MAGNETIC PARTICLE TEST

5. MAGNETIC PARTICLE TEST

5.1. MAGNETIC MATERIALS

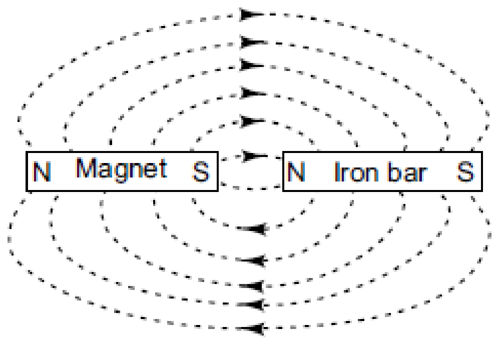
Materials are classified as ferromagnetic, paramagnetic or diamagnetic depending on their behavior in a magnetic field. Ferromagnetic materials are easily magnetized and show a high value of magnetic susceptibility. Also, it is observed that the magnetization of such materials is not proportional to the magnetizing field. This results in considerable variation in magnetic susceptibility magnetic permeability in the magnetizing field.

Paramagnetic materials have magnetic permeability greater than one and of a small positive value magnetic susceptibility.

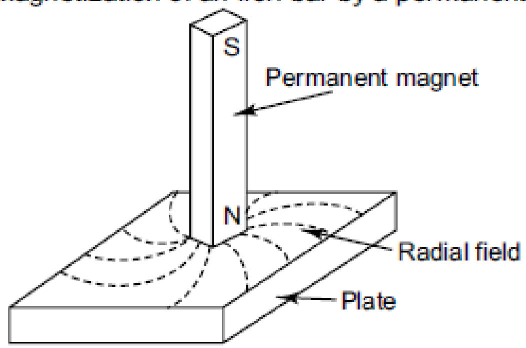
Diamagnetic materials have magnetic permeability less than one and constant magnetic susceptibility.

5.2. MAGNETIZATION OF MATERIALS

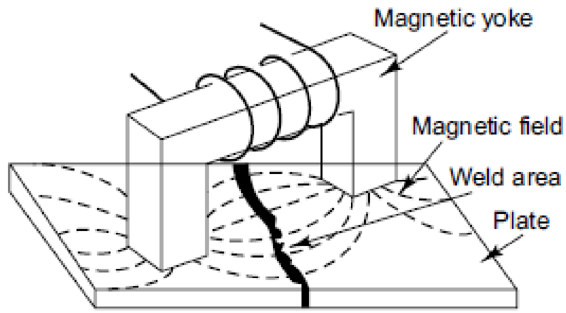
Materials are magnetized by a permanent magnet or by the magnetic field produced by an electric current. The earth's magnetic field also magnetizes materials. Here, we are concerned with magnetization by a permanent magnet or by a magnetic field produced by an electric current. Figure 5.1 illustrates magnetization by permanent magnets.



(a) Magnetization of an iron bar by a permanent bar magnet



(b) Production of a radial field by a permanent bar magnet



(c) Production of a magnetic field by a permanent magnet yoke

Figure 5.1. Magnetization by Permanent Magnets

5.2.1. Magnetic Field Using an Electric Current

Direct as well as alternating currents are used to magnetize components for the magnetic particle test. The choice of current depends on the strength, direction and distribution of the desired magnetic field. A magnetic field produced by direct current (DC) penetrates the cross-section of a component, whereas the field produced by an alternating current (AC) is largely confined to the surface of the component due to the skin effect. The direct current obtained from a rectified AC is invariably used for the magnetic particle test. Rectification of a single-phase AC gives a Half Wave Rectified Current (HWDC). A full wave rectified DC is obtained by rectifying the alternating current such that even in the reverse half of the cycle, the current is allowed to flow into the circuit in the same direction. Figure 5.2 shows the form of current thus obtained.

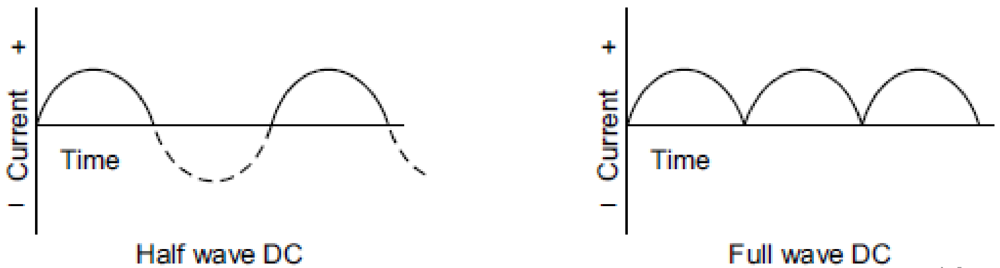


Figure 5.2. Forms of Half and Full Wave DC

DC ranging from 50—6000 amperes is used in the magnetic particle test.

5.2.2. Surge Method

If a surge of high current is passed through a ferromagnetic material for a short duration and the current is then reduced to its steady lower value, the component is magnetized to its saturation value. It is not possible to attain this high state of magnetization with a lower steady current.

5.2.3. Induction Method

This method is used to magnetize ring-shaped components. Here, AC or DC is passed through the primary winding of a transformer, where the ring-shaped component forms a single turn secondary as shown in Fig. 5.3. The magnetic field is produced because of induced current in the part. This type of magnetization helps in the detection of circumferential defects. Materials of high retentivity are subjected to DC current magnetization, while those with low retentivity are subjected to AC or HWDC magnetization. The induction method of magnetization has the advantage that there is no chance of damaging the component surface due to arcing.

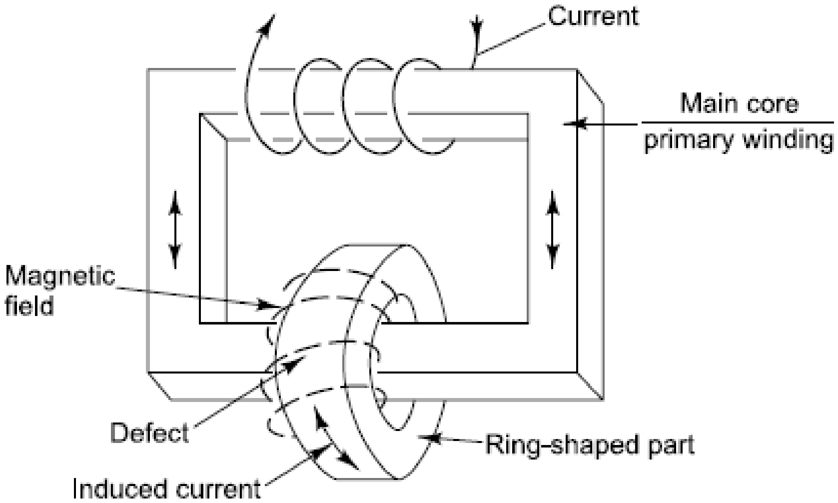


Figure 5.3. Magnetization of Ring-Shaped Components

5.2.4. Solenoid Coil Method

Solenoids carrying current produce a magnetic field along the axis of the solenoid as shown in Fig. 5.4.

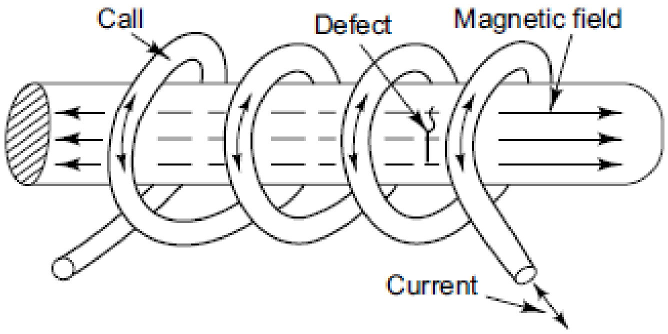


Figure 5.4. Magnetization with a Solenoid Coil

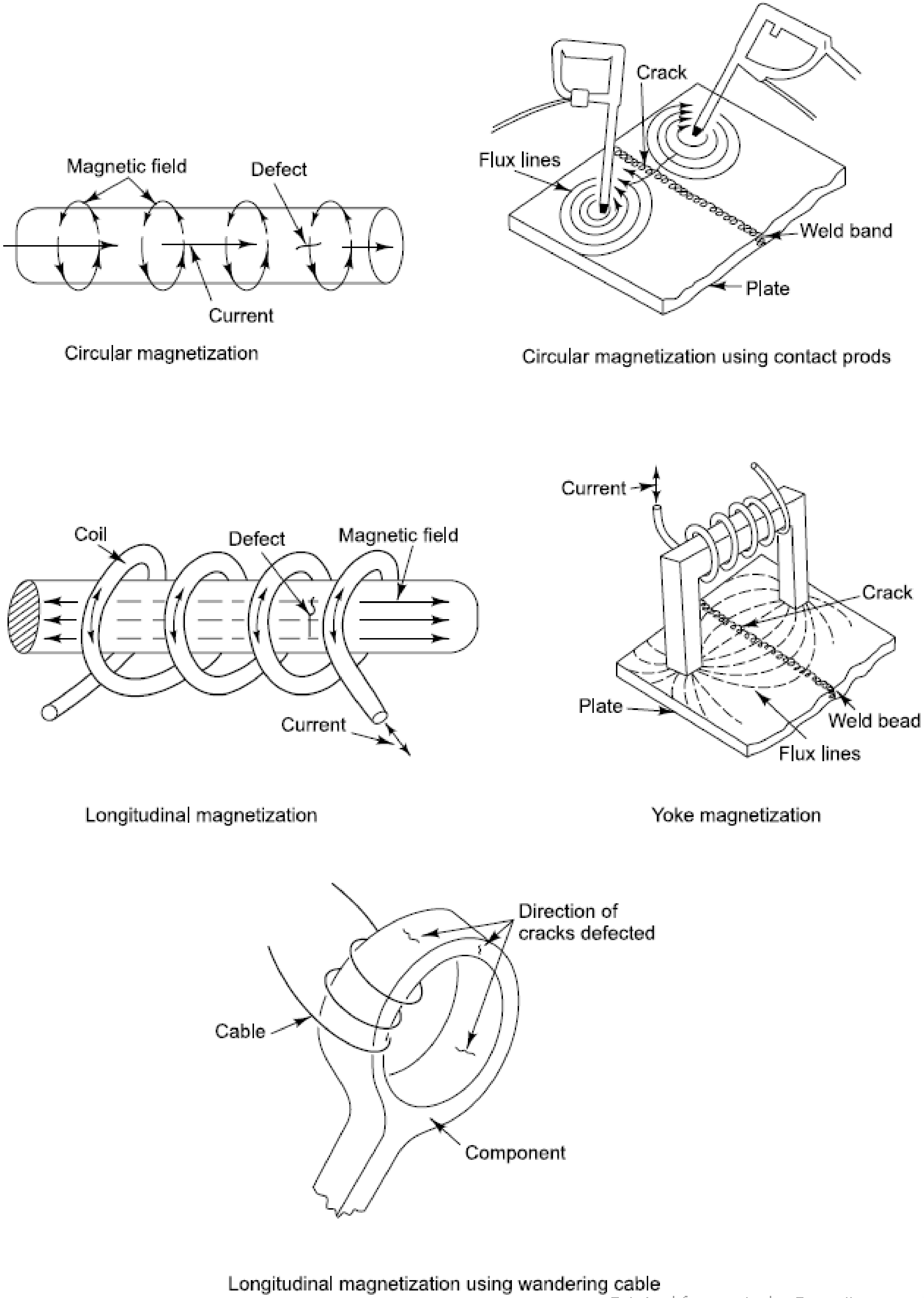


Figure 5.5. Various Arrangements of Magnetization

When a part is placed inside a solenoid coil, a magnetic field is created parallel to the solenoid axis. The field strength inside the solenoid is proportional to the product of current (Amps) and the number of turns of the coil. The strength can be varied either by varying the current or the number of turns. Solenoid-carrying currents are preferred for creating the longitudinal fields in ferromagnetic parts. For large parts, cable wire is wound directly around the part. For small parts, coils wound on movable frames are often used.

5.2.5. Alternating Current Method

A 50-60-cycle frequency AC from commercial power lines is directly used for magnetization in this method. Only single phase is used and voltage is stepped up by using suitable transformers. At a low voltage, magnetizing current up to several thousand amperes is used. When using AC, the skin effect is used to advantage for detection of surface discontinuities.

Depending upon the requirements of magnetization, size and shape of the components, the following arrangements are employed:

- Circular magnetization
- Longitudinal magnetization
- Coil magnetization
- Prod magnetization
- Yoke magnetization

5.3. DEMAGNETIZATION OF MATERIALS

After completion of a magnetic particle test, it is essential to demagnetize the component, as a certain amount of magnetism is retained, depending on the:

- Magnetic characteristics of the material
- Geometry of the component
- Direction of magnetization
- Strength of the magnetic field

The reasons for demagnetization are:

- Residual magnetism may interfere with subsequent machining, causing machined chips of the material to adhere to the surface of the component or the tool

- During welding with an electric arc, residual magnetism may cause deflection of the arc and obstruct proper welding
- The functioning of navigational instruments, which are sensitive to magnetic field, is affected by the proximity of ferromagnetic components having residual magnetism
- Residual magnetism may interfere with the functioning of dynamic components if any chips are held on it like ball bearing-races, gear assemblies, etc. It also affects finishing operations like painting and plating

However, demagnetization may not be necessary under these conditions:

- If the material of the component has low retentivity
- Welded structural components, large castings, boilers, etc. made of high-strength alloys. Residual magnetism does not affect the service performance of such components
- Components that undergo heat-treatment above Curie temperature
- Components that are held in a magnetic chuck during a subsequent operation or components requiring re-magnetization in different directions

Methods of demagnetization

Table 5.1. gives the various methods used for demagnetization.

Component	Method of Demagnetization
Large components of high hardness	AC coil method
	(i) AC through current (decreasing in amplitude in stages)
Small components of medium hardness	(ii) DC through current (decreasing in stages as well as alternating in direction
Localized demagnetization (big or small parts)	(i) AC yoke
	(ii) Reversing DC yoke

5.4. PRINCIPLE OF MAGNETIC PARTICLE TEST

When a homogeneous ferromagnetic material is placed in a magnetic field, it gets magnetized and the magnetic field forms a continuous circuit from pole to pole through the material. If any surface or subsurface discontinuity is present, the magnetic field (and the associated magnetic lines of force) gets deflected and forms a leakage field as shown in Fig. 5.6.

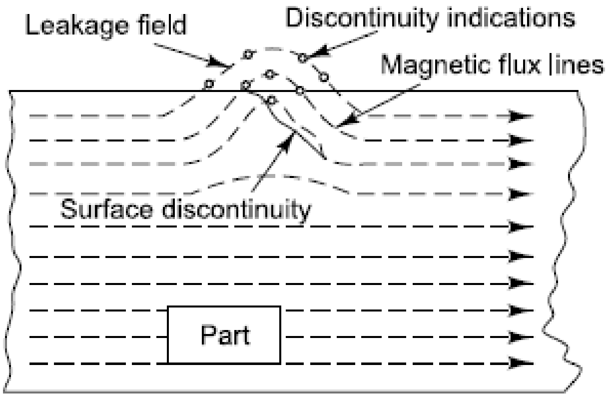


Figure 5.6. Principle of Magnetic Particle Test

If fine particles of magnetic material are applied on the surface of the test material, the leakage field attracts the particles which form an outline of discontinuity and indicate the location, size, shape and extent of the discontinuity. The method is very sensitive for locating fine surface and sub-surface defects.

The methods involved in the magnetic particle test are:

- Cleaning/degreasing of the surface and demagnetizing
- Magnetization of the component
- Application of fine magnetic particles on the surface of the component
- Examination of the component surface for defects
- Demagnetization and temporary protection

Figure 5.7 shows the process flow chart.

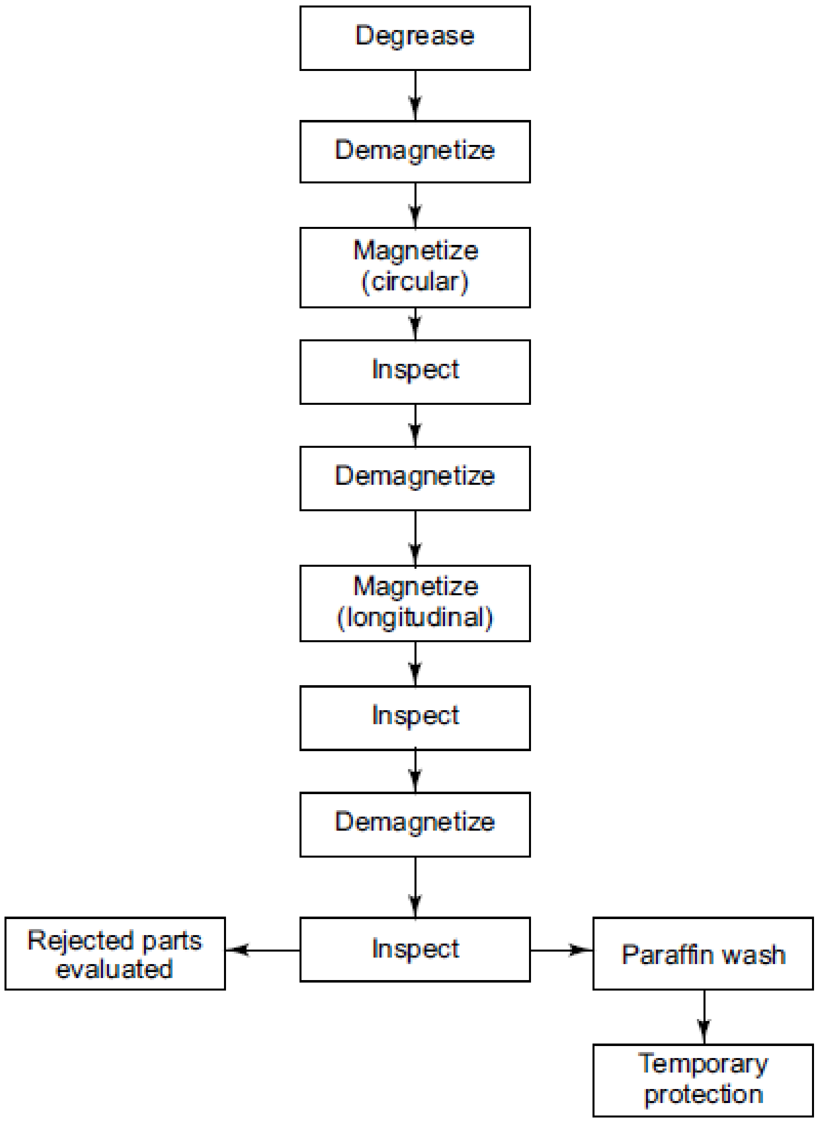


Figure 5.7. Magnetic Particle Test Flow Chart

The following factors influence the indication of discontinuities:

- The initial state of magnetization of the component
- The direction and strength of the magnetizing field with respect to size, shape and orientation of the discontinuity
- The magnetic nature and chemical composition of the component material
- The size, shape, geometry and surface finish of the component
- The physical characteristics of the magnetic particle (e.g. size, shape)

The magnetic particle test methods are grouped as:

- **Dry method:** In this method, finely divided ferromagnetic particles, in dry powder form, are uniformly dusted over the magnetized surface, either by an atomizer or a spray grain. The powder is gray, black or red to provide suitable contrast indication. The method is used to examine rough surfaces and is also convenient for fieldwork.

- **Wet method:** In this method, fine magnetic particles suspended in kerosene or any liquid vehicle are sprayed over the test surface after magnetization. Magnetic particles used here are fine compared to those used for the dry method. The size of the particles is maintained in the range of 10—50 microns which makes this method sensitive to the detection of fine defects.

- **Fluorescent method:** In this method, magnetic particles are coated with a fluorescent dye and used where the surface finish is fine. The components are examined under ultraviolet light (λ = 3650 Å). The method is particularly useful in locating discontinuities in corners, key ways, deep holes etc.

- **Residual method:** In this method, the magnetizing field is withdrawn after magnetizing the component. Magnetic particles are applied on the surface of the component after the field is withdrawn. The method is applicable for components that show high retentivity. It is essential that residual magnetism be strong enough to produce a leakage field at discontinuities.

- **Continuous method:** In this method, a magnetic powder is applied on the component surface when the magnetic field is still on. To produce a meaningful indication during the test, the level of magnetization must be sufficient to produce a strong leakage field to attract and hold fine magnetic particles.

In the usual current flow method of magnetization, the magnetizing current is measured by an ammeter, which reads the root mean square (rms) or average value of current and not the peak current. It is the peak current that determines maximum magnetization. This value is higher than what is indicated by the ammeter reading. Figure 5.8 gives the peak value of current for various wave forms.

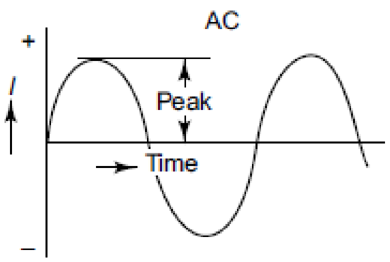
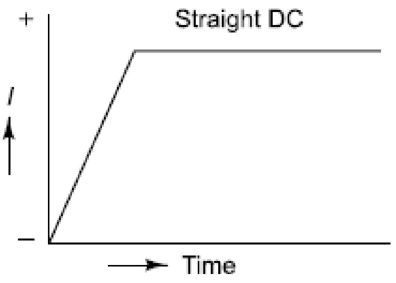
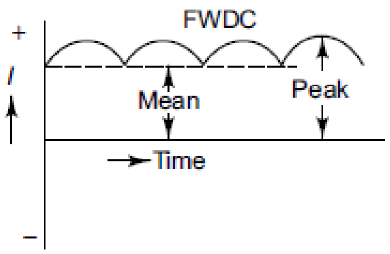
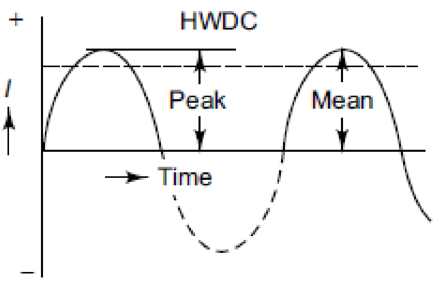
<table>
<tr><th>Wave Form</th><th>Ammeter Reading</th><th>Relationship</th></tr>
<tr><td rowspan="2">
</td><td>I_{rms}</td><td>$I_p = \sqrt{2} \, . \, I_{rms}$</td></tr>
<tr><td>I_{av}</td><td>$I_p = \frac{\pi}{2} \, . \, I_{av}$</td></tr>
<tr><td>
</td><td>I_{mean}</td><td>$I_{peak} = I_{mean}$</td></tr>
<tr><td>
</td><td>I_{mean}</td><td>$I_{peak} = \frac{\pi}{2} \, . \, I_{mean}$</td></tr>
<tr><td>
</td><td>I_{mean}</td><td>$I_{peak} = \pi . I_{mean}$</td></tr>
</table>

Figure 5.8. Relationship between rms and Peak Values of Current

In practice, one comes across components of varying geometrical shapes and cross-sections. This demands some compromise, simplification and approximation in the selection of the most effective method of magnetization. Complicated shapes are considered to be made up of several simple geometrical shapes joined together. The approximate current is applied to each section separately to bring out the longitudinal or transverse defects. Table 5.2 gives the guidelines for selection of current.

Table 5.2. Guidelines for the selection of current

Component Shape	DC	AC	FWDC	HWDC
Current for round components (Amp/mm of diameter)	28	20	18	9
Current for irregular-shaped components (Amp/mm of perimeter)	9	6.4	5.7	2.9

In many cases flexible cables are used, particularly for the examination of bore or lug areas of complex and large components, as shown in Fig. 5.9.

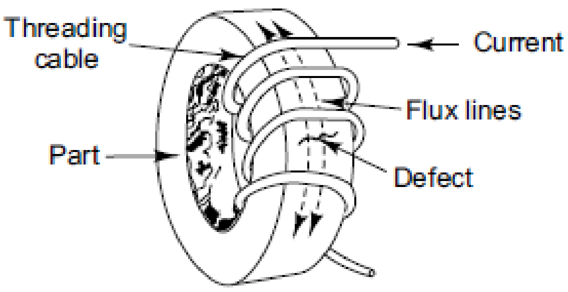


Figure 5.9. Flexible Cable Threading Magnetization

Using flexible cables as coils around large ring-shaped components, successive areas are examined. The optimum magnetizing current is estimated by the relation:

Peak current = $16\ R/N$, where R = Radius of the ring (mm), N = Number of turns of coil

In the coil magnetizing technique, the component is placed inside a current-carrying coil and magnetized in a direction parallel to the axis of the coil as shown in Fig. 5.10.

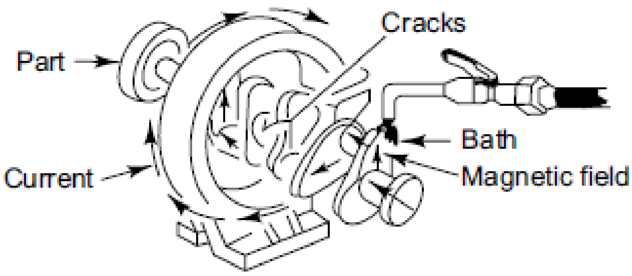


Figure 5.10. Coil Magnetization

Discontinuities transverse to the axis of the coil are detected. The sensitivity of the flaw detection depends on:

- The shape and size of the specimen and coil
- The ampere turns of the coil

The magnetizing current is adjusted such that the magnetizing field is just below saturation value. The state of magnetic saturation is observed by observing the furring of magnetic particles on the surface of the component. For a helical coil of magnetization, the following relation is used for computing magnetizing current:

$$NI = \frac{C}{L/D}$$

where

I = Current in amperes

N = Number of turns in the coil

L/D = Component length to diameter ratio

C = Constant depending on the type of magnetizing current

The various values of this constant are given below:

Value of Constant 'C'	Magnetizing Current
32,000	DC
22,000	AC & FWDC
11,000	HWDC

Where L/D ratio is greater than 15, a value of current corresponding to L/D = 15 is used.

This relationship is valid when the cross-sectional area of the test part is 10% or less of the cross-sectional area of the coil.

Long components are magnetized by moving the coil along the length of the components, giving as many number of coil shots as the length of the component warrants. Whenever the prod type of magnetization is used, the optimum magnetizing current is selected according to guidelines given in Table 5.3.

Table 5.3. Guidelines for Current Selection for Prod Magnetization

Prod Spacing in mm	**Current in Amperes**	
	Section Thickness < 20 mm	**Section Thickness 20 mm and above**
50—100	200—300	300—400
101—150	300—400	400—600
151—200	400—600	600—800

Generally, 9 amperes/mm prod spacing is considered satisfactory.

Permanent magnets are also used to magnetize components, particularly for field applications.

During the application of these techniques, it is useful to remember the following points:

- The magnetizing field should be at right angles to the direction of expected discontinuities as far as possible
- The presence of a non-magnetic surface finish like paint or plating reduces the flaw detection sensitivity. Therefore, the magnetic particle test is carried out prior to the application or after the removal of such coatings, if the coating thickness exceeds 0.025 mm. If the coating thickness is less than 0.025 mm, the test is carried out without removing the coating. The coating should be removed only at contact points in case of the DC magnetization method
- Although guidelines for current selection for various methods of magnetization are given, it is essential to prepare a specific technique for each component, giving the precise value of the current and illustrating the various directions of magnetization

5.5. MAGNETIC PARTICLE TEST EQUIPMENT

The magnetic particle test equipment essentially consists of:

- A means to magnetize the component
- A device for the application of magnetic particles
- A means of demagnetizing the component after the test

Depending on the requirement, the equipment could be portable or stationary.

Portable equipment like permanent magnet yokes, prods and cables are useful for fieldwork, where an electrical power source is not available or in areas of explosive hazards.

In a stationary system, the components of the equipment are mounted on a table. It consists of a transformer working at low voltage between 6—27 volts and giving a current in the range of 2,000—20,000 amperes.

To facilitate demagnetization, current reversing switches are provided in the equipment. A hose with a lever-operated nozzle is provided for the application of the magnetic particles suspended in carrier fluid. The carrier fluid is agitated manually or by a pump to prevent the particles settling.

For large and heavy components, stationary equipment may not be suitable, so a heavy duty DC, multidirectional magnetization system is used. In this system, two or more fields are created in quick succession. This enables the detection of defects oriented in different directions.

5.6. MAGNETIC PARTICLE TEST PROCEDURE

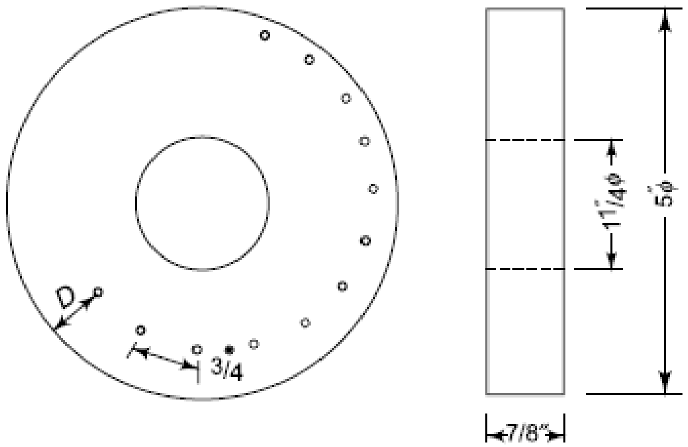
The objective of the magnetic particle test is to ensure that all surface and sub-surface discontinuities such as cracks, inclusions, pores, shrinkages, laps, folds, seams, etc. arising out of manufacturing operations and service constraints, are detected for the evaluation of components. For this, it is necessary that certain surface preparations be carried out before subjecting the components to magnetization and further operations. A process flow chart is given in Fig. 5.7. The first step in the magnetic particle test is to clean the surface. Components with rough and scaled surfaces are pickled in a mixture of 10% H_2SO_4 and 5% HF or 10% HCl and 2-gm/liter-Stanic solution to loosen or remove adherent surface scales, and thoroughly washed in cold water. Components are subjected to shot blasting until all scales are removed. This is followed by degreasing to remove any oil, grease, dirt, corrosion residue or marking dyes. Machined components are not subjected to pickling and shot blasting.

Next, it is often advantageous, though not mandatory to demagnetize the component to relieve it of any residual magnetism and then magnetized according to a pre-established technique.

The component is examined under proper lighting conditions. Indications are interpreted and evaluated in terms of pre-established standards of acceptance. The accepted components are finally cleaned, demagnetized and given a surface protection.

5.7. STANDARDIZATION AND CALIBRATION

The purpose of the standardization of the magnetic particle test system is to ensure that the equipment and accessories are working under conditions of acceptable and reproducible sensitivity. To ensure this, the system is calibrated for detecting the smallest discontinuity with a high degree of confidence. In practice, artificial discontinuities are made in a test piece and variables of the test system are optimized to indicate these discontinuities clearly under practical conditions of observation. Magnetic particle test systems employ standard test blocks containing artificial discontinuities. The block is made of tool steel and is ring-shaped. It contains 12 holes of the same diameter, located at different depths as shown in Fig. 5.11.



Hetz →	1	2	3	4	5	6	7	8	9	10	11	12
Diameter (inch)	← 0.070″ Common in all →											
D (inch)	0,070	0,140	0,210	0,280	0,350	0,420	0,490	0,560	0,630	0,700	0,770	0,840

Figure 5.11. Calibration Block

Before starting each shift of work, the test block is degreased, demagnetized and magnetic checks are carried out. The maximum magnetizing current that gives a satisfactory indication at each hole is established and recorded for the specific magnetic unit. These values are utilized to establish the satisfactory functioning of the test system at periodic intervals. Failure to obtain a satisfactory indication during periodic checks signifies one or all of the following:

- There is a concentration of magnetic particles below the optimum level
- The ammeter reading is inaccurate
- Some other malfunctioning of the equipment

5.8. INTERPRETATION AND EVALUATION

After magnetization and the application of magnetic particles, the surface of the component is examined. In case non-fluorescent particles are used, the examination is carried out under daylight with the help of a magnifying glass at an illumination of 500 lux. If artificial light is used, this illumination can be achieved by a 80 W fluorescent tube or a tungsten filament lamp of 100 W.

The fluorescent method makes use of dyes that glow when exposed to black light.

While examining the component one has to be careful in distinguishing flaw indications from false indications.

Some of the defects and their observed indications are discussed next.

1. *Nonmetallic inclusions*: Insufficient cleaning of the metal during or after melting gives rise to this defect. These defects may or may not show a sharp indication, depending on their severity. Generally, these defects show up as stringers running along the axis of the product or along the fibers in the forging.

2. *Seams*: These defects are observed in rolled products and are formed during rolling due to the presence of laps, surface tears or scales. These defects are generally elongated. A single, deep seam shows a sharp indication but clusters of tiny seams may give misleading a indication.

3. *Cooling cracks*: This defect occurs in steel with high hardenability, such as tool steel. Cracks are deep and give a strong indication along the grain fibers.

4. *Laminations*: These are usually found in plates and are due to the separation of layers, due to the presence of non-metallic film. These defects are parallel to the surface and indications occur only at the sides and cut portions of the plate.

5. *Piping*: These are internal defects and the magnetic particle test does not usually reveal them unless the defects are present at the end of the part. Indications at the end of the part represent a cross-section of the piping.

6. *Forging laps*: These are folds of metal squeezed together during forging. They have irregular contours and occur at right angles to the direction of metal flow. The indications of forging laps are not well defined due to a weak leakage field.

7. *Flash line cracks*: These are associated with and run along the flash line of the forging. They are deep and give strong indications.

8. *Forging bursts*: These are ruptures that occur when forging is carried out at a temperature that is too cold or too hot. Bursts may be on the surface or internal. They consist of numerous small and large cracks all over the forging and are more concentrated at thicker regions of the forgings.

9. *Flakes*: The reason for the occurrence of flakes is the evolution of dissolved gases. Flakes are usually observed on machined surfaces.

10. *Hot tears and thermal cracking*: These are surface cracks occurring due to non-uniform cooling from the casting stage or during heat treatment. In this case, indications are well defined as cracks and are sharp and deep.

11. *Gas porosity*: The magnetic particle test sometimes locates gas porosity and sub-surface blowholes. The indications are not sharp. Some experience is needed to identify these defects.

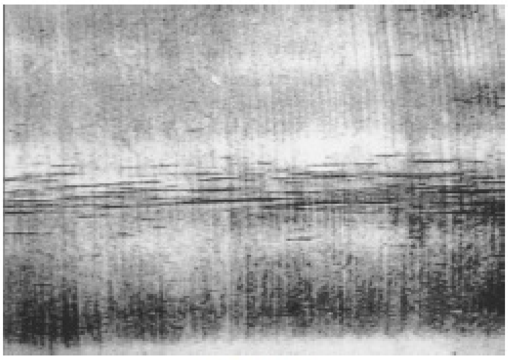
12. *Weld cracks and other weld defects*: Longitudinal or transverse cracks and parent metal cracks give sharp indications and are easy to detect. However, weld defects such as porosity, slag inclusions, inadequate penetration, lack of fusion and undercuts create fuzzy indications. One should be very careful in interpreting such indications.

13. *Heat treatment cracks (quenching cracks)*: Generally these cracks emanate from sharp corners, fillets, holes, slots or any inherent defects such as seams, which act as stress risers during quenching. These cracks are deep and sharp and give strong indications.

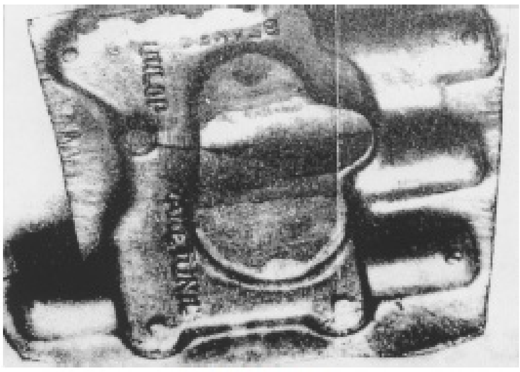
14. *Grinding cracks*: These are seen on highly finished ground surfaces. Cracks are fine, sharp and shallow and occur in groups.

15. *Fatigue cracks*: These occur only in parts that have been in service. Fatigue is a progressive type of brittle fracture, which occurs under cyclic loads. These are mostly surface cracks and give sharp indications, lying in a direction transverse to the direction of local stress.

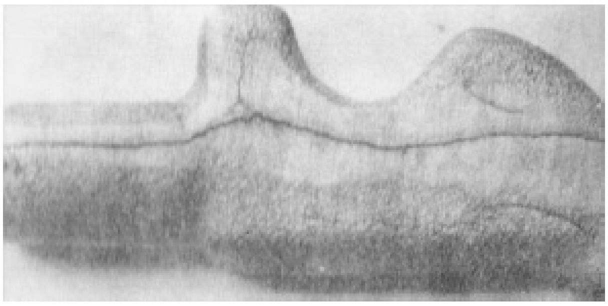
The appearance of some of these defects is shown in Fig. 5.12.



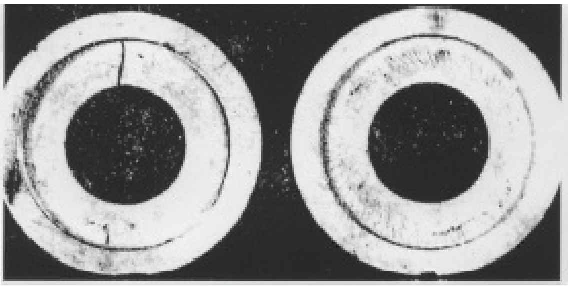
Inclusions



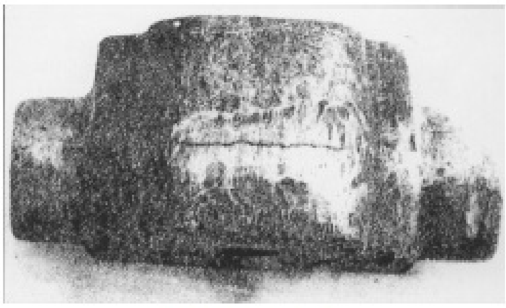
Forging lap



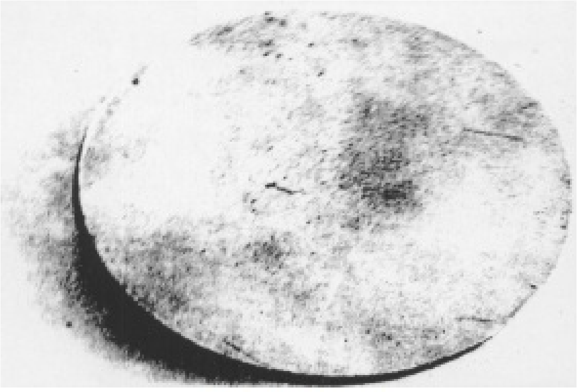
Lap and crack



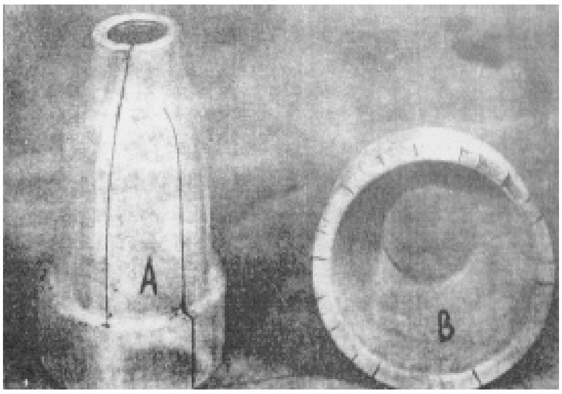
Grinding crack



Flash line crack



Forging burst



Quench crack

Figure 5.12. Some Defect Indications

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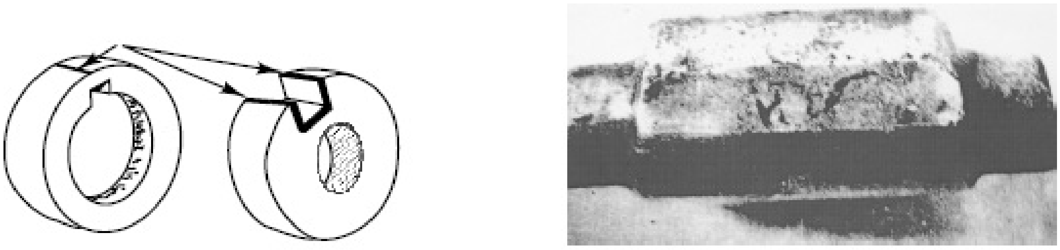
5.8.1. Non-relevant Indications

Sometimes, magnetic particles are attracted to leakage fields that occur for causes other than harmful discontinuities. The cause could be excessive magnetization, sharp variation in dimensions or variation in permeability within the part. Figure 5.13 shows two such examples.



(a) Non–relevant indications (b) Magnetic writing

Figure 5.13. Non-relevant Indications

Such indications disappear when the part is demagnetized and again magnetized at a slightly lower value of magnetizing current.

5.9. EFFECTIVE APPLICATIONS AND LIMITATIONS OF THE MAGNETIC PARTICLE TEST

The magnetic particle test is extensively used for locating and evaluating surface and sub-surface defects in ferromagnetic materials during production, processing and maintenance. A wide variety of industries, e.g. nuclear, aeronautical, shipping, railways, chemical, petroleum, food, paper, etc. utilize this method. However, the surface finish and appropriateness of the technique have a significant effect on the sensitivity and limitations of defect detection.

Table 5.4 gives the range of applications and limitations in flow detection during routine examination.

Table 5.4. Applications and limitations of the magnetic particle test

Product/Process	**Detection of**	**Limitation of Detection (mm)**	
All ferromagnetic materials, castings, weldments, forging, assemblies, ground and machined components	Surface and sub-surface cracks, grinding cracks, heat treatment cracks, stringer type non-metallic inclusions, porosity, laps and folds, fatigue cracks	Laboratory condition	0.5
		Production condition	1—2
		Service condition	1—2

The limits of detection can be significantly improved with improved facilities and techniques.