# Liquid Penetrant Inspection

**Revised by J.S. Borucki, Ardrox Inc., and Gail Jordan, Howmet Corporation**

## Evolution of the Process

The exact origin of liquid penetrant inspection is not known, but it has been assumed that the method evolved from the observation that the rust on a crack in a steel plate in outdoor storage was somewhat heavier than the rust on the adjacent surfaces as a result of water seeping into the crack and forcing out the oxide it had helped to produce. The obvious conclusion was that a liquid purposely introduced into surface cracks and then brought out again would reveal the locations of those cracks.

The only material that fulfilled the known criteria of low viscosity, good wettability, and ready availability was kerosene. It was found, however, that although wider cracks showed up easily, finer ones were sometimes missed because of the difficulty of detecting, by purely visual means, the small amounts of kerosene exuding from them. The solution was to provide a contrasting surface that would reveal smaller seepages. The properties and availability of whitewash made it the logical choice. This method, known as the kerosene-and-whiting test, was the standard for many years. The sensitivity of the kerosene-and-whiting test could be increased by hitting the object being tested with a hammer during testing. The resulting vibration brought more of the kerosene out of the cracks and onto the whitewash. Although this test was not as sensitive as those derived from it, it was quick, inexpensive, and reasonably accurate. Thus, it provided a vast improvement over ordinary visual examination.

The first step leading to the methods now available was the development of the fluorescent penetrant process by R.C. Switzer. This liquid, used jointly with a powder developer, brought penetrant inspection from a relatively crude procedure to a more scientific operation. With fluorescent penetrant, minute flaws could be readily detected when exposed to ultraviolet light (commonly called black light). This development represented a major breakthrough in the detection of surface flaws.

Switzer's work also included the development of the visible-color contrast method, which allowed for inspection under white light conditions. Although not as sensitive as fluorescent penetrant inspection, it is widely used in industry for noncritical inspection. Through the developments described above, liquid penetrant inspection has become a major nondestructive inspection method.

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## Penetrant Methods

Because of the vast differences among applications for penetrant inspection, it has been necessary to refine and develop the two types of penetrants (type I, fluorescent, and type II, visible) into four basic methods to accommodate the wide variations in the following principal factors:

- Surface condition of the workpiece being inspected
- Characteristics of the flaws to be detected
- Time and place of inspection
- Size of the workpiece
- Sensitivity required

The four methods are broadly classified as:

- Water washable, method A
- Postemulsifiable lipophilic, method B
- Solvent removable, method C
- Postemulsifiable hydrophilic, method D

These four methods are described below.

**Water-washable penetrant (method A)** is designed so that the penetrant is directly water washable from the surface of the workpiece; it does not require a separate emulsification step, as does the postemulsifiable penetrant methods. It can be used to process workpieces quickly and efficiently. It is important, however, that the washing operation be carefully controlled because water-washable penetrants are susceptible to overwashing. The essential operations involved in this method are illustrated schematically in Fig. 7.

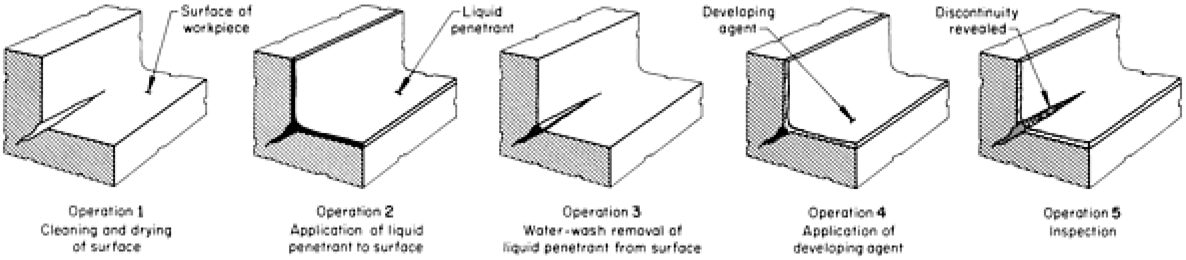

**Fig. 7 Five essential operations for liquid penetrant inspection using the water-washable system**

**Postemulsifiable penetrants (methods B and D)** are designed to ensure the detection of minute flaws in some materials. These penetrants are not directly water washable. Because of this characteristic, the danger of overwashing the penetrant out of the flaws is reduced. The difference between the water-washable and postemulsifiable method lies in the use of an emulsifier prior to final rinsing. The emulsifier makes the residual surface penetrant soluble in water so that the excess surface penetrant can be removed by the water rinse. Therefore, the emulsification time must be carefully controlled so that the surface penetrant becomes water soluble but the penetrant in the flaws does not. The operations involved in the postemulsifiable method are illustrated schematically in Fig. 8 for the lipophilic system and in Fig. 9 for the hydrophilic system. Despite the additional processing steps involved with the postemulsifiable methods B and D, these methods are the most reliable for detecting minute flaws.

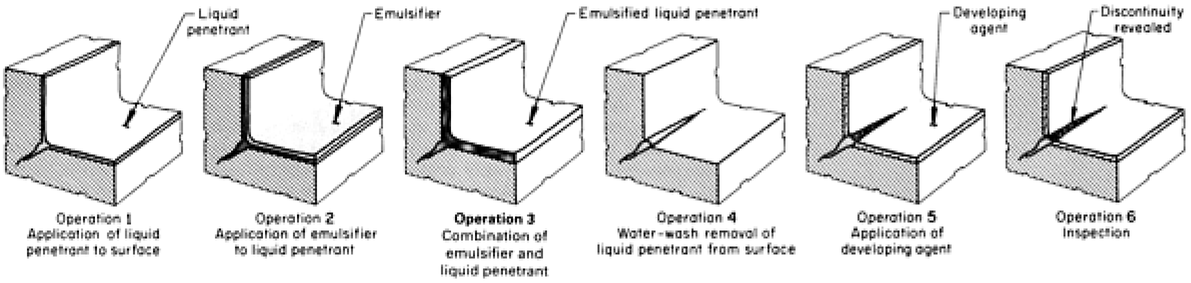

**Fig. 8 Operations (in addition to precleaning) for the postemulsifiable, method B, lipophilic liquid penetrant system**

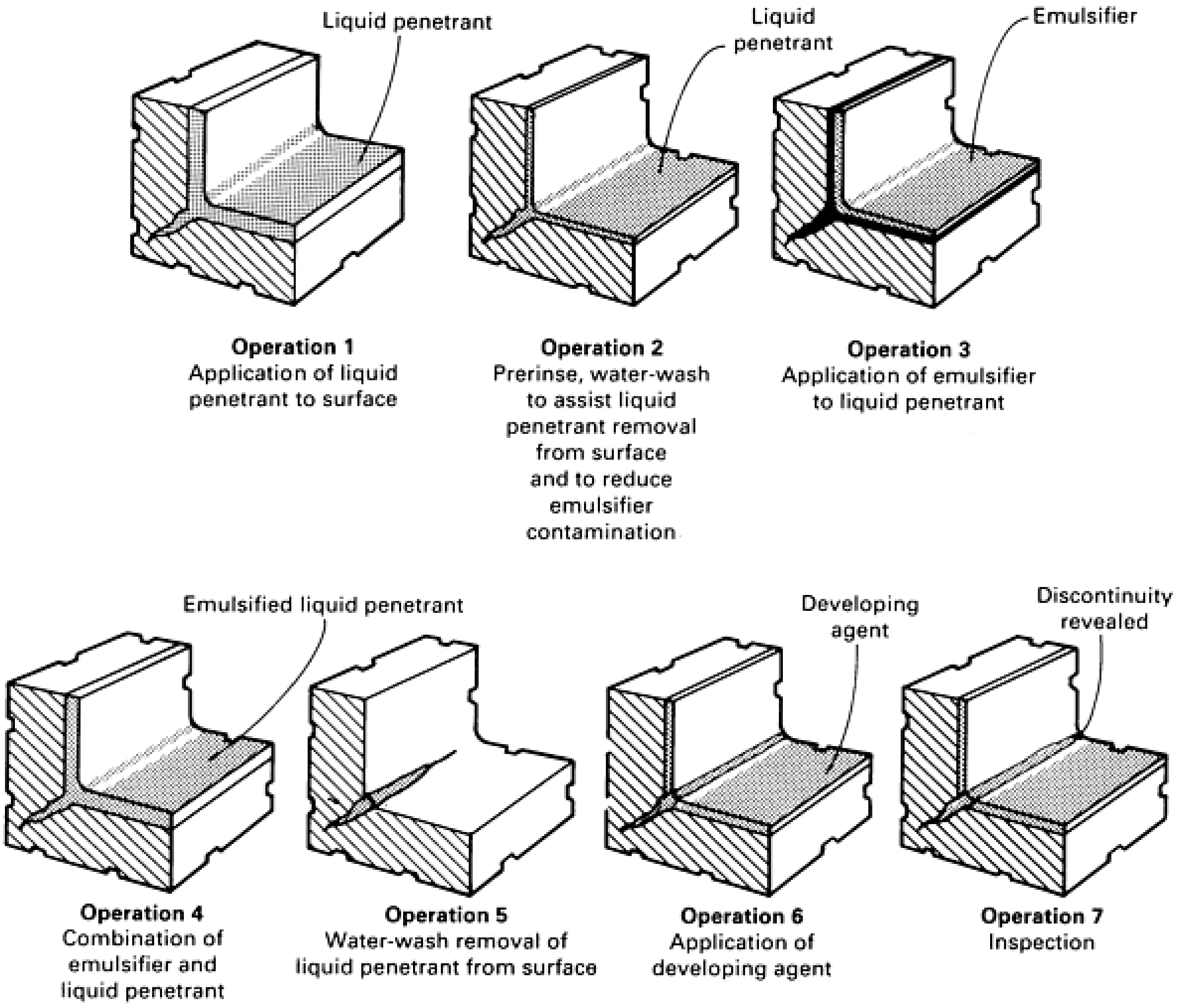

**Fig. 9 Operations (in addition to precleaning) for the postemulsifiable, method D, hydrophilic liquid penetrant system**

**Solvent-removable penetrant (method C)** is available for use when it is necessary to inspect only a localized area of a workpiece or to inspect a workpiece at the site rather than on a production inspection basis. Normally, the same type of solvent is used for precleaning and for removing excess penetrant. This penetrant process is convenient and broadens the range of applications of penetrant inspections. However, because the solvent-removable method is labor intensive, it is not practical for many production applications. When properly conducted and when used in the appropriate applications, the solvent-removable method can be one of the most sensitive penetrant methods available. The operations for this process are illustrated schematically in Fig. 10.

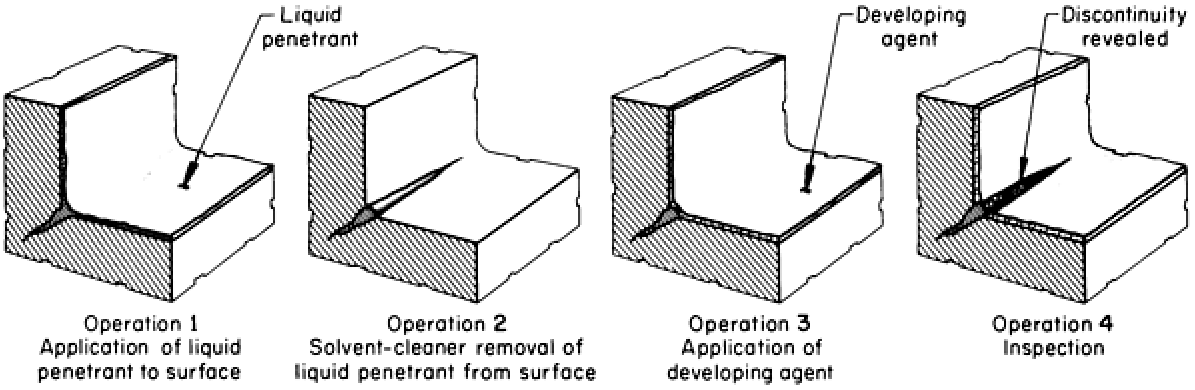

**Fig. 10 Operations (in addition to precleaning) for the solvent-removable liquid penetrant system**

Whichever penetrant method is chosen, the degree and speed of excess penetrant removal depend on such processing conditions as spray nozzle characteristics, water pressure and temperature, duration of the rinse cycle, surface condition of the workpiece, and inherent removal characteristics of the penetrant employed.

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## Description of the Process

Regardless of the type of penetrant used, that is, fluorescent (type I) or visible (type II), penetrant inspection requires at least five essential steps, as follows.

**Surface Preparation.** All surfaces to be inspected, whether localized or the entire workpiece, must be thoroughly cleaned and completely dried before being subjected to penetrant inspection. Flaws exposed to the surface must be free from oil, water, or other contaminants if they are to be detected.

**Penetration.** After the workpiece has been cleaned, penetrant is applied in a suitable manner so as to form a film of the penetrant over the surface. This film should remain on the surface long enough to allow maximum penetration of the penetrant into any surface openings that are present.

**Removal of Excess Penetrant.** Excess penetrant must be removed from the surface. The removal method is determined by the type of penetrant used. Some penetrants can be simply washed away with water; others require the use of emulsifiers (lipophilic or hydrophilic) or solvent/remover. Uniform removal of excess surface penetrant is necessary for effective inspection, but overremoval must be avoided.

**Development.** Depending on the form of developing agent to be used, the workpiece is dried either before or directly after application of the developer. The developer forms a film over the surface. It acts as a blotter to assist the natural seepage of the penetrant out of surface openings and to spread it at the edges so as to enhance the penetrant indication.

**Inspection.** After it is sufficiently developed, the surface is visually examined for indications of penetrant bleedback from surface openings. This examination must be performed in a suitable inspection environment. Visible penetrant inspection is performed in good white light. When fluorescent penetrant is used, inspection is performed in a suitably darkened area using black (ultraviolet) light, which causes the penetrant to fluoresce brilliantly.

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## Materials Used in Penetrant Inspection

In addition to the penetrants themselves, liquids such as emulsifiers, solvent/cleaners and removers, and developers are required for conducting liquid penetrant inspection.

### *Penetrants*

There are two basic types of penetrants:

- Fluorescent, type I
- Visible, type II

Each type is available for any one of the four methods (water washable, postemulsifiable lipophilic, and postemulsifiable hydrophilic, and solvent removable) mentioned in the section "Penetrant Methods" in this article.

**Type I fluorescent penetrant** utilizes penetrants that are usually green in color and fluoresce brilliantly under ultraviolet light. The sensitivity of a fluorescent penetrant depends on its ability to form indications that appear as small sources of light in an otherwise dark area. Type I penetrants are available in different sensitivity levels classified as follows:

- *Level* $\frac{1}{2}$*:* Ultralow
- *Level 1:* Low
- *Level 2:* Medium
- *Level 3:* High
- *Level 4:* Ultrahigh

**Type II visible penetrant** employs a penetrant that is usually red in color and produces vivid red indications in contrast to the light background of the applied developer under visible light. The visible penetrant indications must be viewed under adequate white light. The sensitivity of visible penetrants is regarded as Level 1 and adequate for many applications.

**Penetrant selection and use** depend on the criticality of the inspection, the condition of the workpiece surface, the type of processing, and the desired sensitivity (see the section "Selection of Penetrant Method" in this article).

***Method A, water-washable penetrants*** are designed for the removal of excess surface penetrant by water rinsing directly after a suitable penetration (dwell) time. The emulsifier is incorporated into the water-washable penetrant. When this type of penetrant is used, it is extremely important that the removal of excess surface penetrant be properly controlled to prevent overwashing, which can cause the penetrant to be washed out of the flaws.

***Methods B and D, lipophilic and hydrophilic postemulsifiable penetrants*** are insoluble in water and therefore not removable by water rinsing alone. They are designed to be selectively removed from the surface of the workpiece by the use of a separate emulsifier. The emulsifier, properly applied and left for a suitable emulsification time, combines with the excess surface penetrant to form a water-washable surface mixture that can be rinsed from the surface of the workpiece. The penetrant that remains within the flaw is not subject to overwashing. However, proper emulsification time must be established experimentally and maintained to ensure that overemulsification, which results in the loss of flaws, does not occur.

***Method C, solvent-removable penetrants*** are removed by wiping with clean, lint-free material until most traces of the penetrant have been removed. The remaining traces are removed by wiping with clean, lint-free material lightly moistened with solvent. This type of penetrant is primarily used where portability is required and for the inspection of localized areas. To minimize the possibility of removing the penetrant from discontinuities, the use of excessive amounts of solvent must be avoided.

**Physical and Chemical Characteristics.** Both fluorescent and visible penetrants, whether water washable, postemulsifiable, or solvent removable, must have certain chemical and physical characteristics if they are to perform their intended functions. The principal requirements of penetrants are as follows:

- Chemical stability and uniform physical consistency
- A flash point not lower than 95 °C (200 °F); penetrants that have lower flash points constitute a potential fire hazard
- A high degree of wettability
- Low viscosity to permit better coverage and minimum dragout

- Ability to penetrate discontinuities quickly and completely
- Sufficient brightness and permanence of color
- Chemical inertness with materials being inspected and with containers
- Low toxicity to protect personnel
- Slow drying characteristics
- Ease of removal
- Inoffensive odor
- Low cost
- Resistance to ultraviolet light and heat fade

### *Emulsifiers*

Emulsifiers are liquids used to render excess penetrant on the surface of a workpiece water washable. There are two methods used in the postemulsifiable method: method B, lipophilic, and method D, hydrophilic. Both can act over a range of durations from a few seconds to several minutes, depending on the viscosity, concentration, method of application, and chemical composition of the emulsifier, as well as on the roughness of the workpiece surface. The length of time an emulsifier should remain in contact with the penetrant depends on the type of emulsifier employed and the roughness of the workpiece surface.

**Method B, lipophilic emulsifiers** are oil based, are used as supplied, and function by diffusion (Fig. 11). The emulsifier diffuses into the penetrant film and renders it spontaneously emulsifiable in water. The rate at which it diffuses into the penetrant establishes the emulsification time. The emulsifier is fast acting, thus making the emulsification operation very critical. The emulsifier continues to act as long as it is in contact with the workpiece; therefore, the rinse operation should take place quickly to avoid overemulsification.

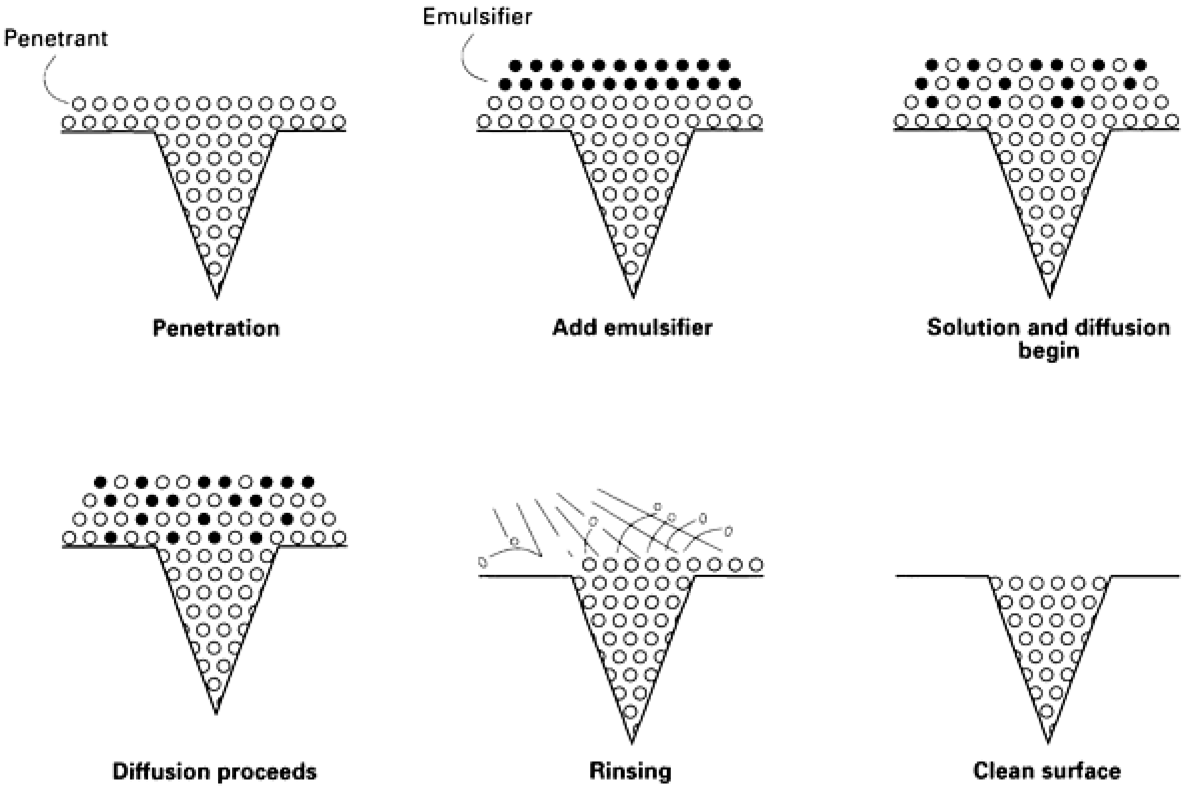

**Fig. 11 Elements in the functioning of lipophilic emulsifiers**

**Method D, hydrophilic emulsifiers** are water based and are usually supplied as concentrates that are diluted in water to concentrations of 5 to 30% for dip applications and 0.05 to 5% for spray applications. Hydrophilic emulsifiers function by displacing excess penetrant from the surface of the part by detergent action (Fig. 12). The force of the water spray or the air agitation of dip tanks provides a scrubbing action. Hydrophilic emulsifier is slower acting than the lipophilic emulsifier; therefore, it is easier to control the cleaning action. In addition to the emulsifier application, method D also requires a prerinse. Utilizing a coarse water spray, the prerinse helps remove the excess penetrant to minimize contamination of the emulsifier. Of greater significance, only a very thin and uniform layer of penetrant will remain on the surface, thus allowing easy removal of the surface layer with minimum opportunity of removing penetrant from the flaws. This step is required because the penetrant is not miscible with the hydrophilic emulsifier.

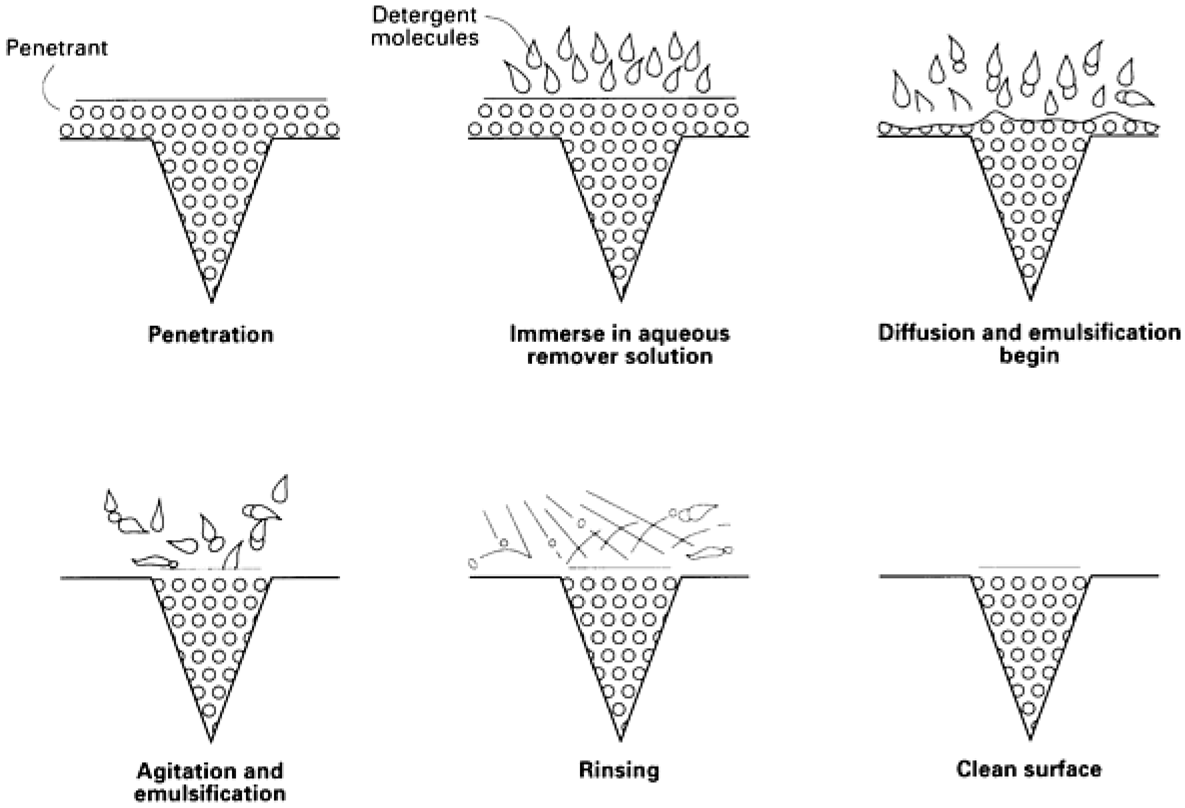

**Fig. 12 Elements in the functioning of hydrophilic emulsifiers**

The penetrant manufacturer should recommend nominal emulsification times for the specific type of emulsifier in use. Actual emulsification times should be determined experimentally for the particular application. The manufacturer should also recommend the concentrations for hydrophilic emulsifiers.

### *Solvent Cleaner/Removers*

Solvent cleaner/removers differ from emulsifiers in that they remove excess surface penetrant through direct solvent action. There are two basic types of solvent removers: flammable and nonflammable. Flammable cleaners are essentially free of halogens but are potential fire hazards. Nonflammable cleaners are widely used. However, they do contain halogenated solvents, which may render them unsuitable for some applications.

Excess surface penetrant is removed by wiping, using lint-free cloths slightly moistened with solvent cleaner/remover. It is not recommended that excess surface penetrant be removed by flooding the surface with solvent cleaner/remover, because the solvent will dissolve the penetrant within the defect and indications will not be produced.

### *Developers*

The purpose of a developer is to increase the brightness intensity of fluorescent indications and the visible contrast of visible-penetrant indications. The developer also provides a blotting action, which serves to draw penetrant from within the flaw to the surface, spreading the penetrant and enlarging the appearance of the flaw.

The developer is a critical part of the inspection process; borderline indications that might otherwise be missed can be made visible by the developer. In all applications of liquid penetrant inspection, use of a developer is desirable because it decreases inspection time by hastening the appearance of indications.

**Required Properties.** To carry out its functions to the fullest possible extent, a developer must have the following properties or characteristics (rarely are all these characteristics present to optimum degrees in any given material or formulation, but all must be considered in selecting a developer):

- The developer must be adsorptive to maximize blotting
- It must have fine grain size and a particle shape that will disperse and expose the penetrant at aflaw to produce strong and sharply defined indications of flaws
- It must be capable of providing a contrast background for indications when color-contrast penetrants are used
- It must be easy to apply
- It must form a thin, uniform coating over a surface
- It must be easily wetted by the penetrant at the flaw (the liquid must be allowed to spread over the particle surfaces)
- It must be nonfluorescent if used with fluorescent penetrants
- It must be easy to remove after inspection
- It must not contain ingredients harmful to parts being inspected or to equipment used in the inspection operation
- It must not contain ingredients harmful or toxic to the operator

**Developer Forms.** There are four forms of developers in common use:

- Form A, dry powder
- Form B, water soluble
- Form C, water suspendible
- Form D, nonaqueous solvent suspendible

The characteristics of each form are discussed below.

***Dry powder developers (form A)*** are widely used with fluorescent penetrants, but should not be used with visible-dye penetrants because they do not produce a satisfactory contrast coating on the surface of the workpiece. Ideally, dry powder developers should be light and fluffy to allow for ease of application and should cling to dry surfaces in a fine film. The adherence of the powder should not be excessive, as the amount of black light available to energize fluorescent indications will be reduced.

For purposes of storage and handling as well as applications, powders should not be hygroscopic, and they should remain dry. If they pick up moisture when stored in areas of high humidity, they will lose their ability to flow and dust easily, and they may agglomerate, pack, or lump up in containers or in developer chambers.

For reasons of safety, dry powder developers should be handled with care. Like any other dust particle, it can dry the skin and irritate the lining of the air passages, causing irritation. If an operator will be working continuously at a developer station, rubber gloves and respirators may be desirable. Modern equipment often includes an exhaust system on the developer spray booth or on the developer dust chamber that prevents dust from escaping. Powder recovery filters are included in most such installations.

***Water-soluble developers (form B)*** can be used for both fluorescent (type I) or visible (type II) postemulsifiable or solvent-removable penetrants. Water-soluble developers are not recommended for use with water-washable penetrants, because of the potential to wash the penetrant from within the flaw if the developer is not very carefully controlled. Water-soluble developers are supplied as a dry powder concentrate, which is then dispersed in water in recommended proportions, usually from 0.12 to 0.24 kg/L (1 to 2 lb/gal.). The bath concentration is monitored for specific gravity with the appropriate hydrometer. Necessary constituents of the developers include corrosion inhibitors and biocides. The advantages of this form of developer are as follows:

- The prepared bath is completely soluble and therefore does not require any agitation
- The developer is applied prior to drying, thus decreasing the development time
- The dried developer film on the workpiece is completely water soluble and is thus easily and completely removed following inspection by simple water rinsing

***Water-suspendible developers (form C)*** can be used with either fluorescent (type I) or visible (type II) penetrants. With fluorescent penetrant, the dried coating of developer must not fluoresce, nor may it absorb or filter out the black light used for inspection.

Water-suspendible developers are supplied as a dry powder concentrate, which is then dispersed in water in recommended proportions, usually from 0.04 to 0.12 kg/L ($\frac{1}{3}$ to 1 lb/gal.). The amount of powder in suspension must be carefully maintained. Too much or too little developer on the surface of a workpiece can seriously affect sensitivity. Specific gravity checks should be conducted routinely, using a hydrometer to check the bath concentration. Water-soluble developers contain dispersing agents to help retard settling and caking as well as inhibitors to prevent or retard corrosion of workpieces and equipment, and biocides to extend the working life of the aqueous solutions. In addition, wetting agents are present to ensure even coverage of surfaces and ease of removal after inspection.

Water-suspendible developer is applied before drying; therefore, developing time can be decreased because the heat from the drier helps to bring penetrant back out of surface openings. In addition, with the developer film already in place, the developing action begins at once. Workpieces are ready for inspection in a shorter period of time.

***Nonaqueous solvent-suspendible developers (form D)*** are commonly used for both the fluorescent and the visible penetrant process. This form of developer produces a white coating on the surface of the part. This coating yields the maximum white color contrast with the red visible penetrant indication and extremely brilliant fluorescent indication.

Nonaqueous solvent-suspendible developers are supplied in the ready-to-use condition and contain particles of developer suspended in a mixture of volatile solvents. The solvents are carefully selected for their compatibility with the penetrants. Nonaqueous solvent-suspendible developers also contain surfactants in a dispersant whose functions are to coat the particles and reduce their tendency to clump or agglomerate.

Nonaqueous solvent-suspendible developers are the most sensitive form of developer used with type I fluorescent penetrants because the solvent action contributes to the absorption and adsorption mechanisms. In many cases where tight, small flaws occur, the dry powder (form A), water-soluble (form B), and water-suspendible (form C) developers do not contact the entrapped penetrant. This results in the failure of the developer to create the necessary capillary action and surface tension that serve to pull the penetrant from the flaw. The nonaqueous solvent-suspendible developer enters the flaw and dissolves into the penetrant. This action increases the volume and reduces the viscosity of the penetrant. The manufacturer must carefully select and compound the solvent mixture. There are two types of solvent-base developers: nonflammable (chlorinated solvents) and flammable (nonchlorinated solvents). Both types are widely used. Selection is based on the nature of the application and the type of alloy being inspected.

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## Selection of Penetrant Method

The size, shape, and weight of workpieces, as well as the number of similar workpieces to be inspected, often influence the selection of a penetrant method.

**Sensitivity and Cost.** The desired degree of sensitivity and cost are usually the most important factors in selecting the proper penetrant method for a given application. The methods capable of the greatest sensitivity are also the most costly. Many inspection operations require the ultimate in sensitivity, but there are a significant number in which extreme sensitivity is not required and may even produce misleading results.

On a practical basis, the fluorescent penetrant methods are employed in a wider variety of production inspection operations than the visible penetrant methods, which are utilized primarily for localized inspections. As stated earlier, penetrants are classified on the basis of penetrant type:

- *Type I:* Fluorescent
- *Type II:* Visible
- *Method A:* Water washable
- *Method B:* Postemulsifiable-lipophilic
- *Method C:* Solvent removable
- *Method D:* Postemulsifiable-hydrophilic

Penetrants are also classified in terms of sensitivity levels:

- *Level* $\frac{1}{2}$*:* Ultralow
- *Level 1:* Low
- *Level 2:* Medium
- *Level 3:* High
- *Level 4:* Ultrahigh

**Advantages and Limitations of Penetrant Methods.** Each penetrant method, whether postemulsifiable (either lipophilic or hydrophilic), solvent removable, or water washable, using fluorescent or visible-dye penetrants, has inherent advantages and limitations.

***The postemulsifiable fluorescent penetrant method*** is the most reliable and sensitive penetrant method. This procedure will locate wide, shallow flaws as well as tight cracks and is ideal for high-production work. On the other hand, emulsification requires an additional operation, which increases cost. Also, this method requires a water supply and facilities for inspection under black light. The postemulsifiable, lipophilic fluorescent penetrant method is less sensitive and less reliable than the hydrophilic method. Its use is therefore declining.

***The solvent-removable fluorescent penetrant method*** employs a procedure similar to that used for the postemulsifiable fluorescent method, except that excess penetrant is removed with a solvent/remover. This method is especially recommended for spot inspection or where water cannot be conveniently used. It is more sensitive than the water-washable system, but the extreme caution and additional time required for solvent removal often preclude its use.

***The water-washable fluorescent penetrant method*** is the fastest of the fluorescent procedures. It is also highly sensitive, reliable, and reasonably economical. It can be used for both small and large workpieces and is effective on most part surfaces. However, it will not reliably reveal open, shallow flaws if overwashed and in some cases, depending on the sensitivity level of the penetrant, will not locate the very tightest cracks. There is also the danger of overwashing by applying water for an excessive period of time or with a pressure sufficient to remove the penetrant from the flaws.

***The postemulsifiable visible penetrant method*** is used whenever sensitivity required is greater than that provided by the water-washable visible penetrant method. However, the additional step of applying emulsifier makes this system more costly than the water-washable visible penetrant dye method that requires water, but otherwise no location limitations are imposed.

***The solvent-removable visible penetrant method*** has a distinct advantage in that all the necessary ingredients are portable; accordingly, it can be used in a practically limitless number of locations, both in the shop and in the field. Because of the problems involved in penetrant removal, however, the method is generally confined to spot inspection or to inspection under circumstances that prohibit the use of other methods because of workpiece size or location.

***The water-washable visible penetrant system*** is the fastest and simplest of all penetrant techniques. It is, however, the least sensitive because the penetrant is likely to be removed from wide, shallow flaws. Therefore, it is most useful in those applications where shallow and relatively wide flaws are not significant. This method is also the least sensitive for locating tight cracks. It requires a water source, but can be performed in almost any location because neither a darkened area nor electricity is required.

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## Equipment Requirements

The equipment used in the penetrant inspection process varies from spray or aerosol cans to complex, automated, computer-driven processing systems. Some of the more generally used types of equipment are described in the following sections.

### *Portable Equipment*

For occasional inspections, especially in the field, where equipment portability is necessary, minimal kits for either visible or fluorescent penetrant inspection are commercially available. (Generally, portable penetrant applications are limited to localized areas or spot inspections rather than entire part surfaces.)

Such a kit for visible penetrant inspection work includes a precleaner, a penetrant, and a penetrant remover and developer, all in pressurized spray cans. Penetrant removal requires wiping with lint-free cloths or paper towels.

A similar kit is available for fluorescent work; a precleaner, a penetrant, penetrant remover and developer are likewise supplied in pressurized cans. Cleaning is accomplished by wiping with lint-free cloths or paper towels. This kit includes a small, portable black light for conducting the inspection.

### *Stationary Inspection Equipment*

The type of equipment most frequently used in fixed installations consists of a series of modular subunits. Each subunit performs a special task. The number of subunits in a processing line varies with the type of penetrant method used. The subunits are:

- Drain and/or dwell stations
- Penetrant and emulsifier stations
- Pre- and post-wash stations
- Drying station
- Developer station
- Inspection station
- Cleaning stations

The drain or dwell stations are actually roller-top benches that hold the parts during the processing cycle. The usual arrangement is to position a drain or dwell station following each of the dip tanks, the wash station, and the drying oven. The subunits are described in more detail below.

**Penetrant Station.** The principal requirement of a penetrant station is that it provide a means for coating workpieces with penetrant--either all over, for small workpieces, or over small areas of large workpieces when only local inspection is required. In addition, means should be provided for draining excess penetrant back into the penetrant reservoir, unless the expendable technique is being used. Draining racks usually serve the additional purpose of providing a storage place for parts during the time required for penetration (dwell time).

Small workpieces are easily coated by dipping them into a reservoir of penetrant. This may be done individually or in batches in a wire basket.

The penetrant container should be equipped with an easily removable cover to reduce evaporation when not in use. A drain cock should also be provided to facilitate draining of the tank for cleaning. Containers are usually made of steel, but stainless steel containers should be used with water-base penetrants.

For large workpieces, penetrant is often applied by spraying or flowing. This is done mainly for convenience but also for economy, because the volume of penetrant needed to immerse a large object may be so great as to increase unnecessarily the original cost of installation. A small reservoir of penetrant equipped with a pump, a hose, and a spray or flow nozzle is usually almost as fast a means of coating large objects as the dipping operation. For this type of operation, the penetrant station consists of a suitably ventilated booth with a rotatable grill platform on which the workpiece is set. A drain under the platform returns penetrant runoff to the sump, from which it is pumped back to the spray nozzle. The booth enclosure prevents the overspraying of penetrant on areas outside the penetrant station.

In some applications, it has been found that only a small amount of penetrant is recoverable and reusable, and this has led to the adoption of the expendable technique for some very large workpieces. In this technique, penetrant is sprayed over the workpiece in a penetrant station similar to the one mentioned previously. The penetrant is stored in a separate pressure tank fitted with a hose and a spray nozzle. The spray booth is not equipped with a sump to recover excess penetrant. Instead, the booth is fitted with water spray nozzles and a drain so that it can serve the multiple purpose of draining and washing. A decision to use the expendable technique and related equipment should be based on a careful analysis and consideration of cost, time, rate of production, and handling problems.

**Emulsifier Station.** The emulsifier liquid is contained in a tank of sufficient size and depth to permit immersion of the workpieces, either individually or in batches. Covers are sometimes provided to reduce evaporation, and drain valves are supplied for cleanout when the bath has become contaminated. Suitable drain racks are also a part of this station and are used to permit excess emulsifier to drain back into the tank.

If large workpieces must be coated with emulsifier, methods must be devised to achieve the fastest possible coverage. Multiple spraying or copious flowing of emulsifier from troughs or perforated pipes can be used on some types of automatic equipment. For the local coating of large workpieces, spraying is often satisfactory, using the expendable technique described for the application of penetrant.

**Pre- and Postrinse Stations.** The water rinsing (washing) of small workpieces is frequently done by hand, either individually or in batches in wire baskets. The workpieces are held in the wash tank and cleaned with a hand-held spray using water at tap pressure and temperature. The wash trough or sink should be large enough and deep enough so that workpieces can be easily turned to clean all surfaces. Splash shields should separate the rinse station from preceding (penetrant or emulsifier) and succeeding (wet developer) stations. Rinse stations are always equipped with at least one ultraviolet light so that the progress of removal of fluorescent penetrant can be easily followed.

The automatic rinsing of small workpieces is satisfactorily accomplished by means of a rotating table. The basket is placed on the table, and water-spray heads are properly located so as to rinse all surfaces of the workpieces thoroughly.

Specially built automatic washers for rinsing workpieces that are large and of irregular contour are often installed. Spray nozzles must be located to suit the individual application.

The removal of excess penetrant by simply submerging the workpiece in water is generally not recommended. However, in some cases, simple submersion in an air-agitated water bath is satisfactory.

The rinse station is subject to corrosion. All steel should be protected by rustproofing and painting. Most satisfactory, but more costly, is the use of stainless steel equipment.

**Drying Station.** The recirculating hot-air drier is one of the most important equipment components. The drier must be large enough to easily handle the type and number of workpieces being inspected. Heat input, air flow, and rate of movement of workpieces through the drier, as well as temperature control, are all factors that must be balanced. The drier may be of the cabinet type, or it may be designed so that the workpieces pass through on a conveyor. If conveyor operation is used, the speed must be considered with the required drying cycle.

Electric-resistance elements are frequently used as sources of heat, but gas, hot water, and steam are also used. Heat input is controlled by suitably located thermostats and is determined by workpiece size, composition, and rate of movement.

Integrated equipment invariably includes the recirculating hot-air drier mentioned previously. Makeshift driers are sometimes used--often because nothing better is available. Electric or gas hot-air blowers of commercial design have been used, but because no control of temperature is possible, these are very unsatisfactory and are ordinarily used only on an emergency basis. Infrared lamps are not suitable for drying washed workpieces, because the radiant heat cannot be readily controlled.

Equipment designed to handle workpieces of special size and shape requires a specially designed drier. Each drier is a separate engineering problem involving a special combination of workpiece composition, mass, surface area, speed of movement, and other considerations unique to the circumstances.

**Developer Station.** The type and location of the developer station depend on whether dry or wet developer is to be used. For dry developer, the developer station is downstream from the drier, but for wet developer it immediately precedes the drier, following the rinse station.

***The dry-developer station*** usually consists of a simple bin containing the powder. Dried workpieces are dipped into the powder, and the excess powder is shaken off. Larger workpieces may not be so easily immersed in the powder, so a scoop is usually provided for throwing powder over the surfaces, after which the excess is shaken off. The developer bin should be equipped with an easily removable cover to protect the developer from dust and dirt when not in use.

Dust control systems are sometimes needed when dry developer is used. Control is accomplished by a suction opening across the back of the bin at the top, which draws off any developer dust that rises out of the bin. The dust-laden air is passed through filter bags, from which the developer dust can be reclaimed for further use (Fig. 13).

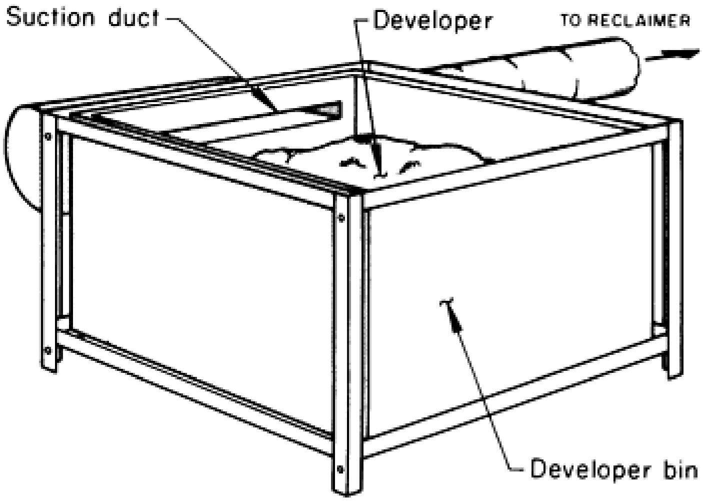

**Fig. 13 Dry-developer bin equipped with dust control and reclaimer system**

Developer powder can also be applied with air pressure. This system requires no bin, but it does require a booth or a cabinet and also makes dust collection mandatory.

Equipment for the automatic application of dry developer consists of a cabinet through which the dried workpieces are passed on a conveyor. The air in the cabinet is laden with dust that is kept agitated by means of a blower. As workpieces pass through, all surfaces are brought into contact with developer powder carried by the air. Air must be exhausted from the cabinet and either recirculated or cleaned by being passed through a dust-collecting filter.

***Wet developer,*** when used, is contained in a tank similar to that used for penetrant or emulsifier. The tank should be deep enough to permit workpieces to be submerged in the developer. There should also be a rack or conveyor on which parts can rest after dipping. This will permit excess developer to run back into the tank.

Suspendible developer baths settle out when not in use; therefore, a paddle for stirring should be provided. Continuous agitation is essential because the settling rate is rapid. Pumps are sometimes incorporated into the developer station for flowing the developer over large workpieces through a hose and nozzle and for keeping the developer agitated.

In automatic units, special methods of applying developer are required. Flow-on methods are frequently used. This technique requires a nozzle arrangement that permits the workpieces to be covered thoroughly and quickly.

**Inspection Station.** Essentially, the inspection station is simply a worktable on which workpieces can be handled under proper lighting. For fluorescent methods, the table is usually surrounded by a curtain or hood to exclude most of the white light from the area. For visible-dry penetrants, a hood is not necessary.

Generally, black (ultraviolet) lights (100 W or greater) are mounted on brackets from which they can be lifted and moved about by hand. Because of the heat given off by black lights, good air circulation is essential in black light booths.

For automatic inspection, workpieces are moved through booths equipped with split curtains, either by hand, monorail, or by conveyor. In some large inspection installations, fully enclosed rooms have been built for black light inspection. Access to the room is provided by a light lock. Inspection rooms must be laid out efficiently to prevent rejected workpieces from reentering the production line. Figures 14 and 15 illustrate typical penetrant inspection components and their layout in an inspection station installation.

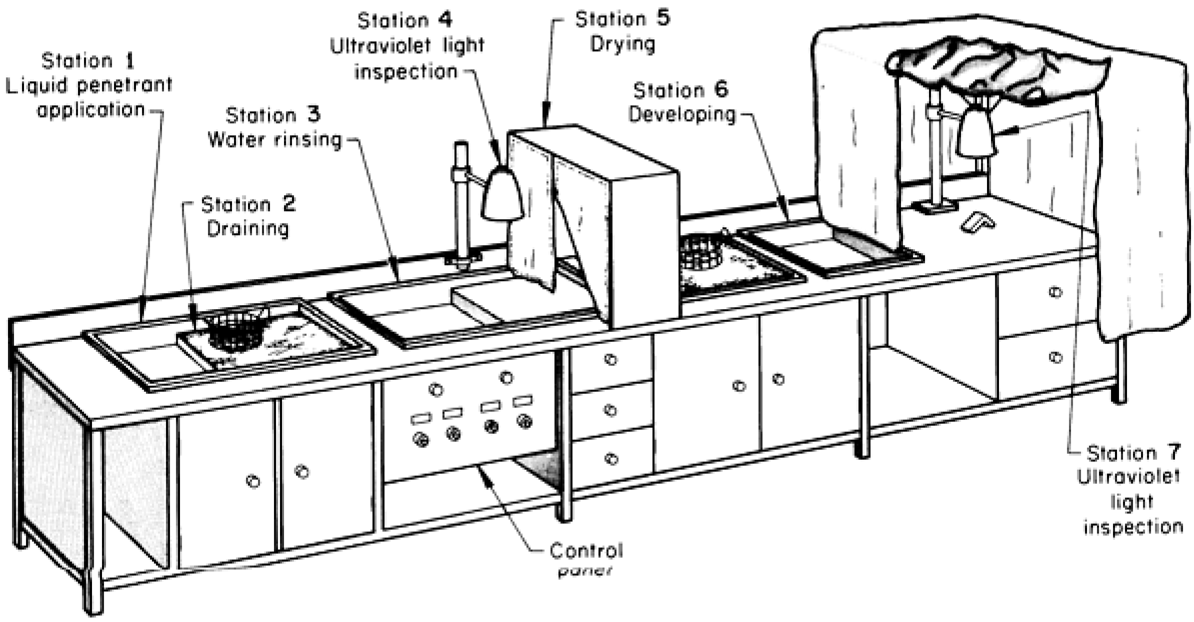

**Fig. 14 Typical seven-station package equipment unit for inspecting workpieces by the water-washable fluorescent penetrant system**

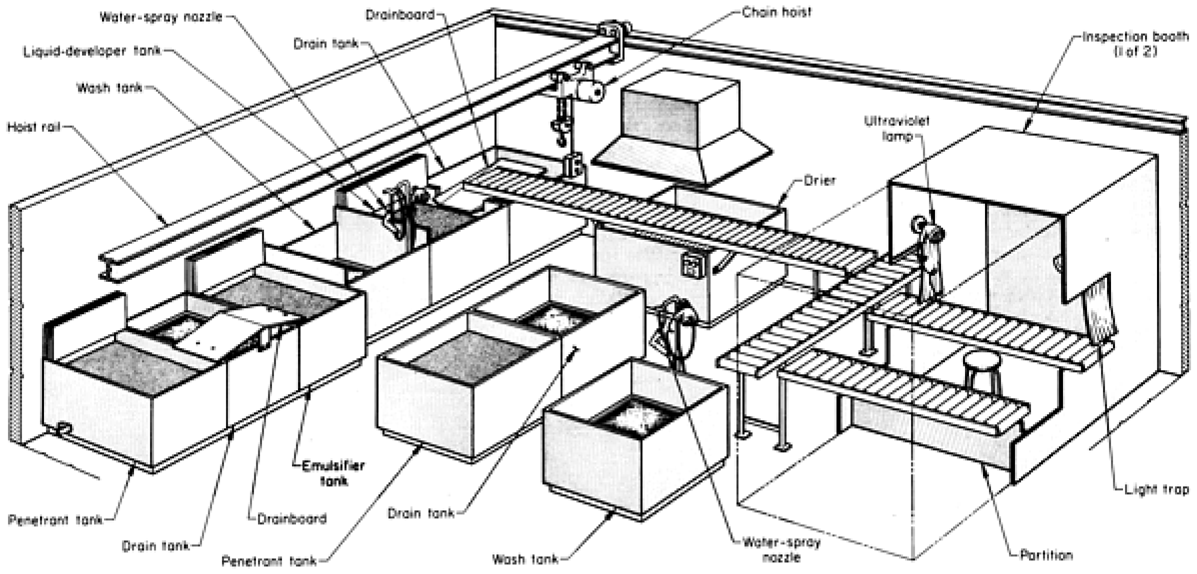

**Fig. 15 Arrangement of equipment used in one foundry for the liquid penetrant inspection of a large variety of castings to rigid specifications. Many of the castings require handling by crane or roller conveyor.**

## *Automated Inspection Equipment*

For many years, the penetrant inspection of production parts has been a manual operation of moving parts from station to station through the penetrant line. Properly trained and motivated operators will do an excellent job of processing and inspecting parts as well as controlling the process. There are, however, many situations in which manual processing simply cannot keep up with the production rates required or control the process properly.

The use of automated inspection systems, therefore, has become a significant factor in performing penetrant inspections of high-volume production parts. Modern automated penetrant inspection systems provide precise and repeatable process control, improved inspection reliability, increased productivity, and lower inspection costs.

Automated penetrant inspection systems incorporate programmable logic control (PLC) units, which are programmed to control the handling of parts through the system, to control the processing cycle precisely, and to monitor the functions at each processing station. Figures 16, 17, and 18 show typical automated penetrant systems currently in use.

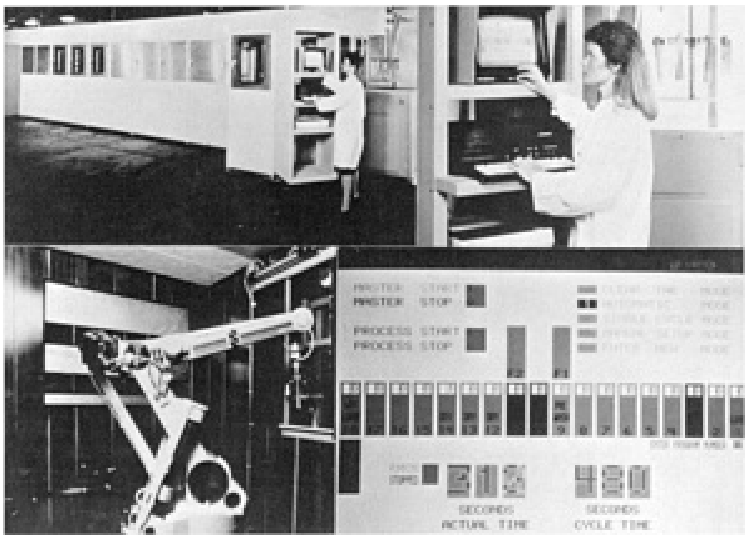

**Fig. 16 Automated inspection equipment setup (upper left) with close-up of operator checking PLC panel (upper right), which includes a screen display (lower right). The setup incorporates material handling devices**

**such as the robot shown (lower left) to transfer workpieces from station to station and to apply penetrants and other solutions needed to inspect components.**

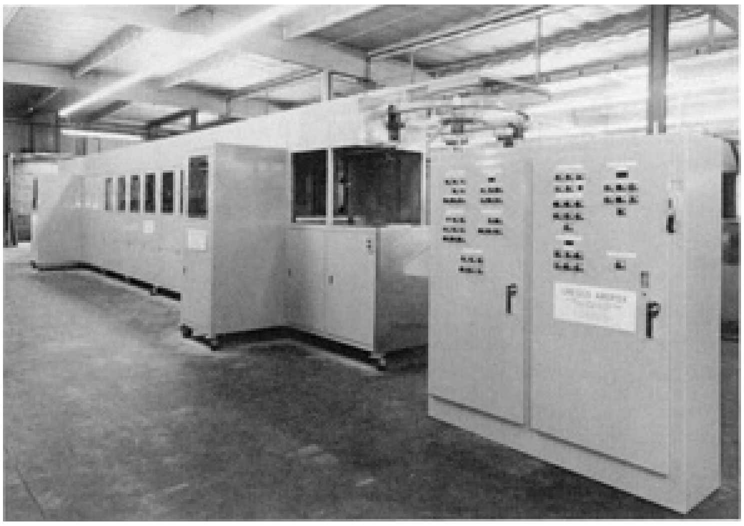

**Fig. 17 Typical automated fluorescent penetrant inspection installation**

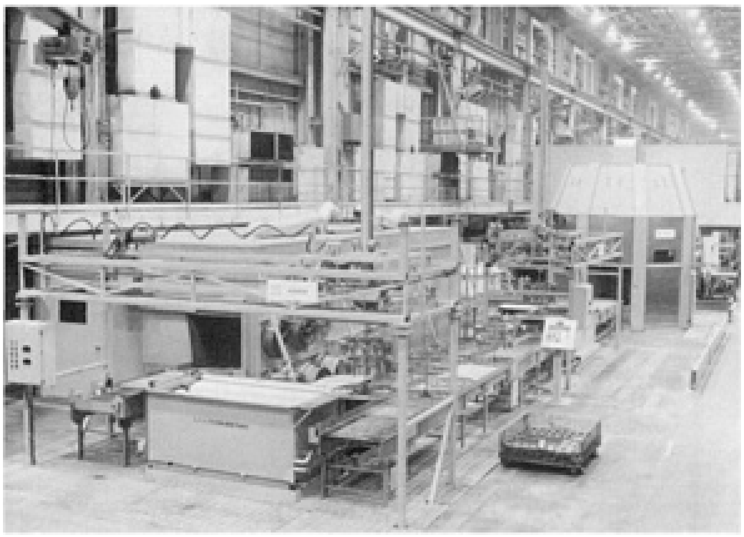

**Fig. 18 Automated inspection installation for the fluorescent penetrant inspection of large workpieces, such as castings. The installation incorporates a complex roller conveyor system.**

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## Liquid Penetrant Inspection

**Revised by J.S. Borucki, Ardrox Inc., and Gail Jordan, Howmet Corporation**

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## Precleaning

Regardless of the penetrant chosen, adequate precleaning of workpieces prior to penetrant inspection is absolutely necessary for accurate results. Without adequate removal of surface contamination, relevant indications may be missed because:

- The penetrant does not enter the flaw
- The penetrant loses its ability to identify the flaw because it reacts with something already in it
- The surface immediately surrounding the flaw retains enough penetrant to mask the true appearance of the flaw

Also, nonrelevant (false) indications may be caused by residual materials holding penetrants.

**Cleaning methods** are generally classified as chemical, mechanical, solvent, or any combination of these.

***Chemical cleaning methods*** include alkaline or acid cleaning, pickling or chemical etching, and molten salt bath cleaning.

***Mechanical cleaning methods*** include tumbling, wet blasting, dry abrasive blasting, wire brushing, and high-pressure water or steam cleaning. Mechanical cleaning methods should be used with care because they often mask flaws by smearing adjacent metal over them or by filling them with abrasive material. This is more likely to happen with soft metals than with hard metals.

***Solvent cleaning methods*** include vapor degreasing, solvent spraying, solvent wiping, and ultrasonic immersion using solvents. Probably the most common method is vapor degreasing. However, ultrasonic immersion is by far the most effective means of ensuring clean parts, but it can be a very expensive capital equipment investment.

Cleaning methods and their common uses are listed in Table 1. A major factor in the selection of a cleaning method is the type of contaminant to be removed and the type of alloy being cleaned. This is usually quite evident, but costly errors can be avoided by accurate identification of the contaminant. Before the decision is made to use a specific method, it is good practice to test the method on known flaws to ensure that it will not mask the flaws.

**Table 1 Applications of various methods of precleaning for liquid penetrant inspection**

| **Method** | Use |
|---|---|
| Mechanical methods | |
| Abrasive tumbling | **Removing light scale, burrs, welding flux, braze stopoff, rust, casting mold, and core material; should not be used on soft metals such as aluminum, magnesium, or titanium** |
| Dry abrasive grit blasting | **Removing light or heavy scale, flux, stopoff, rust, casting mold and core material, sprayed coatings, carbon deposits--in general, any friable deposit. Can be fixed or portable** |
| Wet abrasive grit blasting | **Same as dry except, where deposits are light, better surface and better control of dimensions are required** |
| Wire brushing | **Removing light deposits of scale, flux, and stopoff** |
| High-pressure water and steam | **Ordinarily used with an alkaline cleaner or detergent; removing typical machine shop soils such as cutting oils, polishing compounds, grease, chips, and deposits from electrical discharge machining; used when surface finish must be maintained; inexpensive** |
| Ultrasonic cleaning | **Ordinarily used with detergent and water or with a solvent; removing adherent shop soil from large quantities of small parts** |

| | |
|---|---|
| Chemical methods | |
| Alkaline cleaning | **Removing braze stopoff, rust, scale, oils, greases, polishing material, and carbon deposits; ordinarily used on large articles where hand methods are too laborious; also used on aluminum for gross metal removal** |
| Acid cleaning | **Strong solutions for removing heavy scale; mild solutions for light scale; weak (etching) solutions for removing lightly smeared metal** |
| Molten salt bath cleaning | **Conditioning and removing heavy scale** |
| Solvent methods | |
| Vapor degreasing | **Removing typical shop soil, oil, and grease; usually employs chlorinated solvents; not suitable for titanium** |
| **Solvent wiping** | **Same as for vapor degreasing except a hand operation; may employ nonchlorinated solvents; used for localized low-volume cleaning** |

Equally important in choosing a cleaning method is knowledge of the composition of the workpiece being cleaned. For example, abrasive tumbling can effectively remove burrs from a machined steel casting and leave a surface that is fully inspectable. This method, however, is not suitable for aluminum or magnesium, because it smears these metals and frequently hides flaws. Particular care must be taken in selecting a cleaning method for workpieces fabricated from more than one alloy (brazed assemblies are notable examples); a chemical cleaning method to remove scale, stopoff material, or flux must be chosen carefully to ensure that neither the braze nor the components of the assembly will be attacked.

**The surface finish** of the workpiece must always be considered. When further processing is scheduled, such as machining or final polishing, or when a surface finish of 3.20 μm (125 μin.) or coarser is allowed, an abrasive cleaning method is frequently a good choice. Generally, chemical cleaning methods have fewer degrading effects on surface finish than mechanical methods (unless the chemical used is strongly corrosive to the material being cleaned). Steam cleaning and solvent cleaning rarely have any effect on surface finish.

Some materials are subject to delayed reactions as a result of improper cleaning. Two notable examples are high-strength steel and titanium. If it is ever necessary to chemically etch a high-strength steel workpiece, it should be baked at an appropriate temperature for a sufficient time to avoid hydrogen embrittlement. This should be done as soon after etching as possible but no later than 1 h. Titanium alloys can be subject to delayed cracking if they retain halogenated compounds and are then exposed to temperatures exceeding 480 °C (900 °F). Consequently, halogenated solvents should not be used for titanium and its alloys if their complete removal cannot be ensured.

Choice of cleaning method may be dictated by Occupational Safety and Health Administration and Environmental Protection Agency health and safety regulations. Quantities of materials that will be used, toxicity, filtering, neutralization and disposal techniques, and worker protection all are crucial factors.

## Liquid Penetrant Inspection

**Revised by J.S. Borucki, Ardrox Inc., and Gail Jordan, Howmet Corporation**

## Penetrant Inspection Processing Parameters

It is extremely important to understand the significance of adhering to the established process parameters for a given application. Failure to control the process parameters will affect the quality of the inspection. For example, excessive overwashing or overemulsification can remove the penetrant from the flaws; minimal washing or underemulsification can result in excessive background, which could mask the flaws and render them undetectable.

Processing time in each station, the equipment used, and other factors can vary widely, depending on workpiece size and shape, production quantities of similar workpieces, and required customer specifications for process parameters.

### Postemulsifiable Method

The processing cycles for the postemulsifiable processes, method B (lipophilic) and method D (hydrophilic) are illustrated in the processing flow diagrams (Fig. 19 and 20, respectively). The major difference between the two methods, as described below, is the additional prerinse step utilized in method D.

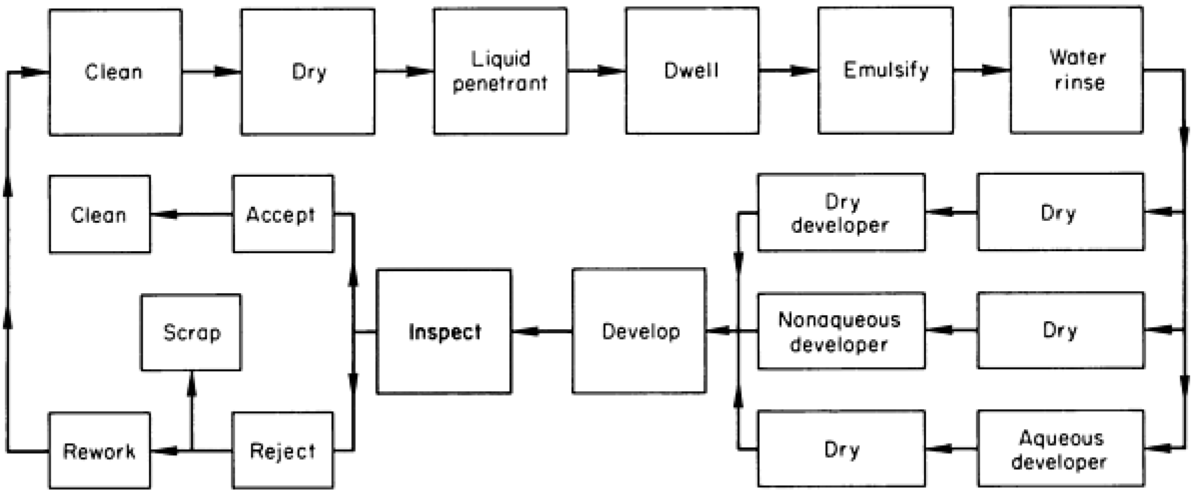

**Fig. 19 Processing flow diagram for the postemulsifiable, method B, lipophilic liquid penetrant system**

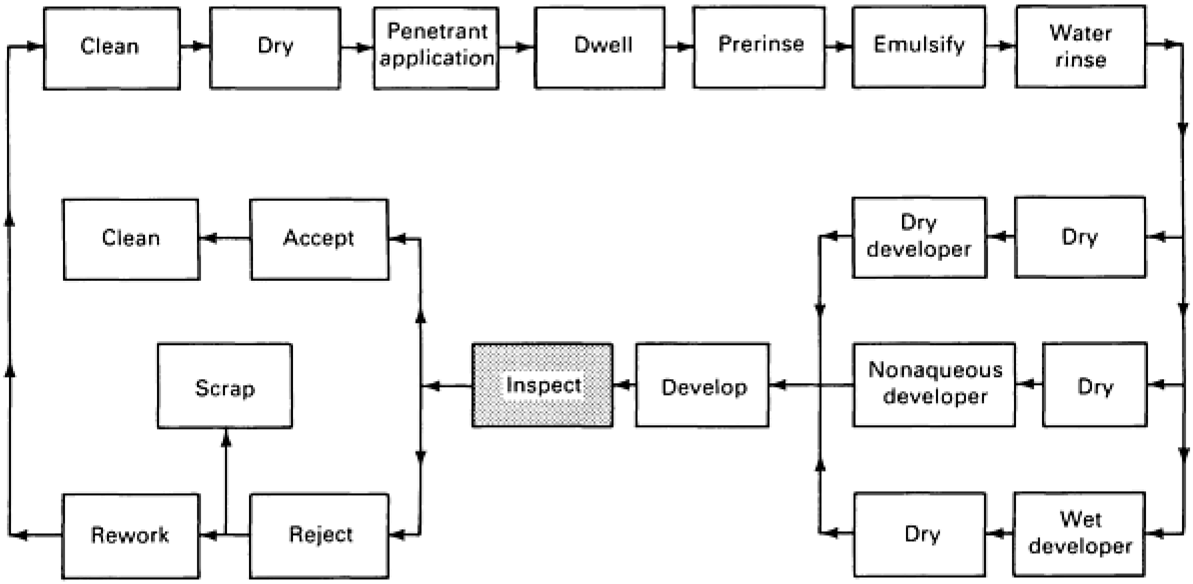

**Fig. 20 Processing flow diagram for the postemulsifiable, method D, hydrophilic liquid penetrant system**

**Application of Penetrant.** Workpieces should be thoroughly and uniformly coated with penetrant by flowing, brushing, swabbing, dipping, or spraying. Small workpieces requiring complete surface inspection are usually placed in a basket and dipped in the penetrant. Larger workpieces are usually brushed or sprayed. Electrostatic spray application is also very effective and economical. After the workpiece has been coated with a light film of penetrant, it should be positioned so that it can drain and so that excess penetrant cannot collect in pools. Workpieces should not be submerged during the entire penetration dwell time. Heating the workpiece is also not necessary or recommended, because certain disadvantages can occur, such as volatilization of the penetrant, difficulty in washing, and a decrease in fluorescence.

***Dwell Time.*** After the penetrant has been applied to the workpiece surface, it should be allowed to remain long enough for complete penetration into the flaws. Dwell time will vary, depending mainly on the size of the defects sought, cleanliness of the workpiece, and sensitivity and viscosity of the penetrant. In most cases, however, a minimum of 10 min and a maximum of 30 min is adequate for both fluorescent- and visible-penetrant types. A lengthy dwell time could cause the penetrant to begin drying on the surface, resulting in difficult removal. If drying does occur, it is necessary to reapply the penetrant to wet the surface and then begin the removal steps. Recommendations from the penetrant supplier will help establish the time, but experimentation will determine optimum dwell time.

***Prerinse.*** When using method D (hydrophilic), a coarse waterspray prerinse is needed to assist in penetrant removal and to reduce contamination of the emulsifier. A coarse water spray is recommended, using a pressure of 275 to 345 kPa (40 to 50 psi). The prerinse water temperature should be 10 to 40 °C (50 to 100 °F). The prerinse time should be kept to a minimum (that is, 30 to 90 s) because the purpose is to remove excess penetrant so that the emulsifier does not become contaminated quickly.

**Emulsifier Application.** It is very important that all surfaces of the workpiece be coated with the emulsifier at the same time. Small workpieces are dipped individually or in batches in baskets or on racks, whichever is the most convenient. For large workpieces, methods must be devised to achieve the fastest possible coverage; two methods often used are spraying or immersing. Localized emulsification of large workpieces can be achieved by spraying. The temperature of the emulsifier is not extremely critical, but a range of 20 to 30 °C (70 to 90 °F) is referred.

***Emulsification Time.*** The length of time the emulsifier is allowed to remain on the workpiece and in contact with the penetrant is the emulsification time and depends mainly on the type of emulsifier employed, its concentration, and on the surface condition of the workpieces. Recommendations by the manufacturer of the emulsifier can serve as guidelines, but the optimum time for a specific workpiece must be established by experimentation. The surface finish, size, and composition of the workpiece will determine more precisely the choice of emulsifier and emulsification time. Emulsification time ranges from approximately 30 s to 3 min and is directly related to the concentration of the emulsifier. If emulsification time is excessive, penetrant will be removed from the flaws, making detection impossible.

**Rinsing.** For all methods, removing the penetrant from the workpiece is probably the most important step in obtaining reproducible results. If penetrant removal is performed properly, penetrant will be stripped from the surface and will remain only in the flaws. More variability in individual technique enters into this particular phase of inspection than any other step. Therefore, removal must be performed with the same sequence of operations time after time if results are to be reproducible. This is especially important when inspecting for tight or shallow flaws.

Rinse time should be determined experimentally for specific workpieces; it usually varies from 10 s to 2 min. For spray rinsing, water pressure should be constant. A pressure of about 275 kPa (40 psi) is desirable; too much pressure may remove penetrants from the flaws. A coarse water spray is recommended and can be assisted with air (the combined water and air pressure should not exceed the pressure recommended for water alone). Water temperature should be maintained at a relatively constant level. Most penetrants can be removed effectively with water in a range of 10 to 40 °C (50 to 100 °F).

Drying is best done in a recirculating hot-air drier that is thermostatically controlled. The temperature in the drier is normally between 65 and 95 °C (150 and 200 °F). The temperature of the workpieces should not be permitted to exceed 70 °C (160 °F). Workpieces should not remain in the drier any longer than necessary; drying is normally accomplished within a few minutes. Excessive drying at high temperatures can impair the sensitivity of the inspection. Because drying time will vary, the exact time should be determined experimentally for each type of workpiece.

**Developing** depends on the form of developer to be used. Various types of developers are discussed below.

***Dry-developer powder (form A)*** is applied after the workpiece has been dried and can be applied in a variety of ways. The most common is dusting or spraying. Electrostatic spray application is also very effective. In some cases, application by immersing the workpiece into the dry powder developer is permissible. For simple applications, especially when only a portion of the surface of a large part is being inspected, applying with a soft brush is often adequate. Excess developer can be removed from the workpiece by a gentle air blast (140 kPa, or 20 psi, maximum) or by shaking or gentle tapping. Whichever means of application is chosen, it is important that the workpiece be completely and evenly covered by a fine film of developer.

***Water-soluble developer (form B)*** is applied just after the final wash and immediately prior to drying by dip, flow-on, or spray techniques. No agitation of the developer bath is required. Removal of the developer coating from the surface of the workpiece is required and easily accomplished because the dried developer coating is water soluble and therefore completely removable by a water rinse.

***Water-suspendible developer (form C)*** is applied just after the final wash and immediately before drying. Dip, flow-on, and spray are common methods of application. Care must be taken to agitate the developer thoroughly so that all particles are in suspension; otherwise, control of the concentration of the applied coating is impossible. Removal of the water-suspendible developer can best be achieved by water spray rinsing. If allowed to remain indefinitely on the workpiece, the developer can become difficult to remove.

***Solvent-suspendible nonaqueous developer (form D)*** is always applied after drying by spraying, either with aerosol containers or by conventional or electrostatic methods. Proper spraying produces a thin, uniform layer that is very sensitive in producing either fluorescent or red visible indications. The volatility of the solvent makes it impractical to use in open tanks. Not only would there be solvent loss, reducing the effectiveness of the developer, but there would also be a hazardous vapor condition. Dipping, pouring, and brushing are not suitable for applying solvent-suspendible developer.

***Developing Time.*** In general, 10 min is the recommended minimum developing time regardless of the developer form used. The developing time begins immediately after application of the developer. Excessive developing time is seldom necessary and usually results in excessive bleeding of indications, which can obscure flaw delineation.

**Inspections.** After the prescribed development time, the inspection should begin. The inspection area should be properly darkened for fluorescent penetrant inspection. Recommended black light intensity is 1000 to 1600 $\mu$W/cm$^2$. The intensity of the black light should be verified at regular intervals by the use of a suitable black light meter such as a digital radiometer. The intensity of the black light should be allowed to warm up prior to use--generally for about 10 min. The inspector should allow time for adapting to darkness; a 1-min period is usually adequate. White light intensity should not exceed 20 lx (2 ftc) to ensure the best inspection environment.

Visible-penetrant systems provide vivid red indications that can be seen in visible light. Lighting intensity should be adequate to ensure proper inspection; 320 to 540 lx (30 to 50 ftc) is recommended. Lighting intensity should be verified at regular intervals by the use of a suitable white light meter such as a digital radiometer. Detailed information on inspection techniques is available in the sections "Inspection and Evaluation" and "Specifications and Standards" in this article.

### *Water-Washable Method*

As indicated by the flow diagram in Fig. 21, the processing cycle for the water-washable method is similar to that for the postemulsifiable method. The difference lies in the penetrant removal step. As discussed in the section "Materials Used in Penetrant Inspection" in this article, the water-washable penetrants have a built-in emulsifier, thus eliminating the need for an emulsification step. One rinse operation is all that is required, and the washing operation should be carefully controlled because water-washable penetrants are susceptible to overwashing.

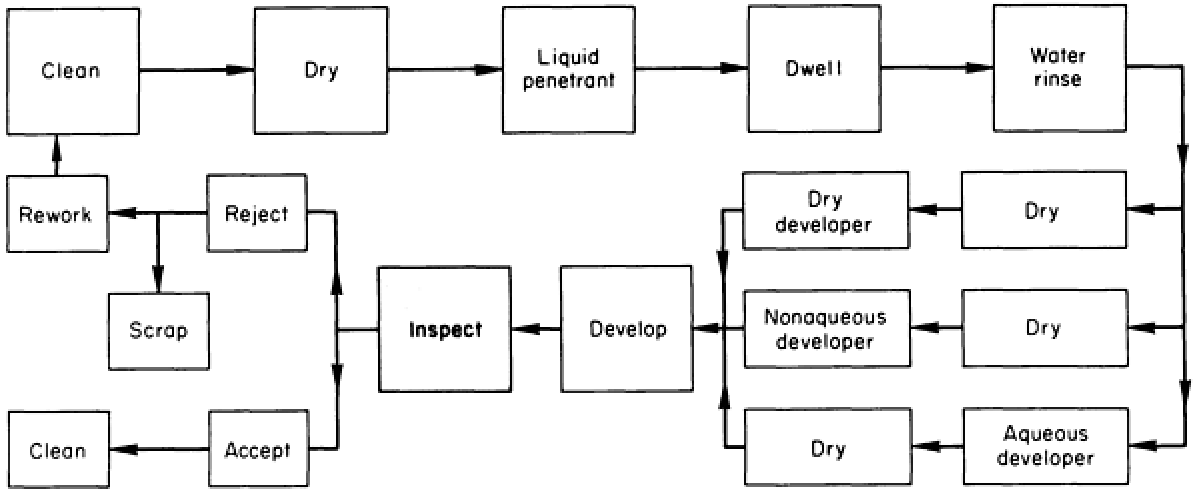

**Fig. 21 Processing flow diagram for the water-washable liquid penetrant system**

**Rinse time** should be determined experimentally for a specific workpiece; it usually varies from 10 s to 2 min. The best practical way of establishing rinse time is to view the workpiece under a black light while rinsing and washing only until the fluorescent background is removed to a satisfactory degree. On some applications, such as castings, an immersion rinse followed by a final spray rinsing is desirable to remove tenacious background fluorescence. This technique, however, must be very carefully controlled to ensure that overwashing does not occur.

**For spray rinsing,** a nominal water pressure of 140 to 275 kPa (20 to 40 psi) is recommended; too much pressure can result in overwashing, that is, the removal of penetrant from within flaws. Hydro-air spray guns can be used. The air pressure, however, should not exceed 170 kPa (25 psi). The temperature of the water should be controlled to 10 to 40 °C (50 to 100 °F). Drying, developing, and inspection process parameters are the same as the postemulsifiable method process parameters described in the section "Postemulsifiable Method" in this article.

### *Solvent-Removable Method*

The basic sequence of operations for the solvent-removable penetrant system is generally similar to that followed for the other methods. A typical sequence is shown by the flow diagram in Fig. 22. A notable difference is that with the solvent-removable method the excess penetrant is removed by wiping with clean, lint-free material moistened with solvent. It is important to understand that flooding the workpiece to remove excess surface penetrant will also dissolve the penetrant from within the flaws.

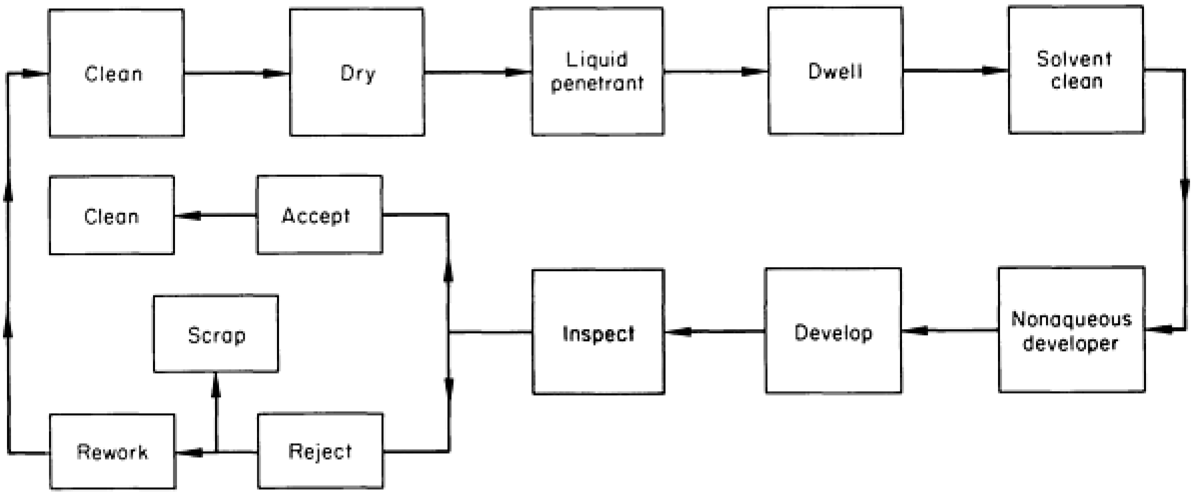

**Fig. 22 Processing flow diagram for the solvent-removable liquid penetrant system**

The processing parameters for the use of developer are the same as those described above for the postemulsifiable method. Dry-powder developers, however, are not recommended for use with the visible solvent-removable penetrant method.

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## Liquid Penetrant Inspection

**Revised by J.S. Borucki, Ardrox Inc., and Gail Jordan, Howmet Corporation**

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## Penetrant Inspection Processing Parameters

It is extremely important to understand the significance of adhering to the established process parameters for a given application. Failure to control the process parameters will affect the quality of the inspection. For example, excessive overwashing or overemulsification can remove the penetrant from the flaws; minimal washing or underemulsification can result in excessive background, which could mask the flaws and render them undetectable.

Processing time in each station, the equipment used, and other factors can vary widely, depending on workpiece size and shape, production quantities of similar workpieces, and required customer specifications for process parameters.

### *Postemulsifiable Method*

The processing cycles for the postemulsifiable processes, method B (lipophilic) and method D (hydrophilic) are illustrated in the processing flow diagrams (Fig. 19 and 20, respectively). The major difference between the two methods, as described below, is the additional prerinse step utilized in method D.

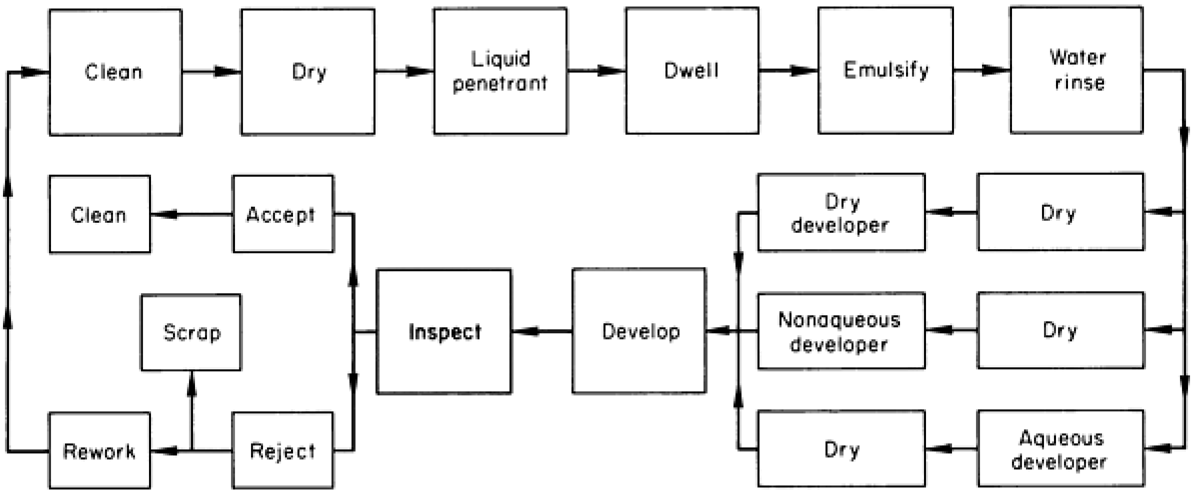

**Fig. 19 Processing flow diagram for the postemulsifiable, method B, lipophilic liquid penetrant system**

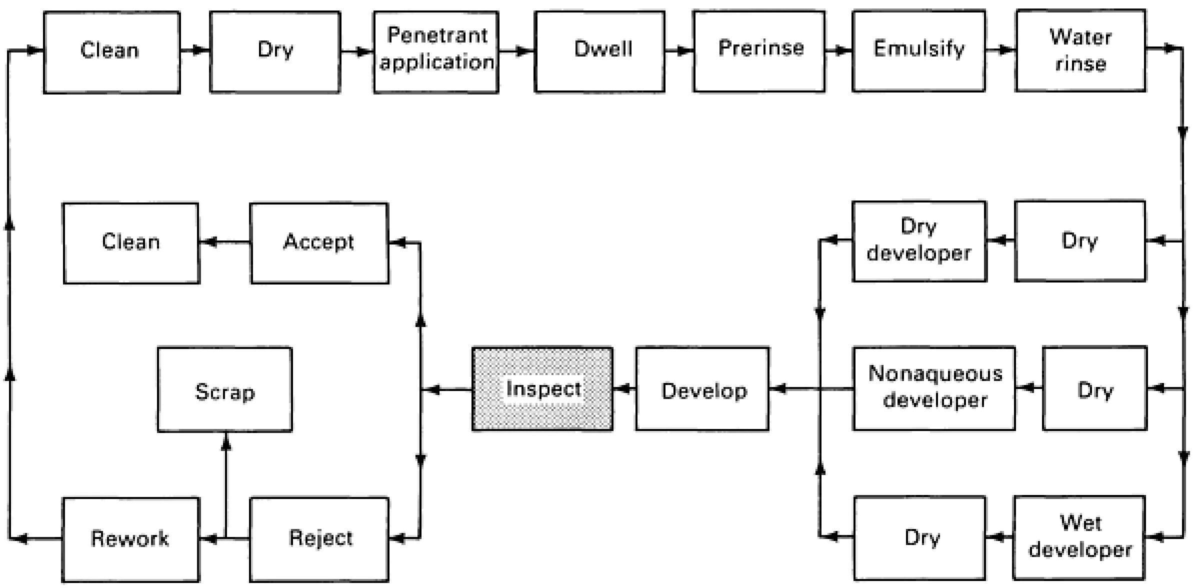

**Fig. 20 Processing flow diagram for the postemulsifiable, method D, hydrophilic liquid penetrant system**

**Application of Penetrant.** Workpieces should be thoroughly and uniformly coated with penetrant by flowing, brushing, swabbing, dipping, or spraying. Small workpieces requiring complete surface inspection are usually placed in a basket and dipped in the penetrant. Larger workpieces are usually brushed or sprayed. Electrostatic spray application is also very effective and economical. After the workpiece has been coated with a light film of penetrant, it should be positioned so that it can drain and so that excess penetrant cannot collect in pools. Workpieces should not be submerged during the entire penetration dwell time. Heating the workpiece is also not necessary or recommended, because certain disadvantages can occur, such as volatilization of the penetrant, difficulty in washing, and a decrease in fluorescence.

***Dwell Time.*** After the penetrant has been applied to the workpiece surface, it should be allowed to remain long enough for complete penetration into the flaws. Dwell time will vary, depending mainly on the size of the defects sought, cleanliness of the workpiece, and sensitivity and viscosity of the penetrant. In most cases, however, a minimum of 10 min and a maximum of 30 min is adequate for both fluorescent- and visible-penetrant types. A lengthy dwell time could cause the penetrant to begin drying on the surface, resulting in difficult removal. If drying does occur, it is necessary to reapply the penetrant to wet the surface and then begin the removal steps. Recommendations from the penetrant supplier will help establish the time, but experimentation will determine optimum dwell time.

***Prerinse.*** When using method D (hydrophilic), a coarse waterspray prerinse is needed to assist in penetrant removal and to reduce contamination of the emulsifier. A coarse water spray is recommended, using a pressure of 275 to 345 kPa (40 to 50 psi). The prerinse water temperature should be 10 to 40 °C (50 to 100 °F). The prerinse time should be kept to a minimum (that is, 30 to 90 s) because the purpose is to remove excess penetrant so that the emulsifier does not become contaminated quickly.

**Emulsifier Application.** It is very important that all surfaces of the workpiece be coated with the emulsifier at the same time. Small workpieces are dipped individually or in batches in baskets or on racks, whichever is the most convenient. For large workpieces, methods must be devised to achieve the fastest possible coverage; two methods often used are spraying or immersing. Localized emulsification of large workpieces can be achieved by spraying. The temperature of the emulsifier is not extremely critical, but a range of 20 to 30 °C (70 to 90 °F) is referred.

***Emulsification Time.*** The length of time the emulsifier is allowed to remain on the workpiece and in contact with the penetrant is the emulsification time and depends mainly on the type of emulsifier employed, its concentration, and on the surface condition of the workpieces. Recommendations by the manufacturer of the emulsifier can serve as guidelines, but the optimum time for a specific workpiece must be established by experimentation. The surface finish, size, and composition of the workpiece will determine more precisely the choice of emulsifier and emulsification time. Emulsification time ranges from approximately 30 s to 3 min and is directly related to the concentration of the emulsifier. If emulsification time is excessive, penetrant will be removed from the flaws, making detection impossible.

**Rinsing.** For all methods, removing the penetrant from the workpiece is probably the most important step in obtaining reproducible results. If penetrant removal is performed properly, penetrant will be stripped from the surface and will remain only in the flaws. More variability in individual technique enters into this particular phase of inspection than any other step. Therefore, removal must be performed with the same sequence of operations time after time if results are to be reproducible. This is especially important when inspecting for tight or shallow flaws.

Rinse time should be determined experimentally for specific workpieces; it usually varies from 10 s to 2 min. For spray rinsing, water pressure should be constant. A pressure of about 275 kPa (40 psi) is desirable; too much pressure may remove penetrants from the flaws. A coarse water spray is recommended and can be assisted with air (the combined water and air pressure should not exceed the pressure recommended for water alone). Water temperature should be maintained at a relatively constant level. Most penetrants can be removed effectively with water in a range of 10 to 40 °C (50 to 100 °F).

Drying is best done in a recirculating hot-air drier that is thermostatically controlled. The temperature in the drier is normally between 65 and 95 °C (150 and 200 °F). The temperature of the workpieces should not be permitted to exceed 70 °C (160 °F). Workpieces should not remain in the drier any longer than necessary; drying is normally accomplished within a few minutes. Excessive drying at high temperatures can impair the sensitivity of the inspection. Because drying time will vary, the exact time should be determined experimentally for each type of workpiece.

**Developing** depends on the form of developer to be used. Various types of developers are discussed below.

***Dry-developer powder (form A)*** is applied after the workpiece has been dried and can be applied in a variety of ways. The most common is dusting or spraying. Electrostatic spray application is also very effective. In some cases, application by immersing the workpiece into the dry powder developer is permissible. For simple applications, especially when only a portion of the surface of a large part is being inspected, applying with a soft brush is often adequate. Excess developer can be removed from the workpiece by a gentle air blast (140 kPa, or 20 psi, maximum) or by shaking or gentle tapping. Whichever means of application is chosen, it is important that the workpiece be completely and evenly covered by a fine film of developer.

***Water-soluble developer (form B)*** is applied just after the final wash and immediately prior to drying by dip, flow-on, or spray techniques. No agitation of the developer bath is required. Removal of the developer coating from the surface of the workpiece is required and easily accomplished because the dried developer coating is water soluble and therefore completely removable by a water rinse.

***Water-suspendible developer (form C)*** is applied just after the final wash and immediately before drying. Dip, flow-on, and spray are common methods of application. Care must be taken to agitate the developer thoroughly so that all particles are in suspension; otherwise, control of the concentration of the applied coating is impossible. Removal of the water-suspendible developer can best be achieved by water spray rinsing. If allowed to remain indefinitely on the workpiece, the developer can become difficult to remove.

***Solvent-suspendible nonaqueous developer (form D)*** is always applied after drying by spraying, either with aerosol containers or by conventional or electrostatic methods. Proper spraying produces a thin, uniform layer that is very sensitive in producing either fluorescent or red visible indications. The volatility of the solvent makes it impractical to use in open tanks. Not only would there be solvent loss, reducing the effectiveness of the developer, but there would also be a hazardous vapor condition. Dipping, pouring, and brushing are not suitable for applying solvent-suspendible developer.

***Developing Time.*** In general, 10 min is the recommended minimum developing time regardless of the developer form used. The developing time begins immediately after application of the developer. Excessive developing time is seldom necessary and usually results in excessive bleeding of indications, which can obscure flaw delineation.

**Inspections.** After the prescribed development time, the inspection should begin. The inspection area should be properly darkened for fluorescent penetrant inspection. Recommended black light intensity is 1000 to 1600 $\mu$W/cm$^2$. The intensity of the black light should be verified at regular intervals by the use of a suitable black light meter such as a digital radiometer. The intensity of the black light should be allowed to warm up prior to use--generally for about 10 min. The inspector should allow time for adapting to darkness; a 1-min period is usually adequate. White light intensity should not exceed 20 lx (2 ftc) to ensure the best inspection environment.

Visible-penetrant systems provide vivid red indications that can be seen in visible light. Lighting intensity should be adequate to ensure proper inspection; 320 to 540 lx (30 to 50 ftc) is recommended. Lighting intensity should be verified at regular intervals by the use of a suitable white light meter such as a digital radiometer. Detailed information on inspection techniques is available in the sections "Inspection and Evaluation" and "Specifications and Standards" in this article.

### *Water-Washable Method*

As indicated by the flow diagram in Fig. 21, the processing cycle for the water-washable method is similar to that for the postemulsifiable method. The difference lies in the penetrant removal step. As discussed in the section "Materials Used in Penetrant Inspection" in this article, the water-washable penetrants have a built-in emulsifier, thus eliminating the need for an emulsification step. One rinse operation is all that is required, and the washing operation should be carefully controlled because water-washable penetrants are susceptible to overwashing.

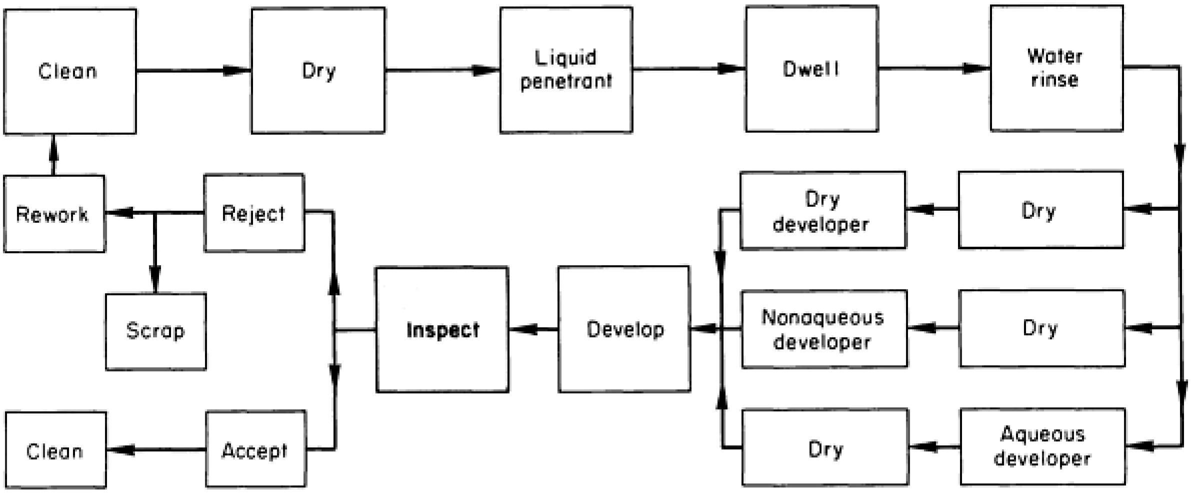

**Fig. 21 Processing flow diagram for the water-washable liquid penetrant system**

**Rinse time** should be determined experimentally for a specific workpiece; it usually varies from 10 s to 2 min. The best practical way of establishing rinse time is to view the workpiece under a black light while rinsing and washing only until the fluorescent background is removed to a satisfactory degree. On some applications, such as castings, an immersion rinse followed by a final spray rinsing is desirable to remove tenacious background fluorescence. This technique, however, must be very carefully controlled to ensure that overwashing does not occur.

**For spray rinsing,** a nominal water pressure of 140 to 275 kPa (20 to 40 psi) is recommended; too much pressure can result in overwashing, that is, the removal of penetrant from within flaws. Hydro-air spray guns can be used. The air pressure, however, should not exceed 170 kPa (25 psi). The temperature of the water should be controlled to 10 to 40 °C (50 to 100 °F). Drying, developing, and inspection process parameters are the same as the postemulsifiable method process parameters described in the section "Postemulsifiable Method" in this article.

### *Solvent-Removable Method*

The basic sequence of operations for the solvent-removable penetrant system is generally similar to that followed for the other methods. A typical sequence is shown by the flow diagram in Fig. 22. A notable difference is that with the solvent-removable method the excess penetrant is removed by wiping with clean, lint-free material moistened with solvent. It is important to understand that flooding the workpiece to remove excess surface penetrant will also dissolve the penetrant from within the flaws.

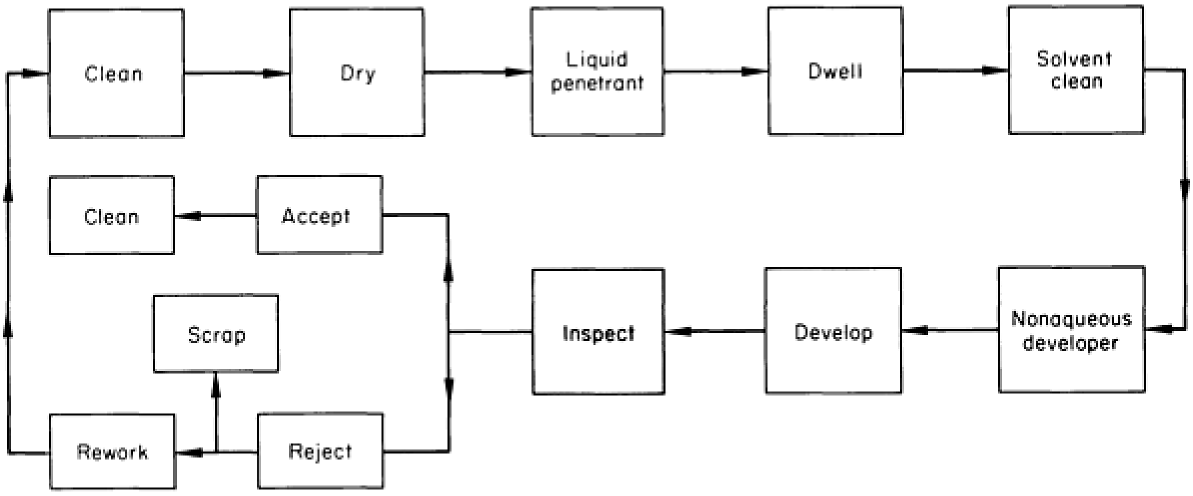

**Fig. 22 Processing flow diagram for the solvent-removable liquid penetrant system**

The processing parameters for the use of developer are the same as those described above for the postemulsifiable method. Dry-powder developers, however, are not recommended for use with the visible solvent-removable penetrant method.

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**Liquid Penetrant Inspection**

**Revised by J.S. Borucki, Ardrox Inc., and Gail Jordan, Howmet Corporation**

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## Postcleaning

Some residue will remain on workpieces after penetrant inspection is completed. In many cases, this residue has no deleterious effects in subsequent processing or in service. There are, however, instances in which postcleaning is required. Residues can result in the formation of voids during subsequent welding or unwanted stopoff in brazing, in the contamination of surfaces (which can cause trouble in heat treating), or in unfavorable reactions in chemical processing operations.

Drastic chemical or mechanical methods are seldom required for postcleaning. When justified by the volume of work, an emulsion cleaning line is effective and reasonable in cost. In special circumstances, ultrasonic cleaning may be the only satisfactory way of cleaning deep crevices or small holes. However, solvents or detergent-aided steam or water is almost always sufficient. The use of steam with detergent is probably the most effective of all methods. It has a scrubbing action that removes developers, the heat and detergent remove penetrants, it leaves a workpiece hot enough to promote rapid, even drying, and it is harmless to nearly all materials. Vapor degreasing is very effective for removing penetrants, but it is practically worthless for removing developers. It is frequently used in combination with steam cleaning. If this combination is used, the steam cleaning should always be done first because vapor degreasing bakes on developer films.

Where conditions do not warrant or permit permanent cleaning installations, hand wiping with solvents is effective. Dried developer films can be brushed off, and residual penetrants can be rinsed off by solvent spraying or wiped off with a solvent-dampened cloth.

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**Liquid Penetrant Inspection**

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## Quality Assurance of Penetrant Inspection Materials

It is important to provide the controls necessary to ensure that the penetrant materials and equipment are operating at an acceptable level of performance. The frequency of the required checks should be based on a facility operating for a full, one-shift operation daily. In general, it is good practice to check the overall system performance on a daily basis. This check should be performed by processing a known defect standard through the line, using appropriate processing parameters and comparing the indications thus obtained to those obtained with fresh, unused penetrant material samples. When the performance of the in-use materials falls below that of the unused materials, the in-use material quality should be checked with the appropriate tests (as described below) and corrected prior to conducting any further penetrant inspection.

Key quality assurance tests to be periodically conducted on in-use penetrants, emulsifiers, and developers are listed in Table 2. Also listed are the intervals at which the light sources and the overall system performance should be checked.

**Table 2 Intervals at which solutions, light sources, and system performance should be checked**

| **Test** | **Minimum test frequency** | Requirement |
|---|---|---|
| Penetrants | | |
| Fluorescent brightness | Quarterly | **Not less than 90% of reference standard** |
| Sensitivity | Monthly | **Equal to reference standard** |
| Removability (method A water wash only) | Monthly | **Equal to reference standard** |
| Water content (method A water wash penetrant only) | Monthly | **Not to exceed 5%** |
| Contamination | Weekly | **No noticeable tracers** |
| Emulsifiers | | |
| Removability | Weekly | **Equal to reference standard** |
| Water content (method B, lipophilic) | Monthly | **Not to exceed 5%** |
| Concentration (method D, hydrophilic) | Weekly | **Not greater than 3% above initial concentration** |
| Contamination | Weekly | **No noticeable tracers** |
| Developers | | |
| Dry-developer form | Daily | **Must be fluffy, not caked** |

| | | |
|---|---|---|
| Contamination | Daily | **Not more than ten fluorescent specks observed in a 102 mm (4 in.) circle of sample** |
| **Aqueous (soluble and suspended) developer** | | |
| Wetting/coverage | Daily | **Must be uniform/wet and must coat part** |
| Contamination | Daily | **Must not show evidence of fluorescence contaminates** |
| Concentration | Weekly | **Concentration shall be maintained as specified** |
| Other | | |
| Black lights | Daily | **Minimum 1000 $\mu$W/cm$^2$ at 381 mm (15 in.)** |
| White light | Weekly | **Minimum 2200 lx (200 ftc)** |
| **System performance** | **Daily** | **Must equal reference standards** |

Military standard 6866 specifies the specific test procedure to use for the tests defined in Table 2. Penetrants applied by spray application from sealed containers are not likely to be exposed to the same working environment as with open dip tanks and are therefore not required to be tested as defined in Table 2 unless contamination is suspected.

**Liquid Penetrant Inspection**

**Revised by J.S. Borucki, Ardrox Inc., and Gail Jordan, Howmet Corporation**

## Maintenance of Materials

With constant open-tank use, penetrant materials are inherently subject to potential deterioration. Such factors as evaporation losses and contamination from various sources can contribute to deterioration. It is essential, therefore, to monitor the condition of these materials as described in Table 2.

**The evaporation** of the volatile constituents of penetrants can alter their chemical and performance characteristics, thus resulting in changes in inherent brightness, removability, and sensitivity. Liquid penetrant materials qualified to MIL-I-25135D (and subsequent revisions) have a flash point requirement of a minimum of 95 °C (200 °F) (per Pensky Martens flash point test procedure), assuring the minimization of evaporation losses.

**The contamination** of water-washable penetrant with water is the most frequent source of difficulty. When present beyond a critical percentage, this contamination will render the penetrant tank useless. For postemulsifiable penetrants, water contamination is not as critical a problem, because water is usually not miscible with postemulsifiable penetrants and will separate from the penetrant, which can then be subsequently removed. Water contamination can be minimized by implementing and following proper processing procedures.

It is important to recognize that acid contamination (carryover from precleaning) will render fluorescent penetrants ineffective. Acid contamination changes the consistency of the penetrant and damages or destroys the fluorescent dye.

Dust, dirt and lint, and similar foreign materials get into the penetrant in the ordinary course of shop usage. These contaminants do no particular harm unless present to the extent that the bath is scummy with floating or suspended foreign material. Reasonable care should be taken to keep the penetrant clean. Workpieces containing adhering sand and dirt from the shop floor should be cleaned before being dipped into the penetrant.

***Contamination of the emulsifier*** must also be considered. Method B, lipophilic emulsifiers inherently become contaminated by penetrant through the normal processing of parts coated with penetrant being dipped into the emulsifier. It is imperative, therefore, that the lipophilic emulsifier have a high tolerance (that is, 10%) for penetrant contamination. Water contamination of the lipophilic emulsifier is always a potential problem due to the nature of the process. Generally, 5% water contamination can be tolerated.

Method D, hydrophilic emulsifiers are not normally subject to appreciable amounts of penetrant contamination, mainly because of the prerinse processing step, which removes most of the excess surface penetrant before emulsification. Because hydrophilic emulsifiers are water based, water contamination is not a problem, except for the fact that the bath concentration must be maintained at the prescribed limits.

In general, emulsifiers that become severely contaminated will not properly emulsify the surface penetrant on the parts. Periodic monitoring is essential.

Developer must also be maintained to ensure proper performance. Contamination of the dry-powder developer with water or moisture in the air can result in caking. Dry developers must remain fluffy and free flowing if they are to perform properly. In addition, contamination from the fluorescent penetrant must not occur. Fluorescent specks in the developer powder could be misinterpreted as an indication. Wet developer (soluble or suspendible) must not become contaminated with penetrant or any contaminant that could affect its ability to wet and evenly cover the workpiece.

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**Liquid Penetrant Inspection**

**Revised by J.S. Borucki, Ardrox Inc., and Gail Jordan, Howmet Corporation**

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## Training and Certification of Personnel

The apparent simplicity of the penetrant method is deceptive. Very slight variations in performing the penetrant process and the inspection can invalidate the inspection results by failing to indicate all flaws. Therefore, many companies require that penetrant inspection be conducted only by trained and certified personnel. Minimum requirements for personnel training and certification are described by various military and industry specifications (such as MIL-STD-410 and ASNT SNT-TC-1A). The following are examples of the most commonly followed training programs; however, specific customer training requirements are usually defined within the contract.

**Training** is minimal for level I penetrant inspection operators (personnel responsible for the processing). However, the penetrant process must be correctly performed to ensure accurate inspection. Operator training consists of the satisfactory completion of a period of on-the-job training, as determined by immediate supervision, conducted under the guidance of a certified level I inspector.

Training for level II inspectors (personnel responsible for the inspection and evaluation) is more extensive than that for the level I operators. Training usually consists of 40 h of formal training, followed by several weeks of on-the-job training under the supervision of a designated trainer, usually a certified level II operator.

**Certification.** Personnel of sufficient background and training in the principles and procedures of penetrant inspection are usually certified by the successful completion of a practical test, which demonstrates their proficiency in penetrant techniques, and a written test, which documents their knowledge of penetrant inspection. Certified personnel are also normally required to pass a periodic eye examination, which includes a color-vision test. Certification can be obtained on-site through a certified level III inspector who may be with an outside source contracted to certify personnel or a company employee who has been certified as a level III inspector by the appropriate agency.

# Liquid Penetrant Inspection

**Revised by J.S. Borucki, Ardrox Inc., and Gail Jordan, Howmet Corporation**

## Inspection and Evaluation

After the penetrant process is completed, inspection and evaluation of the workpiece begin. Table 3 lists the more common types of flaws that can be found by penetrant inspection, together with their likely locations and their characteristics.

**Table 3 Common types, locations, and characteristics of flaws or discontinuities revealed by liquid penetrant inspection**

| **Type** | **Locations** | Characteristics |
|---|---|---|
| Relevant indications | | |
| Shrinkage cracks | Castings (all metals)--on flat surfaces | **Open** |
| Hot tears | Castings (all metals)--at inside corners | **Open** |
| Cold shuts | Castings (all metals)--at changes in cross section | **Tight, shallow** |
| Folds | Castings (all metals)--anywhere | **Tight, shallow** |
| Inclusions | Castings, forgings, sheet, bar--anywhere | **Tight, shallow, intermittent** |
| Microshrinkage pores | Castings--anywhere | **Spongy** |
| Laps | Forgings, bar--anywhere | **Tight, shallow** |
| Forging cracks | Forgings--at inside or outside corners and at changes in cross section | **Tight or open** |
| Pipe | Forgings, bar--near geometric center | **Irregular shape** |
| Laminations | Sheet--at edges | **Tight or open** |
| Center bead cracks | Welds--at center of reinforcement | **Tight or open** |
| Cracks in heat-affected zone | Welds--at edge of reinforcement | **Tight or open** |
| Crater cracks | Welds--at end of bead | **Star-shaped** |

| | | |
|---|---|---|
| Porosity | Castings, welds | **Spherical** |
| Grinding cracks | Any hard metal--ground surfaces | **Tight, shallow, random** |
| Quench cracks | Heat treated steel | **Tight to open, oxidized** |
| Stress-corrosion cracks | Any metal | **Tight to open; may show corrosion** |
| Fatigue cracks | Any metal | **Tight** |
| Nonrelevant indications(a) | | |
| Weld spatter | Arc welds | **Spherical or surface** |
| Incomplete penetration | Fillet welds | **Open, full weld length** |
| Surface expulsion | Resistance welds | **Raised metal at weld edge** |
| Scuff marks | Seam welds | **Surface of seam welds** |
| Press-fit interface | Press fits | **Outlines press fit** |
| Braze runoff | Brazed parts | **Edge of excess braze** |
| Burrs | Machined parts | **Bleeds heavily** |
| **Nicks, dents, scratches** | **All parts** | **Visible without penetrant aids** |

(a) These may be prohibited flaws, but are usually considered nonrelevant in penetrant testing.

**Inspection Tools.** An inspector must have tools that are capable of providing the required accuracy. These tools usually include suitable measuring devices, a flashlight, small quantities of solvent, small quantities of dry developers or aerosol cans of nonaqueous wet developers, pocket magnifiers ranging from 3 to 10×, and a suitable black light for fluorescent penetrants or sufficient white light for visible penetrants. Photographic standards or workpieces that have specific known flaws are sometimes used as inspection aids.

**A typical inspection** begins with an overall examination to determine that the workpiece has been properly processed and is in satisfactory condition for inspection. Inspection should not begin until the wet developers are completely dry. If developer films are too thick, if penetrant bleedout appears excessive, or if the penetrant background is excessive, the workpiece should be cleaned and reprocessed. When the inspector is satisfied that the workpiece is inspectable, it is examined according to a specified plan to be sure no areas have been missed. An experienced inspector can readily determine which indications are within acceptable limits and which ones are not. The inspector then measures all other indications. If the length or diameter of an indication exceeds allowable limits, it must be evaluated. One of the most common and accurate ways of measuring indications is to lay a flat gage of the maximum acceptable dimension of discontinuity over the indication. If the indication is not completely covered by the gage, it is not acceptable.

**Evaluation.** Each indication that is not acceptable should be evaluated. It may actually be unacceptable, it may be worse than it appears, it may be false, it may be real, but nonrelevant, or it may actually be acceptable upon closer examination. One common method of evaluation includes the following steps:

- Wipe the area of the indication with a small brush or clean cloth that is dampened with a solvent
- Dust the area with a dry developer or spray it with a light coat of nonaqueous developer
- Remeasure under lighting appropriate for the type of penetrant used

If the discontinuity originally appeared to be of excessive length because of bleeding of penetrant along a scratch, crevice, or machining mark, this will be evident to a trained eye. Finally, to gain maximum assurance that the indication is properly interpreted, it is good practice to wipe the surface again with solvent-dampened cotton and examine the indication area with a magnifying glass and ample white light. This final evaluation may show that the indication is even larger than originally measured, but was not shown in its entirety because the ends were too tight to hold enough penetrant to reach the surface and become visible.

**Disposition of Unacceptable Workpieces.** A travel ticket will usually accompany each workpiece or lot of workpieces. Provision should be made on this ticket to indicate the future handling of unacceptable material, that is, scrapping, rework, repair, or review board action. There is often room on such tickets for a brief description of the indication. More often, indications are identified directly on the workpiece by circling them with some type of marking that is harmless to the material and not easily removed by accident, but removable when desired.

**Reworking** an unacceptable flaw is often allowable to some specified limit; indications can be removed by sanding, grinding, chipping, or machining. Repair welding is sometimes needed; in this case, the indication should be removed as in reworking before it is repair welded, or welding may move the flaw to a new location. In addition, it is imperative that all entrapped penetrant be removed prior to repair welding, because entrapped penetrant is likely to initiate a new flaw. Verification that the indication and the entrapped penetrant have been removed is required.

Because reworking is usually required, it is good practice to finish it off with moderately fine sanding, followed by chemical etching to remove smeared metal. All traces of the etching fluid should be rinsed off, and the area should be thoroughly dried before reprocessing for reinspection. Reprocessing can be the same as original processing for penetrant inspection, or can be done locally by applying the materials with small brushes or swabs.

**False and Nonrelevant Indications.** Because penetrant inspection provides only indirect indications or flaws, it cannot always be determined at first glance whether an indication is real, false, or nonrelevant. A real indication is caused by an undesirable flaw, such as a crack. A false indication is an accumulation of penetrant not caused by a discontinuity in the workpiece, such as a drop of penetrant left on the workpiece inadvertently. A nonrelevant indication is an entrapment of penetrant caused by a feature that is acceptable even though it may exceed allowable indication lengths, such as a press-fit interface.

## Liquid Penetrant Inspection

**Revised by J.S. Borucki, Ardrox Inc., and Gail Jordan, Howmet Corporation**

## Specifications and Standards

It has not been practical to establish any type of universal standardization, because of the wide variety of components and assemblies subjected to penetrant inspection, the differences in the types of discontinuities common to them, and the differences in the degree of integrity required. Generally, quality standards for the types of discontinuities detected by penetrant inspection are established by one or more of the following methods:

- Adoption of standards that have been successfully used for similar workpieces

- Evaluation of the results of penetrant inspection by destructive examination
- Experimental and theoretical stress analysis

**Specifications.** Normally, a specification is a document that delineates design or performance requirements. A specification should include the methods of inspection and the requirements based on the inspection or test procedure. With penetrant inspection, this becomes difficult. Too often the wording in quality specifications is ambiguous and meaningless, such as "workpieces shall be free from detrimental defects" or "workpieces having questionable indications shall be held for review by the proper authorities."

Specifications applicable to penetrant inspection are generally divided into two broad categories: those involving materials and equipment, and those concerning methods and standards. There are, however, several standards and specifications that are in common use; some of these are listed in Table 4. Because the equipment used for penetrant inspection covers such a broad scope, that is, ranging from small dip-tank setups to large automated installations, most emphasis in standards and specifications has been placed on the materials used in this inspection process.

**Table 4 Partial listing of standards and specifications for liquid penetrant inspection**

| **Number** | Title or explanation of standard or specification |
|---|---|
| ASTM standards | |
| ASTM E 165 | **Standard Practice for Liquid-Penetrant Inspection Method** |
| ASTM E 270 | **Standard Definitions of Terms Relating to Liquid-Penetrant Inspection** |
| ASTM E 1208 | **Standard Method for Fluorescent Liquid-Penetrant Examination Using the Lipophilic Post-Emulsification Process** |
| ASTM E 1209 | **Standard Method for Fluorescent-Penetrant Examination Using the Water-Washable Process** |
| ASTM E 1210 | **Standard Method for Fluorescent-Penetrant Examination Using the Hydrophilic Post-Emulsification Process** |
| ASTM E 1219 | **Standard Method for Fluorescent-Penetrant Examination Using the Solvent-Removable Process** |
| ASTM E 1220 | **Standard Method for Visible-Penetrant Examination Using the Solvent-Removable Process** |
| ASTM E 1135 | **Standard Test Method for Comparing the Brightness of Fluorescent Penetrants** |
| ASTM D 2512 | **Compatibility of Materials with Liquid Oxygen (Impact-Sensitivity Threshold Technique)** |
| Test for AMS-SAE specifications | |
| AMS 2647 | **Fluorescent Penetrant Inspection--Aircraft and Engine Component Maintenance** |

| | |
|---|---|
| ASME specifications | |
| ASME SEC V | **ASME Boiler and Pressure Vessel Code Section V, Article 6** |
| U.S. military and government specifications | |
| MIL-STD-6866 | **Military Standard Inspection, Liquid Penetrant** |
| MIL-STD-410 | **Nondestructive Testing Personnel Qualifications & Certifications** |
| MIL-I-25135 | **Inspection Materials, Penetrant** |
| MIL-I-25105 | **Inspection Unit, Fluorescent Penetrant, Type MA-2** |
| MIL-I-25106 | **Inspection Unit, Fluorescent Penetrant, Type MA-3** |
| **MIL-STD-271 (Ships)** | **Nondestructive Testing Requirements for Metals** |

**Control Systems.** In conjunction with the specifications listed in Table 4, several methods and several types of standards are used to check the effectiveness of liquid penetrants. One of the oldest and most frequently used methods involves chromium-cracked panels, which are available in sets containing fine, medium, and coarse cracks. Many other types of inspection standards have been produced--often for specific indications needed for a unique application. A comparison of indications from two water-washable penetrants of different sensitivity that were applied to a chromium-cracked panel containing fine cracks is shown in Fig. 23.

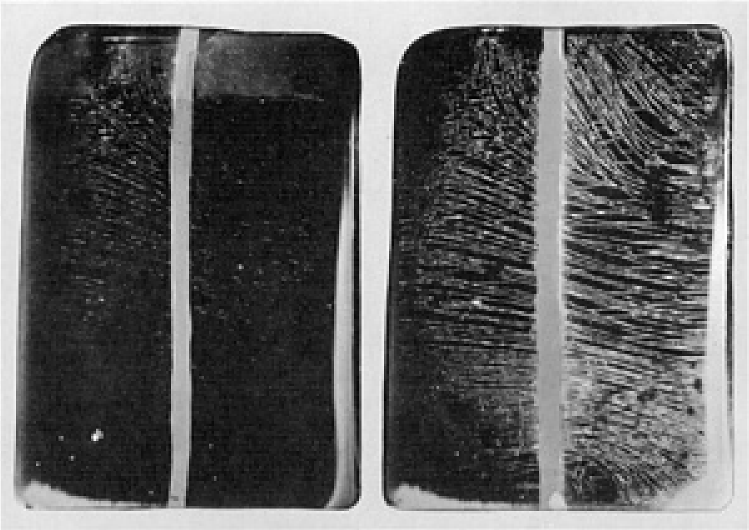

**Fig. 23 Comparison of indications on chromium-cracked panels developed with water-washable liquid penetrants of low sensitivity (panel at left) and high sensitivity (panel at right)**

**Acceptance and rejection standards** for liquid penetrant inspection are usually established for each individual item or group of items by the designer. In most cases, acceptance and rejection standards are based on experience with similar items, the principal factor being the degree of integrity required. At one extreme, for certain noncritical items, the standard may permit some specific types of discontinuities all over the workpiece or in specified areas. Inspection is often applied only on a sampling basis for noncritical items. At the opposite extreme, items are subjected to 100% inspection, and requirements are extremely stringent to the point of defining the limitations on each specific area.

## Magnetic Particle Inspection

**Revised by Art Lindgren, Magnaflux Corporation**

## Introduction

MAGNETIC PARTICLE INSPECTION is a method of locating surface and subsurface discontinuities in ferromagnetic materials. It depends on the fact that when the material or part under test is magnetized, magnetic discontinuities that lie in a direction generally transverse to the direction of the magnetic field will cause a leakage field to be formed at and above the surface of the part. The presence of this leakage field, and therefore the presence of the discontinuity, is detected by the use of finely divided ferromagnetic particles applied over the surface, with some of the particles being gathered and held by the leakage field. This magnetically held collection of particles forms an outline of the discontinuity and generally indicates its location, size, shape, and extent. Magnetic particles are applied over a surface as dry particles, or as wet particles in a liquid carrier such as water or oil.

Ferromagnetic materials include most of the iron, nickel, and cobalt alloys. Many of the precipitation-hardening steels, such as 17-4 PH, 17-7 PH, and 15-4 PH stainless steels, are magnetic after aging. These materials lose their ferromagnetic properties above a characteristic temperature called the Curie point. Although this temperature varies for different materials, the Curie point for most ferromagnetic materials is approximately 760 °C (1400 °F).

Magnetic Particle Inspection

Revised by Art Lindgren, Magnaflux Corporation

## Method Advantages and Limitations

Nonferromagnetic materials cannot be inspected by magnetic particle inspection. Such materials include aluminum alloys, magnesium alloys, copper and copper alloys, lead, titanium and titanium alloys, and austenitic stainless steels.

In addition to the conventional magnetic particle inspection methods described in this article, there are several proprietary methods that employ ferromagnetic particles on a magnetized testpiece. Three of these methods--magnetic rubber inspection, magnetic printing, and magnetic painting--are described in the Appendix to this article.

**Applications.** The principal industrial uses of magnetic particle inspection are final inspection, receiving inspection, in-process inspection and quality control, maintenance and overhaul in the transportation industries, plant and machinery maintenance, and inspection of large components.

Although in-process magnetic particle inspection is used to detect discontinuities and imperfections in materials and parts as early as possible in the sequence of operations, final inspection is needed to ensure that rejectable discontinuities or imperfections detrimental to the use or function of the part have not developed during processing. During receiving inspection, semifinished purchased parts and raw materials are inspected to detect any initially defective material. Magnetic particle inspection is extensively used on incoming rod and bar stock, forging blanks, and rough castings.

The transportation industries (truck, railroad, and aircraft) have planned overhaul schedules at which critical parts are magnetic particle inspected for cracks. Planned inspection programs are also used in keeping plant equipment in operation without breakdowns during service. Because of sudden and severe stress applications, punch-press crankshafts, frames,