1, whilst a dilute alkali with a hydrogen ion concentration of 0·0000000001, or 10^{-10}, gram-ions per litre has a pH value of 10.

3 COLORIMETRIC DETERMINATION OF pH VALUES Colorimetric determination of pH values is effected either by the use of indicator papers, which are available in strips similar to litmus paper, or by chemicals (also known as indicators) which change colour according to the pH value of the solution. With this latter method, the indicators are added to the solution under test, and the pH value is determined by comparison with standard "buffer" solutions (paragraph 3.2) or by the use of a comparator having standard colour discs (paragraph 3.3).

3.1 **Indicator Papers.** Indicator papers offer a simple method of determining the pH value of slightly acid electro-plating solutions, such as nickel plating, within an accuracy of 0·3 pH unit, but with highly coloured solutions, such as chromic acid baths, the colour of the solution may interfere slightly with the true colour of the paper.

3.1.1 The papers consist of strips, having bands of seven different colours, the centre band serving as the indicator, the remaining six bands acting as the colour scale for the particular indicator paper used. The pH value of the solution is the value given against the measuring band which most nearly matches the colour of the broad indicator band. Preferably, the colours should be compared in daylight, although reasonable results can be obtained in ordinary electric light, but no attempt should be made to compare the colours under fluorescent tube lighting.

3.1.2 As an example of the indicator papers available, one proprietary series has three ranges of pH values, i.e. 3·0 to 4·5, 3·9 to 5·4 and 5·2 to 6·7.

3.1.3 When using the papers, the fingers must be clean and dry. The paper should be immersed in the solution for one second, after which it should be removed and the surplus solution shaken off. The pH value should then be determined immediately as indicated in paragraph 3.1.1, but where a true match is not obtained, intermediate values must be obtained.

3.2 **Chemical Indicators.** The principle upon which the colorimetric determination of pH values by chemical indicators is based is the fact that with certain organic dyestuffs (indicators) the colour change of the selected indicator is over the pH range of the solution under test and is both gradual and reproducible.

3.2.1 In order to determine the pH values by this method, it is necessary to use as standards standardised buffer solutions to which a definite amount of indicator has been added. A series of hard-glass test tubes will be required, each containing buffer

solutions differing from each other in steps of pH 0·2, and each containing the same quantity of the appropriate indicator. A set of nine or ten of such tubes is generally required to show the full range of colour of the indicator.

NOTE : A "buffer" is the salt of a weak acid or base, and is used to prevent a sharp change in pH on addition of acid or alkali. The buffer solutions are usually made up by dissolving proprietary types of buffer tablets in 1 ml. of water.

3.2.2 The colour change of the indicator takes place over a limited portion only of the pH scale, and the change is completed over a range of about 1·6 pH units. The colour change over the sensitive range is both gradual and reproducible, and there is no further change outside this range. For example, if a few drops of methyl red solution is added to a solution of acetic acid, the acetic acid will be coloured red. If then a solution of sodium hydroxide (an alkali) is added drop by drop to reduce the hydrogen ion content ratio progressively, no further colour change will take place until the pH value exceeds 4·2 when, with each addition of sodium hydroxide the red colour will gradually change to yellow, until the solution becomes entirely yellow at a pH value of 6.3, after which, as explained earlier, no further change will take place.

3.2.3 A quick approximate estimation of the pH value can be made by the use of a proprietary type of universal chemical indicator, which is made up of a number of indicators, each showing a colour change over a different portion of the pH scale, and having a range of pH 3·0 to pH 11·0. The colour of one proprietary indicator (i.e. the B.D.H. Universal Indicator) changes from pale red at pH 3·0, through various shades of orange, yellow, green, blue and violet, to reddish-violet at pH 11·0, each colour corresponding to a definite pH value. A list of the colours assumed by this indicator is given in Table 1.

TABLE 1

Colour	*pH Value*
Pale Red	3·0
Red	4·0
Orange Red	5·0
Orange	6·0
Yellow	6·5
Greenish-yellow	7·4
Green	8·0
Bluish-green	8·5
Greenish-blue	9·0
Blue	9·5
Violet	10·0
Reddish-violet	11·0

3.2.4 The most suitable indicators for the determination of pH values are those which show a distinct change of colour, as opposed to indicators which have only one colour phase, since a small change in depth of colour is more difficult to detect than a small change in shade. Table 2 lists suitable indicators with their effective pH range and colour change.

TABLE 2

Name of Indicator	*pH Range*	*Colour Change*
Brilliant cresyl blue (acid range)	0·0 to 1·0	Red-orange to blue
Cresol red (acid range)	0·2 to 1·8	Red to yellow
m-Cresol purple (acid range)	1·0 to 2·6	Red to yellow
Thymol blue (acid range)	1·2 to 2·8	Red to yellow
Tropaeolin 00	1·3 to 3·0	Red to yellow
Bromophenol blue	3·0 to 4·6	Yellow to violet
Bromocresol green	3·8 to 5·4	Yellow to blue
Methyl red	4·2 to 6·3	Red to yellow
Chlorophenol red	4·8 to 6·4	Yellow to Red
Bromocresol purple	5·2 to 6·8	Yellow to purple
Bromothymol blue	6·0 to 7·6	Yellow to blue
Phenol red	6·4 to 8·0	Yellow to Red
Diphenol purple	7·0 to 8·6	Yellow to purple
Cresol red (second range)	7·2 to 8·8	Yellow to Red
m-Cresol purple (second range)	7·6 to 9·2	Yellow to violet
Thymol blue (second range)	8·0 to 9·6	Yellow to violet
Cresolphthalein	8·2 to 9·8	Colourless to red
Plenolphthalein	8·0 to 9·8	Colourless to red
Thymolphthalein	9·3 to 10·5	Colourless to blue
Alizarin yellow GG	10·0 to 12·0	Colourless to yellow
Alizarin yellow R	10·1 to 12·0	Yellow to orange
Brilliant cresyl blue (second range)	10·8 to 12·0	Blue to yellow
Tropaeolin O	11·1 to 12·7	Yellow to orange

NOTE : Although several indicators are listed above for pH range 8·2 to 12·0, the colour changing qualities are not good, and the general use of these indicators is not recommended. However, several good mixed indicators are available which adequately cover this higher range. (See paragraph 3.2.3.)

3.2.5 The test is made by adding an amount of indicator to a sample of the solution taken from the bath and comparing it with the buffer solution containing the indicator (paragraph 3.2.1). The volume of the buffer solution and that of the solution to be tested should be identical, as should the quantity of indicator added to each. The amount of buffer solution added depends on the equipment used, e.g. in the standard buffer tubes supplied with the B.D.H. Small Comparator, 0·3 ml of indicator is added to 5 ml of buffer. Comparison of the colour of the test solution against the set of buffer solutions will determine the apparent pH value.

NOTE : The apparent pH value obtained by colorimetric methods differs from the true value obtained by electrometric methods (paragraph 4) by an amount equal to about 0·2 to 0·6 pH units, due to "salt error". An indication of the exact difference for various solutions is given under the appropriate headings in later paragraphs, but it should be noted that where comparator papers or discs (paragraph 3.3) are provided for use with specific plating solutions, it is usual for the appropriate correction to have already been made in the scale.

3.2.6 No reliance should be placed on the result indicated by colours at the extreme end of the range of an indicator, as a pH value outside the range will give only the end-colour (paragraph 3.2.2). In such instances, the test should be repeated, using an indicator with an overlapping range (Table 2).

3.3 **Determination of pH values by Comparator.** A further colorimetric method of estimating pH values is by means of a comparator, the Lovibond comparator described below being typical of the principle employed.

3.3.1 The pH value of a solution is determined by comparing the colour of a test solution containing indicator with permanent coloured glasses which have been standardised against buffer solutions containing indicator.

3.3.2 The comparator consists of a case having a hinged front, the back portion being provided with an opal glass screen and two partitions to take test tubes containing the solution under test. In the front hinged portion are two round holes situated side by side opposite to the glass screen and coinciding with the partitions for the test tubes.

3.3.3 The standard colour glasses, nine in number and representing a complete colour change of one indicator in steps of 0·2 pH (this compares with a set of graded buffer solution indicators, see paragraph 3.2.1), are fitted into a flat disc which may be rotated in the front portion of the case, thus bringing each of the standard colours in turn opposite the left-hand hole behind which is a test tube of the solution under test.

3.3.4 The right-hand test tube contains 10 ml of the same test solution to which has been added 0·5 ml (generally) of the appropriate indicator. This coloured solution is viewed through the right-hand hole and is compared with the permanent colour standards on the left-hand side. In this way compensation is made for the inherent colour of the solution being tested.

NOTE : When unbuffered or only slightly buffered samples are to be tested, greater accuracy can be obtained by use of the Lovibond Nessleriser. With this instrument the proportion of indicator solution needed in the test solution is reduced to a minimum, so that the pH value of the indicator itself has a negligible effect on the result.

3.3.5 The comparator should be held before a uniform source of white light, a window having a northern aspect (southern aspect in the southern hemisphere) being most

suitable. White light equipment is available for use where a source of north light is not available or where readings must be taken at night. In no circumstances should observations be made in direct sunlight.

3.3.6 It is important that the liquid to be tested should be as clear as possible, since turbidity reduces the amount of light transmitted and consequently dulls the colours.

3.3.7 The pH value corresponding to the colour in the field of view is indicated by a figure which appears in a third hole in the front of the case.

4 ELECTROMETRIC DETERMINATION OF pH VALUES The essential elements of a typical electrometric pH measuring instrument are a reference electrode, a glass electrode and a meter which indicates the pH value in terms of the unit scale described in paragraph 2.3. A diagrammatic representation of the measuring system is given in Figure 1.

NOTE : In some instruments, a hydrogen, quinhydrone or some other metallic element may be used in place of the glass electrode, but these are generally for specified applications where the abrasive or chemical action of the solution under test prohibits the use of a glass electrode.

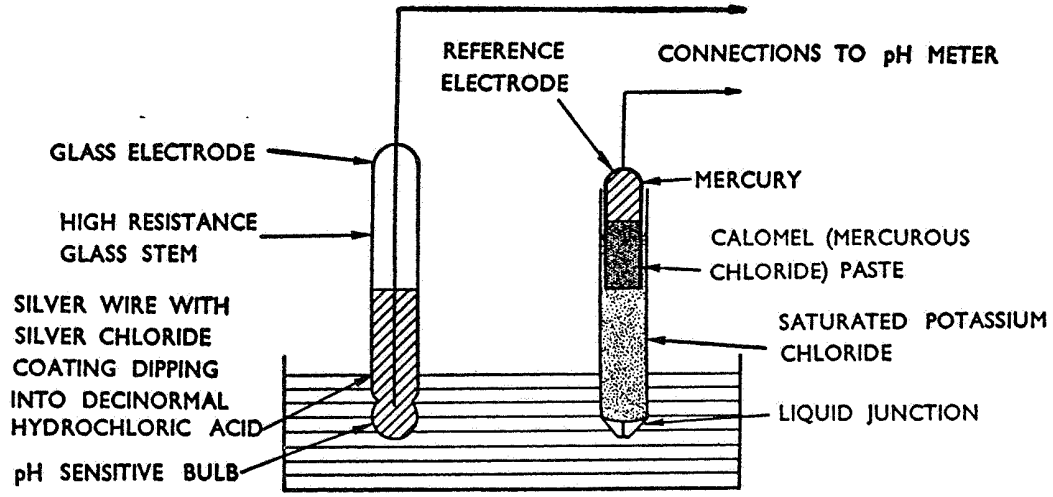


Figure 1 TYPICAL pH MEASURING SYSTEM

4.1 When a material is immersed in a solution, a small potential difference is developed between the surface of the material and the solution. With a glass electrode, the potential developed varies with the pH of the solution, and the change in potential for a variation of one pH unit at 20°C. is 58·17 millivolts. A special glass is used for the electrode in order to obtain the highest possible conductivity through the glass wall, and thus simplify the measurement of the potential difference. The glass used must also have a high immunity to attack by alkalis. A connection is made between the inner surface of the bulb and the meter by means of a wire sealed inside the electrode and immersed in a conducting solution.

4.2 The second electrode produces a reference voltage (i.e. one which is independent of the pH of the solution being measured) and is also connected to the meter. The reference electrode is usually of the calomel type, and contact is made with the solution under test by means of a liquid junction. Since the e.m.f. produced by the calomel

half-cell is a constant, variations of the e.m.f. of the glass electrode/calomel half-cell are dependent upon the potentials developed by the concentration of the hydrogen ions on the glass electrode itself.

4.3 In order to estimate the e.m.f. of the glass electrode/calomel half-cell, it is balanced by means of a potentiometer bridge system against a standard source of current, usually from a Weston cell built into the instrument or, more precisely, against an equivalent current tapped off from the power supply of the instrument via a suitable potentiometer. The whole system is standardised against buffer solutions of known pH value to compensate for the asymmetrical potential of the glass electrode/calomel half-cell system which can vary due to slight physical and chemical changes in the glass membrane. This potential also varies from electrode to electrode.

4.4 It is advisable to check the instrument periodically against two or more different buffers, at different ranges of the pH scale, to ensure that the glass electrode is working correctly and that the instrument is giving reproducible linear values.

4.5 Measurements in quick succession of solutions having widely differing pH values should be avoided if possible. A number of such solutions can be grouped into close pH ranges, one group being measured at a time, allowing a period of 10 to 15 minutes between each range so that the electrode can be soaked in distilled water.

4.6 The most recent development in pH measurement by the electrometric method is the direct-reading pH meter which, basically, consists of an electronic amplifier terminating in an indicator which gives a direct reading of the pH being measured by the electrode system. The instruments are available either in portable form for spot checks or as permanent installations for continuous checking. The latter is considered further in paragraph 5.3.4.

4.7 **Care of Electrodes.** Cleanliness is essential to the correct functioning of the electrodes, and they should be removed from the test solution as soon as possible, washed in distilled water and then stored in clean water.

4.7.1 Storage in water is necessary to prevent the cells drying out, since this causes incorrect potentials (paragraph 4.3) to arise in the glass membrane surfaces. However, should the electrodes become dry inadvertently, they should be soaked in distilled water or in a buffer solution having a pH value near the normal working range, and periodic check readings should be taken over a range of two or three different buffer solutions to ensure that the electrode is not faulty. Standard buffers complying with B.S. 1647 should be used where possible.

4.7.2 If the reading soon settles down to a steady value, then the electrode can be expected to give reliable comparative results in use.

5 APPLICATION OF pH MEASUREMENT TO PRETREATMENT AND FINISHING PROCESSES pH measurement is of not much practical value for the control of processing solutions below a value of 2 pH or above 12 pH. Where strongly alkaline solutions are to be checked by electrometric methods, it is necessary to use a special grade of glass electrode, since many grades are subject to cation (paragraph 6.4).

5.1 **Pretreatment Processes.** As stated in paragraph 1, little use is made of pH measurement for pickling solutions, since these are normally either strongly acid or strongly alkaline, and can be checked by routine titration. However, an indication would be given of the solution becoming exhausted if the pH value of acid solutions rose above pH 1·0 and that of alkaline solutions fell below pH 12·0. It should be borne in mind that when alkaline solutions are checked with indicators, concentrations of caustic material will often result in false readings, e.g. phenolphthalein in strong caustic solution gives a transient magenta colour which then disappears until the solution is diluted many times.

5.2 **Water Washing.** Adequate measure of the effectiveness of water washing after the application of processes such as mechanical cleaning, degreasing and alkaline soak, can be obtained if the pH value of the rinse water is checked. Optimum conditions will be achieved if the rinsing is continued until a near neutral pH value of between 6·0 and 8·0 units is recorded.

5.3 **Protective Treatments.** Every plating solution, and most of the processes allied to plating, have a specific range of pH values within which maximum deposition or optimum conditions are achieved. It follows, therefore, that even regulation of the deposition and the elimination of certain plating troubles is possible if the pH value of the solution is checked frequently and rectified as necessary. This paragraph describes the application of pH measurement to various protective treatments used for aircraft parts and the uses of continuous process control instruments. Table 3 lists the ranges of pH values which are suitable for the solutions with which this paragraph is concerned ; in general, the optimum pH value is in the centre of the ranges given.

5.3.1 **Sulphuric Acid Anodising.** The process of sulphuric acid anodising is described in Leaflet **BL/7-1.** Specification DTD 910 specifies that the pH values of the sealing solutions used must be determined. The figures given in Table 3 are those applicable when the glass electrode method is used, but if the colorimetric method is employed, using bromo-thymol blue as indicator for Solution A and bromo-cresol purple for Solution B, the apparent pH values are 0·3 to 0·4 higher than the corresponding glass electrode values.

5.3.2 **Hot Half-Hour Chromate Bath.** This process is described in Leaflet **BL/7-3.** DTD 911 specifies the requirements for acceptance of parts treated by this process, and to achieve these, a freshly-prepared bath should be within the pH ranges given in Table 3, according to the material being treated.

(i) As the bath ages it will be necessary to lower the pH of the solution to produce a satisfactory film, due to the accumulation of magnesium salts. The pH value should, however, be as high as possible consistent with the good film appearance, and must be adjusted by the addition of ammonia (to replace loss by evaporation), chromic acid or sulphuric acid, as required.

(ii) Addition of ammonia (S.G. 0·880) at the rate of 8 fluid ozs. per 100 gallons of chromate bath rises the pH value of the bath by approximately 0·1. The ammonia should be diluted with at least its own volume of water before addition to the hot solution.

(iii) Addition of chromic acid at the rate of 10 ozs. per 100 gallons, or sulphuric acid (S.G. 1·84) at the rate of 5 ozs. per 100 gallons, reduces the pH value of the bath by approximately 0·1. The sulphuric acid should be diluted with at least twice its own volume of water before addition to the hot solution.

(iv) The figures given in Table 3 are those applicable when the glass electrode method is used, but if the colorimetric method is employed, using bromo-cresol purple as an indicator, the apparent pH values are 0·3 to 0·4 higher than the corresponding glass electrode values.

TABLE 3

Treatment Solution	*pH Range*
Anodising	
fluoborate	4·00 to 4·60
sulphuric anodising sealing solution (Type A of DTD 910)	6·00 to 7·00
sulphuric anodising sealing solution (Type B of DTD 910)	5·60 to 6·00
dye solutions	5·20 to 6·20
nickel or cobolt acetate dye sealing rinse	5·50 to 5·80
Brass	10·50 to 11·50
Bronze (tin)	12·00 to 13·00
Cadmium	
cyanide	12·00 to 13·00
fluoborate	4·00 to 4·60
black finish (nickel or zinc)	5·60 to 5·90
Copper	
Rochelle	9·50 to 10·00
cyanide	12·00 to 13·00
acid-sulphate	3·20 to 3·80
Chromating (hot half-hour bath of DTD 911)	
magnesium-manganese alloys (viz. DTD 118)	6·05 to 6·13
magnesium-manganese alloys (viz. DTD 140, DTD 142)	6·13 to 6·18
magnesium-aluminium alloys	5·90 to 6·05
magnesium-zirconium (all types)	5·90 to 6·00
Nickel	
black bath	5·80 to 6·10
bright bath (Hinrichsen)	4·00 to 4·30
bright bath (Weisberg)	4·00 to 4·30
Watts (DTD 905) (Heavy deposition) (A pH value of 5·6 to 5·8 is often used for commercial deposition)	3·00 to 4·00
double salt type	5·60 to 5·90
Silver (cyanide)	11·50 to 12·00
Tin (stannate)	12·00
Zinc	
acid	3·50 to 4·60
cyanide	13·20 to 13·70
fluoborate	2·50 to 4·00

5.3.3 **Chrome Manganese Bath.** This process is described in Leaflet **BL/7-3.** The pH value of the solution is not critical and will range from pH 4 when freshly made to about pH 6 when almost spent. An exhausted bath can be revived by the addition of further manganese sulphate or by the careful addition of sulphuric acid.

5.3.4 **Nickel Plating.** Nickel solutions should not be allowed to become alkaline, since this results in irregular and brittle deposits of poor colour. In addition, contamination of nickel solutions with metals such as copper, zinc and iron is quite common, but adjustment of the pH value to 6·2 precipitates out these metals as their hydroxides. After the removal of the hydroxides by filtration, the solution should once more be adjusted to its optimum pH value for plating.

(i) In large scale nickel plating processes (and in certain other processes where consistency of deposition is essential) a permanent pH control system is sometimes used to safeguard against undesirable changes of pH value. A typical electrometric scheme is shown in Figure 2.

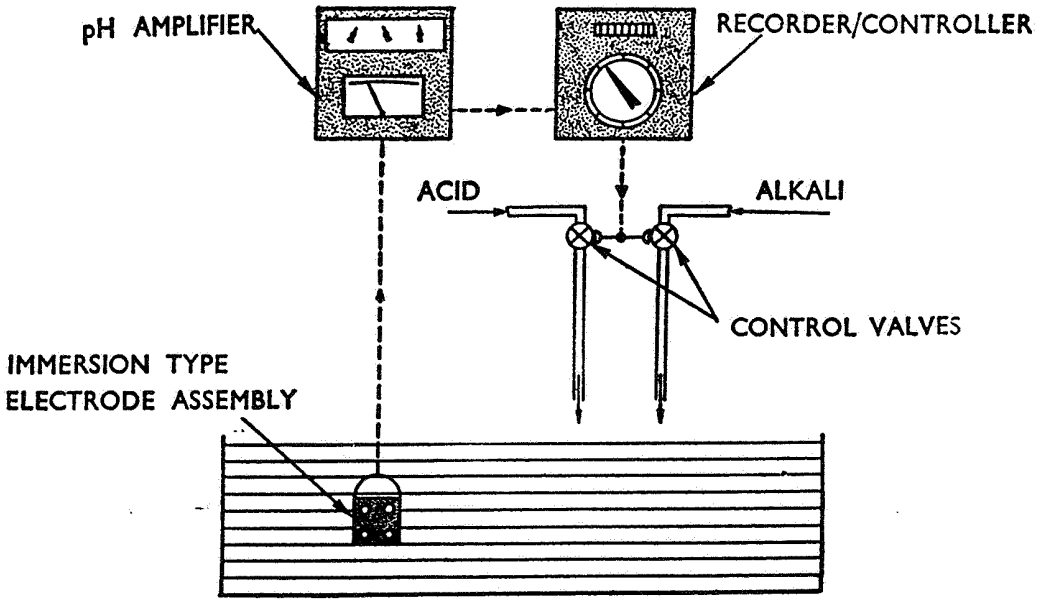


Figure 2 TYPICAL NICKEL PLATING pH CONTROL SCHEME

(ii) In the scheme illustrated in Figure 2, an electrode assembly of the immersion type is permanently installed in the solution and feeds an industrial pH amplifier. This in turn drives a combined recorder-controller which, besides providing a permanent record of the bath operation, actuates control valves on either acid or alkali addition supply-lines, as required. The rate of addition can be made proportional to the deviation of the measured values from that necessary for optimum plant working. In some instances, use is made of an alternative flow-type electrode assembly which is fed by a sample continuously pumped from the bath.

(iii) The figures given in Table 3 are those applicable when the glass electrode is used, but if the colorimetric process is employed, the apparent pH values are 0·2 to 0·6 higher than the corresponding glass electrode values.

(iv) So far as the Watts solution specified in DTD 905 is concerned, the apparent pH values, using bromo-phenol blue as indicator, will be 0·5 higher than the corresponding glass electrode values. Should the pH value fall below the specified range, additions of nickel hydroxide or nickel carbonate should be made, followed by filtering. If the electrolyte tends regularly to assume a low pH value during use the chloride concentration of the bath should be checked, but if this is in order, then the anode area should be increased.

6 GLOSSARY OF TERMS

6.1 **Asymmetrical Potential.** A potential originating in a lack of symmetry of the two surfaces of the glass.

6.2 **Base.** A substance which dissolves in water with the formation of hydroxyl ions.

6.3 **Calomel Electrode (Standard).** A half-element consisting of mercury, a paste of mercury, calomel and a standard solution of potassium chloride saturated with calomel.

6.4 **Cation.** The ion in an electrolyte which carries the positive charge and which migrates towards the cathode under the influence of a potential difference. Cations have no effect on pH measurement below about 9, but above that value the potential difference between the glass and the solution may be affected, resulting in the e.m.f. of the glass electrode being no longer related to pH. The errors may be quite large at pH values of 12 to 13.

6.5 **Ion.** A charged atom, molecule or radical whose migration effects the transport of electricity through an electrolyte.

6.6 **Salt Error.** The degree of acidity or alkalinity of a solution does not depend entirely on pH, since it is also affected by neutral salts. A high concentration of neutral salts produces an error in pH readings, but such errors rarely exceed 0·5 pH unit.

6.7 **Turbidity.** Lack of clarity, muddiness.

6.8 **Weston Cell.** A standard cell with an e.m.f. of 1·0183 volts at 20°C. for an almost indefinite period. It consists of an amalgamated cadmium anode covered with crystals of cadmium sulphate, dipping into a saturated solution of salt, and a mercury cathode covered with solid mercurous sulphate.

BL/10-3

Issue 2.

15th June, 1970

BASIC

TESTING OF MATERIALS AND CHEMICAL SOLUTIONS

TESTING OF METALLIC MATERIALS

1 INTRODUCTION

1.1 This Leaflet gives guidance on the testing of metallic materials. It should be read in conjunction with the latest issue of British Standard A4, entitled "Test Pieces and Test Methods for Metallic Materials for Aircraft", with the latest issues of British Standards L100, S100, S500, T100 and TA100 (which deal with the inspection and testing procedures for aluminium and its alloys, steel, steel sheet and strip, steel tubes and titanium alloys respectively), and with the relevant material specifications.

1.2 Information on tensile testing, previously contained in Issue 1 of this Leaflet, and on bend testing, previously contained in Leaflet **BL/10-4**, has been brought up to date and included in Issue 2 of this Leaflet.

1.3 The topics discussed in this Leaflet are as follows:—

Paragraph	*Topic*
2	General
3	Tensile Tests
4	Ductility Tests
5	Hardness Tests
6	Impact Tests

2 GENERAL

2.1 The particular tests called for in material specifications are designed to ensure that the material will be satisfactory for the purpose for which it is required. The range of tests will therefore vary considerably between materials and between different forms of the same material. A tensile test at room temperature is always a requirement and in addition one or more of the ductility, hardness or impact tests are usually specified.

2.2 At the present time most British testing laboratories are using machines calibrated in British units (i.e., pounds, inches, foot pounds force, etc.) and many material specifications still require results to be notified in these units. The introduction of International Standards (S.I.) units into the aircraft industry will result in a gradual changeover from the British system, and current material specifications are being issued quoting only S.I. units. Testing equipment will also be brought into line with this International Standard.

2.3 The S.I. units applicable to the testing of metallic materials are as follows:—

mass	:	kilogram	(kg)
force	:	newton	(N)
stress	:	hectobar	(hbar)
work, energy	:	joule	(J)
dimensions	:	millimetre	(mm)

NOTE: It should be noted that the units 'N', 'J' and 'hbar' are not related to the force of gravity and this must be taken into consideration when making calculations. 1 hbar = 10N/mm², = 1.02 kgf/mm², =0.65 tonf/in².

3 TENSILE TESTS

3.1 General

3.1.1 Tensile tests are normally carried out at room temperature (10 to 30°C) and this paragraph deals mainly with the procedures and test pieces employed with this type of test. Certain materials, however, are manufactured specifically for use in regions of high temperature (e.g. turbine engines or external surfaces of high speed aircraft) and additional tests are necessary to ensure that these materials meet the requirements for such a use. While the methods used to carry out these tests are basically similar to those used for tensile tests at room temperature, certain differences exist and these are discussed in paragraph 3.11.

3.1.2 The principles of tensile testing are applied in the determination of certain data relating to the properties of materials and these include tensile strength, proof stress, percentage elongation, percentage reduction in area and Young's Modulus of elasticity. Definitions of this data are given in subsequent paragraphs.

3.1.3 When a tensile test piece (Figure 1) is subjected to a steadily increasing load, it will extend proportionally to the load until a point is reached (varying with different metals) after which the extension increases at a progressively greater rate than loading and failure by fracture occurs. The tensile strength of the material is the maximum load obtained on the sample divided by the original cross-sectional area.

3.1.4 Samples of the material to be tested are often cut from the parent metal and accompany it through all stages of heat treatment. In other instances, for example with small castings, a percentage of the items is selected for test purposes. It is from these samples that the test pieces are manufactured. A system of cast and/or batch code markings (see Leaflet **BL/2-2**) should be used to identify the sample with the parent metal or particular cast so that the samples are known to be truly representative of the material to which they belong.

3.1.5 The results of tensile tests may be affected by a number of factors, e.g. gauge length in relation to the cross-sectional area and the type of material from which the specimen is machined. These factors are taken into consideration in the specification.

3.1.6 Local unsound areas may occur in cast materials, especially in areas subject to shrinkage or porosity, so that small test pieces cut from a normal test sample may give unduly low results. Conversely, unduly high results may be obtained if the test piece includes part of a chilled zone of a test sample.

3.1.7 Steel samples of large cross-section may, due to heat treatment, exhibit non-uniform properties through the section; bright drawn material may also exhibit non-uniform mechanical properties through its cross-section. The difference in tensile strength or proof stress, measured at different positions within a sample, may amount to several hectobars.

3.1.8 Certain aluminium alloys possess natural age hardening qualities (Leaflet **BL/9-1**). It is therefore essential to allow sufficient time for the natural precipitation to take place before carrying out the tests, otherwise low tensile and unduly high ductility properties will be indicated.

3.2 Test Pieces

3.2.1 General Requirements

(i) The form and dimensions of standard round and flat test pieces, and of strips cut from tubes, are specified in BS A4. These test pieces are illustrated in Figure 1 and the dimensions listed in Tables 1 and 2.

NOTE: The gauge lengths specified in Tables 1 and 2 are used for measurement after fracture and should not be confused with the extensometer gauge length which is used for measuring extensions during testing. Extensometers are manufactured in the sizes 25 mm and 50 mm.

(ii) Care must be taken during machining to avoid overheating, bending and surface distortion, special care being necessary with small specimens. A good finish is essential, since a rough surface finish or tool marks on the gauge length of the test piece may result in low mechanical test properties, particularly with materials of low ductility.

(iii) Material specifications normally stipulate the standard size of test piece to be used and this is mandatory provided that the sample is of sufficient size. When the material is too small, i.e. a small casting or bar, the largest practical size of test piece selected from Tables 1 or 2, as appropriate, should be used.

(iv) Certain specifications permit testing to full section and the extent of machining should be only sufficient to remove scale or give a symmetrical form. It is particularly important in this case to select a length of material which is free from bends or kinks as these faults will make it very difficult to achieve accurate results.

(v) It is necessary to maintain the dimensions over the gauge length as these have a considerable effect on the results obtained from a test. The parallel portion must not vary in diameter or width by more than 0.03 mm and measurement must be accurate to within 0.2 per cent or 0.005 mm, whichever is the greater.

(vi) Material specifications state the position from which the test sample should be taken, and in some cases as many as three samples are required so that the effect of grain flow or direction of rolling can be judged.

3.2.2 Proportional Test Pieces

(i) These test pieces are round in section and have a specific relationship of gauge length to diameter of 5:1. The gauge length is important when measuring elongation due to the "waisting" of the test piece when under load. If, for example, the waisting affects 10 mm of the parallel portion of the test piece the *percentage* elongation over a 50 mm gauge length would be vastly different from that over a 100 mm gauge length. An international standard has been agreed of 5.65 $\sqrt{}$ cross-sectional area (i.e. 5 $\times$ diameter). If a test piece is manufactured to dimensions other than those shown in Table 1 then the geometric proportions must be maintained.

(ii) The gripped ends of the test piece must be co-axial with the parallel portion and suitably shaped for the holders of the testing machine. Threaded or shouldered ends are normally used.

3.2.3 **Non-proportional Test Pieces**

(i) For material less than 10 mm thick a flat test piece may be used, the standard size being 12.5 mm wide and normally the full thickness of the material. Table 2 gives the dimensions of test pieces of this type and it should be noted that the gauge length/cross-sectional area ratio varies considerably. Accurate measurement and calculation of the cross-sectional area is necessary as this determines the load to be applied to achieve a particular stress. For material more than 10 mm thick a proportional test piece should be used.

(ii) When flat test pieces are produced by means of a press tool, sufficient material must be left along the gauge length to permit machining to the final width.

3.2.4 **Test Pieces for Tubes.** Tensile test pieces for tubes may consist of either a length of tube (which is tested in full section), a strip cut from the tube or, for thick walled tubes, a round test piece turned from the wall of the tube.

(i) **Full Section Test Pieces.** For these test pieces the tubular section should be plugged at the ends to facilitate gripping in the test machine, but care must be taken to ensure that the tube is not cold worked during this operation. The length of the tube between the inner ends of the plugs should be at least 50 mm more than the gauge length. Elongation should normally be measured over a 50 mm gauge length unless otherwise required by the material specification.

NOTE: Plugs should be parallel over the gripping length and at least as strong as the tube.

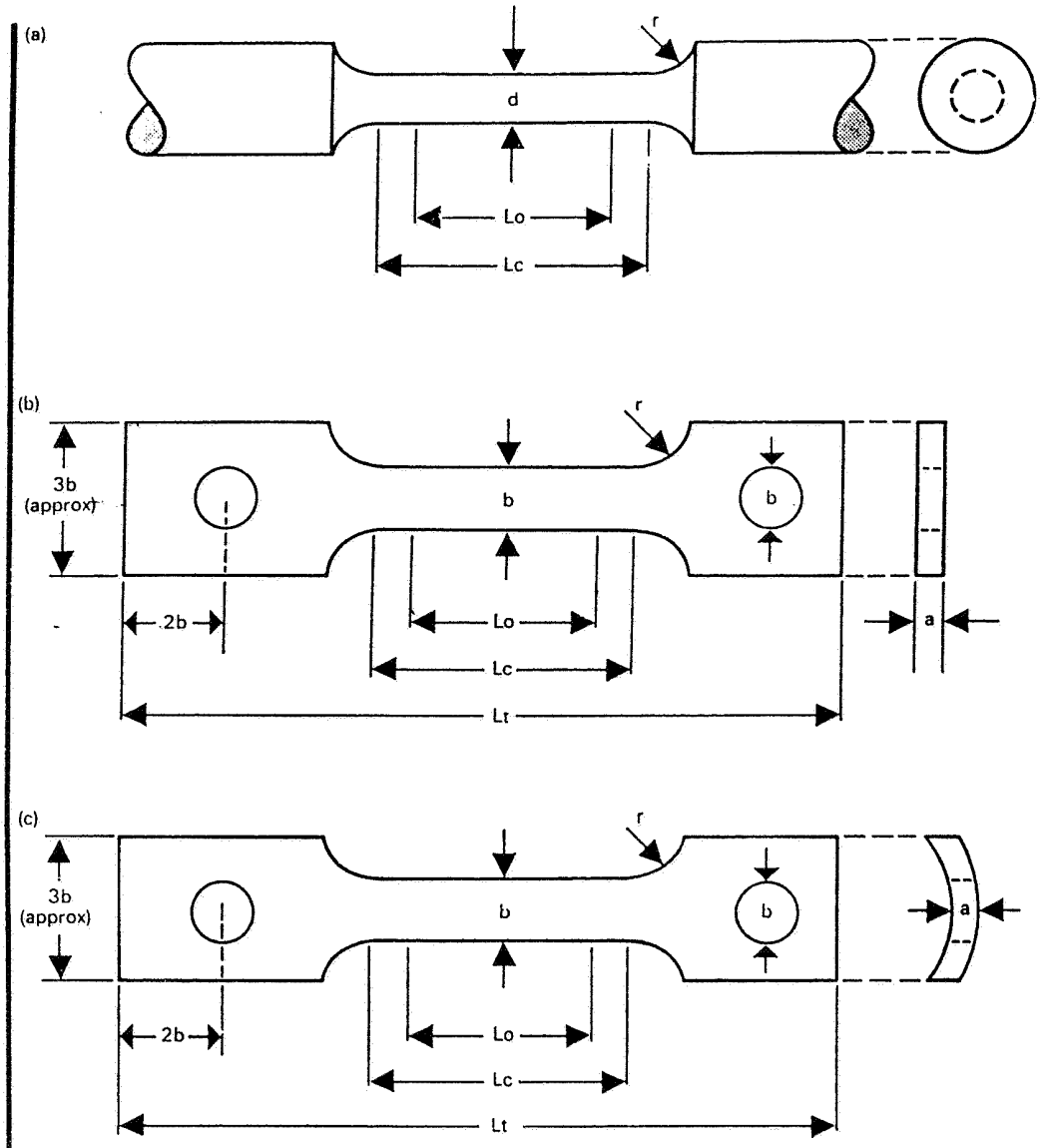
(ii) **Test Pieces Cut from Tube.** These test pieces are illustrated in Figure 1 (c) and the dimensions are those given in Table 2. The first listed should be considered as the standard size. The strip may not be flattened over the gauge length but the gripping ends may be flattened as required to fit the holders. For the purposes of calculation, for tubes of more than 100 mm outside diameter, the cross-sectional area may be taken as 'ab' (Figure 1c), but for smaller tubes the formula

$ab\left(1 + \frac{lb^2}{6Dd}\right)$ should be used.

'D' and 'd' are the outside and inside diameters of the tube respectively.

(iii) **Proportional Test Pieces.** The preparation of test pieces machined from the wall of a tube should be identical to the procedure recommended in paragraph 3.2.2.

3.2.5 **Test Pieces for Wire.** For the purpose of tensile testing, a length of wire, unmachined and in full section, is used as a test piece. If the determination of percentage elongation is required the gauge length is stated in the material specification, but if tensile strength only is required the length is not important. Results must be discounted if obtained when the wire breaks at one of the grips.



Key: Lt = total length of test piece
Lo = original gauge length
Lc = minimum parallel length
r = blend radius
a = thickness of test section
b = width over gauge length
d = diameter of test section

Figure 1 STANDARD TENSILE TEST PIECES

Table 1 DIMENSIONS OF PROPORTIONAL ROUND TEST PIECES

Gauge length = 5.65 $\sqrt{So}$

Nominal Cross-Sectional Area (So)	*Diameter* (d)	*Gauge Length* (Lo)	*Minimum Parallel Length* (Lc)	*Minimum Radius (r)*	
				Wrought Metals and Cast Steel	*Other Cast Metals*
mm^2	mm	mm	mm	mm	mm
150	13.82	69	76	13	26
100	11.28	56	62	10	20
50	7.98	40	44	8	16
25	5.64	28	31	5	10
12.5	3.99	20	22	4	8

Table 2 DIMENSIONS OF RECTANGULAR SECTION TEST PIECES

Width (b)	*Gauge Length* (Lo)	*Minimum Parallel Length* (Lc)	*Minimum Radius* (r)	*Total Length* (Lt)
mm	mm	mm	mm	mm
12.5	50	63	25	200
6	24	30	12.5	100
3	12	15	6	50

3.3 **Percentage Elongation and Percentage Reduction in Area.** Knowledge of the ductility of a material can be obtained from the ordinary tensile test by measuring, after fracture, the percentage elongation which has occurred over a specified length of the test piece, and by the percentage reduction in cross-sectional area at the position where the fracture occurs. Ductility is also measured by different types of test and these are described in paragraph 4.

3.3.1 **Percentage Elongation**

(i) Unless otherwise permitted by the relevant testing procedure or material specification, percentage elongation results should be determined wherever practicable on standard test pieces conforming with the dimensions specified in BS A4. If samples are tested in full section, the elongation should be determined on the gauge length specified in the appropriate material specification.

(ii) The elongation of the test piece is normally in two distinct phases, i.e., the uniform elongation which takes place over the whole gauge length, and the additional stretching which occurs at the waist formed at the point of fracture (see Figure 2).

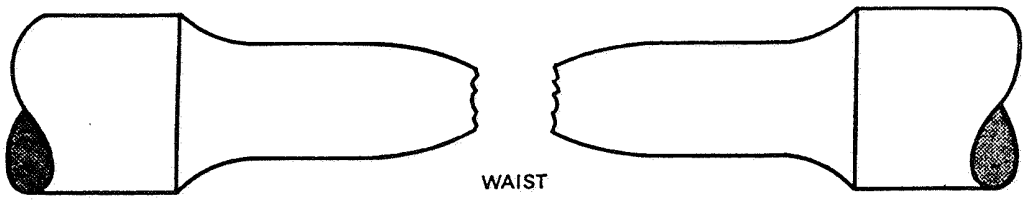


Figure 2 FRACTURED TEST PIECE SHOWING WAISTING

(iii) The extent of elongation depends on the form of the test pieces, and comparable figures can only be obtained from test pieces in which the gauge length bears a fixed ratio to the square root of the cross-sectional area, as is the case with all proportional test pieces.

(iv) The practice of marking two or more alternative gauge lengths in different positions on rod or wire test pieces is advisable so that, should a fracture occur towards one end of the test piece, the whole of the elongation associated with the waisting can be measured between the points selected.

(v) For certain copper alloys and materials where a fracture is likely to occur through a deeply incised mark, a suitable quick-drying paint or lacquer should be applied to the test piece and the gauge length lightly marked with dividers. A lacquer suitable for this purpose may be prepared by dissolving 10 grams of Nigrosene (spirit soluble) and 25 grams of Shellac in one litre of methylated spirit.

(vi) Where the specified minimum elongation is 5 per cent or more the gauge length should be marked on the test piece by scratches or light centre-pops before commencing the test and the distance between the marks measured after fracture.

(vii) Where the specified minimum elongation is less than 5 per cent, one end of the gauge length should be marked by two crossed scribe lines and the other end by an arc of gauge length radius struck from the crossed lines. After fracture, the broken test specimen should be placed in a suitable fixture and axial pressure applied (preferably by means of a screw), to a degree just sufficient to hold the broken pieces firmly together during measurement. A second arc of the same radius should then be struck from the original centre, the distance between the two arcs being measured by a suitable instrument, e.g. a Brinell microscope.

(viii) The percentage elongation can be determined by the formula:—

$$\text{Percentage elongation} = \frac{Lu\text{-}Lo}{Lo} \times 100 \text{ where:—}$$

Lo = Original gauge length, and

Lu = Gauge length after fracture.

(ix) Any statement of results of this test must include information on the type of test piece, its section and gauge length.

3.3.2 **Percentage Reduction in Area.** There appears to be no definite relationship between the percentage elongation and percentage reduction of area for most materials, and it is essential that both measurements are taken in order to assess correctly the ductility of any particular material. For example, certain steels exhibit a considerable reduction of cross-section area with only moderate elongation, whilst others behave in the reverse manner.

(i) The percentage reduction of area can be determined by the formula:—

$$\text{Percentage Reduction in Area} = \frac{So-Su}{So} \times 100 \text{ where:—}$$

So = Original cross-sectional area, and

Su = The minimum cross-sectional area obtained by measurement of the fractured test specimen.

(ii) In practice the reduction in area is usually determined by means of an adjustable caliper from which the percentage reduction in area may be read directly.

3.4 **Limit of Proportionality.** The limit of proportionality is the stress (load divided by the cross-sectional area of the test piece) at which the strain (elongation divided by original gauge length) ceases to be proportional to the stress.

3.5 **Yield Point.** The yield point is the stress at which a substantial amount of plastic deformation takes place under constant or reduced load. This sudden yielding is characteristic of low carbon and annealed steels, but in other metals plastic deformation begins gradually and its incidence is indicated by measuring the proof stress (paragraph 3.7).

3.6 **Young's Modulus of Elasticity.** Young's Modulus, referred to as a constant 'E' is $\frac{\text{stress}}{\text{strain}}$, where stress $= \frac{\text{load}}{\text{area}}$ and strain is extension per unit length.

3.6.1 For steel the constant 'E' is approximately 20000 hectobar (200 kN/mm²). Thus a stress of 1 hbar will produce an extension or contraction of 1/20000 of the original length. The working stress for mild steel under steady load conditions is approximately 10 hbar and the strain produced by this stress will be 10/20000 mm per mm length of specimen.

3.6.2. The constant 'E' may be found for a particular metal by comparing the extensions produced by two different loads within the elastic range.

3.7 **Proof Stress**

3.7.1 **General Considerations.** For design purposes it would be convenient to know the highest stress that a material could withstand without deformation. The limit of elasticity (proportionality) is a very difficult point to determine however, particularly with materials which have no definite yield point, and proof stress has been chosen as a value which can be reproduced with accuracy. Proof stress is defined as the stress which is just sufficient to produce, under load, a non-proportional elongation equal to a specified percentage of the gauge length.

(i) In specifying proof stress the non-proportional elongation quoted in most specifications is either 0.1 % or 0.2 % and this figure should always be included in the results of proof stress measurement.

(ii) According to BS A4, and unless otherwise stated in the relevant material specification, the primary method of proof stress determination is by means of an accurately determined stress/strain diagram (see paragraph 3.7.2). The extensions corresponding to suitable increasing values of stress are measured by an extensometer (see paragraph 3.10) and are plotted in appropriate units of extension to form a stress/strain curve as illustrated in Figure 3. This may be done either autographically or manually.

(iii) Where permitted by the relevant testing procedure or specification, alternative methods of proof stress determination, such as the Four-Point Method and the Three-Point Method described in BS A4 may be used. In these instances also the extensions must be measured by a suitable extensometer.

(iv) The tensile properties of the test piece are unaffected by loading and unloading within the limit of proportionality, but if the test piece is loaded beyond this limit, then unloading and reloading will result in an incorrect proof stress value being obtained. To obviate unnecessary loading and unloading every care should be taken in the early stages of the test to ensure that the testing machine grips (paragraph 3.8) are correctly aligned.

(v) It is also necessary to ensure that the extensometer is securely mounted and that bending or twisting of the specimen during mounting is avoided. The weight of the extensometer is usually disregarded, but for very thin sheet specimens or thin-walled tubes, it may be necessary to support the instrument, preferably by a system of light springs.

(vi) Tests should be carried out at room temperature (i.e. 10 to 30°C) unless otherwise specified. The speed at which the load is applied is unimportant within the elastic range, but BS A4 recommends that strain rate should be 0.001 to 0.005 per minute in the plastic range.

3.7.2 **Stress/Strain Diagram Method.** As indicated in paragraph 3.7.1 (ii) the stress/strain diagram method is the primary method of proof stress determination. A typical stress/strain diagram is illustrated in Figure 3.

(i) The magnitude of the initial tensioning stress OA will depend on the limit of proportionality of the material under test. Generally, this should be as high as practicable (although not more than 20 per cent of the anticipated proof stress) to obviate the possibility of machine factors (e.g. backlash) adversely affecting the accuracy of the stress/extension readings in the early stages of the test.

(ii) However, since certain high strength aluminium alloys, magnesium alloys and austenitic steels have relatively low limits of proportionality, it is good practice to employ a low initial tensioning stress, and thereafter increments of approximately 1 hectobar where the operator is not familiar with the stress/extension characteristics of the material under test. If too low a tensioning stress is applied, the initial points on the graph may be scattered and should be ignored.

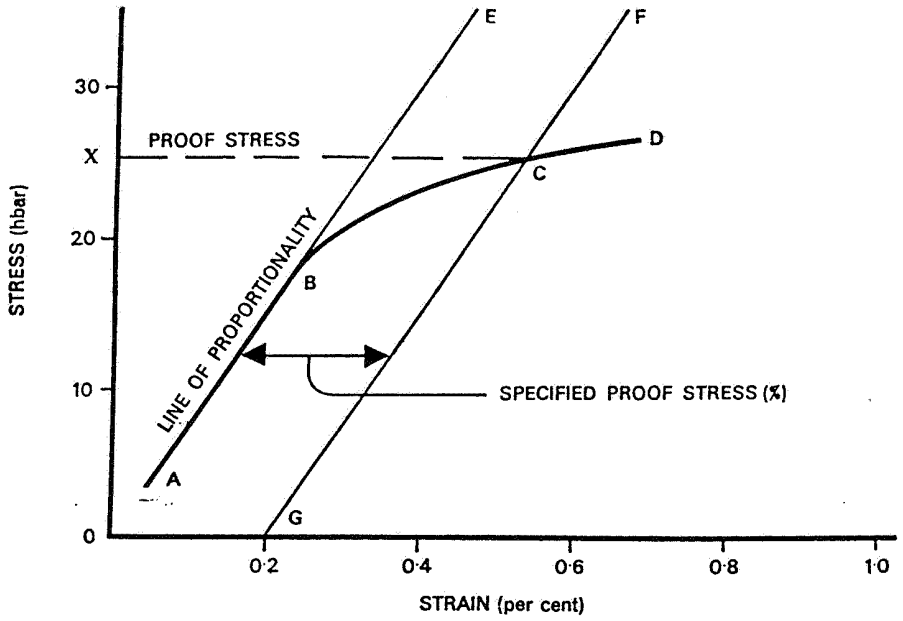


Figure 3 TYPICAL STRESS/STRAIN DIAGRAM

(iii) The value of Young's Modulus of a given material is reasonably constant, thus the theoretical extension of any given increment of stress within the limit of proportionality may be readily calculated. If the extensions are calculated for the increments of stress used in plotting that portion of the stress/extension diagram between A and B of Figure 3, it is possible to verify that the test is proceeding satisfactorily by comparing the calculated values with those actually obtained. A difference of more than 0.002 mm between the calculated and actual extension for a stress increment of 5 hbar for non-ferrous, or of 10 hbar for ferrous materials, is usually an indication of some abnormality in either the testing apparatus or the specimen which should be investigated before proceeding with the test.

(iv) The stress/strain diagram should be plotted on the longest convenient scale. On the horizontal ordinate, 100 mm should represent not more than 0.2 mm extension. The line GF is drawn parallel to the extended straight line of proportionality ABE and distant from it by an amount representing the specified percentage of the extensometer gauge length (e.g. 0.1 mm for a 0.2 per cent proof stress on a gauge length of 50 mm). The proof stress is the stress OX corresponding to the point of intersection of the curve ABCD by the line GF.

(v) When testing clad materials such as L72 it will be found that a double slope is produced. The change of slope occurs when the cladding materials extends plastically.

3.7.3 **Four-Point Method.** In general the four-point method should only be used when the stress/strain diagram of the material under test conforms to the general shape of the diagram shown in Figure 3.

(i) This method is based on the knowledge that proportional elongation of a test piece continues on the line of proportionality up to the point of fracture, and is always proportional to the stress. In other words, at any specified stress the elastic extension is always greater than it would be at a lower stress. This can be proved by applying proof stress to a test piece and measuring the total extension. Subsequent unloading will leave a permanent extension and the difference between this and the total extension will be seen to be equal to the elastic extension at proof stress. This statement is true for all metals except magnesium, from which a certain amount of non-proportional extension is regained; hence, in the case of magnesium, non-proportional extension cannot properly be called "permanent" extension (see Figure 4). It is also assumed that if an appropriate length of the stress/strain curve is taken to be a straight line, an approximate value for proof stress can quickly be found. In practice the error is seldom greater than 0.3 hectobar.

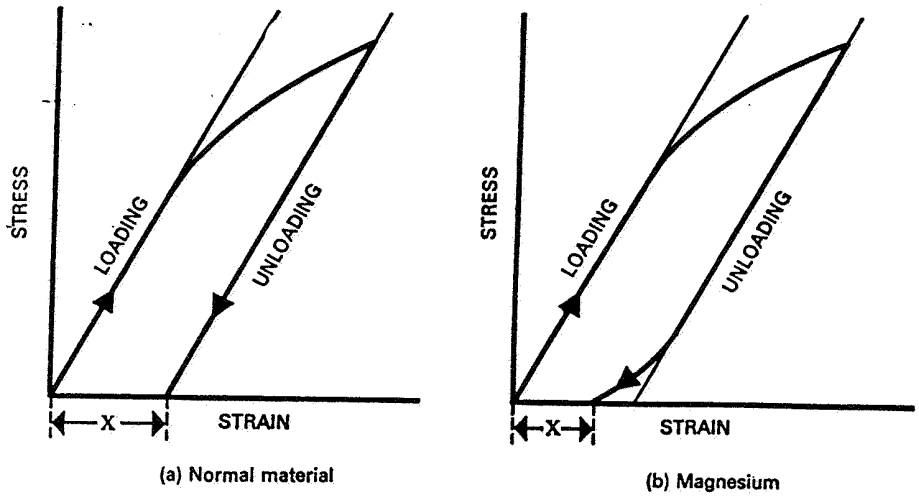


Figure 4 LOADING AND UNLOADING DIAGRAMS

(ii) In general, the range of readings adopted, either specified or selected, should not be more than about a quarter of the specified minimum proof stress, thus the range employed for a material of 24 hectobar minimum specified proof stress should not exceed 6 hectobar.

(iii) **Conducting the Test.** The following example is included to illustrate the requirements of BS A4 and should be studied in conjunction with that specification and Figure 5.

Material	:	Aluminium alloy
Gauge length	:	40 mm
Extensometer gauge length	:	50 mm
Diameter of test piece	:	7.98 mm
Cross-sectional area	:	50 mm^2
Specified minimum stress	:	24 hbar
Assumed maximum stress	:	28 hbar
Specified proof stress	:	0.2 per cent (0.1 mm)
Young's Modulus	:	70 kN/mm^2 (7000 hbar)

Procedure:—

(a) Set up the test piece in the testing machine and attach an extensometer over the gauge length.

(b) Apply a tensioning stress of 4 hbar (OA) and set the extensometer at zero.

NOTE: 4 Hbar is equivalent to a load of 204 kgf for this size test piece (i.e. $4 \times 50 \times 1.02$).

(c) Apply a further stress of 4 hbar (selected because 4 divides easily into both 24 hbar and 28 hbar) and carefully measure the extension 'x'. Check this extension by a calculation using Young's Modulus.

Answer = 0.03 mm.

(d) From 'x' calculate and record the extensions at points 'C' and 'B' thus;
at minimum proof stress of 24 hbar the total extension should be,

$$x \left(\frac{24-4}{4}\right) + 0.1 \text{ mm} = 0.03\,(5) + 0.1 \text{ mm} = 0.15 + 0.1 = 0.25 \text{ mm};$$

and at maximum proof stress of 28 hbar the total extension should be,

$$x \left(\frac{28-4}{4}\right) + 0.1 \text{ mm} = 0.03\,(6) + 0.1 \text{ mm} = 0.18 + 0.1 = 0.28 \text{ mm}.$$

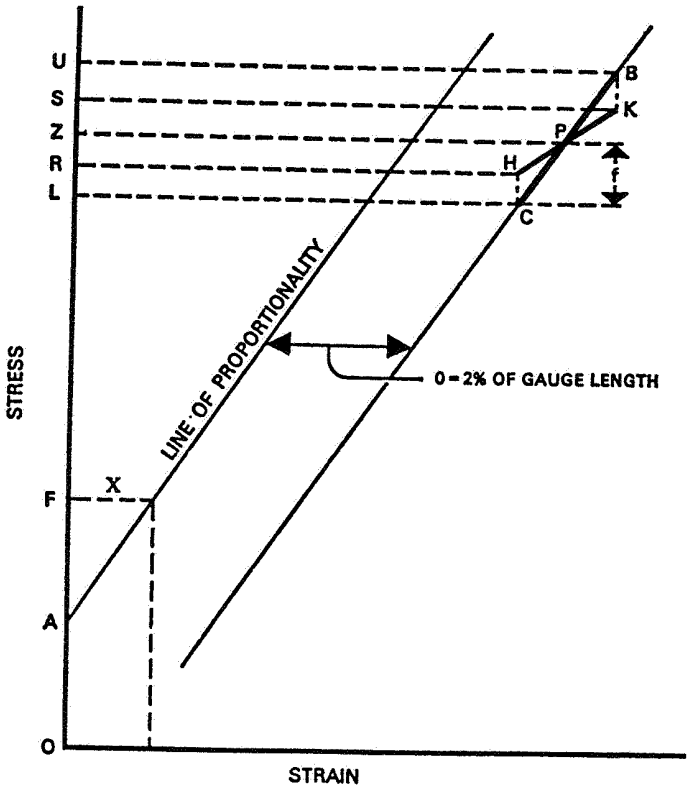


Figure 5 FOUR-POINT METHOD

(e) Load the test piece until the extension calculated for 'C' (0.25 mm) is obtained. If the total load applied (OR) is equivalent to a stress of more than 24 hbar the material satisfactorily exceeds the minimum stress requirement. A stress in excess of 24 hbar means that a proportional extension in excess of 0.15 mm has taken place and therefore the non-proportional extension must be less than 0.1 mm (0.2 per cent).

(f) Load the test piece further until the extension calculated for 'B' (0.28 mm) is indicated. If the total load applied is equivalent to a stress of less than 28 hbar then the material does not exceed the assumed maximum proof stress. A stress lower than 28 hbar indicates that a proportional extension of less than 0.18 mm has taken place and therefore the non-proportional extension is greater than 0.1 mm (0.2 per cent).

(g) The approximate proof stress may be obtained by plotting the points shown in Figure 5. 'HK' represents part of the stress/strain curve, and 'CB' part of the 0.2 per cent proof stress line. The proof stress is indicated by the intersection of these lines at 'P'.

(h) In practice it is not necessary to draw a graph, proof stress being calculated from the formula:—

$$\text{Proof Stress (OZ)} = \text{OL} + \text{f where f} = \frac{(\text{OR–OL}) \times (\text{OU–OL})}{(\text{OR–OL}) + (\text{OU–OS})}$$

the figures being obtained from the calculations in the steps outlined above.

(j) Maximum stress may be obtained by removing the extensometer and loading until fracture of the test piece occurs.

3.7.4 **Three-Point Method.** In certain circumstances, for example when it is required to check the effectiveness of a heat treatment, it may only be necessary to determine that the test sample meets a minimum proof stress requirement. The three-point method is a convenient way of carrying out this check.

(i) The procedure adopted is the same as for the four-point method except that only the minimum proof stress calculation is made, the test piece being loaded until this extension is achieved. If the total load is equivalent to a stress greater than the minimum proof stress then the material is satisfactory.

3.7.5 **Beaumont Determinator Method.** The main advantage of this method is that accurate proof stress values may be determined without the need for plotting a stress/extension diagram. The determinator consists of an instrument employing special charts for various materials which are related to the load indicator of the testing machine. The proof load is indicated on a dial gauge.

3.8 **Methods of Gripping.** Some of the various types of mechanisms used for gripping the test pieces are described in the following paragraphs.

3.8.1 **Pin Grips.** For sheet and strip standard test pieces (e.g. item 'b' of Figure 1) pin grips are mostly used, the pins fitting into the holes provided in the test piece.

3.8.2 **Wedge Grips.** A cross-sectional view of a typical wedge-grip arrangement is shown in Figure 6. The wedges are manufactured of hardened steel, the surface adjacent to the test piece being roughened to provide a positive grip, whilst the remaining surfaces have a smooth finish to facilitate the sliding of the wedges down the shackle adaptor. By this method the test piece is gripped progressively tighter as the load increases.

(i) Wedge grips are used for flat test pieces and, when arranging the grips in the shackle holders, at least two-thirds of the length of each pair of grips should hold the test piece, otherwise the grips will tend to tilt.

(ii) Before inserting the grips in the holders, the sliding surfaces should be coated with graphite grease. Should the wedges be too tightly fixed after a test piece has fractured to be removed normally, a tube should be applied under pressure to the lower end of the grips until they are freed.

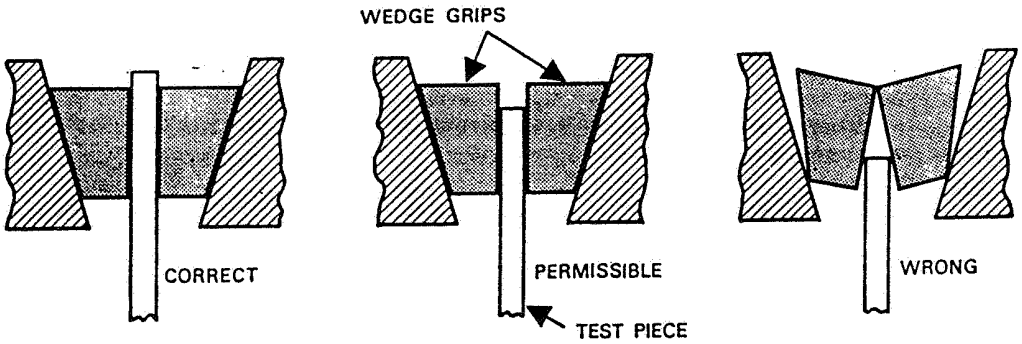


Figure 6 ARRANGEMENT OF WEDGE GRIPS

3.8.3 **Threaded Shackles.** Shackles of this type are used to accommodate the screwed ends of round test pieces.

3.8.4 **Split Collet.** A cross-sectional view of a typical split collet type gripping mechanism is shown in Figure 7. Grips of this type are used for testing shouldered test pieces.

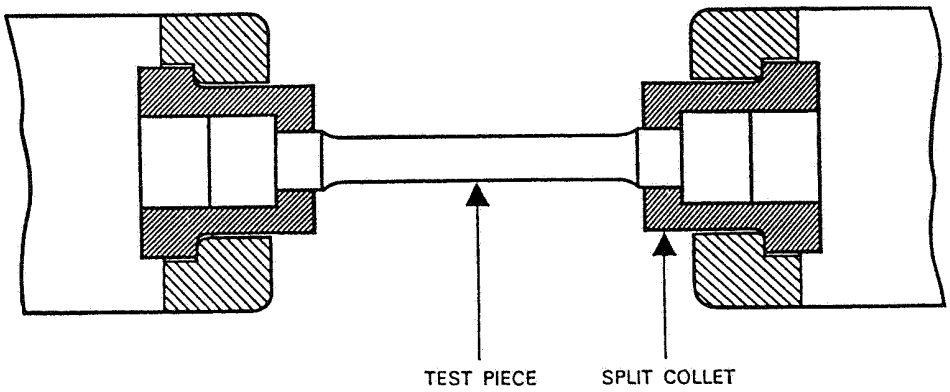


Figure 7 SPLIT COLLET GRIPS

3.9 **Tensile Testing Machines.** Except for machines operating hydraulically, most tensile testing machines load the test piece by means of weights and a system of levers. The value of the load is altered by varying either the weight or the effective leverage and most machines are designed to record automatically the load applied. In hydraulically operated machines (Figure 8), the pressure of oil in the straining cylinder is measured by a dynamometer which operates a lever mechanism to indicate the load on a dial.

3.9.1 On early machines it was necessary to have two operators to carry out a tensile test; one to apply the stress and balance the weighing head whilst the other recorded load and extension readings for the stress/strain graph. Most modern machines are fitted with autographic devices for measuring both load and extension, the most accurate results being obtained by the use of transducers attached to the extensometer and load recording mechanism. Signals from the transducers are amplified to drive a pen, and a graph is produced from which proof stress, tensile stress and extension may be readily determined.

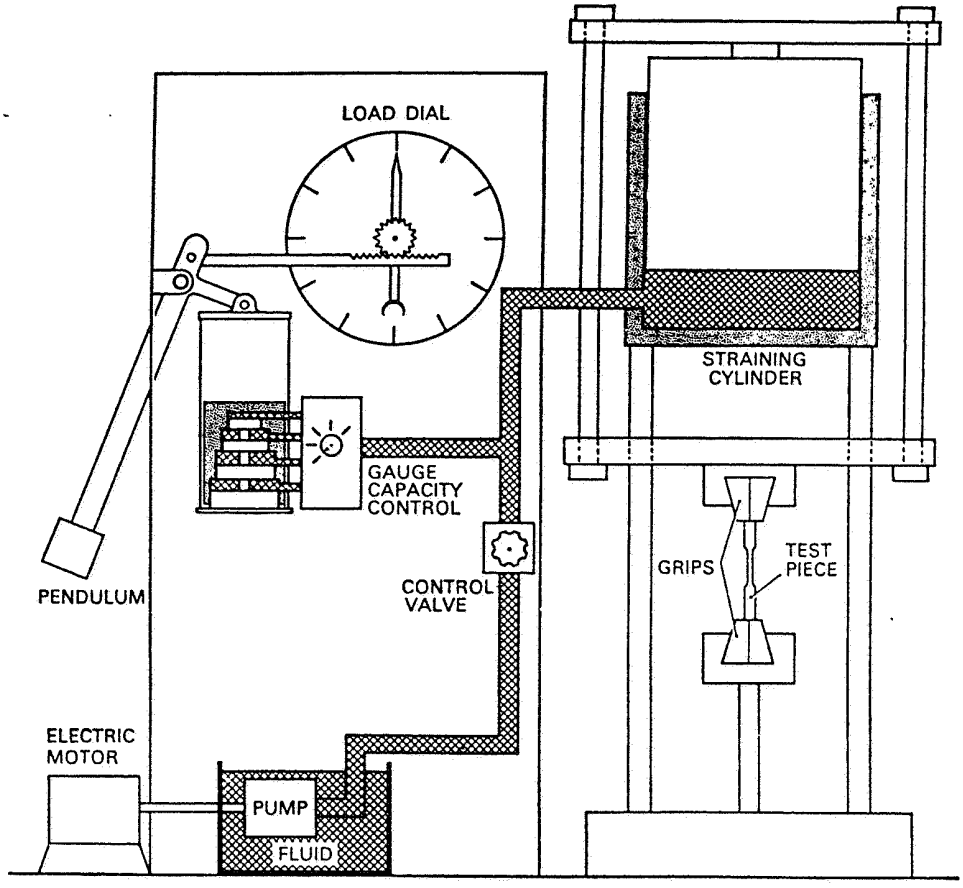


Figure 8 HYDRAULICALLY OPERATED TENSILE TESTING MACHINE

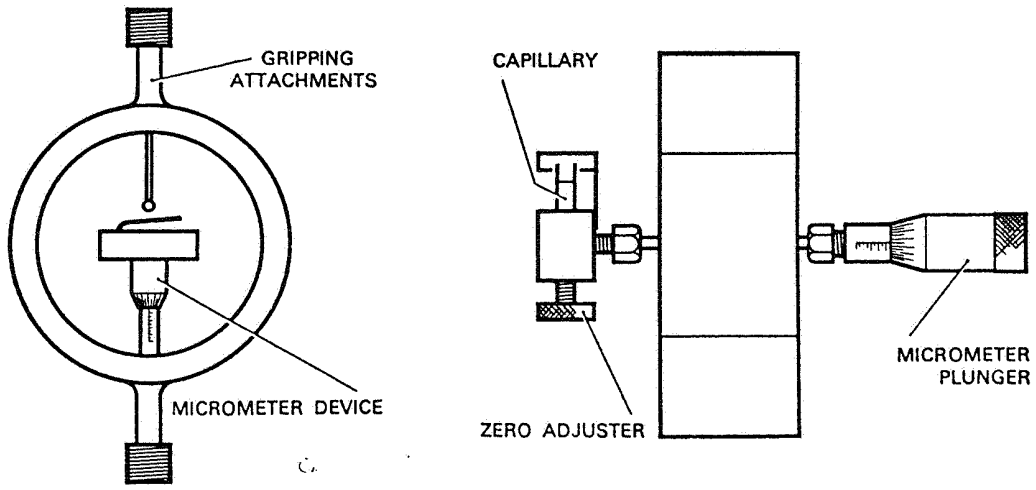
3.9.2 Tensile testing machines must be verified periodically to ensure that their accuracy is maintained. BS 1610 lays down the acceptable methods of verification and the limits of error permitted for various types of test. The methods are discussed briefly in the following paragraphs.

(i) **Dead Weights.** The simplest method of load verification is to hang certified weights from the upper specimen grips. This is only practicable with small capacity machines, due to the handling and transportation difficulties involved.

(ii) **Proving Levers.** Certified levers and weights are used with this method in order to increase the effective force acting on the machine. Larger capacity machines may be verified by this method, but again handling and transportation of the equipment present difficulties.

(iii) **Proving Rings.** (Figure 9 (a)). These are portable alloy steel rings each fitted with a micrometer across the internal diameter. The distortion produced at various stresses is noted during calibration and provides a scale for subsequent machine verification. The rings are manufactured in various capacity ranges and mounted in the testing machine in the same way as a test piece. By using two or more rings together verification of large capacity machines is possible.

(iv) **Standardising Boxes.** (Figure 9 (b)). These are hollow steel cylinders, filled with mercury and completely closed. A capillary tube and micrometer plunger are connected separately to the inside of the cylinder. When carrying out a test, the level of mercury in the capillary is first adjusted to a datum mark by setting the micrometer at zero and rotating the zero adjuster. Application of a compression load will expel mercury from the cylinder into the capillary and the level may be reset to the datum mark by unscrewing the micrometer plunger. The reading shown on the thimble is then converted into units of stress from tables engraved on the box.



(a) Proving Ring

(b) Standardising Box

Figure 9 METHODS OF LOAD VERIFICATION

3.10 **Extensometers.** Extensometers are used for measuring extension over the gauge length of a test piece during a tensile test. Strains within the elastic limit are extremely small, e.g., in a mild steel test piece of 50 mm gauge length the total amount of elastic extension is about 0.05 mm. To measure such small lengths the extensometer must be extremely accurate.

NOTE: BS 3846 details the methods of calibration of extensometers and also lists the limits of error acceptable for various types of tensile test.

3.10.1 Mechanically operated extensometers use leverage to amplify strain and the extension is measured by means of a dial gauge or micrometer attachment. Another type makes use of small mirrors attached to rollers in the extensometer, the change in angle when the test piece is strained being viewed on a large scale by means of a telescope.

3.10.2 Most modern extensometers have provision for the attachment of a transducer, which converts extension into an electric current. This is led to a milliammeter from which extension may be read directly without the need for measurement.

3.11 **High Temperature Tests.** High temperature tensile testing is often necessary with modern aircraft materials and may be a simple tensile test similar to those carried out at room temperature, or a prolonged test to determine creep strain.

3.11.1 **Equipment.** The testing machines used are similar to those required for tests at room temperature except for the addition of a heating furnace. This is lowered over the test piece and grips to increase the temperature to that required by the material specification. Special extensometers are used so that the actual measurement can be taken outside the furnace at room temperature on each side of the test piece. A minimum temperature soaking time of one hour is required to ensure that thermal expansion does not affect test readings.

3.11.2 **High Temperature Tensile Test.** After heating the test piece to the required temperature, a normal tensile test is carried out. A stress/strain graph must be drawn, either by manual or autographic means and used to determine the proof stress, Young's Modulus, tensile strength or elongation as required by the material specification. BS A4, Part 1, Section 2, details the procedures to be used and lays down the limits on stress and temperature.

3.11.3 **Creep and Rupture Tests.** When a metal is subjected to both stress and high temperature over a long period, continuous and permanent elongation takes place and this is termed "creep", the final fracture due to creep being known as "rupture". This phenomenon occurs within the normal limits of proportionality and must be studied when a metal is to be used in a high temperature environment in order to determine working clearances and component life. Figure 10 shows the effect of time on creep strain and it can be seen that the use of a material beyond the secondary stage would lead to rapid failure.

(i) Experimental tests of up to 30000 hours duration are frequently conducted in order to determine the creep characteristics of a material, but tests of this length are neither necessary nor desirable for routine testing purposes. Tests of 100 hours duration are typical of current material specifications and determination of percentage strain at a specified temperature and stress is normally sufficient to prove a batch of material. In some cases "time to rupture" is also required and this may extend the duration of the test.

(ii) Creep characteristics vary with changes in temperature making it essential to control the temperature of the furnace to within close tolerances. The tolerances specified in BS A4 are less than 1 per cent and to achieve this accuracy rare metal thermocouples (platinum/platinum-rhodium) are often used in controlling the furnace electronically. The thermocouples are calibrated frequently by comparison with the freezing points of pure metals.

(iii) Creep testing machines are fitted with a load maintaining device to ensure that the specified stress is maintained throughout the test.

(iv) The test pieces used for creep testing may be identical to those described in paragraph 3.2, but some material specifications require the use of a notched test piece and this is fully described in BS A4, Part 1, Section 3.

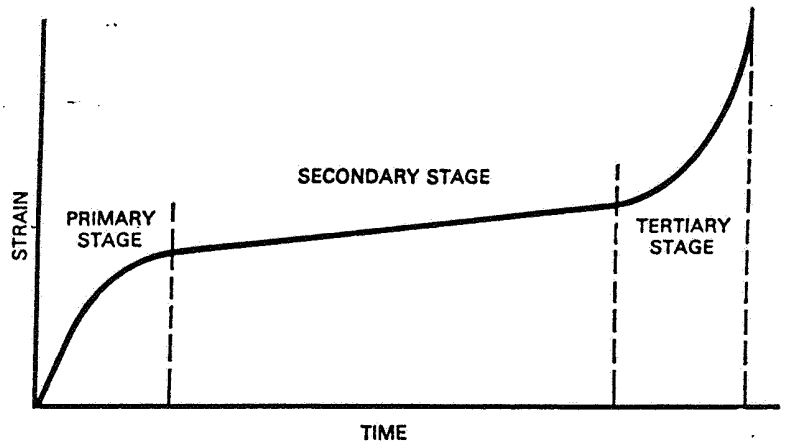


Figure 10 CREEP STRAIN/TIME DIAGRAM

4 DUCTILITY TESTS The ductility of a material is usually determined by means of a simple bend test, but other tests are often specified when a material is required for a particular use, i.e. wire, rivets or tubes. Information on the bend test requirements for weld test specimens is given in Leaflet **BL/6-4.**

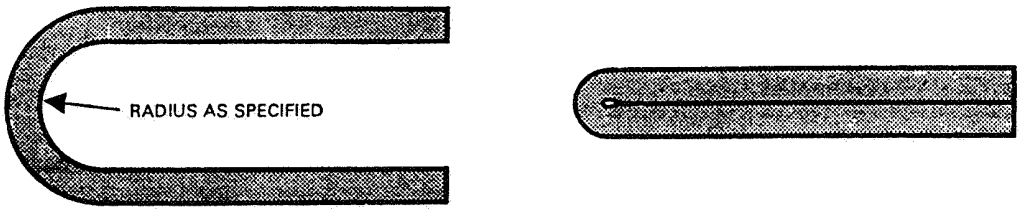
4.1 **Simple Bend Test.** The term "simple bend test" refers to a test in which a straight solid test piece of round or rectangular section is submitted to appreciable plastic deformation (without reversing the direction of flexure during the test) for the purpose of assessing the ductility of the material represented by the test piece. In some instances bend testing is considered to be an alternative or useful additional test to tensile testing and sometimes (but not often) it is used as an alternative test to the flattening test normally specified for tubular sections.

4.1.1 The capacity of a material to withstand deformation in a particular direction without cracking, or other specified forms of failure can be assessed by a simple bend test. The severity of the test is governed by the width/thickness ratio of the test piece for a given final internal radius. Experiments have shown that the test is less severe for a test piece of round section than for one of square section of equal thickness.

4.1.2 Where prescribed in the relevant specification, the simple bend test on sheets and strips used for aircraft purposes should, according to BS A4, be carried out on test pieces of 12.5 mm width, the edges of which should be smoothed and chamfered until approximately semi-circular in form. Such test pieces must be cut from the material in the direction relevant to the direction of rolling, as prescribed in the appropriate specification. The test should be made by bending the test piece through the angle (usually 180°) and over the radius prescribed in the specification, either by means of a former applied at mid-span (see paragraph 4.1.5), or by bending the test piece round a mandrel having the required radius (see paragraph 4.1.6).

4.1.3 During the bending of the test piece, it is often difficult to avoid a local decrease in the radius (a defect known as "peaking") but it should be noted that this may prevent comparison with results obtained by a different method of testing.

4.1.4 Where the standard or specification makes reference to a "close bend test" this indicates that the test piece should be bent through 180°, and that the "U" bend thus formed should subsequently be closed until the inner surfaces are in general contact. Examples of open and closed test pieces are illustrated in Figures 11 (a) and 11 (b) respectively.



(a) (b)

Figure 11 OPEN AND CLOSED TEST PIECES

4.1.5 Where thin materials are to be tested, the recommended method of producing the bend is by pressing the test piece into a block of soft lead using a former, as illustrated in Figure 12. To avoid damaging the test piece by excessive pressure, it should be pressed into the lead until it assumes an angle of about 90°, after which it should be bent around the former with the fingers or with a mallet until it assumes the standard "U" shape. During this later stage of manipulation, pressure on the former should not be increased.

NOTE: This method must be used when it is doubtful whether the metal will satisfy the bend test requirements.

4.1.6 A method of forming the test piece by means of a special bending machine is illustrated in Figure 13. Other methods of producing bends with formers used in conjunction with rollers, radiused supports or vee-blocks are given in BS 1639, and suitable methods of applying force to test pieces bent around mandrels are also given. Equipment for making bend tests is supplied with most of the universal testing machines.

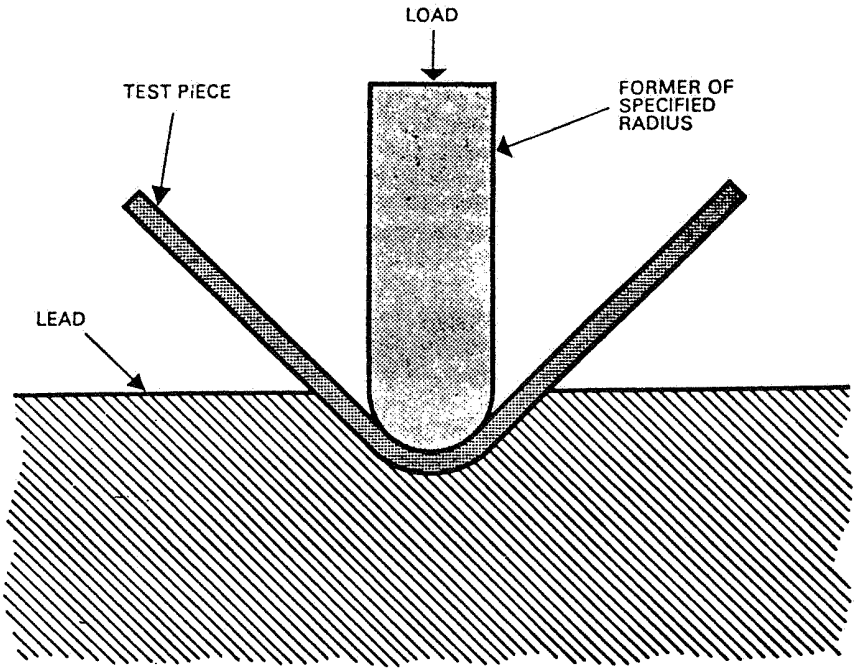


Figure 12 FORMING BEND TEST PIECE WITH LEAD BLOCK AND FORMER

4.1.7 When a test piece manufactured of ductile material is gradually bent from its original straight form through 180°, the "fibres" on the outer surface are stretched through the elastic limit and beyond to the yield point or even further, depending on the type of material and its physical condition. For a test to be satisfactory, the outer surface of the test piece must, after bending, be free from cracks visible to the naked eye, except that small cracks at the edges may be disregarded.

4.2 **Reverse Bend Test.** This test is specified for steel wire used for the manufacture of springs.

4.2.1 To make the test, one end of the test piece should be placed between suitable formers with inner edges rounded to a radius of 3 times the diameter or thickness of the material, the assembly being secured in a vice or testing machine.

4.2.2 The projecting end of the test piece should then be bent at right angles to the fixed end, first to one side and then the other (Figure 14), until the test piece breaks.

4.2.3 The number of bends the material should withstand without fracture is stated in the material specification.

4.2.4 As with the simple bend test, peaking (paragraph 4.1.3) is difficult to avoid and the results obtained by different methods of making the test are only approximate. If there is any doubt about the ability of a material to withstand the test, it must be tested in a machine which is reproducible in action, and which applies a component of axial tension sufficient to prevent peaking the test piece during the test.

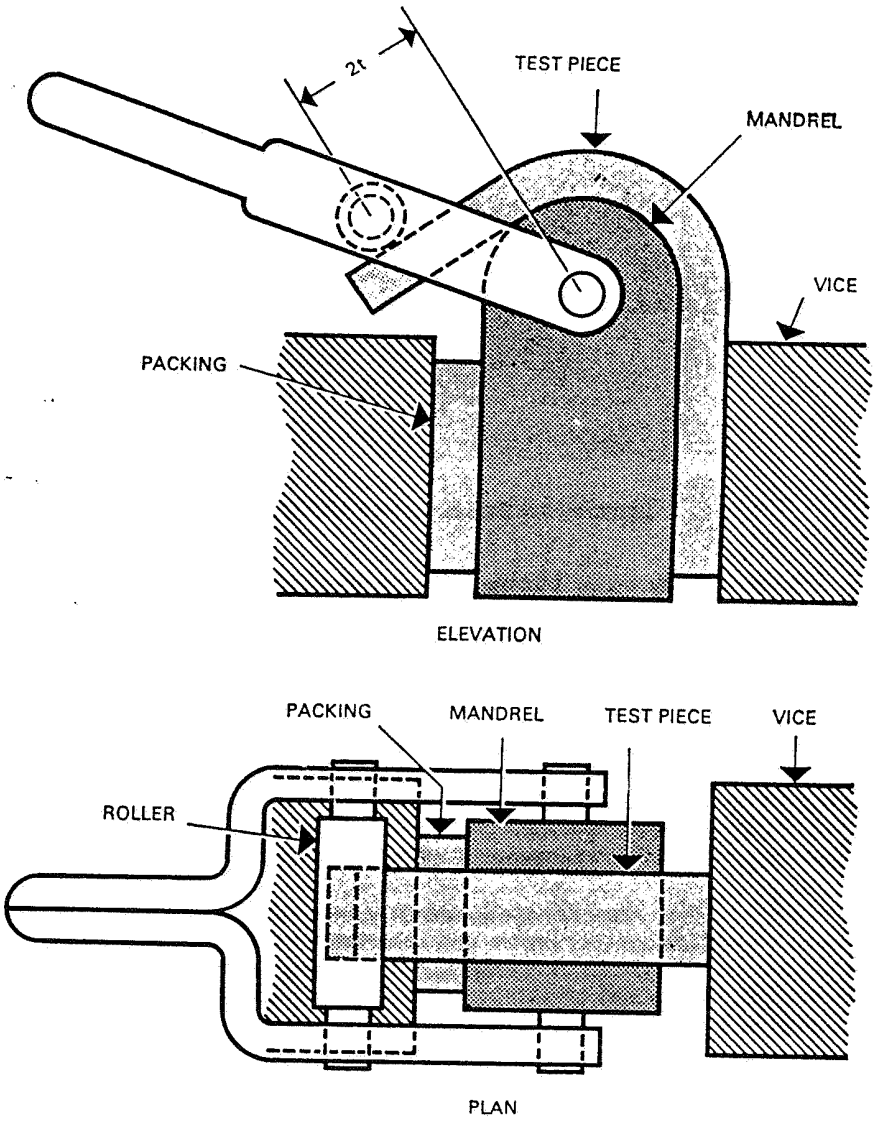


Figure 13 MACHINE FOR BENDING TEST PIECES

4.2.5 For a test to be considered satisfactory, the test piece must withstand the number of bends required by the specification without showing cracks visible to the naked eye, except that small cracks at the edges may be disregarded.

4.3 **Wrapping Test.** This test is sometimes specified for wire. The wire is wrapped around a former of the same diameter a specified number of times (usually 8) and then unwound. It must withstand this test without cracking.

4.4 **Torsion Tests.** These tests are also specified for wire, particularly that used for the manufacture of rivets, cables or bolts. There are two forms of tests.

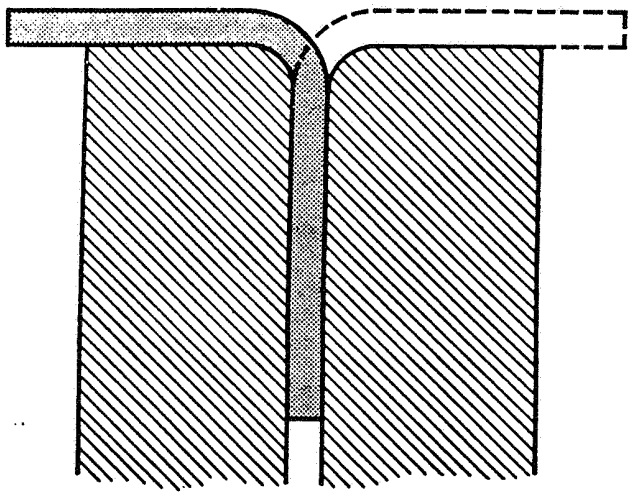


Figure 14 REVERSE BEND TEST

4.4.1 **Normal Torsion Test.** In this test a length of wire is selected (usually 100 × diameter) and twisted in a torsion machine which holds one end of the wire in a vice and rotates the other end at a speed of up to 60 revolutions per minute. The number of turns specified for steel wire is usually 15, but the test is continued until fracture occurs so that an examination of the fractured surface can be made.

4.4.2 **Reverse Torsion Test.** This is a test normally specified for wire from which bolts or rivets are manufactured. The test sample is gripped in two jaws which are a specified distance apart, one jaw being fixed and the other free to rotate. The free jaw is rotated a specified number of times in one direction and then turned back to the original position. No defects must be visible in the wire after test.

4.5 **Proof Bend Test.** This test is specified in some material specifications, usually for circular steel tubes, and as an alternative to a hardness test, on circular, solution-treated aluminium alloy tubes. It is only applied to tubes which are more than 12·5 mm diameter and which are neither too short nor too heavy for the testing machine (a length of approximately 1.5 m of tube is required to carry out the test).

4.5.1 The test procedure specifies that the test specimen shall be supported at two points and loaded at a third. This may be achieved by means of either a cantilever machine (Figure 15) or a beam machine on which the load is applied in the centre.

4.5.2 The particular material specification will state the 0.2 per cent proof stress figure to be used in calculating the bending moment to be applied to the machine. The bending moment is calculated from the formula:—

$$M = S \times \frac{(D^4 - d^4)}{32D \times 100}$$

Where M = Bending moment (Nm).
S = Specified proof stress (hbar).
D = Outside diameter of tube (mm).
d = Inside diameter of tube (mm).

4.5.3 **Testing Machine.** Figure 15 shows a typical approved testing machine of the cantilever type. A beam 'D' is pivoted at 'B' and loaded to give the required moment. The specimen 'T' is supported at 'A' and 'B' by suitably shaped blocks ('A' above and 'B' below) and a force 'F' is applied to raise the beam off the stop 'S'. Bending of the tube is recorded on the dial gauge 'G' at point 'C'.

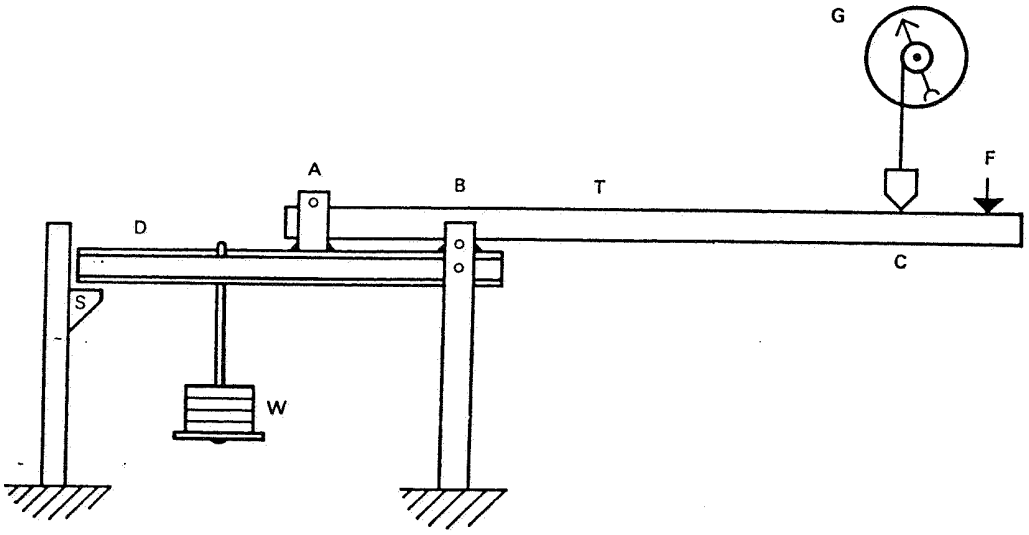


Figure 15 CANTILEVER PROOF BEND TESTING MACHINE

4.5.4 **Test Procedure**

(i) With the beam loaded to give the moment about its pivot which was calculated from the material specification and the formula given in paragraph 4.5.2, the tube is mounted between blocks A and B, and the dial gauge set to zero.

(ii) The force F is then applied to the tube until the beam is just lifted from its support. This force is maintained for 15 seconds and the dial gauge reading noted to record the elastic deflection of the tube.

NOTE: The elastic deflection may be calculated, if desired, from formulae quoted in the relevant testing instructions (e.g. BS T100 or L100). but in this case the distances AB and BC must be fixed.

(iii) Removal of the force will leave a permanent set in the tube and this will be shown on the dial gauge. Unless otherwise stated in the material specification, this reading must not exceed 5 per cent of the elastic deflection.

4.6 **Flattening Test.** This test may be applied to tubes of any shape or size, the selected test specimens being required to withstand, without cracking, flattening to a dimension stipulated in the appropriate material specification. Flattening is effected between flat surfaces by hammer blows or by pressure, a distance piece being placed inside the tube to limit the degree of flattening. Square or streamlined tubes are flattened across their diagonal or major axis as appropriate.

4.7 **Bend Test.** This test may be used as an alternative to the flattening test. A strip is cut transversely from the tube and bent 180° over a former of specified radius in such a way that the bore of the tube is at the inside of the bend. The strip must withstand this treatment without cracking.

4.8 **Drifting Test.** This test is applied particularly to light alloy tubing. The specimen must be cut at 90° to the longitudinal axis and all sharp edges removed. The drift is in the shape of a cone with (normally) an included angle of 30°, and is forced into the tube under steady pressure until the specified increase in tube diameter is obtained at the cut edge. The specimen must withstand drifting without any signs of cracking.

5 HARDNESS TESTS

5.1 General Requirements

5.1.1 Hardness is the resistance of a material to indentation and by pressing a suitably shaped indenter into the surface of the material being tested a comparison of hardness values can be made. Hardness values are normally required by the material specification and tests are also conducted to ascertain the effectiveness of case hardening, hardening and tempering, and heat treatment at the various stages of manufacture.

5.1.2 The surface hardness of a material is not always consistent and this is most evident in forgings and castings where irregular shape has led to uneven cooling. Similar conditions may be obtained by excessive grinding or machining which heat the surface, or by other manufacturing processes which may cause work hardening. Material specifications take these factors into account and require several impressions to be made and the mean value taken to calculate the hardness number. In other cases it may be necessary to make the test in a specified position (for example, on a portion of a casting which will be a bearing surface) and this will be stated on the relevant drawing.

5.1.3 Methods of measuring the size of the impression made by the indenter vary, but for the measurement of absolute (as opposed to comparative) hardness values, British Standards 240 and 427 stipulate that the surface area of the impression must be calculated, and the load applied to make the impression, divided by this area to give the hardness number. For production testing, and for checking the effectiveness of heat treatments, however, this is not essential and sufficiently accurate comparisons can be made by measuring the depth of the impression.

5.1.4 When test methods are used which require accurate measurement of the impression, the condition of the surface of the material is important and it is usually necessary to polish the test sample with fine grade emery cloth to obtain a satisfactory impression. This applies particularly when the indenter is lightly loaded. If direct readings are taken from the movement of the indenter, surface conditions are not so important; the only effect of a rough surface is the negligible difference in resistance offered to penetration of the indenter.

5.1.5 The rate of application of load to the indenter is specified in the relevant British Standard and is usually controlled automatically. In cases where the rate of application is controlled manually it should be remembered that rapid loading will induce a measure of kinetic energy and result in a deeper impression and lower hardness number.

5.1.6 The three main methods of carrying out hardness tests are outlined in BS A4 and described in the subsequent paragraphs. Other types of machine may be used but the type of indenter, load applied, and methods of measuring the impression, must comply with the appropriate standard. Material specifications normally stipulate the Brinell test for hardness measurement, but if this is unsuitable for any reason the Vickers test may be used. The relative values of hardness numbers derived from these two tests are shown in BS 860. For comparative measurement the Rockwell test is permitted.

5.2 **Brinell Test.** In the Brinell test a spherical indenter is used and a specified load applied by means of a press. The hardness number is obtained by dividing the force used by the spherical area of the impression.

5.2.1 The size of the impression is determined by measurement of the diameter, and the spherical area calculated from the formula:—

$$\frac{\pi D}{2}\left[D - \sqrt{(D^2 - d^2)}\right]$$

Where D = diameter of ball.
d = diameter of impression.

The measurement is made by means of a microscope engraved with a suitable graticule.

5.2.2 It would be possible to calculate the spherical area of the impression from measurement of the depth, but this is not done for three reasons:—

(i) The lip formed round the edge of the impression is not consistent but varies with different metals. Measurement from the normal surface would be difficult.

(ii) Elastic recovery after removal of the indenter is proportionally much greater in depth than in diameter and would yield larger errors.

(iii) The depth of the impression is much less than the diameter, and errors in measurement would be proportionally greater.

5.2.3 Originally the diameter of the Brinell indenter was 10 mm and the force employed 3000 kgf. The size of the impression made thus limited the method to the testing of large pieces, and was impracticable for testing soft metals or thin sheets. Furthermore, the results obtained were not proportional due to the shape of the indenter; the diameter (d) varied in relation to the spherical area.

5.2.4 In order to obtain comparable results and permit the use of the Brinell test on all types of metal a method was determined which produced a geometric similarity in all cases. It was found that if a d/D ratio of 0.25 to 0.5 was maintained, comparable results were achieved. It was also found that if the ratio of pressure $(P)/D^2$ was kept constant for a particular metal then different sized balls could be used and would give the same hardness number. This constant (P/D^2) is listed in BS 240 for various metals; examples being, steel: 30, aluminium alloy: 10, copper: 5, lead: 1. Ball diameters are standardised at 1, 2, 5 and 10 mm. Thus when testing steel with an indenter of 5 mm diameter, a force of $D^2 \times 30$, i.e. $5^2 \times 30 = 750$ kgf must be used. For a material not listed it would be necessary to carry out a series of tests using different loads until an impression giving a d/D ratio near to 0.375 was obtained. The constant P/D^2 could then be calculated for this material for future reference.

5.2.5 The accuracy of the results obtained by the Brinell test depend on the formation of an accurate impression and it has been found that, when testing hard steel, deformation of the ball indenter leads to inconsistent results. Steel balls are satisfactory up to hardness values of approximately 500, and this can be extended to about 630 by use of a work-hardened ball. Above this value, results, although satisfactory for purposes of comparison, are not proportional to those obtained on softer materials. This means that the Brinell hardness number (written HB) 300 is twice as hard as HB 150, but HB 800 is not twice as hard as HB 400.

5.2.6 **Brinell Machine**

(i) The standard Brinell machine operates hydraulically. A handpump is used to increase pressure in the operating cylinder and a form of dead-weight control ensures application of the correct force. When pressure in the cylinder reaches the correct value a proportional weight lifts and remains "floating" for as long as the correct force is being applied to the indenter.

(ii) A number of similar machines are manufactured which are used for carrying out Brinell tests, the main improvements being in the rapidity of testing. All must use a ball indenter and load calculated in accordance with the Brinell method however, and measurement of the diameter of the impression must be made in order to comply with BS 240.

(iii) Measuring microscopes with a graticule scale are often used to measure the mean diameter of the impression but in some machines the image is projected onto a ground glass screen for direct reading.

(iv) To obviate the need to make the calculation $HB = \frac{P}{\frac{\pi D}{2}\left[D - \sqrt{(D^2 - d^2)}\right]}$, tables are provided in BS 240 from which the hardness number may be read directly by entering the mean diameter of the impression. It should be noted that these tables provide for d/D ratios outside the range to 0.25 to 0.5 which means that hardness values obtained from the extremities of the tables will not be proportional.

5.2.7 **Test Blocks.** In order to check the accuracy of the machine being used, test blocks of a specified hardness are provided by the manufacturer. A normal hardness test carried out on these blocks will verify readings obtained on the machine. The hardness number of the test block used should approximate to that of the material to be tested.

5.2.8 **Testing Precautions.** In order to ensure satisfactory results from a test the following precautions should be observed:—

(i) Surface of material should be smooth. If circumstances permit, it is advisable to polish lightly with fine emery paper to remove any surface defects.

(ii) The impression should not be near an edge. BS 240 states that the minimum distance from the edge is $2\frac{1}{2} \times$ diameter of impression.

(iii) The thickness of the material to be tested must be at least 10 × depth of impression. BS 240 contains a table showing the minimum thickness of material to be used in tests with standard balls at various loads.

(iv) The test specimen should be adequately supported and square to the ball holder.

(v) Load should be applied for 15 seconds.

(vi) Diameter of impression should be measured in two places at right angles and the mean value taken to find the hardness number.

(vii) When quoting results of the Brinell test the ball diameter and load should also be quoted, e.g. HB 10/3000 = 240.

5.3 **Vickers Test.** The Vickers hardness test is similar to the Brinell in that an impression is made by applying a load to an indenter and the hardness number is derived from measurement of the impression.

5.3.1 In the Vickers test a diamond in the shape of a square based pyramid is used and the measurement is made across the diagonal (d) of the impression. The hardness number is derived from the formula:—

$$HV = \frac{2P \sin \theta/2}{d^2}$$

Where P = load (kg).
d = diagonal of impression (mm).
θ = included angle between faces of pyramid.
HV = Vickers hardness number.

5.3.2 The included angle between opposite faces of the pyramid is 136° and is derived from the ideal form of Brinell impression (d/D = 0.375). This ensures that hardness numbers on the Vickers and Brinell scales coincide approximately until increased pressure on the ball indenter causes distortion and divergence from the true scale. By using a diamond indenter of this shape, geometric similarity is assured and a proportional scale of hardness numbers is achieved. As no distortion of the indenter occurs, much higher values of hardness may be tested by this method.

5.3.3 As the Vickers system gives a constant angle of indentation, any change of load will be accompanied by a proportional change in the size of impression, so that the hardness number for a given material will always be the same, regardless of the load applied. The advantage of this is that the load can be altered to suit the material under test; a small load would be used on thin sheet or a finished product. Standard loads of 5, 10, 20, 30, 50, 100 and 120 kg are used whenever possible, but it is recommended that the largest practicable load be used to reduce the effects of surface irregularities, and to minimise errors in measurement.

5.3.4 **Measurement.** The square impression made by the diamond pyramid has distinct advantages over the circular impression with regard to measurement. The lip formed by the indenter is confined to the sides of the square impression, thus errors in measurement are less and arise only from the slight difference in area between the form of the impression and a true square. Measurement across the points is also much easier and more accurate than measurement of a circular impression.

5.3.5 **Vickers Machine** (Figure 16). In this machine the load is applied directly by weights, the rate and duration of loading being controlled automatically to that required by BS 427. Proportional weights are hung on a scale pan at the rear of the machine to give the required force on the indenter. Leverage on the arm operating the indenter is 20:1 so that only small weights are required and these may be selected according to the type of test being undertaken.

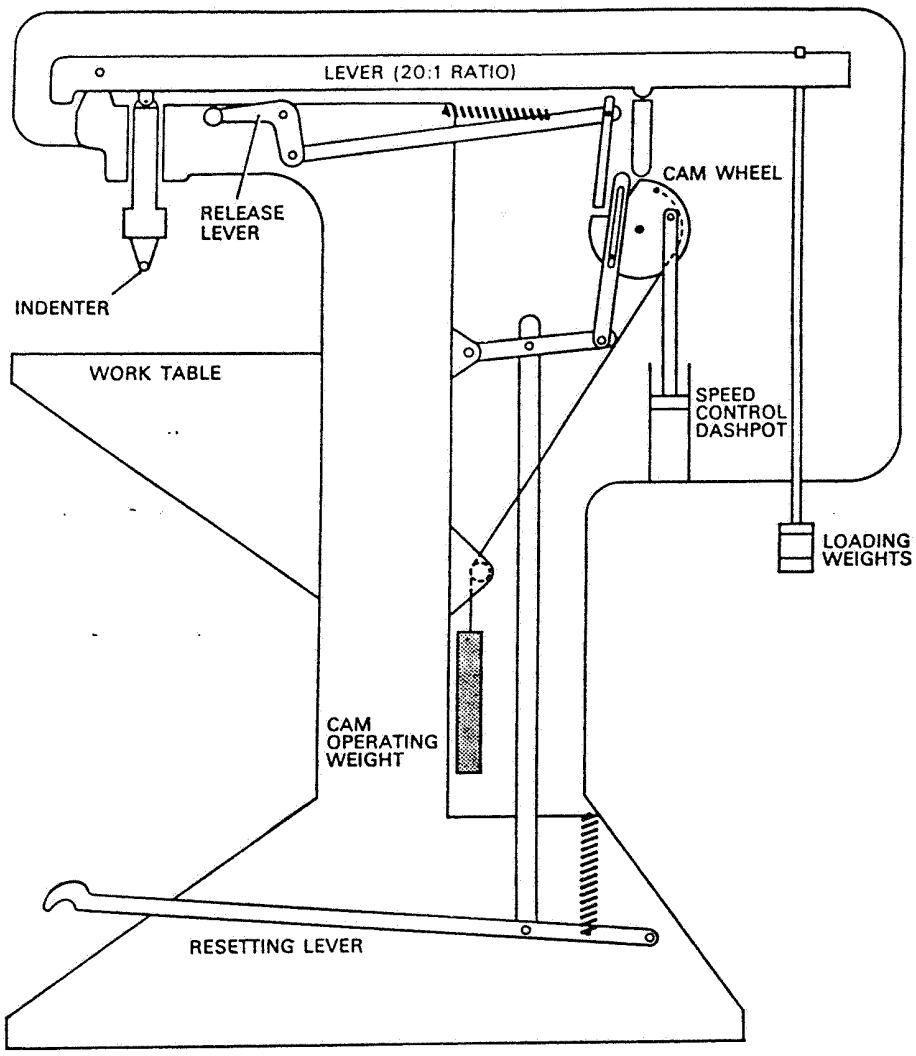


Figure 16 VICKERS HARDNESS TESTING MACHINE

5.3.6 **Optical Microscope.** The measuring microscope is an integral part of the machine and is mounted alongside the indenter. The test sample is attached to a sliding table and may be moved into the range of the microscope immediately after an impression is made.

(i) The eyepiece incorporates knife edge adjusters for measurement of the impression as shown in Figure 17. The adjuster for 'A' is the datum adjuster and moves all knife edges together, while the adjuster for 'B' is connected to a digital counter for easy reading of the diagonal dimension (in mm).

(ii) A normal reading is made in the following manner:—

(a) 'A' is set against the left-hand corner of the impression.

(b) 'B' is adjusted until it touches the right-hand corner of the impression and the reading noted.

(c) The microscope is swung through 90° and steps (a) and (b) repeated for the other diagonal.

(d) The mean diagonal dimension is entered in the appropriate table in BS 427 to find the Vickers hardness number.

(iii) On some machines a third knife edge 'c' is incorporated in the microscope and is used for rapid production testing when the hardness is required to be within a stipulated range. In this case the procedure is as follows:—

(a) Set knife edge 'B' to the reading which gives the maximum hardness value.

(b) Bring 'C' up to 'B'.

(c) Reset 'B' to the reading which gives the minimum specified hardness value.

(d) Carry out a test, then line up knife edge 'A' with the left-hand corner of the impression.

(e) If the hardness of the material is satisfactory then the right-hand corner of the impression will be between knife edges 'B' and 'C' as shown in Figure 17(b).

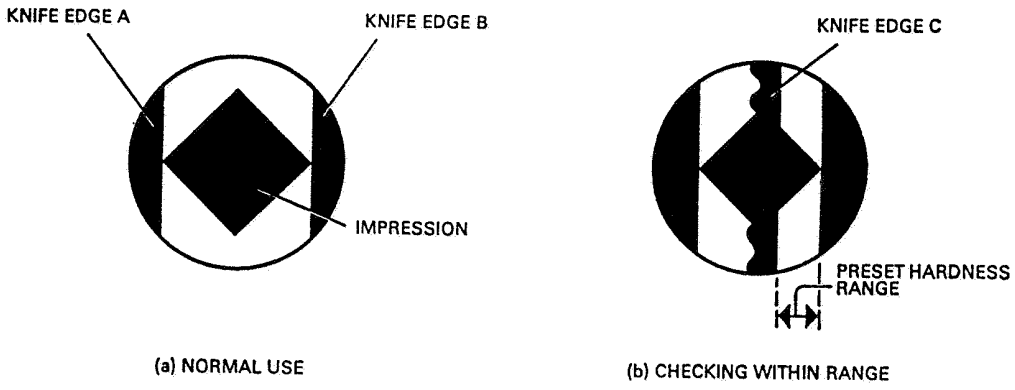


Figure 17 MEASUREMENT OF VICKERS IMPRESSION

5.3.7 **General Observations.**

(i) The Vickers machine may be verified by use of test blocks of known hardness as described in paragraph 5.2.7.

(ii) In view of the small size of the impression made by the Vickers test, the condition of the surface of the test sample is of more importance than with the Brinell test and should be either ground or polished to ensure accurate results.

(iii) When testing case hardened materials several impressions should be made at increasingly lighter loads until two identical readings are obtained. This is necessary due to the effect of the softer core on the thin case-hardened layer.

(iv) When reporting the results of Vickers hardness tests the load used should also be included, e.g. HV/5 = 550, indicates a Vickers hardness number of 550 using a 5 kg load.

(v) Tables of Vickers hardness numbers for various standard loads will be found in BS 427.

5.4 **Rockwell Test.** The Rockwell method differs from the previously discussed tests in that the depth of penetration of the indenter is gauged mechanically and indicated directly to the operator. No physical measurement is necessary.

5.4.1 Because of the method of measurement, the Rockwell test is not suitable for the measurement of absolute hardness numbers and is not normally permitted by material specifications. The scale of hardness numbers is proportional to the depth of penetration of the indenter and not to the hardness of the material (1 scale unit = 0.002 mm penetration). It is a very useful method of making rapid hardness tests during the manufacture of a material however, as preparation of the surface is usually unnecessary.

5.4.2 Two types of indenter are used; a steel ball for use with unhardened steel and soft metals, and a spherical tipped diamond cone known as a 'Brale' indenter for use with harder materials.

5.4.3 The method of forming the impression is as follows:—

(i) A light (minor) load is applied to the indenter and the dial gauge set to zero.

(ii) A heavier (major) load is applied to the indenter and released when the dial needle has settled.

(iii) The hardness number is then read directly from the dial gauge with the minor load still applied.

5.4.4 This method ensures that the machine is under the same stress when the dial is set and when the reading is taken thereby taking into account machine factors and backlash. The elasticity of the material is of no importance as it does not enter into the hardness reading.

5.4.5 A number of different dial scales may be used in the Rockwell machine depending on the particular tests being carried out. The scales 'B' and 'C' are most used, and are included on a single dial. The 'B' scale is used with a 1.588 mm ($\frac{1}{16}$ inch) diameter ball indenter and major load of 90 kg, while the 'C' scale is used with a 'Brale' indenter and major load of 140 kg. A 10 kg minor load is used in each case. Scale units are identical but the 'C' scale zero coincides with the 'B' scale 30. Other scales are used for special purposes, e.g. thin sheet material, very soft metals or very hard metals.

5.4.6 Because of the different scales available with this method of hardness testing it is necessary to specify which was used for a particular test, e.g. HR/C40 indicates a Rockwell hardness number of 40 on the 'C' scale.

5.4.7 **Standard Rockwell Machine.** In the working of this machine, the minor load is applied by raising the test specimen to the indenter and continuing upward movement until the required load is indicated by a small pointer on the dial gauge. The major load is provided by a lever and proportional weight and applied by means of a release lever, rate of application being controlled by a dashpot to ensure consistent readings. BS 891 describes the use of this machine.

5.4.8 **Rockwell Superficial Hardness Tester.** This machine operates on the same principles as the standard machine, but is only used for the 'N' and 'T' scales. The minor load is only 3 kg and major loads used are 15, 30 and 45 kg. One scale unit is equal to a movement of 0.001 mm, therefore the scale is more accurate than on the standard machine. The machine is ideally suited for testing very thin metal sheet or finished products where a small indentation is essential. BS 4175 deals with the methods to be used for Rockwell superficial hardness tests.

5.5 **Care of Equipment.** Proper maintenance of the equipment is essential if consistent results are to be obtained. This is particularly important when light loads are used and the effects of friction become more pronounced.

5.5.1 Pivots and bearings should be examined periodically and particular attention paid to knife edges which support heavy loads.

5.5.2 Damage to indenters may occur, and will usually be noticed on the Brinell and Vickers test when the impression is viewed under the measuring microscope. The impressions made by the Rockwell indenters are not viewed, however, and these indenters should be examined for damage at frequent intervals.

5.5.3 Measuring microscopes should be checked by means of a calibrated scale to ensure that the focus is correct.

6 IMPACT TESTS Impact tests are necessary as a check of the impact resistance qualities of a metal and to ensure that temper brittleness has not been introduced during heat treatments. There are two types of machine used for testing aircraft materials, both of which use a pendulum weight to fracture the specimen. The energy absorbed by the specimen is measured from the angle through which the pendulum swings after causing the fracture. The Izod test is quoted in the majority of British material specifications but when there is a requirement for testing at sub-ambient or elevated temperatures the Charpy test is recommended. This is because of the difficulties associated with mounting the test piece in the Izod machine and completing the test within the stipulated 6 seconds after removal from the heating/cooling bath. The Izod machine is illustrated in Figure 18.

NOTE: Perusal of BS 131 will show that pendulum energy is still quoted in ft lb and that test results should include this unit. It will also be noted that while the standard square test pieces are dimensioned in millimetres the Izod round test piece is demensioned in inches. The S.I. unit being introduced as the unit of energy is the joule (J) and this will be stipulated in some material specifications. 1 ft lb = 1.356J.

6.1 **Test pieces.** The standard impact test pieces are illustrated in Figure 19. Subsidiary test pieces are permitted when the test specimen is too small to permit manufacture of the standard test piece, but it should be noted that no reliable relationship has been established between results obtained with test pieces of different sizes. Results obtained with identical test pieces on different types of machine are also difficult to correlate, so that comparisons should only be made between tests on similar machines using identical test pieces.

6.1.1 Test pieces are notched to concentrate stress and may have one, two or three notches depending on the test requirements of the particular material. The position of the notch in relation to the direction of rolling is most important and should always be at right angles to the grain flow. With small bar specimens the test piece can only be prepared in this way but with larger material it may be possible for the notch to be cut *with* the grain flow and this would result in very low impact test result

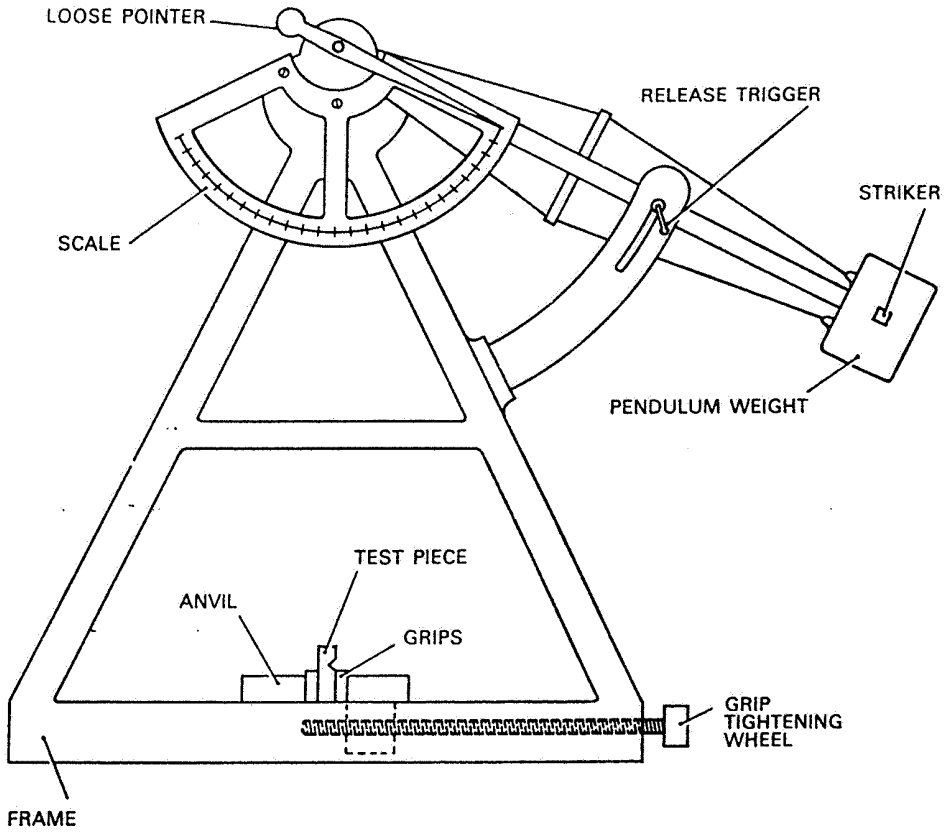
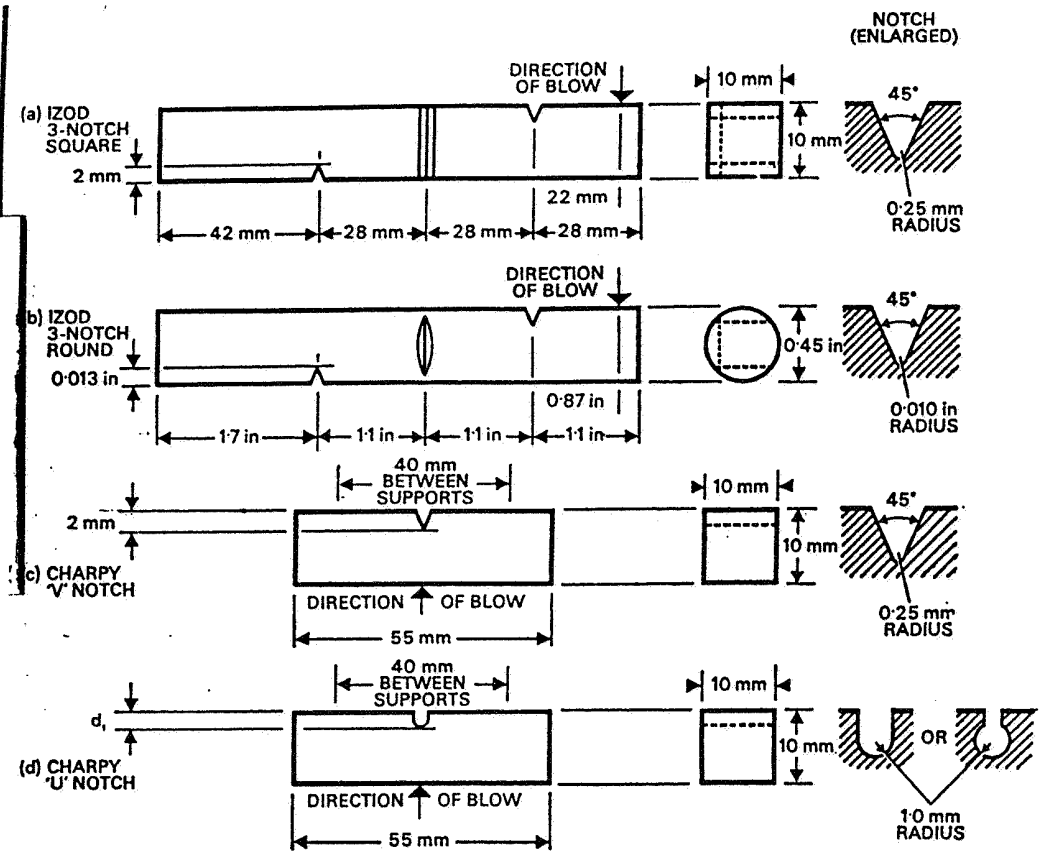


Figure 18 IZOD IMPACT TESTING MACHINE

6.1.2 BS 131 stipulates that test pieces shall be machined all over to ensure accurate results. The condition of the notch is particularly important with some materials and the relevant specification may require it to be formed in a certain way; otherwise it may be cut by any suitable machining operation which will provide a smooth contour. Reference should be made to this British Standard for details of dimensional tolerances.

6.2 **The Izod Test.** This test is carried out on a machine with a striking energy of, normally, 120 ft lb (163J) although smaller machines of 20 ft lb (27J) and 60 ft lb (81J) energy are sometimes used for testing materials of low energy absorption. A cantilever type of test piece, mounted in a vice at the base of the machine, is fractured by means of a striker attached to a pendulum weight.

6.2.1 A trigger mechanism is used to release the pendulum from the 'cocked' position and it then falls through an angle of 60° to strike the test piece at a distance of 22 mm above the notch. As the pendulum continues its swing it carries with it a loose pointer which stops at the maximum angle reached by the pendulum. The energy absorbed by the test piece is recorded on a scale located behind the pointer.



NOTE: depth of notch (d_1), for 'U' notch is 2, 3 or 5 mm and for 'keyhole' notch 3 or 5 mm. Required depth is stated in material specification.

Figure 19 STANDARD IMPACT TEST PIECES

6.2.2 It is important that the test piece is gripped in the vice so that the notch is level with the surface of the rear jaw and facing the striker. A simple gauge is provided with the machine to assist in achieving this position.

6.3 **The Charpy V-Notch Test.** BS 131 states that this test should be carried out on a machine with a striking velocity of 4.5 to 6.0 m/s and also specifies two striking energies; 100 to 120 ft lb (136 to 163J) and 200 to 240 ft lb (272 to 326J). The Charpy machine satisfies these requirements by using a pendulum fitted with detachable weights. The angle through which the pendulum falls is 160° in both cases. The machine may also be adapted for making Izod tests by changing the pendulum head and fitting a cantilever test piece attachment.

6.3.1 The test piece used for normal tests is illustrated in Figure 19 (c), and is mounted horizontally on the machine with the notch facing away from the pendulum and in line with the striker. It rests on supports 40 mm apart, and because of the ease of mounting tests may be performed quickly. For this reason the Charpy machine is ideal for conducting tests at sub-ambient or elevated temperatures.

6.3.2 The method of measuring the energy absorbed by the test piece is the same as on the Izod machine, but in this case a triple scale is employed from which the maximum rise of the pendulum may be read in degrees, in kgm or in kg/mm².

6.3.3 For normal use the pendulum is held by a trigger stop at an angle of 160° from the test piece, but a second stop is sometimes provided from which the pendulum may be released when carrying out a test to Izod requirements.

6.3.4 The size of pendulum weights to be used will normally be dictated by the material specification and will generally be such that a striking force of 100 to 120 ft lb (136 to 163J) is applied only to materials with impact values less than 50 ft lb (68J).

6.4 **The Charpy U-Notch Test.** This test is carried out on a standard Charpy machine but uses the test piece shown in Figure 19 (d). The shape of the notch has no significant effect on the test and, for ease of manufacture, may be chosen from either of those shown in the illustration. The depth of notch to be used will be stated in the relevant material specification (usually 5 mm).

6.5 **Care of Equipment.** Impact testing machines are initially calibrated by direct measurement of the weights, angles and dimensions involved, and these should not require alteration. The nature of the test is such, however, that considerable shocks are transmitted to the machine and the following periodical checks are recommended to ensure continued accuracy:—

(i) Check that the machine is vertical by means of a spirit level placed on the vice or test piece supports as appropriate.

(ii) Operate the machine normally but without a test piece and ensure that the loose pointer registers zero.

(iii) Hang the pendulum vertically and ensure that the appropriate energy is indicated on the scale.

(iv) Inspect the striker and the vice or test piece supports for signs of dents, cracks or other damage which could affect test results.

(v) Lubricate the pendulum bearing and vice operating mechanism in accordance with the manufacturer's instructions.

BL/10-9

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BASIC

TESTING OF MATERIALS AND CHEMICAL SOLUTIONS

PERFORMANCE TESTING OF PENETRANT TESTING MATERIALS

1 INTRODUCTION This leaflet gives guidance on tests devised to show whether materials used for the penetrant inspection processes described in Leaflet **BL/8-2**, Penetrant Dye Processes, and Leaflet **BL/8-7**, Fluorescent Penetrant Processes, are in a satisfactory condition for further use.

1.1 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.

1.2 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.

1.3 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 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.

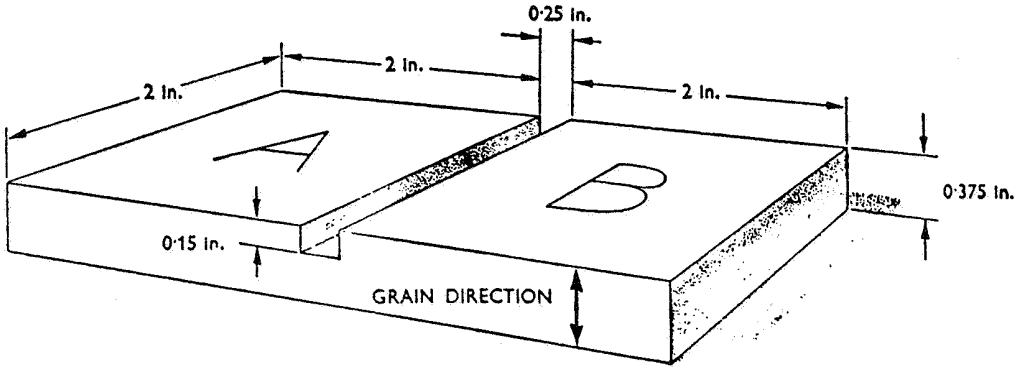

Figure 1 TEST PIECE