

MODULE 17



7250 West Credit Avenue, Mississauga, Ontario L5N 5N1 Tel: (905) 542-2176 Fax: (905) 542-1318

MODULE 17

**SURFACE
INSPECTION****CONTENTS**

Introduction and objectives	1
Liquid penetrant inspection	2
Basics	2
Properties of penetrants	6
Methods of excess penetrant removal	8
Types of developer	9
Procedures for liquid penetrant inspection	11
Interpretation	22
Personnel qualifications	27
Magnetic particle inspection	28
Magnetism	28
Methods of magnetic particle inspection	34
Procedures	41
Interpretation	42
Personnel qualifications	46
Other inspection methods	48
Flux leakage methods	48
Eddy current method	49
Potential drop method	52
Leak testing	53
Summary	54
Guides and exercises	55

MODULE 17

SURFACE INSPECTION

Introduction

Many potential defects in welds are discontinuities open to the surface. Cracks, in particular, often break the surface although they may be too fine to see with the naked eye. They may, however, be detected with various surface inspection techniques such as those described in this module. Surface inspection methods can be considered as extensions of visual inspection, enhancing the ability to find defects open to the surface, although some techniques have a limited ability to detect defects just below the surface. Surface inspection methods are not complex, but since there may be some potential safety or health hazards such as the use of solvents, ultraviolet light, or electrical equipment, they should only be used by trained and qualified personnel. Module 1 provides some information on safety aspects in welding, and the suppliers should be consulted for detailed information.

In this module the two most important methods—liquid penetrant and magnetic particle—will be discussed in some detail with only brief mention of some other surface inspection methods.

Objectives

The objectives of this module are to provide the inspector with a clear understanding of the main surface inspection techniques and their method of application on welds. After successfully completing this module you should be able to:

- Describe the basic principles of the main surface inspection methods
- Explain how the methods are applied to welds
- Describe the equipment used, procedures, and techniques
- Recognize causes of false and nonrelevant indications
- List advantages and disadvantages of the main methods

Basics

LIQUID PENETRANT INSPECTION

Liquid Penetrant Inspection (LPI, also called Penetrant Testing, PT) is a versatile method capable of locating cracks, porosity, laps and folds which are open to the surface. The method is based on the ability of the penetrating liquid to be drawn into a discontinuity. When the object is wiped clean, the liquid remains in the discontinuity but can be drawn out by adding a developer, such as a fine powder, which acts as a blotter. The penetrant shows up against the developer providing an indication of the discontinuity on the surface.

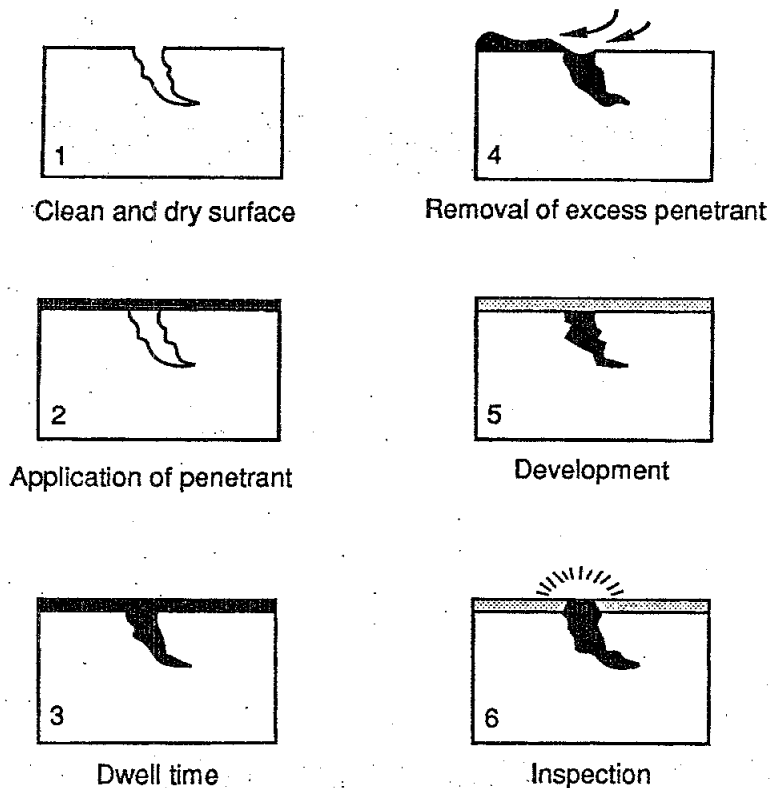


Figure 1.. The principle of liquid penetrant inspection.

ESSAY TYPE TEST QUESTION.

There are six basic steps involved in performing LPI which are illustrated in Fig. 1.

1. Prepare the surface of the part to be inspected by cleaning and degreasing.
2. Apply the penetrant to the surface.
3. Allow a period of time for it to be drawn into any discontinuities.
4. Remove the excess penetrant in a manner that ensures retention of the penetrant in any discontinuities.
5. Apply a developer to draw the penetrant liquid from the discontinuities out to the surface and thereby provide an enhanced indication of the discontinuities.
6. Examine and assess the discontinuities visually under appropriate viewing conditions. Clean the part and, if necessary, apply a corrosion preventative.

It is a simple, inexpensive method, but a good understanding of how it operates and the correct procedures are necessary to get the best results. First, let us consider the basic principles on which the method is based.

Consider the forces acting on the molecules in a liquid (Fig. 2). For a molecule within the bulk of the liquid there are other molecules all around it, and the net force on the molecule is zero. But a molecule in the surface layers of the liquid only has other molecules below it. There is thus a net attraction on the surface molecule tending to pull it into the bulk. As a result of this the surface has an energy which is usually described in terms of a tension force—the *surface tension*. The surface tension is the property that makes liquids try to reduce their surface area—the reason liquids tend to break up into little droplets when spilled.

Surface tension

Surface Inspection

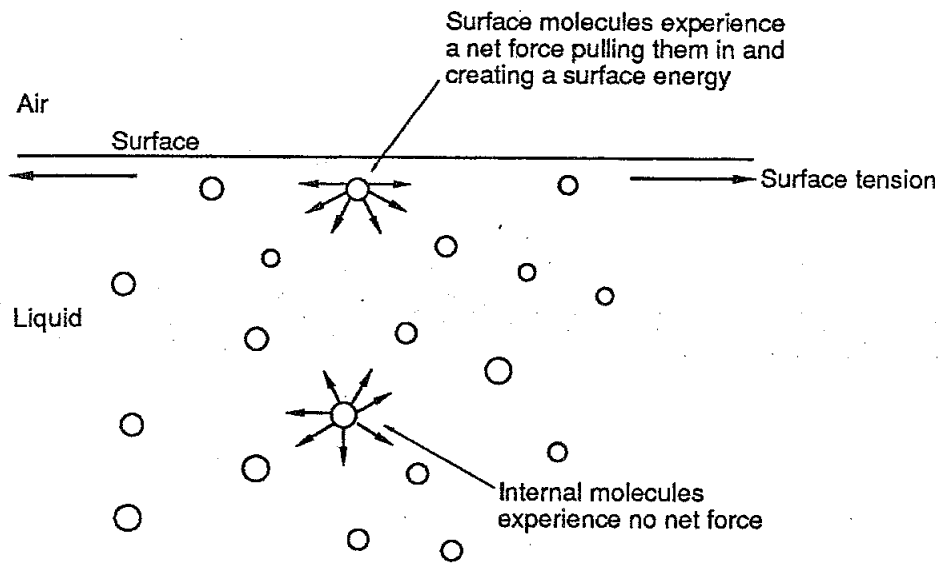


Figure 2. The origin of surface tension forces in a liquid.

Wetting

When a liquid is placed on a solid it may take a variety of shapes. Some liquids form balls whereas others might spread out into thin films (Fig. 3). At the point where the liquid touches the solid a specific angle is formed for a given liquid and solid. This is the *contact angle* which depends on many factors including the properties of the solid and the surface tension of the liquid. If the contact angle is very small, the liquid 'wets' the solid. The contact angle for a liquid can be reduced by adding a detergent (a 'surfactant') and thereby improving the wettability.

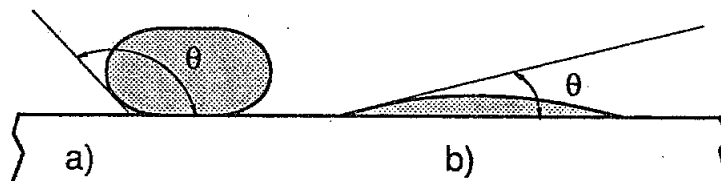


Figure 3. The shape of a drop on a solid depends on the contact angle, θ . In a) the contact angle is large and a droplet forms. In b) the contact angle is small and the liquid spreads out wetting the surface.

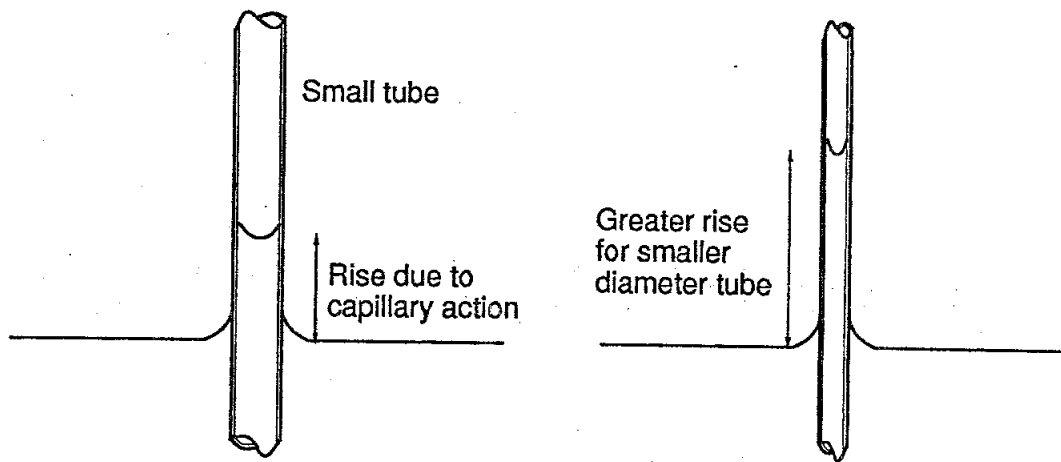


Figure 4. The rise of water in a small glass tube due to capillary action.

Capillary action

Has BEEN
T.A.

These properties influence the phenomenon of *capillary action*. When a small glass tube is dipped into water, the water tends to rise up the tube above the level in the surrounding water. The extent of the rise depends on surface tension, the contact angle, and especially on the diameter of the tube (Fig. 4). For very small diameter tubes the rise can be quite appreciable giving the impression that the liquid is 'defying gravity.' Capillary action is responsible for the rise of sap in a tree. It is also the principle behind liquid penetrant inspection.

The liquid penetrant placed on a surface does not just seep into a crack. It is drawn in through capillary action. It does not depend on gravity so it works in any position. The undersurface of a component can be examined because the penetrant will be drawn up into discontinuities even against gravity. It is also clear that the ability of a penetrant to be drawn into a defect depends critically on the properties of the liquid and the surface to which it is applied. Grease or other contaminants on the surface could prevent the capillary action from taking place and prevent useful examination. To be effective, the liquid penetrant inspection method requires careful attention to preparation of the surface.

Properties of penetrants

The penetrants used in inspection are commercially available liquids containing visible dyes that have been carefully formulated to combine a large number of desirable properties (see sidebar). The foremost requirement is, of course, the ability to penetrate very small openings which depends on the surface tension and wetting ability. The rate at which the liquid flows and penetrates openings is influenced by the *viscosity*. High viscosity liquids penetrate slowly but low viscosity liquids may drain away too rapidly with a tendency to drain out of shallow defects.

Penetrants should essentially be nonvolatile although a small amount of evaporation at the defect helps to intensify the dye content and prevent excessive spreading of indications. Rapid evaporation of volatile solvents could imbalance the formula of the penetrant, decrease the ability to spread, and cause the penetrant to dry up.

A further desirable property of a penetrant is that it not lead to corrosion of the part being tested. The compatibility of the inspection materials with the metal under test should be checked, particularly when dealing with special alloys (e.g., titanium and nickel alloys) that could be sensitive to specific elements such as sulphur or chlorides (halogens).

Classification of methods

There are several methods by which the penetrant principle is used in inspection, and the standards—such as ASTM E-165—group them in various ways. Penetrant inspection methods can be classified according to the

- Type of dye
- Method of excess penetrant removal
- Form of developer

Types of dye

In order for the penetrant to contrast with the developer to reveal the presence of a defect, the penetrant contains a dye. Two types of dyes are used:

- Fluorescent
- Nonfluorescent or visible

Properties of an Ideal Penetrant

- Penetrates very fine openings
- Remains in coarse openings
- Resists evaporation
- Easily removed from surface
- Mobility to reappear from openings quickly
- Spreads in very thin films
- Resists colour fading
- Noncorrosive
- Nonflammable
- Stable under storage
- Nontoxic
- Inexpensive

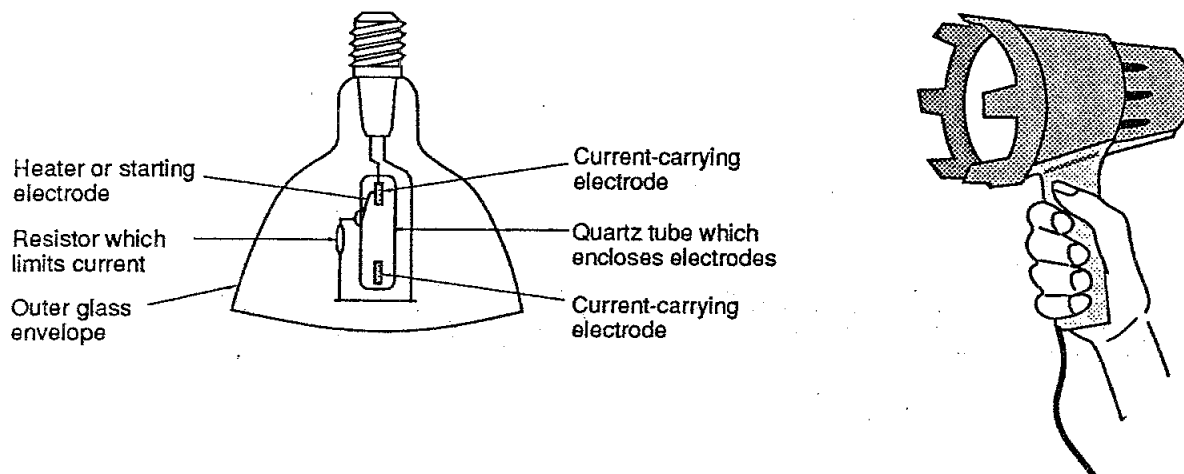


Figure 5. Mercury vapour lamp used as a source of black light (ultraviolet radiation) for viewing fluorescent penetrants.

Fluorescent dyes are almost colourless but they emit visible light when viewed under ultraviolet radiation, commonly called 'black light' (Fig. 5). Viewing must be in a darkened area so that the fluorescent dye contrasts with the developer. Different levels of fluorescent brilliance are available (known as the fluorescent index). Nonfluorescent (visible) dyes are brilliant coloured dyes (usually bright red) that are visible under normal lighting conditions. The coloured dye contrasts with the developer which is usually white.

Methods of excess penetrant removal

There are four basic methods used for removing the excess penetrant. These are:

- Direct removal by water washing
- Addition of an emulsifying agent (lipophilic remover) prior to water washing
- Addition of a detergent (hydrophilic remover) prior to water washing
- Use of a volatile solvent remover

The water-washable (WW) fluorescent penetrant process is applied to testing of castings, welds, and rougher forgings particularly in light magnesium and aluminum alloys. In the airframe industry water-washable fluorescent penetrant inspection is used for structural parts such as wing stringers and wheels. In the production of turbine engines the process is used for inspecting flame tubes, nozzle guide vanes, rings, and other nonrotating components.

Post-emulsifiable or post-remover (PE/PR) penetrants cannot be removed by water rinsing alone. They require special agents (lipophilic emulsifiers or hydrophilic removers) to make them water-removable. They are widely used with a fluorescent penetrant but not commonly used with a visible dye penetrant. These processes have been used, for example, for inspection of rotating components of gas turbines and undercarriage structures. They have been widely used during overhaul of aircraft engines because their potential sensitivity for fatigue cracks at an early stage is much greater than that of the water-washable processes.

Solvent removers are volatile organic solvents that can remove penetrant directly. Being quite volatile, these removers dry quickly prior to the application of developer. This feature makes them particularly useful for spot or localized testing.

Types of developer

There are four types of developers in use:

- Dry powder
- Nonaqueous
- Water-soluble
- Water-suspendable

Dry powder developers are light, free-flowing, powders which can be applied by powder gun, electrostatic spray, or in a dust storm cabinet. They are only used with fluorescent penetrants. It is important that the developer not become contaminated with penetrant as the specks can appear as indications.

Surface Inspection

Equipment and materials

Nonaqueous developers consist of developer particles suspended in a volatile organic solvent. This is the type normally used with the solvent-removal process for spot checking of welds. Before use they must be thoroughly agitated so that a uniform suspension is applied. They are applied as a spray from a gun or aerosol and when dry form a white coating on the surface which provides contrast for the penetrant.

Both water-soluble and water-suspendable developers are supplied as powders to be made up in water at a recommended concentration. They can be applied by spray or by immersing the object after which the part is actively dried. Control of the concentration of the developer is done by checking the specific gravity.

One attraction of penetrant testing is that complex equipment is not required. Although permanent inspection stations with tanks and spray facilities are used for some applications, the process lends itself to portable applications such as localized inspection and spot testing. Fig. 6 shows an inspection station for fluorescent penetrant testing of

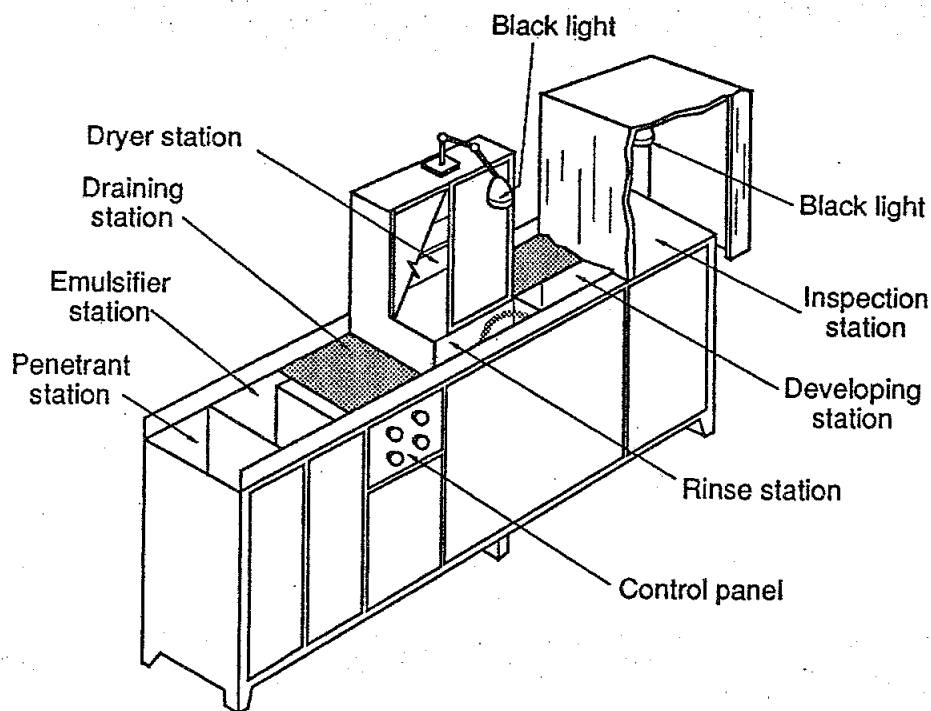


Figure 6. Inspection station for small components using post-emulsifiable fluorescent penetrant method.

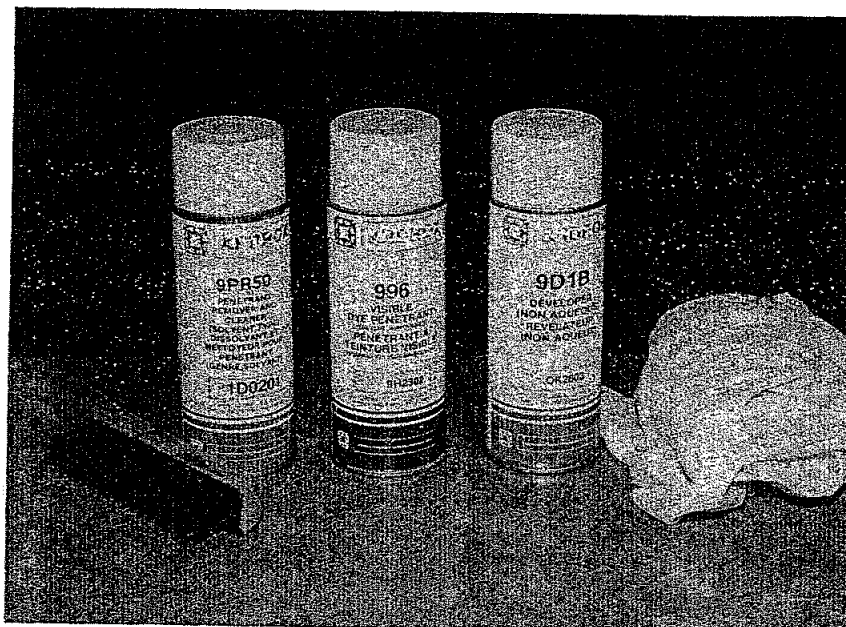


Figure 7. Portable kit for the solvent-removal visible dye penetrant process.

small components. Regular checking of the materials in each of the tanks—penetrants, emulsifiers, etc.—is necessary to avoid contamination and maintain quality.

Much penetrant testing in the welding industry is carried out with simple portable kits. An example is shown in Fig. 7 and comprises penetrant, developer, and cleaner in handy aerosol cans together sometimes with a can gun, wiping cloths, and a wire brush. A kit for fluorescent testing would include a black light that could be powered from a regular 115 volt socket.

Procedures for liquid penetrant inspection

Although the liquid penetrant process is simple, it is necessary to follow the correct procedures carefully in order to obtain good results. Remember, it is not sufficient to just find some defects, you must find *all* the defects that should be found by the method being employed. That means carefully following a prescribed procedure throughout the inspection. In this section we will discuss each step of the method and the

procedures involved. First, it is worth commenting on the choice of method. The major determining factors are

- Types of discontinuities sought
- Surface condition
- Facilities and location of test

Inspection of welds, especially on site, is governed by the last factor. Thus most penetrant inspection of welds is done with the solvent-removal method using a visible (colour contrast) dye penetrant. This is the method with which most welding inspectors need to be thoroughly familiar.

Conversely, a welded valve assembly on the shop floor with adequate facilities would suggest the fluorescent water-washable penetrant method. A weld repair of a turbine blade, demanding extra high sensitivity, would suggest the post-emulsified fluorescent penetrant method. As a rough guide the following are suggested:

- Fluorescent post-emulsified penetrant for high sensitivity applications such as detection of fatigue cracks
- Water-washable penetrant for detection of surface porosity in castings or rough surfaces in castings and forgings
- Solvent-removal with visible dye for most weld inspections in normal fabrication where portability is desirable.

In general, the methods should not be mixed up. A component should not be tested with one method then tested later with another. Traces of dyes from a visible penetrant can remain in discontinuities even after cleaning. If tested later with the fluorescent process, the residue not only inhibits penetration but absorbs ultraviolet light thereby reducing the degree of fluorescence.

A major advantage of the liquid penetrant inspection process is that it can be applied to a wide range of materials including ferrous and nonferrous metals, glass, and certain ceramics and plastics. It can be applied to aluminum and austenitic stainless steels that cannot be inspected by magnetic particle methods.

Qualifying procedures

It is necessary, however, to verify that the inspection liquids do not adversely affect the material, particularly in respect to subsequent corrosion behaviour. For some applications (e.g., titanium) nonchlorinated inspection kits may be specified. It should also be noted that penetrants and solvents may dissolve some plastics, especially polyvinylchloride (PVC). Any plumbing in an inspection station should use metal pipes rather than plastic.

Once a procedure has been established it is maintained. But there may be occasions when it must be changed. For example, a change in the temperature causes the penetrant materials to behave differently and a new procedure may be required. Changes in procedure can be qualified by using a comparator block on which a direct comparison is made between the new procedure and the standard. Fig. 8 shows a comparator block with surface cracks produced by heating and quenching a specially heat treated aluminum block. One section is used for the new procedure and the other for the standard.

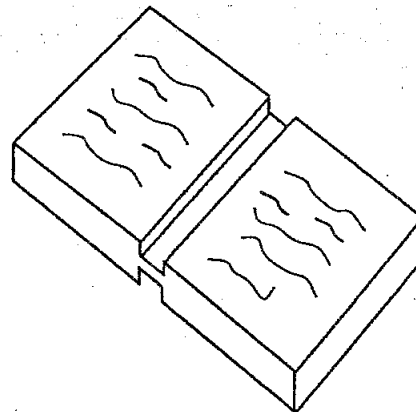


Figure 8. Comparator block made from an aluminum alloy, heat treated to produce surface cracks.

Surface preparation

Penetrant testing relies on the ability of the penetrant to be drawn into discontinuities that are open to the surface. This means that surfaces must be thoroughly cleaned and dried before application of the penetrant if the method is to succeed. Layers of paint or plating that could cover a discontinuity must be removed to provide access to the penetrant (Fig. 9). Washing alone is not enough; the layer must be removed so that the discontinuity is open to the surface. Some

Surface Inspection

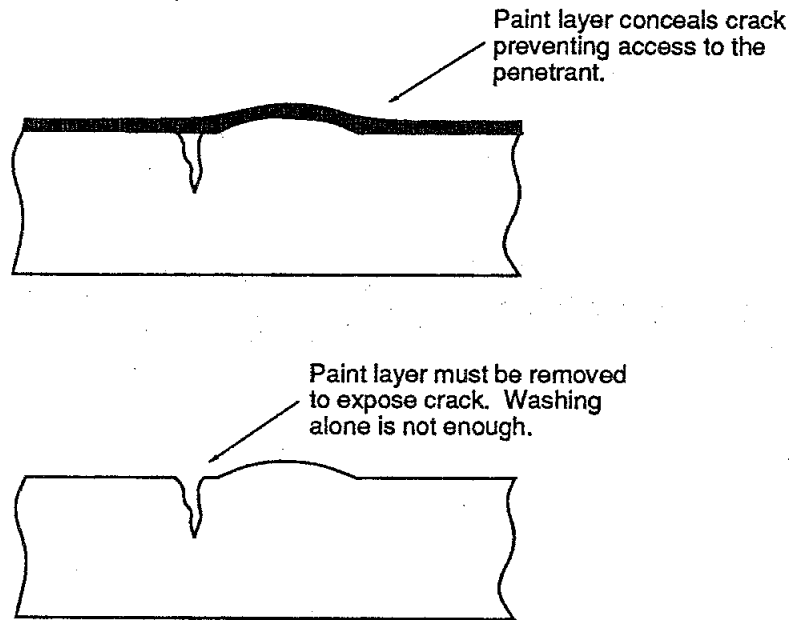


Figure 9. Paint layers must be completely removed prior to liquid penetrant inspection.

operations such as shot blasting, grinding, peening, and machining can flow the metal surface and close up discontinuities. If such surface finishing operations are required, it is important that they are not performed prior to penetrant testing.

Any contaminants such as oil, grease, rust, slag, etc., can interfere with the penetrant process. Not only can they fill up crevices in the surface but they interfere with the ability of the penetrant to spread, thus preventing it from being drawn into discontinuities. Furthermore, as Fig. 10 shows, rust and scale may trap penetrant, leading to false indications.

Most oils and greases can be removed by vapour degreasing. Paints, organic coatings, and plating require vigorous removal techniques using acid or caustic cleaner, or other solvents. After use, these cleaners

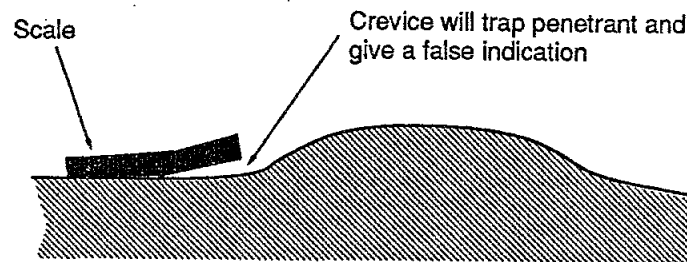


Figure 10. Rust and scale must be removed from the surface to prevent false indications.

must be completely removed from the part. Water-based cleaners are removed by clean water washing followed by drying, typically for one hour in a recirculating hot air oven at 125°C. For spot inspection using portable kits, organic solvents are used for cleaning as illustrated in Fig. 11.

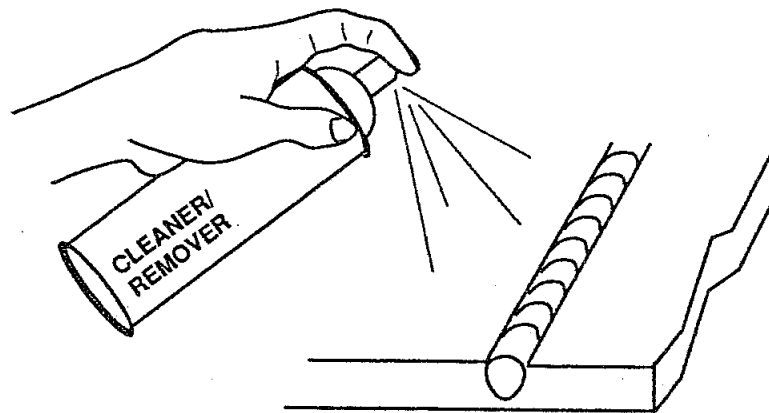


Figure 11. Solvent cleaner/remover used for cleaning the area prior to applying penetrant. Wipe off solvent and dirt with a cloth.

Removal of the cleaning materials is essential because they may remain trapped in discontinuities and prevent entry of the penetrant. In addition, some materials can cause fluorescent decay if they come into contact with fluorescent dyes. If water washing has been used, thorough drying or other water-removal method is necessary to ensure no water remains in any discontinuities.

Most mechanical means of cleaning (machining, grinding, or blasting) are not satisfactory because they peen the surface causing the metal to flow over discontinuities closing them up (Fig. 12). Light wire brushing with appropriate brushes with a minimum of pressure may be used and is especially useful for localized applications.

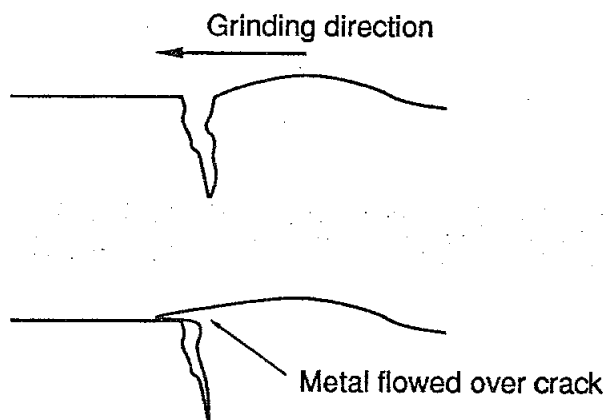


Figure 12. Grinding should not be used prior to liquid penetrant examination because flowed metal can close up cracks.

Operating temperatures

The normal operating temperature for penetrants should be in the range 12° to 52°C (60° to 125°F) according to ASTM E-165. At lower temperatures the penetrant becomes sluggish and does not easily enter discontinuities. Above this range, increased evaporation of the liquid limits the process. If the part has been heated for drying or if welding has recently been completed, it must be allowed to cool before applying the penetrant. Because of this, liquid penetrant testing is not suitable for checking partially completed welds maintained at their interpass temperature. Conversely, if the part is cold, for example during a field inspection in winter, it must be warmed before applying penetrant and the temperature maintained during the complete inspection period.

Application of penetrant

Penetrants may be applied by a variety of means including immersion, flow-on, brushing, and spraying. Small parts can conveniently be dipped into a tank of penetrant whereas for large components brushing or spraying is more appropriate. After applying the penetrant the component is left to drain, avoiding entrapment of penetrant caused by the geometry of the component.

Portable kits have aerosol cans of penetrant (Fig. 13) which allows the penetrant to be applied in any position. When applying from an aerosol, watch the surface. If the penetrant pulls back in droplets the surface should be recleaned.

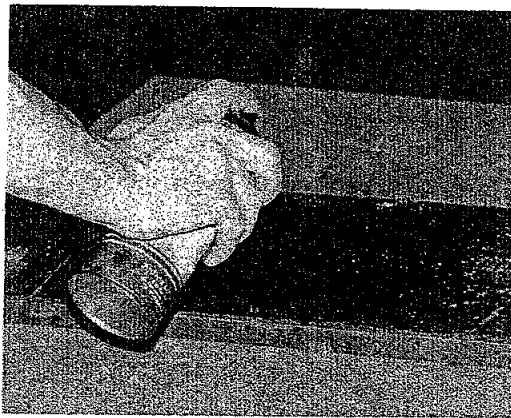


Figure 13. Applying penetrant from an aerosol.

Dwell times

Following application of the penetrant, sufficient time must be allowed for it to enter any discontinuities open to the surface. The contact or dwell time varies according to the application and the type of discontinuity being sought. Some typical suggested dwell times are shown in Table 1. For the portable solvent-removal method times are typically 5 to 30 minutes. Longer times may be necessary to penetrate extremely fine, tight discontinuities. If the longer penetration time results in drying of the penetrant, it should be rewetted with penetrant for a minute before removal.

Surface Inspection

Table 1. Suggested minimum dwell times.

Material	Form	Types of discontinuity	Minimum penetrant dwell time	Minimum developer dwell time
Aluminum Magnesium Steel Brass, bronze	Castings and welds	Cold shuts, porosity, lack of fusion and cracks	5 min	7 min
Titanium High temperature extrusions	Wrought plate, forgings and extrusions	Laps, cracks	10 min	7 min

Excess penetrant removal

It is in the method of excess penetrant removal that the various processes mainly differ. In some, the excess is removed directly, in others it is treated first before removal. The advantage of using a separate treatment to make the penetrant removable is that it can be done selectively. The steps in the process are illustrated in Fig. 14. If the excess penetrant on the surface is treated but the penetrant in the discontinuities is not affected, the excess can be removed without disturbing penetrant in the discontinuities. This makes the process more sensitive, particularly for shallow defects. With direct removal there is the risk that penetrant is removed from the discontinuities as well as the surface, thereby reducing the sensitivity of the process.

Water-washable penetrants have a built-in emulsifier enabling them to be removed directly by water washing. This is usually done with a spray, but immersion in an agitated water bath is sometimes used. The water temperature should be 20° to 30°C. Excessive water washing must be avoided so that penetrant is not leached from the discontinuities.

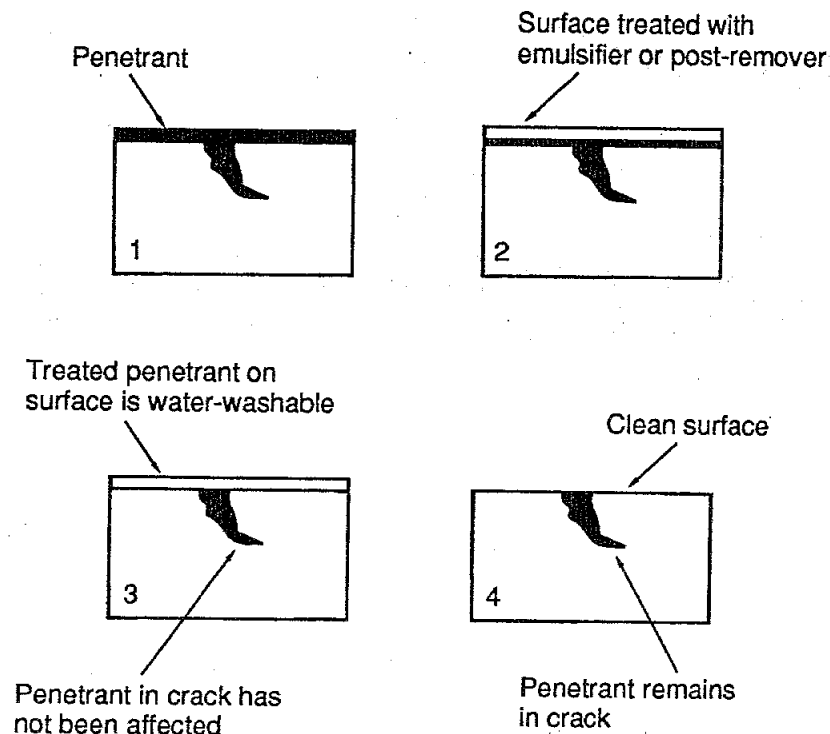


Figure 14. The use of a separate treatment to make the excess penetrant water-washable allows the selective removal of penetrant on the surface but leaves penetrant in discontinuities untouched.

Solvent-removable penetrants are removed directly with an organic solvent. This is the type used in most portable inspection kits. After the dwell time, excess penetrant on the surface is wiped off with a dry clean towel or cloth, repeating if necessary until most traces of penetrant have been removed. Following this, the surface is wiped clean of all penetrant with a cloth lightly moistened with solvent cleaner/remover (Fig. 15). The surface should *not* be sprayed directly with solvent as this could remove penetrant from discontinuities.

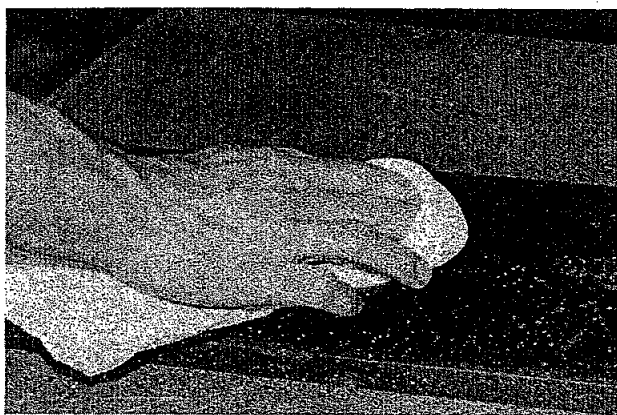


Figure 15. When using solvent-removal do not spray on to the surface. Clean excess with dry cloth first, then do a final clean with a cloth lightly moistened with cleaner.

Post-emulsifiable (PE) penetrants require an emulsifying agent to be applied before the excess penetrant can be removed by water washing. The emulsifier can be applied by immersion or by spraying (Fig. 16), but should not be brushed on since this could remove penetrant from discontinuities. The emulsifier must remain in contact with the surface long enough to mix with the excess penetrant but not long enough to reach penetrant in the discontinuities. A typical time is 2 minutes following which the part is washed, usually by spray.

Post-removers (PR) using a dilute detergent solution are used in a similar fashion, and with only limited solvent action, close control over removal of excess penetrant can be achieved. Immersion or spray can be used to apply the remover and contact time is typically 2 or 3 minutes before washing with water.

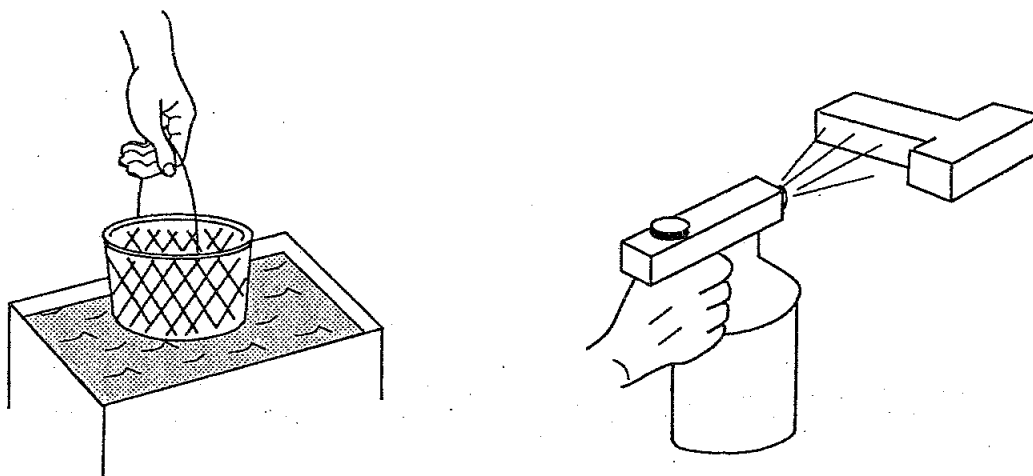


Figure 16. Application of emulsifiers by dipping or spraying. Brushing should not be used.

Applying the developer

If a dry powder developer or a nonaqueous suspension developer is used, the part must be completely dry before application. Drying is done with warm air in a recirculating oven or by a warm air blast. It is important that the temperature of the surface does not exceed 52°C (125°F) as excessive drying could cause penetrant evaporation. If a water-based developer is used, the part is dried after application of the developer. In the case of solvent-removal penetrants, the surface is dried by natural evaporation.

Developers require a period of time to allow penetrant in discontinuities to be drawn out. Typically the contact time is about half of the penetrant dwell time, dry powder developers requiring typically 10 minutes before inspection. When using nonaqueous developers, as in portable kits, the part is sprayed from an aerosol just enough to wet it evenly. It then dries to an even white layer (Fig. 17). Excessive developer will mask indications. Since the developer is a suspension, the aerosol can must be shaken vigorously before use until the agitators rattle inside.

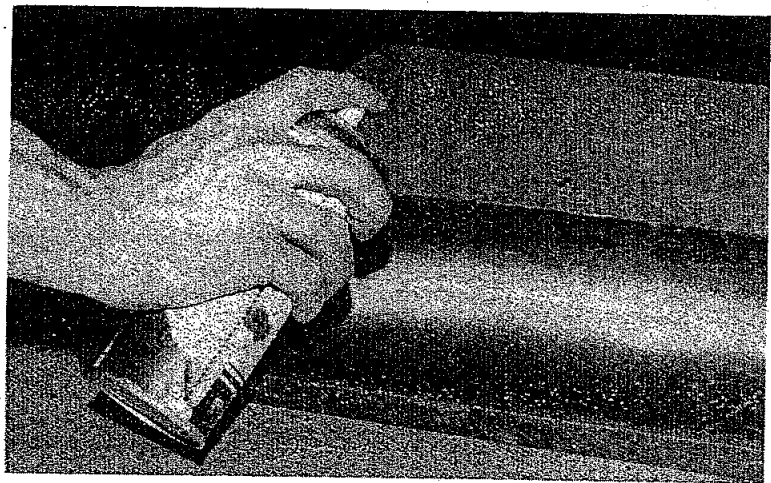
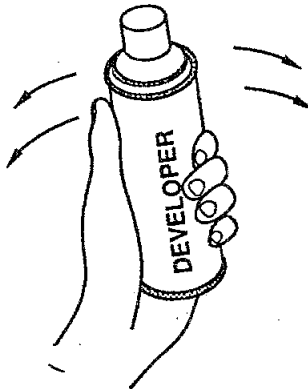


Figure 17. Applying nonaqueous developer from an aerosol. Shake the can thoroughly before use.

Viewing

Viewing of fluorescent penetrant requires a darkened area and a source of black light (ultraviolet). With portable fluorescent kits, the black light should be turned on and allowed to warm up for 5 to 10 minutes before use and left on during the course of inspection. Visible (colour contrast) penetrants should be viewed under good white light.

Interpretation

The first step in interpreting liquid penetrant indications is to distinguish between those caused by flaws and those that are either false indications or are nonrelevant. False indications are those not associated with a discontinuity of any kind. They could arise from finger marks, contamination, tool marks, and so forth (Fig. 18). False indications can be minimized by careful attention to the procedure, particularly the cleaning or washing stages.

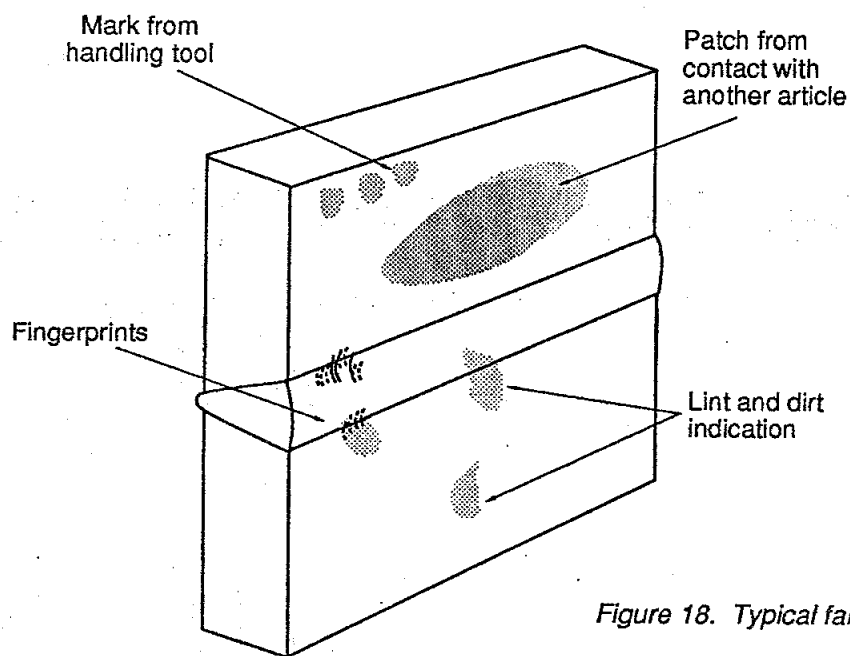


Figure 18. Typical false indications.

Nonrelevant Indications

Nonrelevant indications are true indications but are caused by discontinuities that are features of the design or the material and not by flaws. For example, Fig. 19 shows a backing bar that will produce an indication from the tight gap between the bar and the plate. This is a feature of the design and not a flaw. Nonrelevant indications can appear

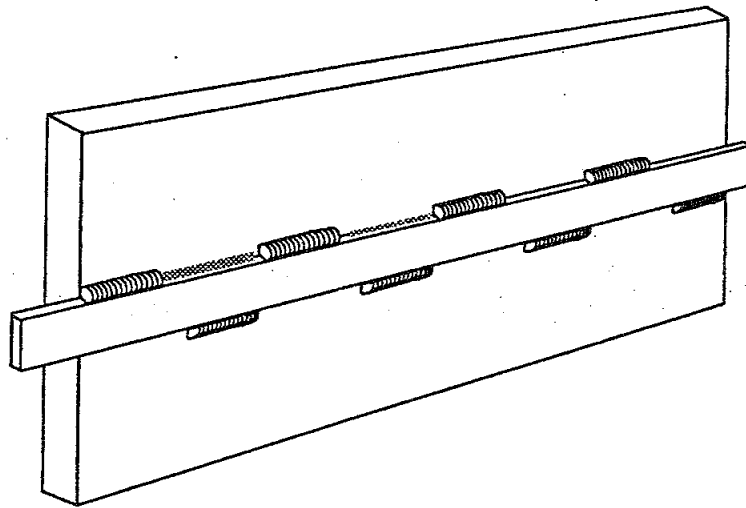


Figure 19. Nonrelevant indications by liquid penetrant on edge of backing bar.

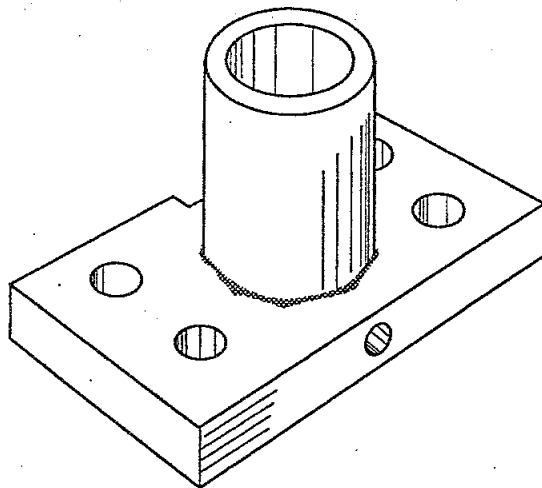


Figure 20. Nonrelevant indication by liquid penetrant on press-fitted assembly.

in articles that are press fitted or keyed (Fig. 20) and from surface features such as loosely adherent scale or burned-in sand on castings. Such nonrelevant indications must be carefully noted since they could interfere with correct interpretation.

Relevant indications

After eliminating false and nonrelevant indications the remaining indications are interpreted then evaluated against some acceptance criterion. The two main steps are determining the type of discontinuity causing the indication and determining its extent. The cause of an indication is established largely from the shape of the indication. There are five main categories:

- Continuous line
- Intermittent line
- Rounded
- Small dots
- Diffused or weak

Line indications

Continuous line indications (Fig. 21) are caused by cracks, lack of fusion, incomplete penetration, forging laps, scratches, or die marks. Cracks usually appear as jagged lines and forging laps as smooth, wavy lines. Seams provide continuous lines that differ from cracks in that the lines are straight rather than jagged.

The same discontinuities that cause continuous line indications can also cause intermittent line indications (Fig. 22). If the surface has been worked, for example by grinding, the crack may be covered over in places giving rise to an intermittent line indication. Very tight cracks

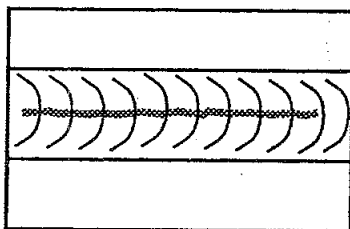


Figure 21. Continuous line indication caused by a crack.

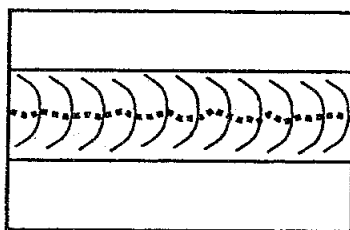


Figure 22. Intermittent line indication.

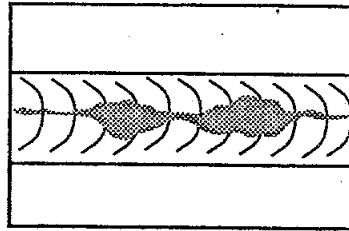


Figure 23. Bleeding of penetrant from a deep crack.

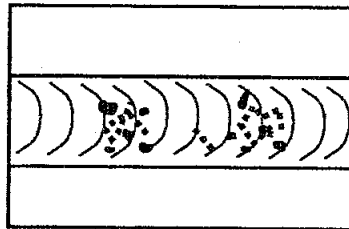


Figure 24. Round indications from porosity.

Round Indications

yield similar signs. Further evidence on cracks may be obtained by the rate at which indications form. Large cracks will give an indication almost immediately whereas very tight cracks may take several minutes to reveal their presence. A deep crack continues to bleed with the indication spreading on the surface (Fig. 23). A very deep crack will continue to produce an indication even after recleaning and redeveloping several times.

Round indications (Fig. 24) are usually caused by porosity, gas holes or pin holes. Deep cracks may also appear as round indications because of spreading. Small dots result from fine openings such as pin holes or from the surface of a coarse grain casting. Diffused or weak indications can be caused by surface porosity but they are more likely false indications from insufficient cleaning.

The extent of the discontinuity is judged directly from the size of the indication but this must be done as soon as a clear indication is visible. If left, the penetrant can spread in the developer thus exaggerating the size of the flaw. Normally the indication should be measured within 30 minutes of applying the developer.

Surface Inspection

Acceptance criteria

Liquid penetrant testing is considered an extension of visual inspection and is often judged by the same criteria. For example, CSA W59-(M)1989 requires that liquid penetrant testing be evaluated on the basis of the requirements for visual inspection. Any indications identified as cracks or lack of fusion are unacceptable under CSA W59-(M)1989. Any indications identified as porosity must be measured for size and spacing and the acceptance criteria applied. Since undercut is evaluated on the basis of its depth, the liquid penetrant method cannot be applied since it does not provide an accurate measure of discontinuity depth.

Corrections

If defects are found by liquid penetrant testing, the weld is normally required to be repaired. The tested area must be cleaned to remove the developer and any remaining penetrant. With the portable systems this can be done by spraying with cleaner/remover then wiping with a clean cloth. Even careful cleaning cannot remove all traces of penetrant that may be trapped in discontinuities. Some materials, such as aluminum, are particularly sensitive to contamination from penetrant when welded. The entire area must be cleaned and the portion of the weld containing the defect removed by chipping or grinding before rewelding.

 Energy, Mines and
Resources Canada Énergie, Mines et
Ressources Canada

LIQUID PENETRANT - CONTRÔLE PAR RESSUAGE

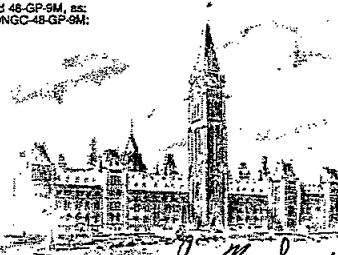
This certifies that **Bobby Shaftoe**
La présente atteste que

has qualified according to the C.G.S.B. Standard 48-GP-6M, as:
défaut la certification suivante selon la norme ONGC-48-GP-6M:

LEVEL	NIVEAU	1	-----
LEVEL	NIVEAU	2	9/73
LEVEL	NIVEAU	3	1/86

SEE REVERSE FOR PERIOD OF VALIDITY
LE VERSO INDIQUE LA PÉRIODE DE VALIDITÉ

REG. NO. 209
N° MATRICULE

 *J. Newbury*

FOR CERTIFYING AGENCY
POUR L'ORGANISME DE CERTIFICATION

Figure 25. Example of a wallet-size certificate for Liquid Penetrant Method.

Personnel qualifications

Personnel performing liquid penetrant inspection may be certified under Canadian General Standards Board (CGSB) 48-GP-9M "Certification of Nondestructive Testing Personnel (Liquid Penetrant Method)." A wallet-size certificate is shown in Fig. 25. A welding inspector certified under CSA W178.2 who is performing liquid penetrant inspection must also be certified to CGSB 48-GP-9M. The same applies to a test equipment operator working for an inspection company certified under CSA W178.1.

MAGNETIC PARTICLE INSPECTION

Magnetic particle inspection or testing (often abbreviated MPI or MT) is another surface inspection method capable of detecting discontinuities such as cracks that are open to or just below the surface. Because it depends on the magnetic properties of the material it is, however, limited to ferrous materials. That is, it works on structural steels, low alloy steels and so forth, but not on austenitic stainless steels, copper, aluminum, or other nonferrous metals.

Magnetism

Like liquid penetrant inspection it is often regarded as an extension of visual inspection, enhancing the ability of the eye to detect discontinuities in the surface. It is a simple, inexpensive method, requiring little equipment, but a good understanding of the method, procedures, and interpretation is necessary to obtain good results. In describing the method we will first discuss the fundamental principles on which it is based.

Everyone knows that a magnet, such as the one shown in Fig. 26, can attract a piece of iron. It does this because beyond the ends of the magnet there is a magnetic field. This field can be represented by lines of force emanating from the ends of the magnet which are termed *poles*.

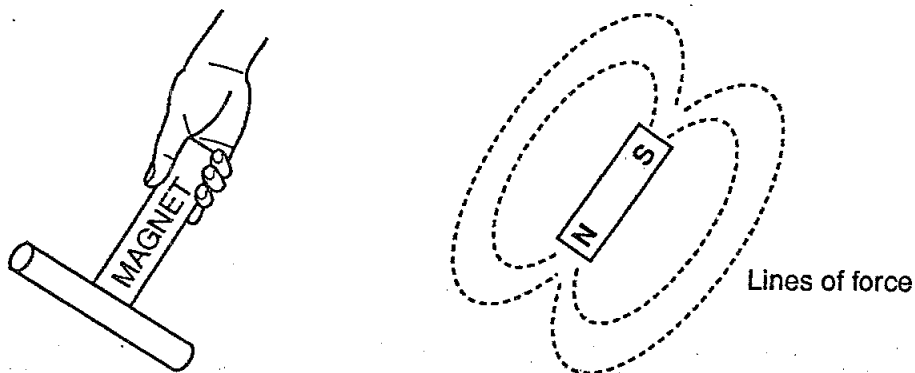


Figure 26. A bar magnet has two poles—a north and a south—from which lines of force emanate. The lines of force represent the magnetic field.

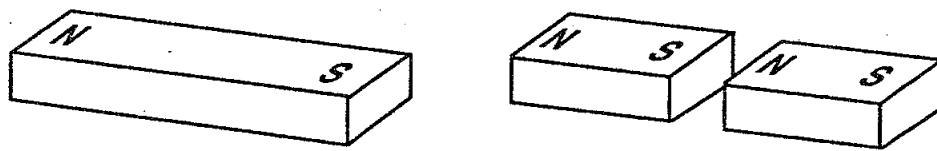


Figure 27. If a bar magnet is cut in two, new poles form at the cut ends.

A magnet must always have two poles—a north and a south. If a magnet is broken in half, as in Fig. 27, new poles are formed from which the lines of force emerge. Lines of force are continuous so that a line emerging from a north pole must curve round and reenter at the south pole to form a complete magnetic circuit.

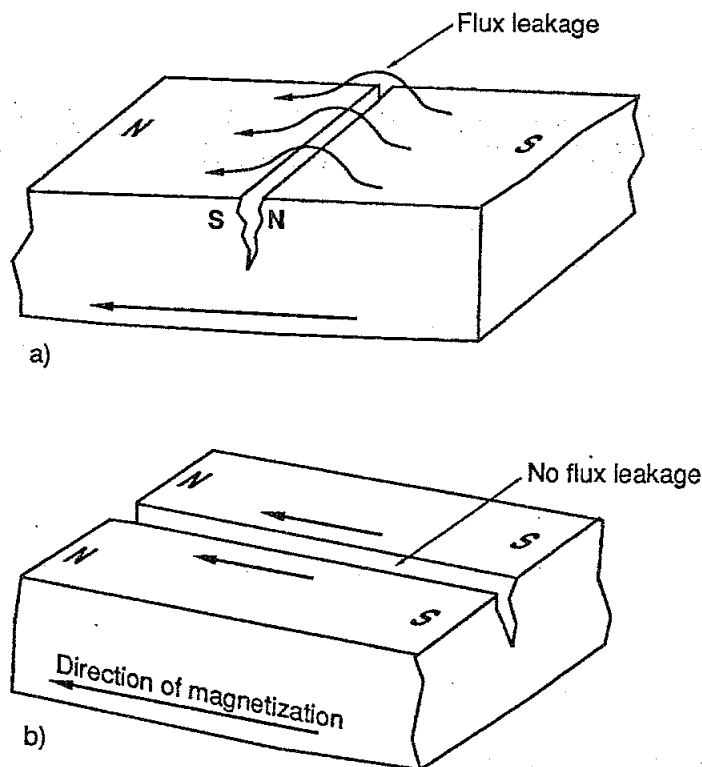


Figure 28. A magnetized piece of steel with a crack. In a) the direction of magnetization is across the crack. New poles form at the crack faces and a flux leakage field forms across the gap. In b) the direction of magnetization is parallel to the crack and no flux leakage field forms.

Magnetic induction

From this it can be seen that if a piece of iron or steel with a crack in it is magnetized as Fig. 28 shows, the faces of the crack form north and south poles and a magnetic field is created across the gap. This local field (known as *flux leakage*) can attract a powder of magnetic particles that build up across the crack thus revealing its location. This is the principle of the magnetic particle inspection method. It is very important to note that north and south poles only form on the crack faces if the lines of force try to cross the gap. If the lines run parallel to the crack no poles will form, and there will be no local field across the gap that can be detected.

When a ferrous material is placed in a magnetic field, magnetism is induced in it. The strength of the induced magnetism is measured by the *flux density* which can be thought of as the density of the lines of force. The induced flux depends on the type of material and even different ferrous materials behave differently. This can be expressed mathematically:

$$B = \mu H$$

where H is a measure of the magnetizing field strength (see Table 2 for units), B is the strength of the induced flux, and μ is known as the *permeability*. The value of μ is about the same for air and most non-ferrous materials, meaning that they are essentially transparent to magnetic fields. But μ can be 1 000 times larger for some types of steel. The permeability, μ , is not constant for a given material but depends on the field strength. Some typical values for ferrous materials are shown in Fig. 29. Note that the permeability of cast iron is smaller than most steels which means that a stronger magnetic field would have to be applied to induce a given flux.

Table 2. Magnetic units.

Quantity	Symbol	Old unit	S.I. Unit	Conversion
Magnetic field strength	H	oersted (Oe)	amperes per metre, A/m	1 Oe = 79.58 A/m
Magnetic flux density	B	gauss (G)	tesla (T)	1 G = 10^{-4} T

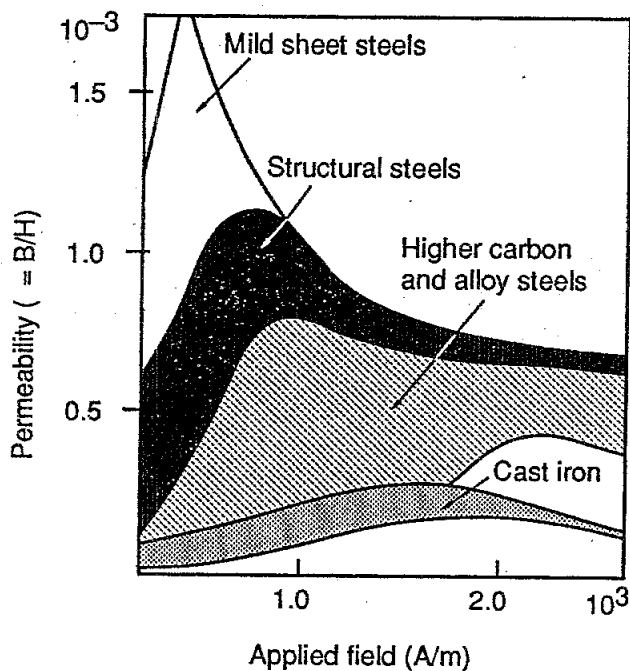


Figure 29. The permeability of various ferromagnetic materials. Permeability varies with the applied field strength.

Saturation

Suppose we apply a magnetic field, H , to a piece of steel and measure the induced flux, B . As we increase H we may obtain a curve similar to the one shown in Fig. 30. As the field strength becomes very large, the flux reaches a maximum and the material cannot be magnetized any more. At this stage it has reached *saturation*.

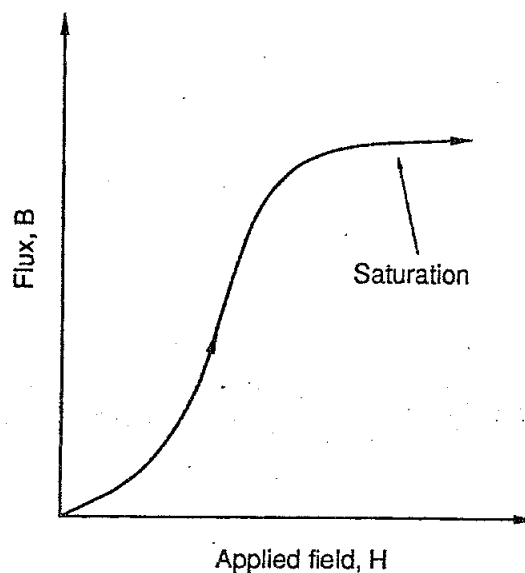


Figure 30. B-H curve showing saturation at high field strengths.

B-H curve

On decreasing the field it is found that the value of B does not retrace the original curve, but remains higher (Fig. 31). In fact, when the field reaches zero (i.e., the magnetizing field is removed) the material still shows a flux, B . That is, it remains magnetized or shows residual magnetism. This level of B is called the *retentivity*. A material with a high retentivity could be used as a permanent magnet. To remove this retained flux, the field would have to be applied in the opposite direction. The strength of the reverse field necessary to bring the induced flux to zero is known as the *coercive force*.

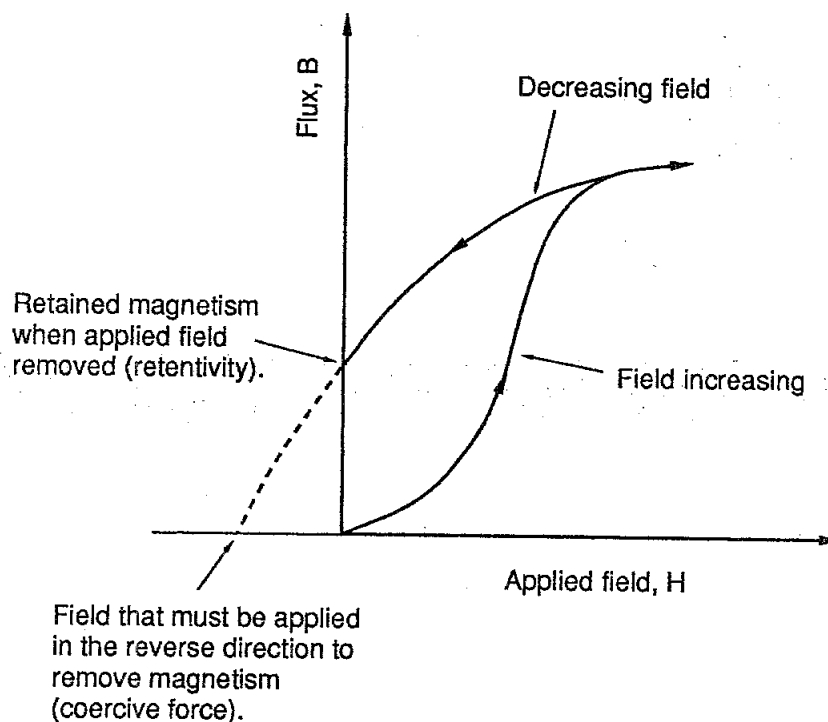


Figure 31. B-H curve for increasing and decreasing applied field showing the definition of retentivity and coercive force.

From this description of the magnetic behaviour of materials we may summarize some of the requirements for the magnetic particle testing method:

- A sufficiently high magnetic flux must be induced in the material.

Electric current

T.Q

- The applied field strength required depends on the permeability of the material.
- The permeability depends on the type of material and can be affected by alloy content and heat treatment.
- The applied field should not be so high as to cause saturation. The range normally used is 30 to 70% of the saturation value. Saturation reduces the permeability and decreases the flux leakage field.
- After the field is removed, the material may remain magnetized.

In addition to being magnetized by the field of another magnet, materials may also be magnetized by the field produced from an electric current. When an electric current flows through a wire a magnetic field is formed around it (Fig. 32). The lines of force are circular (circular magnetization), so the direction of the field at any point is always 90° to the direction of the current.

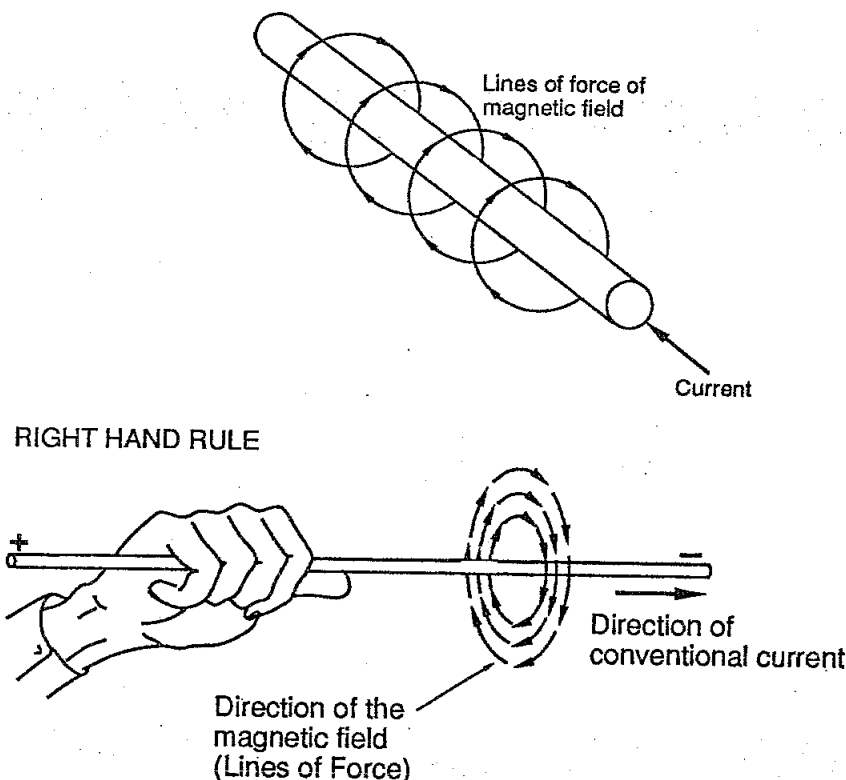


Figure 32. Magnetic field produced by an electric current. The direction of the field can be established from the Right Hand Rule. When the thumb points in the direction of the conventional current, the fingers point in the direction of the magnetic field.

The strength of the magnetic field due to an electric current may be increased by winding the wire into a coil. The field around each loop now adds to that from the next loop so increasing the net field strength. The net field has a direction along the axis of the coil (longitudinal magnetization) as seen in Fig. 33. If a bar of iron is placed inside the coil it will become magnetized. This is the principle of the electromagnet.

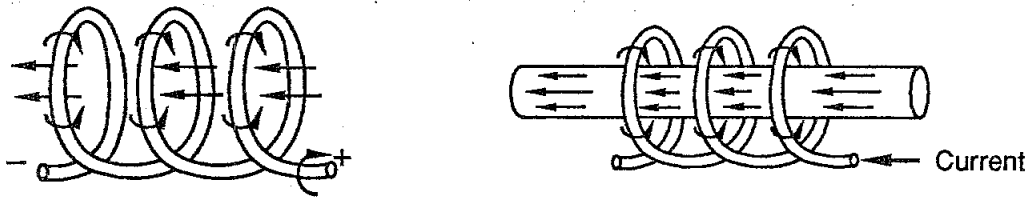


Figure 33. Magnetic field from a current-carrying coil. The direction of the field is along the axis of the coil. An iron bar placed inside the coil will become magnetized along its length.

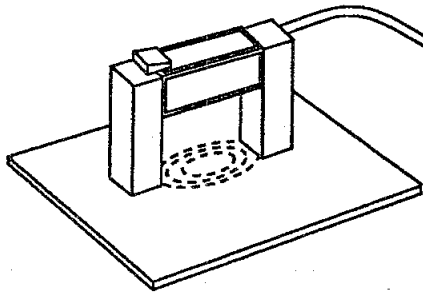
Methods of magnetic particle inspection

The strength of the magnetic field produced by an electric current in a coil of a given diameter is proportional to the magnitude of the current and the number of turns of wire in the coil. The relative strength of a field from a coil is sometimes indicated by the 'ampere turns.'

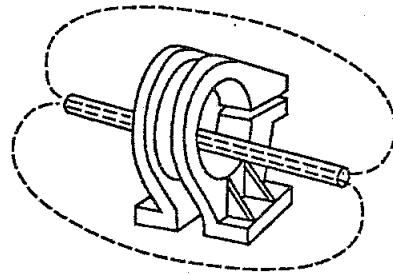
To perform inspection of a ferrous material by magnetic particles, it is necessary to induce a magnetic flux in the part by applying a magnetic field. This can be done in several ways, each of which is used for inspection in various applications:

- Place the part across the poles of a permanent magnet (magnetic flow technique)
- Place the part across the poles of an electromagnet (magnetic flow technique)
- Place a wire or coil carrying a current near the part (current induction technique)
- Pass an electric current directly through the part (current flow technique)

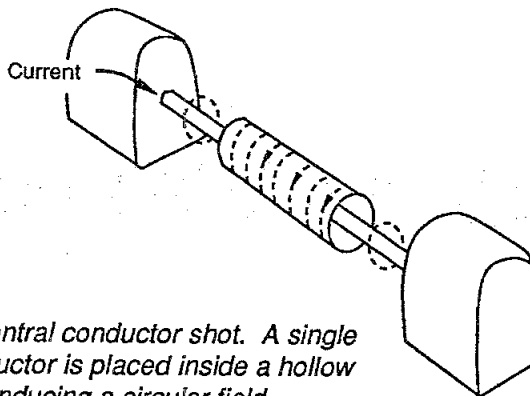
Examples of these methods are illustrated in Fig. 34. In studying these sketches note very carefully the direction of the induced flux because this determines which flaws can be detected.



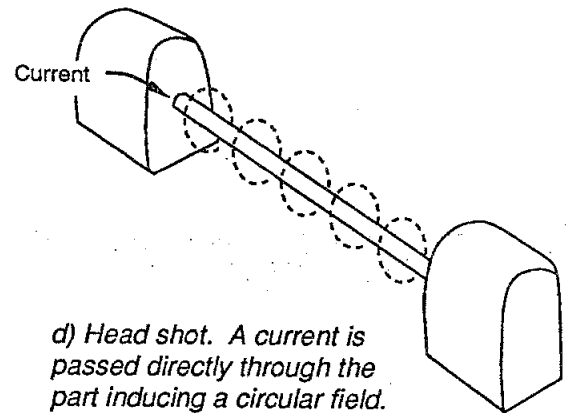
a) Yoke. An electromagnetic is used to produce a longitudinal field between the poles. Permanent magnet yokes may also be used.



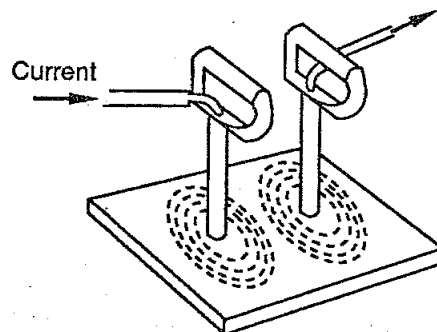
b) Coil shot. The part is placed inside the coil and a longitudinal field is induced.



c) Central conductor shot. A single conductor is placed inside a hollow part inducing a circular field.



d) Head shot. A current is passed directly through the part inducing a circular field.



e) Prods. A current is passed directly through the area of interest by using two prods. A circular field is induced.

Figure 34. Various means for inducing a magnetic flux in a part to be inspected. Guidance on required current levels can be found in ASTM E709.

Surface Inspection

Direction of field

As we have seen, to create flux leakage at a discontinuity, the lines of flux must cross the discontinuity. Discontinuities parallel to the lines of flux are not detectable, while those at an angle to it, are. The optimum angle is 90° to the flux lines. Thus the yoke shown in Fig. 34(a) which creates a longitudinal field between the poles is best at detecting flaws lying transverse to the yoke (Fig. 35). If placed across a weld for

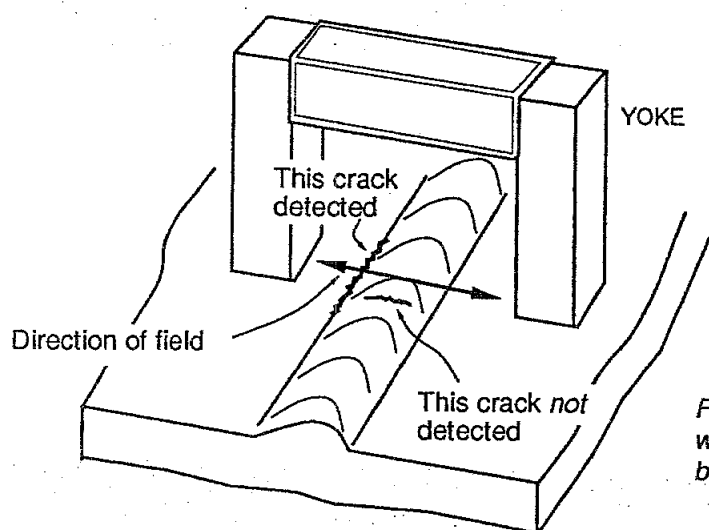


Figure 35. A yoke placed across a weld will detect discontinuities along the weld but not transverse discontinuities.

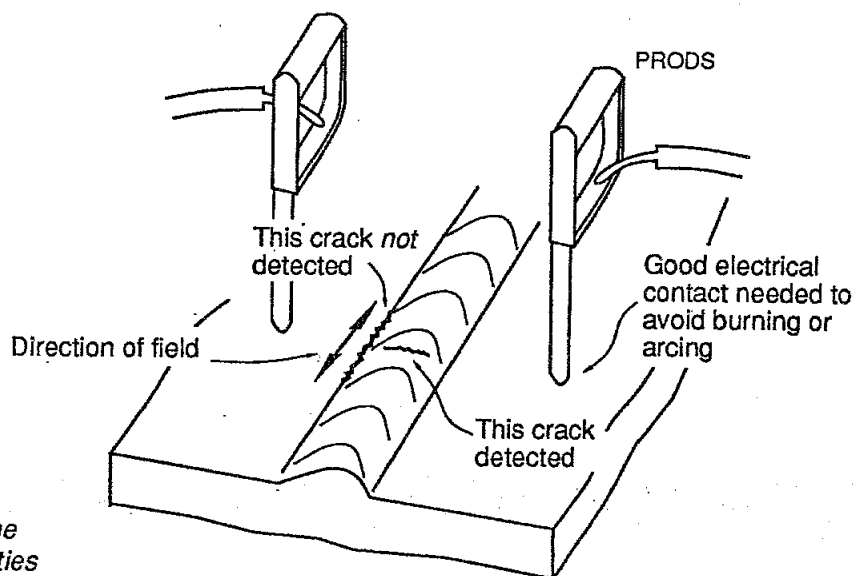


Figure 36. Prods placed across the weld detect transverse discontinuities but not those lying parallel to the weld.

Equipment

Prods

Arc strikes

example, a yoke would detect cracks lying along the weld but not transverse cracks. In contrast, the prods shown in Fig. 34(e) create a magnetic field by passing a current through the piece. The field is transverse to a line between the prods. If placed across a weld, prods would detect cracks lying transverse to the weld as illustrated in Fig. 36.

For the inspection of small parts permanent installations are often used. The methods shown in Fig. 34(c) and (d) are usually used in this way. For portable inspection of welds on large fabrications the most common methods are prods and yokes. Prods are simply electrical contacts that apply large currents to the piece. A switch is incorporated in the handle or in a foot switch so that the current is not turned on until the prods are in place. Likewise, the current is turned off before removing the prods. This is most important otherwise the prods will arc and create defects.

If the power is on when the prod contacts the workpiece it will arc just the same as an electrode. The arc strike melts a small amount of metal which cools very rapidly and becomes hard. In addition, some of the prod material is melted into the arc strike which contaminates it. Arc strikes are serious because they could start a fracture or a fatigue crack. Arc strikes from prods must be considered the same as those from an electrode. CSA W59-(M)1989 requires that they be avoided, and if they occur on dynamically loaded structures they must be removed by light grinding and the region checked for soundness. The prods are usually made of copper, aluminum, or steel. In some applications the risk of contamination from arcing may preclude certain types of prods.

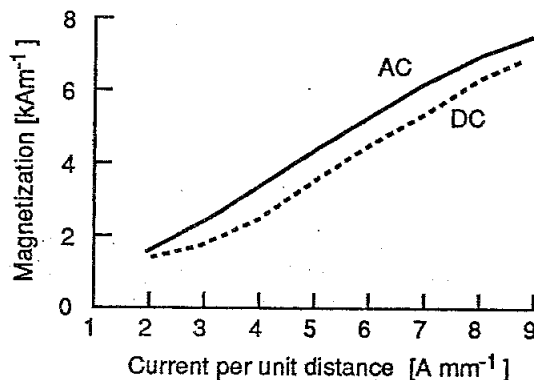


Figure 37. With prods the level of magnetization increases linearly with the current per unit distance of prod spacing. Typically a current of 4 amps per mm of spacing is used in practice.

Yokes

Either AC or DC current can be used with prods although AC is more common. Typically electrical power is supplied from a small transformer with 2 to 15 V open circuit voltage and 1 000 to 1 500 amps capacity. Typical current levels would be about 4 amps per mm (100 amps per inch) of prod spacing (Fig. 37).

Yokes are electromagnets having flexible extensions to the core allowing the poles to be placed in contact with the piece under test (Fig. 38). Since the piece is magnetized by completing the magnetic circuit between the poles, good surface contact is required at the poles. If a gap is present, the induced flux will be considerably reduced. Unfortunately, this can be a limitation of the method for there is no easy way of measuring the induced flux. Thus poor contact could result in insufficient flux without the operator knowing.

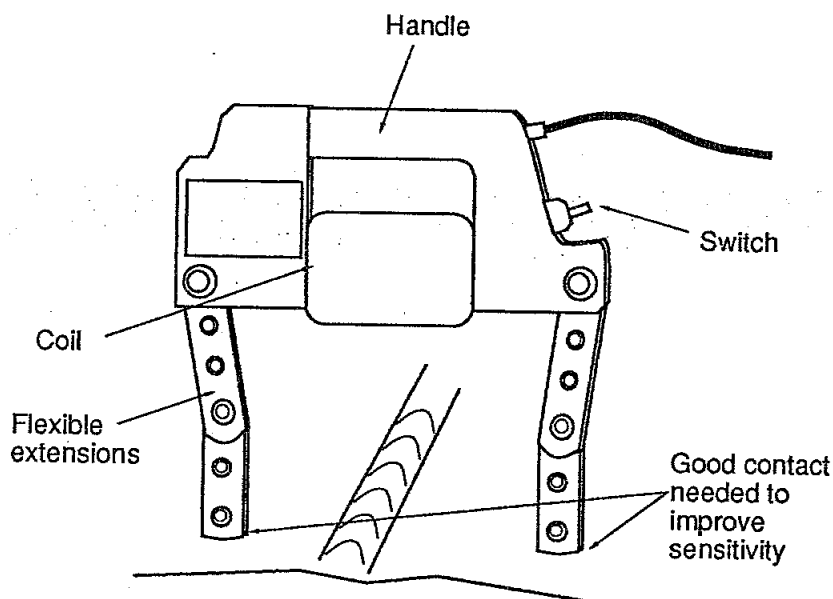


Figure 38. Typical yoke with flexible extensions.

Yokes can be operated with AC or DC current and, again, AC is the more common. Power supplies often provide either AC or DC. Because the coil has a large number of turns, the current is only about 5 to 10 amps, much lower than that used with prods. AC yokes can therefore be operated directly from a 115 V receptacle.

AC versus DC (Current flow technique-prods)

AC only magnetizes the surface and therefore this type of system can only detect discontinuities extending to the surface. In contrast, DC has the ability to produce a field penetrating below the surface and therefore has some capability to detect subsurface flaws, up to 2 to 3 mm below the surface. In large installations requiring very high currents, full-wave rectification (FWDC) may be used to produce direct current. DC used in portable systems is usually half-wave rectified (HWDC) having a pulsating effect which enhances mobility of the particles. Fig. 39 summarizes the effect of current type.

AC versus DC (Magnetic flow technique-yokes)

Yokes (AC or DC) generally have little ability to detect subsurface defects because of extensive external flux leakage but provide good sensitivity to surface defects. AC yokes are less sensitive to surface contact problems than DC yokes. Thus on curved or rough surfaces AC yokes are preferred.

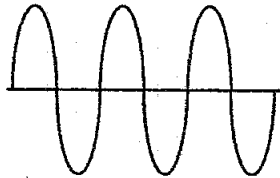
		Disadvantages	Advantages
Alternating current AC		Subsurface discontinuities are not detectable	Best sensitivity to surface defects. Good particle mobility
Single phase, half-wave rectified direct current HWDC			Good sensitivity to both surface and subsurface defects. Pulsing effect gives good particle mobility
Three phase, full-wave rectified direct current FWDC		Applicable to large high current installations. Leaves high residual magnetic field in the test piece	Good sensitivity to subsurface defects

Figure 39. Summary of the effects of current type for current flow technique (prods).

Magnetic particles

The magnetic particles used to detect the flux leakage across a discontinuity can either be applied dry or in a liquid suspension. The dry powder method is more satisfactory on rough surfaces or where sensitivity to buried defects is required and lends itself to portable testing of welded fabrications. Particles may be coloured to enhance visibility and can be applied with a powder bulb, atomiser, or spray gun. A light puff of air removes excess particles. Contrast may be improved by spraying a white paint or liquid penetrant developer over the area prior to testing (Fig. 40). Dry powder media can withstand surface temperatures up to approximately 300°C which allows the process to be used during welding on preheated plates. Nor are magnetic powders affected by the cold, making the method valuable for field work in the winter.

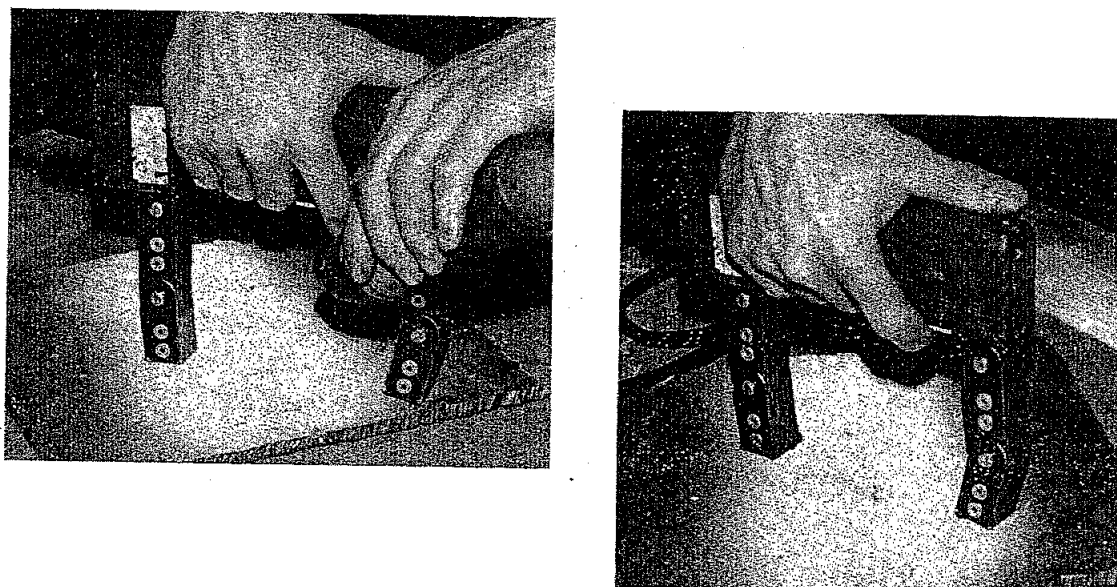


Figure 40. Application of dry magnetic powder. The weld has been sprayed with LPI developer to enhance visibility of the magnetic powder. A small crack is visible in the photo on the right.

The wet method is more sensitive as the particles are smaller. This makes the method more suitable for finding very fine flaws on smooth surfaces. The liquid suspension may be sprayed or flowed on, or the part immersed in a tank. For portable use, aerosol cans are available. For increased visibility fluorescent particles may be used and these are viewed under black light.

Procedures

KNOW THESE
SIX STEPS.

Although magnetic particle testing is simple and convenient, a good understanding of the process and care in following the correct procedure are necessary to obtain good results. CSA W59-(M)1989 requires that the procedure and technique described in ASTM E709 be used. The steps involved are:

- Prepare the test surface
- Magnetize the test piece
- Apply the indicating medium
- Examine the surface and interpret the indications
- Demagnetize
- Postclean

Parts for magnetic particle inspection should be clean and dry. Aerosol cans of cleaning fluid are usually provided with portable kits. Surface roughness tends to decrease inspection capability by distortion of the magnetic field or by hindering the migration of the particles to the site of a discontinuity. Light grinding, without smearing the surface, may be necessary. Magnetic particle inspection will still work through a thin coating of paint, but the paint must be removed at points of electrical contact if prods are used.

The current required for magnetization should be specified in the test procedure. Typical values for prods are 90 to 125 amps for each 25 mm (1 in.) of prod spacing. Prods should not be too close or too far apart. Optimum spacing is in the range of 100 to 250 mm.

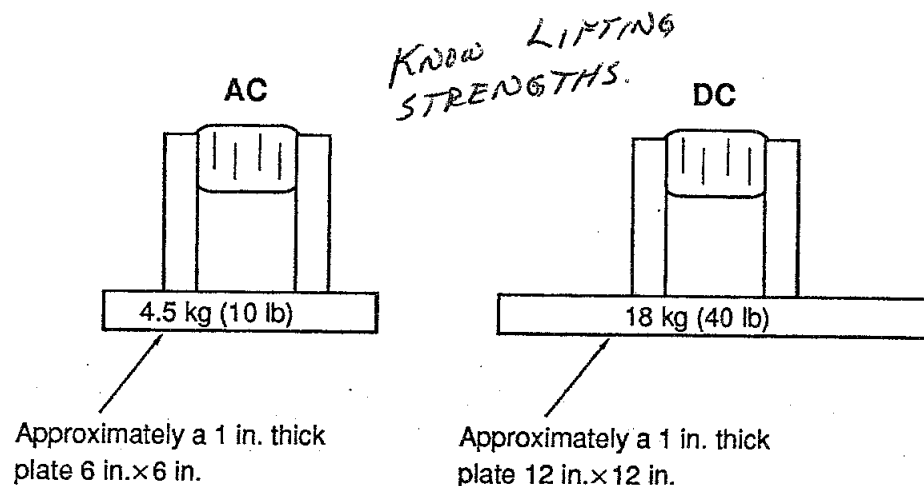


Figure 41. Typical lifting requirements to assess the field strength of a yoke.

Requirements for yoke magnetization may be specified in terms of the weight that the yoke can lift (Fig. 41). Typical values are 18 kg (40 lb) for a DC yoke and 4.5 kg (10 lb) for AC. It should be remembered, however, that this does not guarantee adequate induced flux in the test piece if magnetic contact is poor.

Because the detection of discontinuities depends on the direction of the field, procedures require that at least two tests be carried out with the flux fields at 90° to each other. Typically a yoke would be placed across a weld at 45° (as shown in Fig. 40), then at 45° in the other direction.

The magnetic powder or prepared bath (wet media) is normally applied while the piece is magnetized, but in continuous-testing stations using wet media, procedures may require the application of the liquid before magnetization. In such applications the magnetizing current is only applied for about half a second so the attraction of the particles to discontinuities relies on the residual magnetism. With the dry method, excess powder can be removed by blowing lightly on the piece while it is still magnetized.

Interpretation

Considerable care is required in the interpretation of magnetic particle indications because many types of false or nonrelevant indications can form. False indications may arise simply from the geometry of the piece under test which may trap particles even without them being

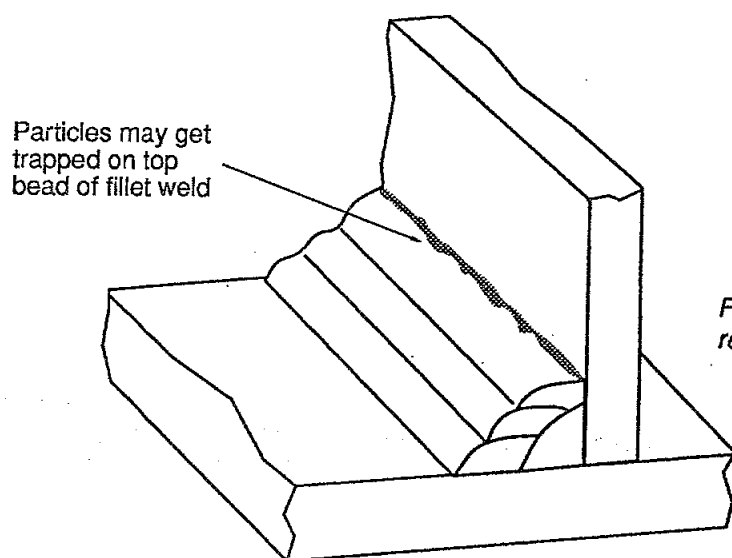


Figure 42. Possible false indication resulting from geometry of the weld bead.

Nonrelevant indications

magnetized. For example, the upper toe of the horizontal multipass fillet weld shown in Fig. 42 could form a small shelf which might retain particles even though no sizable undercut is present.

Indications form wherever there is a distortion of the magnetic flux, not only due to discontinuities but anywhere the permeability changes. Variations in permeability can arise from differences in composition, microstructure, hardness, heat treatment, or work hardening. For example, the iron bar shown in Fig. 43 has been bent then straightened to produce a work-hardened region. This causes an indication when

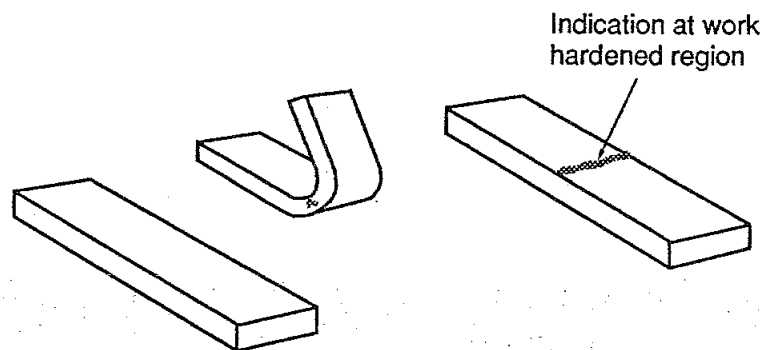


Figure 43. Nonrelevant indication at work-hardened region of a bar when tested with magnetic particle. Hardening the steel reduces the permeability.

tested with magnetic particles. Similarly the heat affected zone of a weld may have sufficiently different microstructure and hardness that indications form at the boundary with the base metal or the weld metal. As another example, a carbon steel welded with stainless steel electrodes would show indications along the edge of the weld which could easily be mistaken for a crack (Fig. 44).

Other sources of nonrelevant indications are use of an excessive magnetizing field and residual magnetism in the piece from a previous inspection or handling steel with electromagnets. A knowledge of the materials and welding procedures may assist in identifying nonrelevant indications. In addition, tests on representative samples of the sound welds will enable the operator to recognize the patterns and locations of nonrelevant indications.

Surface Inspection

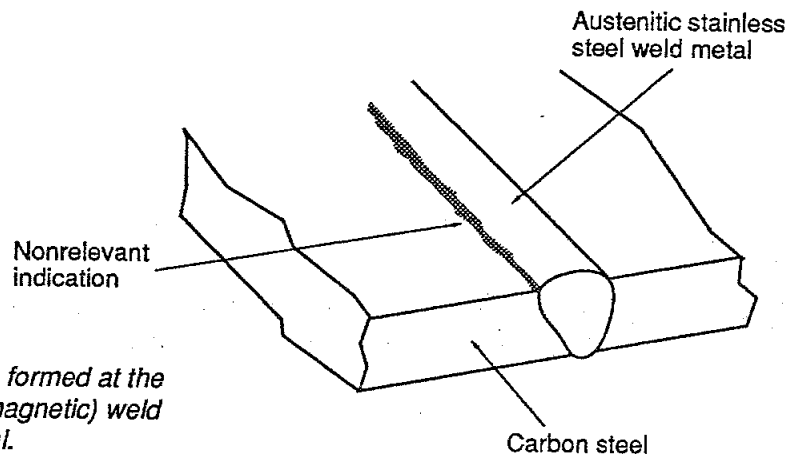


Figure 44. Nonrelevant indication formed at the junction between austenitic (nonmagnetic) weld metal and carbon steel base metal.

Relevant Indications

The identity of the discontinuity causing relevant indications can often be found by noting the pattern and location of the particle buildup. Cracks form well-defined indications with tightly held, heavy powder buildup (Fig. 45). Deeper cracks hold more powder. Subsurface cracks

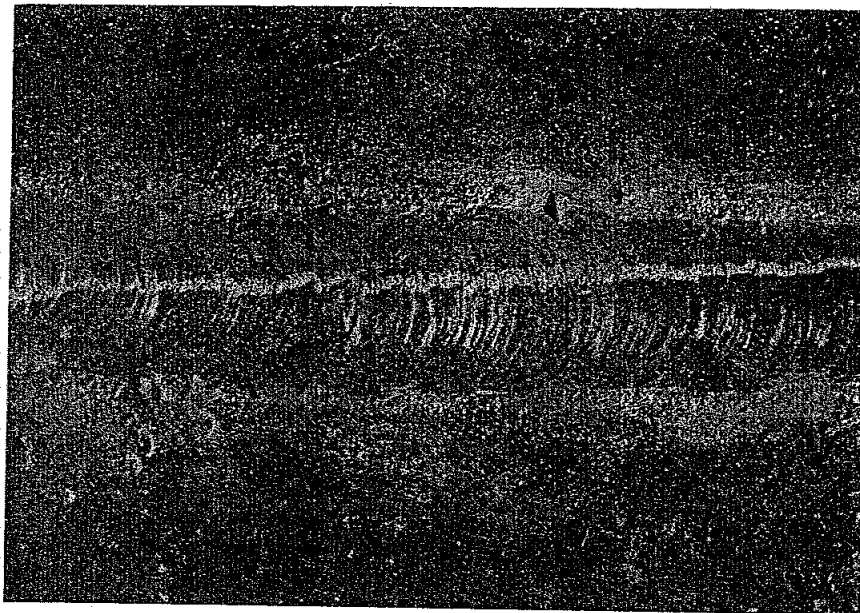


Figure 45. Indication caused by a crack open to the surface showing a heavy buildup of tightly held powder.

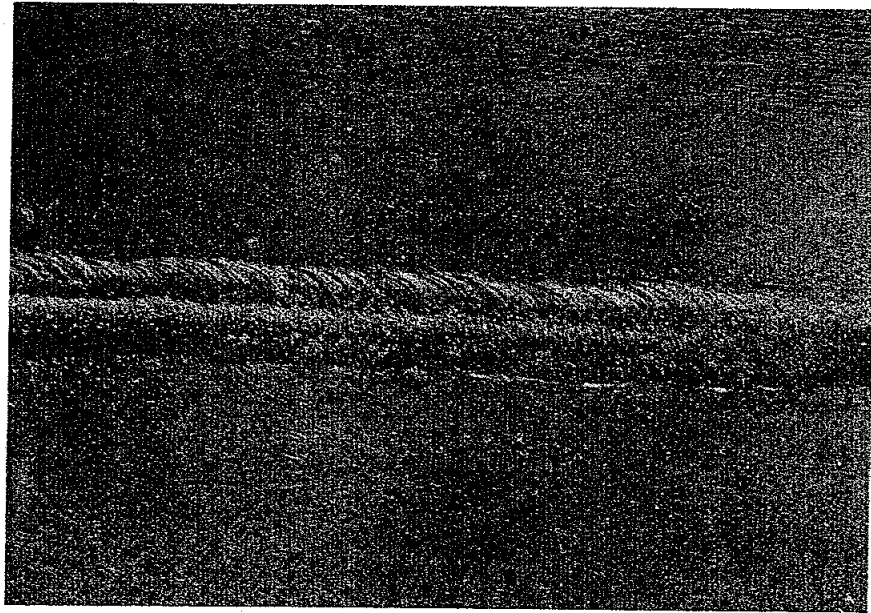


Figure 46. Indication caused by subsurface crack showing less buildup and less tightly held powder.

show wider indications with less buildup (Fig. 46). Incomplete fusion has a similar indication and the location at the edge of the weld helps identify it. The difficulty of locating and interpreting subsurface defects is why other methods are more suited to subsurface detection.

Porosity or slag inclusions produce vague indications with less powder buildup. Undercut can also be revealed but with a less well-defined indication than a crack or lack of fusion; and as with liquid penetrant inspection there is no accurate measure of the depth.

Acceptance criteria

Magnetic particle indications are evaluated on the basis of their length and the interpretation of the cause according to specified acceptance criteria. For example, CSA W59-(M)1989 requires magnetic particle inspection to be evaluated on the same basis as radiography. Cracks of any size are not permitted and porosity and fusion-type defects become unacceptable when their size and frequency of occurrence exceeds specified amounts. Note that in CSA W59-(M)1989 these amounts differ for statically and dynamically loaded structures.

Residual magnetism

In some cases removal of the residual magnetism may be specified. Typical situations are:

- When the part is to be plated or painted and adhering particles would interfere
- On shafts or other rotating components where adhering particles could contribute to failure
- Parts to be machined
- When followed by welding where residual magnetism could cause arc blow
- When a residual field is undesirable in service, e.g., aircraft parts
- When stringent postcleaning requires all inspection materials to be removed

Demagnetization is not normally required for large welded fabrications where the steels have relatively low retentivity. When specified, demagnetization can be carried out in a number of ways which generally rely on reversing and reducing the magnetic field. With some systems this is simply achieved by gradually reducing the current. Demagnetization also occurs if the piece is heat treated above about 770°C.

Reports

Magnetic particle examinations should be carefully documented. Reports should show the procedure used, including the method, current and type (AC, HWDC, etc.), and direction of magnetization, and should be signed by the operator. The results should show the size, location, and interpretation of indications. Sketches are useful. In some cases direct recording of the indications by photographs or by using pressure-sensitive tape transfers may be desirable.

Personnel qualifications

Personnel performing magnetic particle inspection may be certified under Canadian General Standards Board (CGSB) 48-GP-8M "Certification of Nondestructive Testing Personnel (Magnetic Particle Method)." Fig. 47 shows a wallet-size certificate. A welding inspector certified under CSA W178.2 (or a test equipment operator working for an inspection company certified under CSA W178.1) who is performing magnetic particle inspection must also be certified to CGSB 48-GP-8M. The CSA certificate is shown in Fig. 48.

Energy, Mines and Resources Canada / Énergie, Mines et Ressources Canada

MAGNETIC PARTICLE - ESSAIS MAGNÉTIQUES

This certifies that: / La présente atteste que: **Bobby Shaftoe**

has qualified according to the C.G.S.B. Standard 48-GP-8M, as: / détient la certification suivante selon la norme ONGC-48-GP-8M:

LEVEL 1 / NIVEAU 1: 11/78

LEVEL 2 / NIVEAU 2: 1/86

LEVEL 3 / NIVEAU 3:

SEE REVERSE FOR PERIOD OF VALIDITY / LE VERSO INDIQUE LA PÉRIODE DE VALIDITÉ

REG. NO. / N° MATRICULE: 209

FOR THE ISSUING AGENCY / POUR L'ORGANISME DE CERTIFICATION: J. Newbury

Figure 47. CGSB certificate for magnetic particle testing.

CSA STANDARD W178 / Qualification Code for Welding Inspection Organizations

Canadian Welding Bureau

TEST EQUIPMENT OPERATOR CERTIFICATE

Bobby Shaftoe

has met the qualification requirements of CSA Standard W178 for a Test Equipment Operator as indicated by the CWB stamp

Nondestructive Testing to CGSB Standards 48GP: 4M, 7M, 8M, 9M, CWB

Mechanical Testing: Inspection & Testing (Ontario)

Metallographic Testing:

while employed by:

a certified welding inspection organization whose designated personnel and standard test procedures for specific product categories have been approved by the Canadian Welding Bureau to CSA Standard W178.

T104 / 25 Nov. 1991 / MANAGER, CERTIFICATION SERVICES

CONDITIONS: This card is the property of the Canadian Welding Bureau and can be recalled at any time. Fraudulent use may involve permanent cancellation.

CWB FORM 466/83

Figure 48. Certificate for Test Equipment Operator (CSA W178.1) The 8M refers to CGSB-48-GP-8M which covers magnetic particle testing.

Flux leakage methods

OTHER INSPECTION METHODS

Recently there have been developments of alternative ways of detecting the magnetic flux leakage around discontinuities rather than by using magnetic particles. One of these is a magnetic tape, similar to a thick video tape, which is placed over the magnetized part (Fig. 49). The flux leakage locally magnetizes the tape which can be 'played back' by passing it over a reading head to record the location, size, and strength of the magnetic image.

Similarly, a probe coil, acting like a tape-playing head, can be used to scan the magnetized part directly (Fig. 50). Electric currents are induced in the coil as it passes over the flux leakage field. Hall detectors

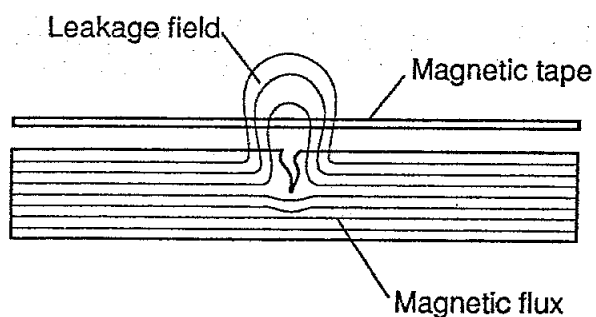


Figure 49. Using magnetic tape to record the location of a leakage field.

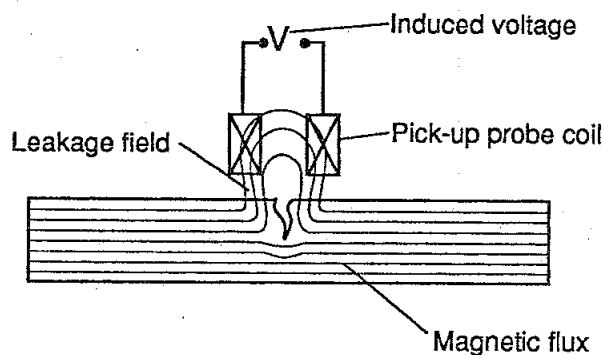


Figure 50. Detection of flux leakage field with a probe coil.

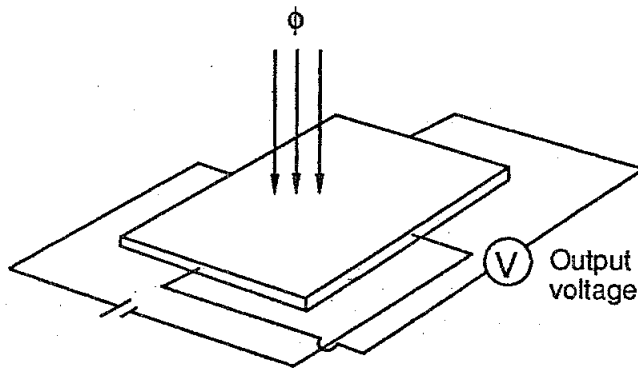


Figure 51. Principle of the Hall detector. The change of potential, V , transverse to the flow of a current, is measured when subjected to a magnetic field, ϕ .

Eddy current method

can also be used to detect local flux leakage fields. This device is based on measuring the small electrical potential created at right angles to an electric current when it is placed in a magnetic field (Fig. 51). These methods lend themselves to fully automated mass testing of similar components.

If a coil carrying an alternating current is placed near a piece of metal as in Fig. 52, the magnetic field induces a small current in the metal known as an *eddy current*. The eddy current itself creates a magnetic field that opposes the original field and this can be detected by the change of inductive reactance of the energizing coil. A flaw in the piece of metal will disturb the eddy current which can thus be detected through

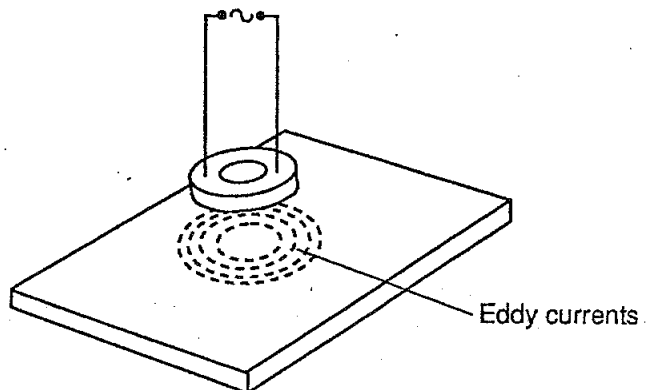


Figure 52. Eddy currents induced in a piece of metal by a nearby coil carrying an alternating current.

Eddy current equipment

the reactance. This is the principle of the eddy current testing method. It has the advantage of being a noncontact method and does not require the material to be magnetic. In fact, it is best applied to smooth surfaces of nonmagnetic materials and lends itself to continuous on-line inspection of products such as tubes. The depth of penetration in nonferrous metals can be about 6 mm but in steel penetration is severely limited, being no more than about 0.25 mm. The use of special techniques may increase this somewhat.

An eddy current test system in its simplest form is shown in Fig. 53. It comprises an oscillator, a test coil, and a voltmeter across the leads to the coil. In Fig. 54 a discontinuity has caused the eddy current path to be larger which has changed the reactance of the test coil. This is detected by a deflection of the voltmeter.

Figure 53. Simplified setup for eddy current testing.

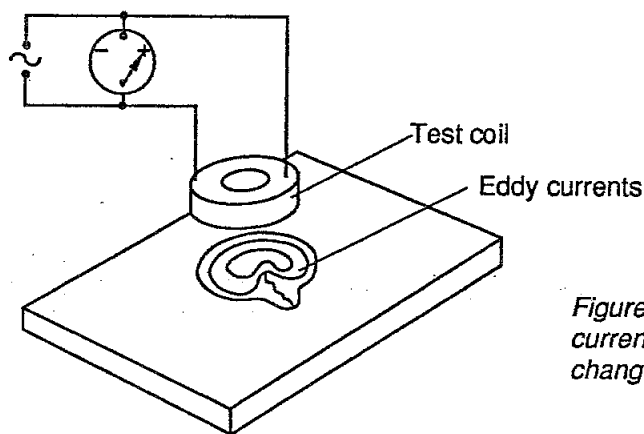
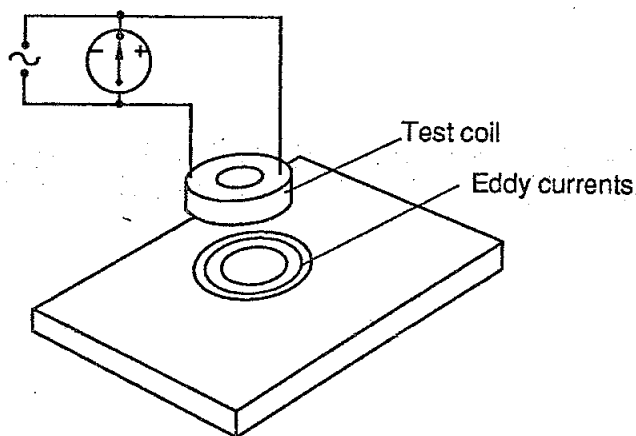


Figure 54. Disturbance of the eddy current by a discontinuity causes a change in voltage across the coil.

In practice the circuitry for eddy current testing is more complex, usually incorporating a bridge circuit, and the results may be displayed on a cathode ray tube screen. Various types of coils are used with some devices employing separate driver and pickup coils operating in a send/receive mode. The shape of the coil determines the direction of flow of the eddy current and consequently the orientation of defects that can most easily be detected.

A typical application of the eddy current method is the on-line inspection of seam welds in nonferrous pipes. An encircling coil is used creating a circumferential eddy current which is disrupted by any longitudinal defects in the seam welds. Fig. 55 illustrates the arrangement.

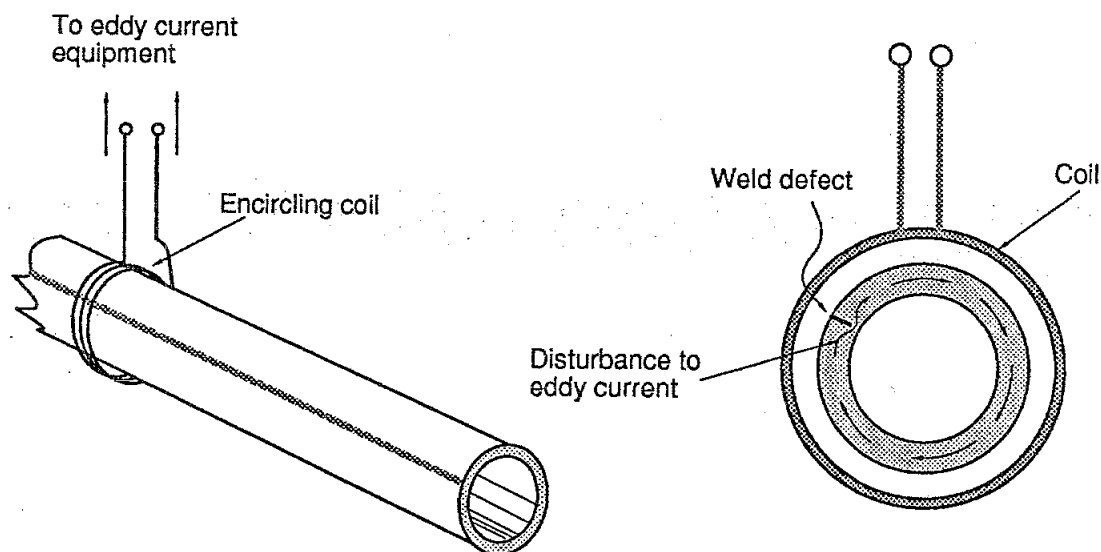


Figure 55. Typical application of the eddy current technique for inspecting seam welds in tubes.

Eddy current techniques are not widely applied to weld inspection in heavy fabrication because the rough surfaces and irregular material make the detection of defects difficult. New technology, however, is overcoming these obstacles and increasing application to welds may be expected. Personnel using eddy current methods may be certified to CGSB 48-GP-13M "Certification of Nondestructive Testing Personnel (Eddy Current Method)."

Potential drop method

The potential drop method is a relatively recent development that has been applied mainly to measuring fatigue crack growth. It is possible to obtain quite accurate measures of the depth and shape of a fatigue crack growing from the surface using this method. Fig. 56 shows the general principle. A current is applied to a specimen across a region where the crack is growing or expected to grow. Between the two current probes are two other probes which measure the potential difference. As the crack grows the potential between these two points changes and with appropriate signal processing it is possible to determine the depth of the crack at that point. If an array of probes is attached to the specimen along the length of the crack and each one sampled in sequence, it is possible to generate the profile of the crack front as a function of time. AC systems are limited to measuring surface cracks only while the use of DC allows for deeper penetration. The potential drop method is expected to be increasingly applied to the in-service monitoring of fatigue damage in structures.

Where a flaw extends completely through the section it may create a leak which would be unacceptable if the part is to be used for retaining a liquid or a gas. For some applications, therefore, a leak test may be required. Leak tests do not require high pressures but they do not replace high pressure hydrostatic or pneumatic proof tests for pressure vessels when the latter are specified.

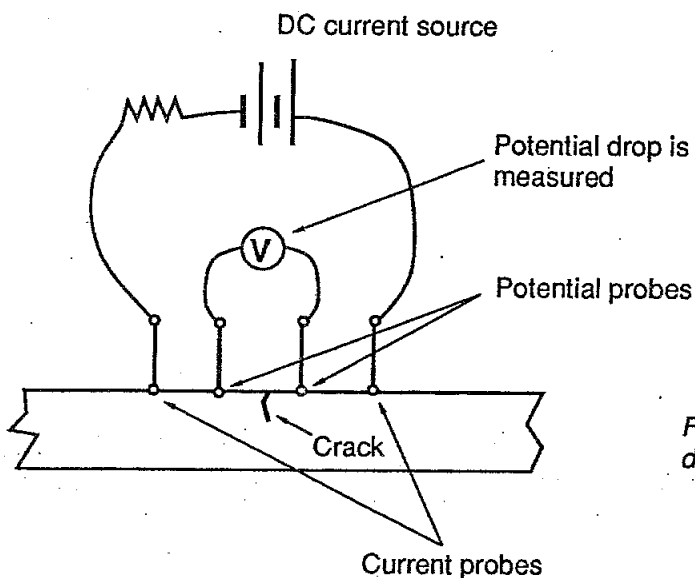


Figure 56. Principle of the potential drop method for crack growth.

Leak testing

Leak tests can be carried out by filling the vessel or container with low pressure air with a tracer such as helium added. Helium is a light gas that can penetrate extremely fine spaces. Any helium escaping through the walls would be detected with a helium detection instrument (a 'sniffer'). This is the most sensitive type of leak test.

A less sensitive but more convenient method uses a vacuum box to create a pressure difference across the wall. The area tested is coated with a soap film viewed through the transparent vacuum box. Any leaks show as bubbles when a vacuum is drawn into the box. Typically the vacuum is 2 to 8 psi.

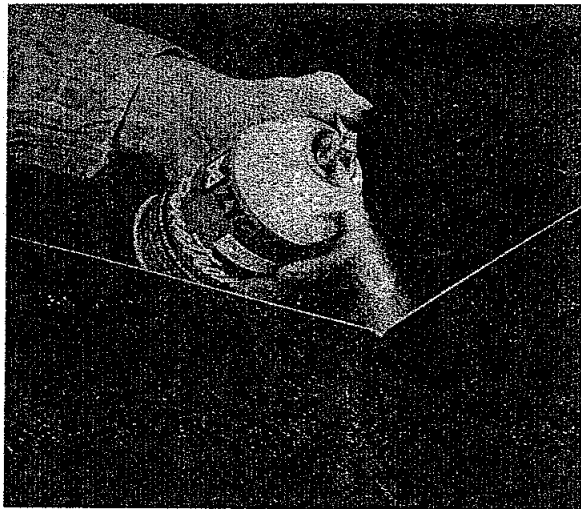
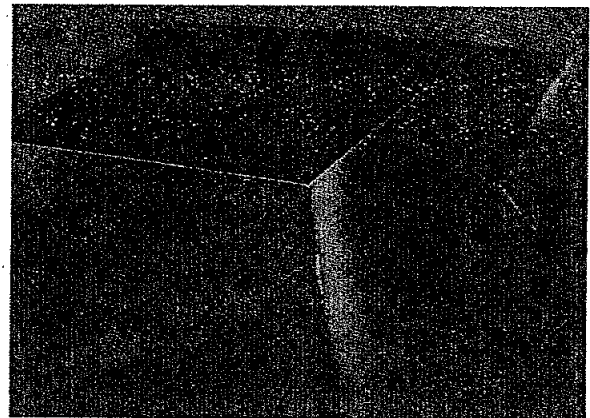


Figure 57. Leak testing using the liquid penetrant method. Fluorescent penetrant is first sprayed on one side of the seam.

Figure 58. Fluorescent indication on the other side of the seam provides evidence of a leak.



A simpler method, but without the sensitivity of vacuum or pressure methods, is to use a liquid penetrant. The penetrant is applied to one side and immediately following this the developer is applied to the opposite side. A period of time is then allowed for the penetrant to work through any leaks and show up as an indication on the other side. Typical delay times might be about three times the dwell times for normal surface inspection. Figs. 57 and 58 illustrate the use of liquid penetrant for leak detection.

Summary

Surface inspection methods are valuable means of detecting potential defects that are open to the surface. They can detect such things as fine cracks, porosity, and lack of fusion that might not be visible to the naked eye during a visual inspection. Like any other inspection method, they must be performed to prescribed procedures and the results interpreted according to defined acceptance criteria. The two most important surface inspection methods used in the welding industry are the liquid penetrant and the magnetic particle methods and we have discussed those in detail in this module. We have described the basic principles of the penetrant action, types of dyes, and methods for removing excess penetrant. We have given details of the procedures used, particularly for the solvent removal method normally used on welds, and discussed the interpretation of indications.

The section on magnetic particle testing has covered the basics of magnetism and has shown how an external magnetic field or an electric current can be used to induce a magnetic flux in a steel component. We have emphasized the importance of recognizing the direction of the field since only discontinuities in certain orientations are detectable. Again, procedures and interpretations of indications, have been discussed.

In addition, the module has presented a brief description of a few other surface inspection techniques including flux leakage and eddy current. It is hoped that the module helps the inspector gain a good understanding of surface inspection methods and assists in facilitating their correct application.

GUIDES AND EXERCISES

MODULE 17

SURFACE INSPECTION

SURFACE INSPECTION

MODULE 17

Guides & Exercises

To obtain maximum benefit from this module we suggest that you follow this guide and complete the exercises as indicated. It is important that you work through the text methodically, studying each section thoroughly before moving on. The exercises are designed to give you an indication of whether you have learned the material and can move on or whether you need to go back and study the section again.

Do the exercises honestly. They will not help you unless you take them seriously. If you get a question wrong go back through the text until you understand where you have gone wrong and know the correct answer.

The length of time required to complete the module will vary from student to student. Find your own pace. Do not rush. Remember you are trying to learn something, not win a race.

Some people like to underline sections when they read a text. We suggest that you use caution if you do this. What you think is important first time you read it may be different after reading it three times. We suggest you read a section three times thoroughly before highlighting anything.

The last exercise is designed to give you an indication of whether you are ready to take the WIC closed-book exams. The exercise questions are of a similar standard to the official exams. Do not take the exam until you feel you are ready and you may wish to study several Modules before taking the exams on each. The details of the examination procedures are on a separate sheet.

If you have any difficulties with this Module do not hesitate to ask for help. You may find you learn more by attending seminars which are given periodically, and you should also contact your local WIC Chapter to see if they can be of assistance. Remember, if you fail the examination you can always try again later.

After working through each guide, check your answers (starting on page 64) for accuracy. If any of your answers are wrong, restudy the guide subject matter in the text until you understand it before moving on to the next guide.

Guide 1

Read carefully pages 1 to 10 and answer the following questions:

1. The property of liquids that makes them try to reduce their surface area is known as:
 - a) Capillary action
 - b) Surface tension
 - c) Viscosity
2. True or false?

"The ability of a liquid to wet a solid surface can be measured in terms of the contact angle."
3. The phenomenon by which water rises up a narrow tube or by which a liquid can penetrate a crack is known as:
 - a) Capillary action
 - b) Surface tension
 - c) Viscosity
4. How must a fluorescent dye be viewed?
5. Which of the following penetrants require treatment with a separate agent before the excess can be removed?
 - a) Post-emulsifiable
 - b) Water-washable
 - c) Post-remover
 - d) Solvent-removable
6. What type of developer is normally used with the solvent-removal process for spot checking of welds?

Surface Inspection

Guide 2

Read carefully pages 10 to 22 and answer the following questions:

1. True or false?

"The fluorescent postemulsified penetrant process is often recommended for high sensitivity applications such as detection of fatigue cracks."

2. Does the liquid penetrant process work on stainless steel and aluminum?

3. Give one way in which a change to a liquid penetrant procedure could be qualified.

4. True or false?

"When using liquid penetrant inspection, the surface must be ground smooth to remove all irregularities before applying the penetrant."

5. According to ASTM E-165, the surface temperature for liquid penetrant inspection should not be outside the range:

- a) 12° to 52°C (60° to 125°F)
- b) 21° to 24°C (70° to 75°F)
- c) -18° to 38°C (0° to 100°F)

6. When using the solvent-removable method why should the solvent not be sprayed directly on the surface to remove excess penetrant?

7. True or false?

"When using post-emulsifiable penetrants, the emulsifier must remain in contact with the surface long enough to mix with the excess penetrant but not long enough to reach penetrant in the discontinuities."

8. What could be the effect of spraying on too much developer?

Guide 3

Read carefully pages 22 to 27 and answer the following questions:

1. What is the difference between a false indication and a nonrelevant indication?
2. What is the most likely cause of false indications?
3. Which of the following indications is most likely to be caused by a crack?
 - a) Rounded
 - b) Diffused or weak
 - c) Continuous line
4. Which of the following indications is most likely to be caused by porosity?
 - a) Rounded
 - b) Diffused or weak
 - c) Continuous line
5. According to CSA W59-M1989 the criteria used for evaluating liquid penetrant testing are the same as those for:
 - a) Ultrasonic inspection
 - b) Visual inspection
 - c) Radiographic inspection
6. True or false?

"If a small crack is found by LPI in an aluminum weld, it may be repaired by simply welding over it to melt out the crack."
7. Is there a standard for certifying operators using the liquid penetrant inspection method?

Guide 4

Read carefully pages 28 to 34 and answer the following questions:

1. The local magnetic field across a crack in a magnetized piece of steel is known as:
 - a) Flux leakage
 - b) Saturation
 - c) Induction
2. The strength of the flux induced when a material is placed in a given magnetic field depends on what property of the material?
3. The level of residual magnetic flux remaining in a ferromagnetic material when an applied field is removed is known as:
 - a) Coercive force
 - b) Saturation
 - c) Retentivity
4. What is the range of applied field (relative to saturation) normally used in magnetic particle inspection?
5. The lines of force in a magnetic field formed by an electric current are:
 - a) Parallel to the direction of the current
 - b) At right angles to the direction of the current
6. The direction of the magnetic field in the centre of a coil is:
 - a) Parallel to the axis of the coil
 - b) At right angles to the axis of the coil
7. Which of the following terms might be used to indicate the strength of the magnetic field in a coil?
 - a) Volt/amp characteristic
 - b) Ampere turns
 - c) B-H curve

Guide 5

Read carefully pages 34 to 42 and answer the following questions:

1. True or false?

"The most favourable direction for detecting a crack when using prods is when the crack lies along the line between the prods."

2. When trying to detect a centreline crack in a weld, you would place a yoke:

- a) Along the weld axis
- b) Across the weld

3. How are arc strikes avoided when using prods?

4. What would be a typical current for prods spaced 150 mm (6 in.) apart?

5. True or false?

"An advantage of alternating current is the ability to detect defects up to 3 mm below the surface."

6. What advantage does the wet fluorescent particle method have over the dry particle method?

7. True or false?

"Although surfaces should be clean and dry, it is still possible for a yoke to work through a thin coating of paint."

8. What weight should an AC yoke be capable of lifting?

- a) 4.5 kg (10 lb)
- b) 45 kg (100 lb)
- c) 0.45 kg (1 lb)

Guide 6

Read carefully pages 42 to 47 and answer the following questions:

1. Write down at least three changes in a material that could cause a magnetic particle indication in the absence of a discontinuity.
2. Give one source of nonrelevant indications not due to material changes?
3. A well-defined line indication with tightly held, heavy powder buildup is likely to represent:
 - a) Porosity
 - b) A sub-surface crack
 - c) A crack open to the surface
4. According to CSA W59-M1989 the criteria used for evaluating magnetic particle testing are the same as those for:
 - a) Ultrasonic inspection
 - b) Visual inspection
 - c) Radiographic inspection
5. Give two applications when demagnetization might be specified.
6. True or false?

"A disadvantage of magnetic particle inspection is that it is impossible to obtain any kind of permanent record of the indication."
7. Is there a standard for the certification of operators for magnetic particle inspection?

Guide 7

Read carefully pages 48 to 54 and answer the following questions:

1. What is the name of the device that measures the small electrical potential created at right angles to an electric current when placed in a magnetic field?
2. True or false?
"The eddy current technique only works on ferromagnetic materials such as steel."
3. What is a typical maximum depth of detection for the eddy current method in nonferrous metals?
 - a) 6 mm
 - b) 35 mm
 - c) 0.25 mm
4. Is there a standard for certifying operators for the eddy current method?
5. For what research application has the potential drop method been used?
6. True or false?
"If a leak test is done on a pressure vessel, the normal hydrostatic proof test may be omitted."

ANSWERS

Guide 1

1. b)
2. True
3. a)
4. Under black light
5. a) and c)
6. Nonaqueous

Guide 2

1. True
2. Yes
3. Use a comparator block
4. False. Grinding can flow the surface and conceal defects.
5. a)
6. It may leach penetrant out of discontinuities
7. True
8. It could mask indications

Guide 3

1. False indications are not associated with discontinuities, nonrelevant indications are
2. Poor cleaning
3. c)
4. a)
5. b)
6. False. Retained penetrant could contaminate the repair. The metal containing the crack must be removed before repair.
7. Yes. CGSB 48-GP-9M

Guide 4

1. a)
2. Permeability
3. c)
4. 30-70%
5. b)
6. a)
7. b)

Guide 5

1. True
2. b)
3. Turn the power on after the prods are in place, and turn power off before removing prods
4. About 600 amps
5. False. AC has no depth capability.
6. Higher sensitivity
7. True
8. a)

Guide 6

1. Composition, microstructure, work hardening, heat treatment
2. Excessive magnetizing field, residual magnetism
3. c)
4. c)
5. See the list on page 46
6. False. Photographs or adhesive tape transfers can be used
7. Yes, CGSB 48-GP-8M

Guide 7

1. Hall detector
2. False
3. a)
4. Yes, CGSB 48-GP-13M
5. Measuring the growth of fatigue cracks
6. False

MODULE 17

TEST

This test is designed to determine whether you are ready to attempt the formal examination.

Complete the ANSWER SHEET and compare the results with the TEST KEY. If you score less than 70% we suggest you restudy the material.

1. The ability of a liquid to penetrate a narrow opening depends on the phenomenon of—
 - a) Fluorescence
 - b) Capillary action
 - c) Density
 - d) Viscosity
 - e) Lipophilic
2. When using a post-emulsifiable penetrant, the excess penetrant is removed—
 - a) Immediately after the dwell time by water washing
 - b) Immediately after the dwell time by using a solvent
 - c) After brushing on an emulsifier then water washing
 - d) After dipping or spraying on an emulsifier then water washing
 - e) After brushing on an emulsifier then using a solvent
3. What is the normal operating temperature range for a liquid penetrant according to ASTM E-165?
 - a) 21° to 24°C (70° to 75°F)
 - b) Any temperature
 - c) 12° to 52°C (60° to 125°F)
 - d) 60° to 125°C (140° to 257°F)
 - e) -18° to 38°C (0° to 100°F)
4. To remove excess penetrant when using the solvent-removable process in a portable kit for spot checking—
 - a) Wipe away excess penetrant with a clean cloth then wipe surface clean with a cloth lightly moistened with solvent remover
 - b) Spray surface with solvent remover then wipe clean with a cloth
 - c) Apply solvent remover by dipping or spraying and allow to soak in for a few minutes before wiping clean
 - d) Apply solvent remover by brushing then wipe clean with a cloth
 - e) Spray surface with solvent remover and allow to dry by natural evaporation

5. Which of the following best describes the basis of the magnetic particle inspection method?
- a) The increased resistance to the flow of electric current when a discontinuity is present
 - b) The attraction of magnetic particles to a flux leakage field formed when a discontinuity lies parallel to an applied magnetic field
 - c) The attraction of magnetic particles to a flux leakage field formed when a discontinuity lies at an angle to the induced magnetic flux
 - d) The attraction of magnetic particles to the strong fields formed when a material is magnetically saturated
 - e) The attraction of magnetic particles to a discontinuity that occurs when the coercive force is applied to remove the induced flux
6. In which direction is the magnetic field at the centre of a short coil of 50 turns and 50 mm diameter?
- a) The field is zero inside the coil
 - b) In a radial direction
 - c) Tangential, i.e., in the same direction as the current flowing in the turns of the coil
 - d) Parallel to the axis of the coil
 - e) It depends on the current in the coil
7. When using an AC yoke, two tests are done with the angle of the yoke at 90° to each other. Why?
- a) To ensure good magnetic contact is maintained
 - b) Because discontinuities lying parallel to the line between the poles of the yoke are not readily detected
 - c) To remove residual magnetism from the first test
 - d) Because discontinuities lying normal to the line between the poles of the yoke are not readily detected
 - e) Two tests are not necessary when using AC
8. What is the depth capability for AC magnetic particle methods?
- a) 3 mm
 - b) 3 mm for AC prods only
 - c) 6 mm in nonferrous metals
 - d) 6 mm in steel
 - e) No effective depth capability

Surface Inspection

9. According to CSA W59-M1989 the criteria for evaluating magnetic particle testing are the same as those for—
- a) Radiographic inspection
 - b) Visual inspection
 - c) Eddy current inspection
 - d) Ultrasonic inspection
 - e) Liquid penetrant inspection
10. Which of the following statements is true?
- a) The eddy current method is based on detecting the flux leakage around a discontinuity using a Hall detector
 - b) The eddy current method is based on detecting changes in the inductive reactance of a coil due to disturbance of the eddy current by a discontinuity and can be used on nonferrous metals
 - c) The eddy current method is based on detecting changes in the inductive reactance of a coil due to disturbance of the eddy current and can only be used on ferromagnetic metals
 - d) The eddy current method is based on measuring the change in voltage across a discontinuity when an eddy current flows
 - e) The eddy current method normally uses direct current in order to increase depth capability

Welding Institute of Canada Answer Sheet Module 17

Complete the "Answer Sheet" and compare your answers with those in the "Test Key." If you score less than 70% we suggest you restudy the material.

Please circle only ONE letter corresponding to the answer you think is most correct.

QUESTION	ANSWER				
1	a	b	c	d	e
2	a	b	c	d	e
3	a	b	c	d	e
4	a	b	c	d	e
5	a	b	c	d	e
6	a	b	c	d	e
7	a	b	c	d	e
8	a	b	c	d	e
9	a	b	c	d	e
10	a	b	c	d	e

The answer sheet below is provided in the event you wish to retest yourself.

QUESTION	ANSWER				
1	a	b	c	d	e
2	a	b	c	d	e
3	a	b	c	d	e
4	a	b	c	d	e
5	a	b	c	d	e
6	a	b	c	d	e
7	a	b	c	d	e
8	a	b	c	d	e
9	a	b	c	d	e
10	a	b	c	d	e

Welding Institute of Canada Test Key Module 17

Compare your answer sheet to this key.

QUESTION	ANSWER				
1	a	(b)	c	d	e
2	a	b	c	(d)	e
3	a	b	(c)	d	e
4	(a)	b	c	d	e
5	a	b	(c)	d	e
6	a	b	c	(d)	e
7	a	(b)	c	d	e
8	a	b	c	d	(e)
9	(a)	b	c	d	e
10	a	(b)	c	d	e