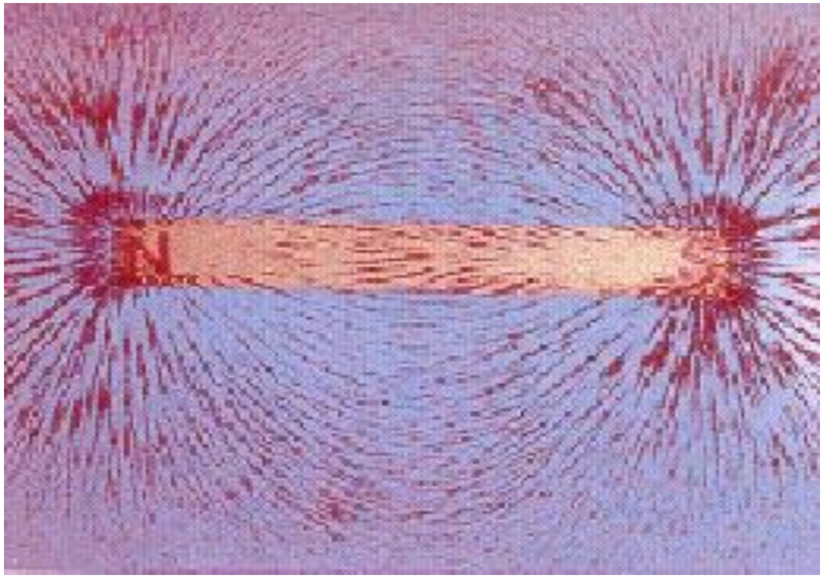
# MAGNETIC PARTICLE TESTING

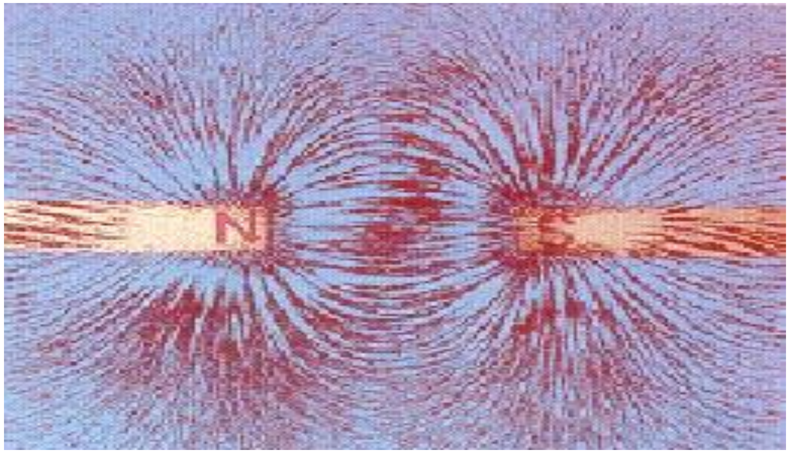
# Introduction

- **Magnetic particle inspection can detect both production discontinuities (seams, laps, grinding cracks and quenching cracks) and in-service damage (fatigue and overload cracks).**
- **Magnetism is the ability of matter to attract other matter to itself. Objects that possess the property of magnetism are said to be magnetic or magnetized and magnetic lines of force can be found in and around the objects.**
- **Magnets are classified**
  - **Permanent**
  - **Temporary**
- **Magnet qualities (**interaction with a magnetic field )
  - **Diamagnetic**
  - **Paramagnetic**
  - **Ferromagnetic**

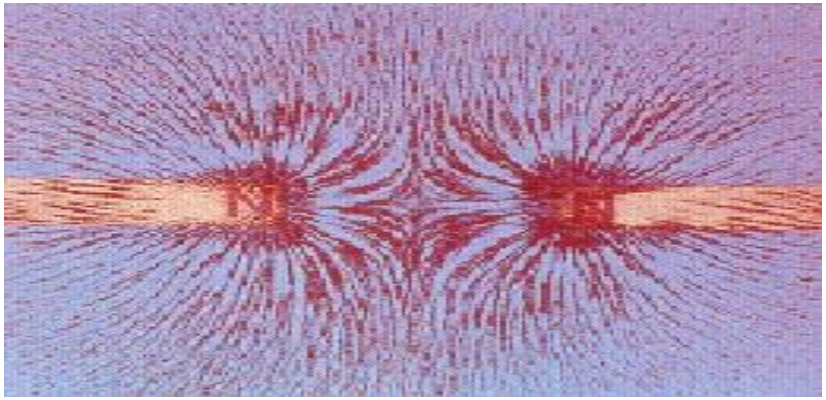
# Introduction to Magnetism




Magnetic lines of force
around a bar magnet




Opposite poles attracting



Similar poles repelling

i. **Diamagnetic materials** which have a weak, negative susceptibility to magnetic fields.

- Diamagnetic materials are slightly repelled by a magnetic field and the material does not retain the magnetic properties when the external field is removed.
- Most elements in the periodic table, including copper, silver, and gold, are diamagnetic.

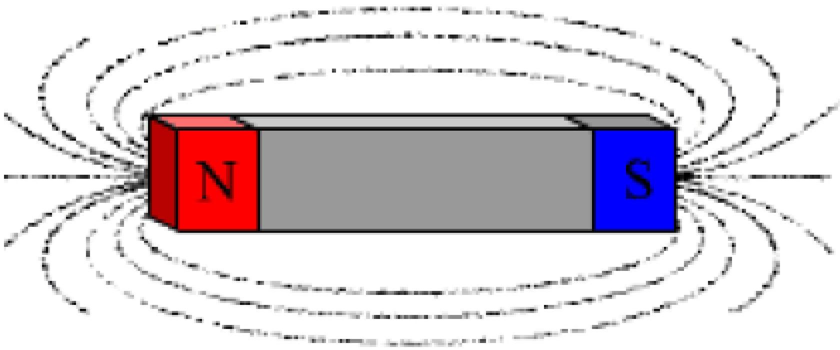
ii. **Paramagnetic materials** which have a small, positive susceptibility to magnetic fields.

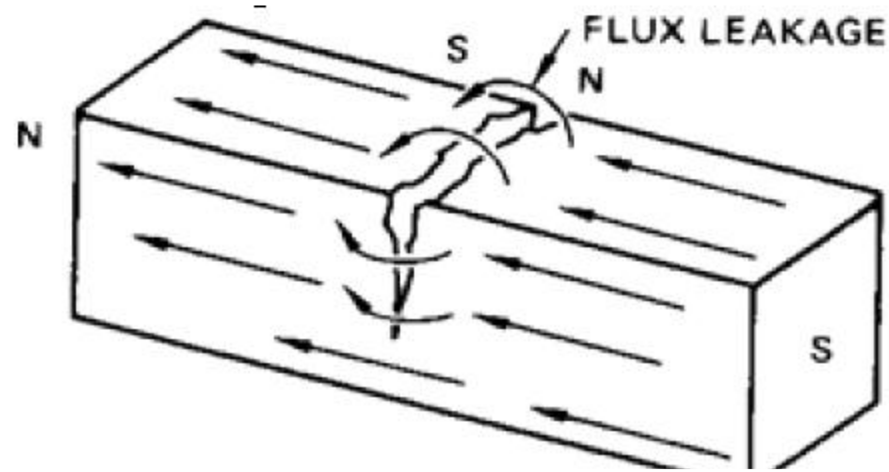
- These materials are slightly attracted by a magnetic field and the material does not retain the magnetic properties when the external field is removed.
- Examples of paramagnetic materials include magnesium, molybdenum, and lithium.

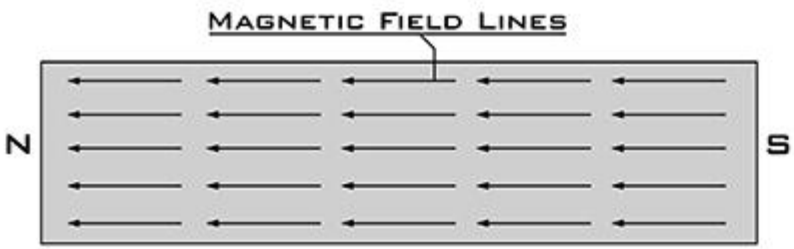
- **Ferromagnetic materials** have a large, positive susceptibility to an external magnetic field.
- They exhibit a strong attraction to magnetic fields and are able to retain their magnetic properties after the external field has been removed.
- Iron, nickel, and cobalt are examples of ferromagnetic materials. Components made of these materials are commonly inspected using the magnetic particle method

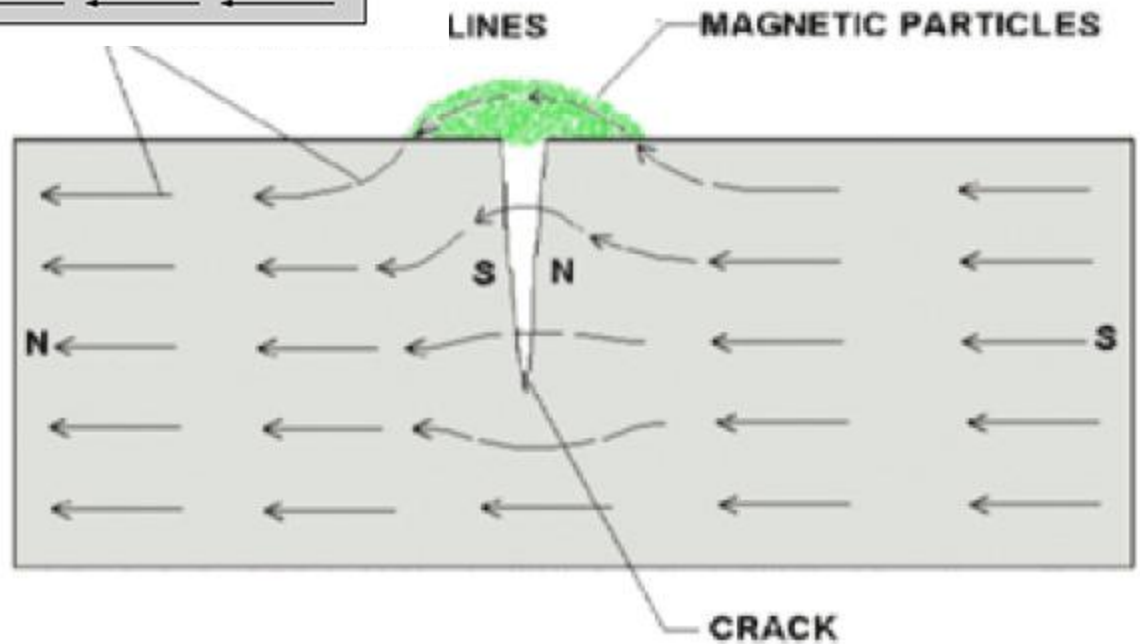
# Principles of MPI

- Specimen is magnetised so as to produce the magnetic lines of force
- Lines of force is interrupted, whenever there is a discontinuity, due to this some magnetic lines may exit and re-enter the specimen.
- the points of exit and re-enter form opposite magnetic poles.
- When minute magnetic particles are sprinkled into the specimen, these particles are attracted by these magnetic poles to create a visual indication approximating the size and shape of the flaw.
- magnetic particle may be powder or liquid suspension


N
S


FLUX LEAKAGE
S
N
N
S


MAGNETIC FIELD LINES
N
S


LINES
MAGNETIC PARTICLES
S
N
N
S
CRACK

# Basic physics of magnetism

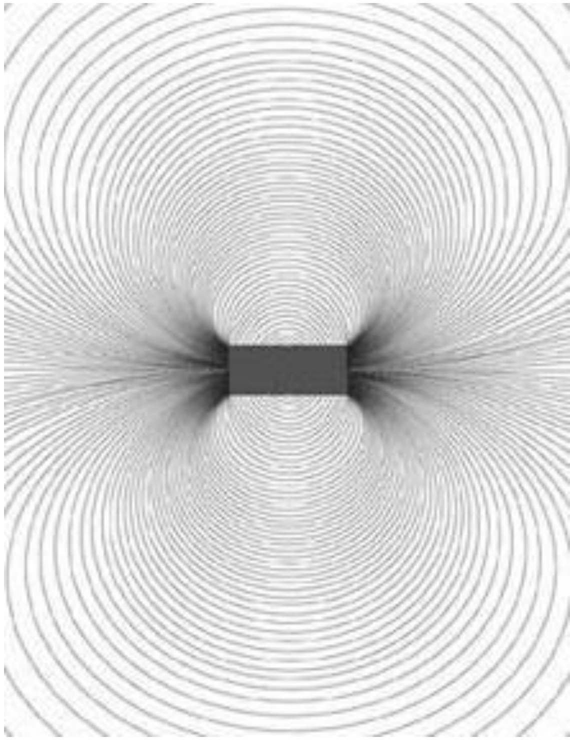
- **Flux Density (B).** Is flux (no. of lines of force) per unit area. Its measured in Gauss.
- **Magnetic flux:** Magnetic lines of force existing in magnetic field are called as magnetic flux. The unit of magnetic flux is Maxwell.
- **Magnetizing Force (H).** Is that the force which tends to set up magnetic flux in a material.
- **Reluctance:** is the resistance of the material to the establishment of a magnetic field. Reluctance of material determines the determines the magnitude of the flux produced.
- **Permeability.** The ease with which a material can be magnetized. The ability of a material to conduct magnetic lines of force.
  - $\mu = B/H$
  - Unit is H/M (henry/Meter)

- **Polarity**: in magnetism , polarity refers to north and south poles in space.
  - Eg. Magnetized rod in space.
- **Magnetic field**: it’s the area around the magnet in which the magnetic forces are observable.
- **Magnetic force**: it’s a force of attraction or repulsion that one body has upon another.
- **Coercive force**: it’s the measure of the ability of a ferromagnetic material to withstand an external magnetic field with out becoming demagnetized.
- R**etentivity**: the ability of a coil to retain some of its magnetism within the core after the magnetisation process has stopped.
- **Residual Magnetism or Residual Flux -** The magnetic flux density that remains in a material when the magnetizing force is zero.

(Note that residual magnetism and retentivity are the same when the material has been magnetized to the saturation point. However, the level of residual magnetism may be lower than the retentivity value when the magnetizing force did not reach the saturation level).

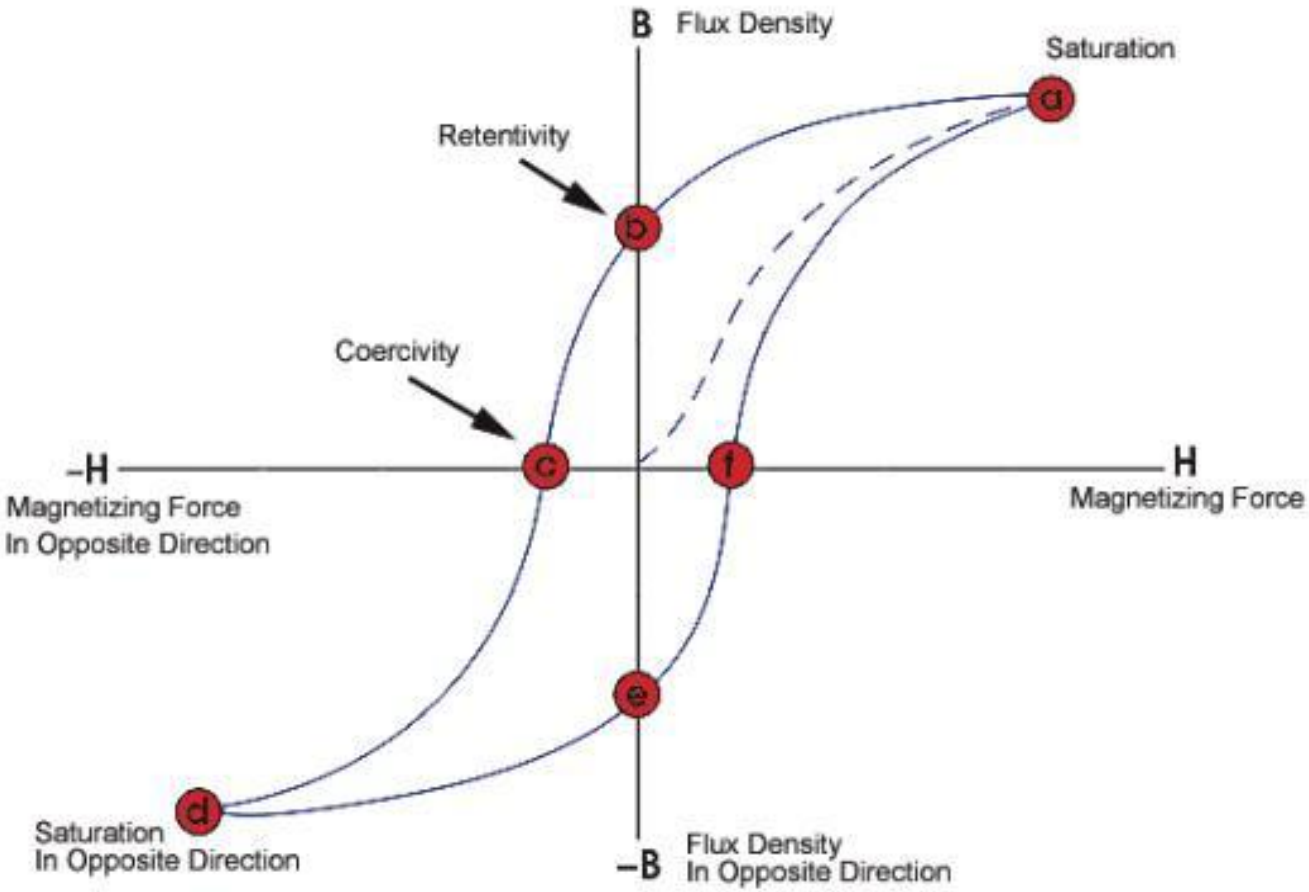
## *General Properties of Magnetic Lines of Force*

- Magnetic lines of force have a number of important properties, which include:
- They seek the path of least resistance between opposite magnetic poles (*in a single bar magnet shown, they attempt to form closed loops from pole to pole)*.
- They never cross one another.
- They all have the same strength.
- Their density decreases with increasing distance from the poles.
- Their density decreases (*they spread out) when they move from* an area of higher permeability to an area of lower permeability.
- They are considered to have direction as if flowing, though no actual movement occurs.
- They flow from the south pole to the north pole within a material and north pole to south pole in air.



# Hysteresis Loop

- A hysteresis loop shows the relationship between the induced magnetic flux density (**B) and the magnetizing force (H). It is often referred to as the *B-H loop.***
- The loop is generated by measuring the magnetic flux of a ferromagnetic material while the magnetizing force is changed.
- A ferromagnetic material that has never been previously magnetized or has been thoroughly demagnetized will follow the dashed line as **H is increased.**
- **As the line demonstrates, the greater the amount of current applied (*H+), the stronger the magnetic field in the component (B+). At point "a“***almost all of the magnetic domains are aligned and an additional increase in the magnetizing force will produce very little increase in magnetic flux.


B Flux Density
Saturation
a
Retentivity
b
Coercivity
c
f
-H
H
Magnetizing Force
In Opposite Direction
Magnetizing Force
e
d
Saturation
In Opposite Direction
-B
Flux Density
In Opposite Direction

- The material has reached the point of magnetic saturation. When **H is reduced to zero, the curve will move from point** ***"a" to point "b". At this point, it can be seen that some magnetic flux remains in the material even though the magnetizing force is zero. This is referred to as the point of retentivity on the graph and indicates the level of residual magnetism in the material (Some of the magnetic domains remain aligned but some have lost their alignment). As the magnetizing force is reversed, the curve moves to point "c", where the flux has been reduced to zero. This is called the point of coercivity on the curve (the reversed magnetizing force has flipped enough of the domains so that the net flux within the material is zero). The force required to remove the residual magnetism from the material is called the coercive force or coercivity of the material.***

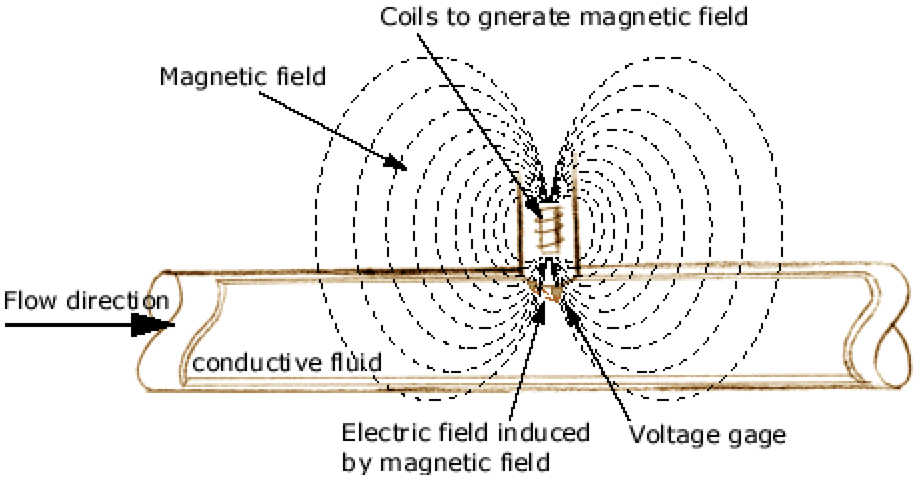
- As the magnetizing force is increased in the negative direction, the material will again become magnetically saturated but in the opposite direction, point "***d". Reducing H to zero brings the curve to point "e". It will have a level of residual magnetism equal to that achieved in the other direction. Increasing H back in the positive direction will return B to zero. Notice that the curve did not return to the origin of the graph because some force is required to remove the residual magnetism. The curve will take a different path from point "f" back to the saturation point where it with complete the loop***

# Methods of Magnetization

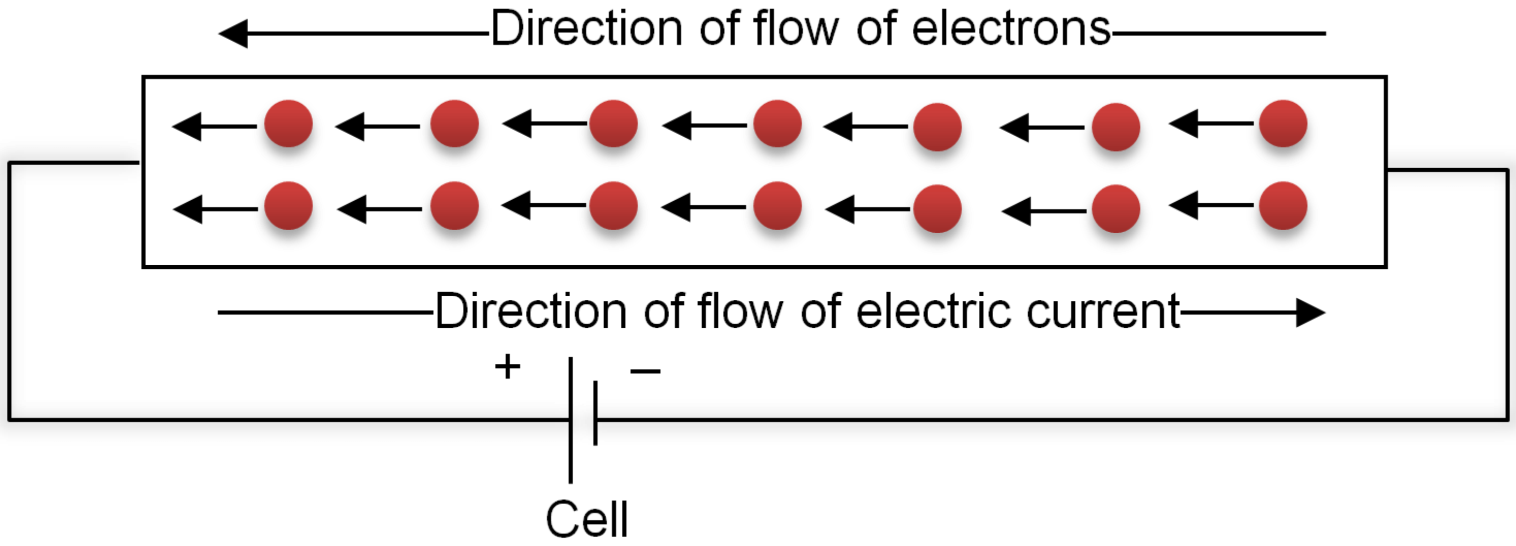
The Basic principles of magnetisation is to produce magnetic lines of force across the expected direction of cracks. If the likely crack direction is unknown , then test must be performed in two directions at right angles.

The basic magnetisation methods are.

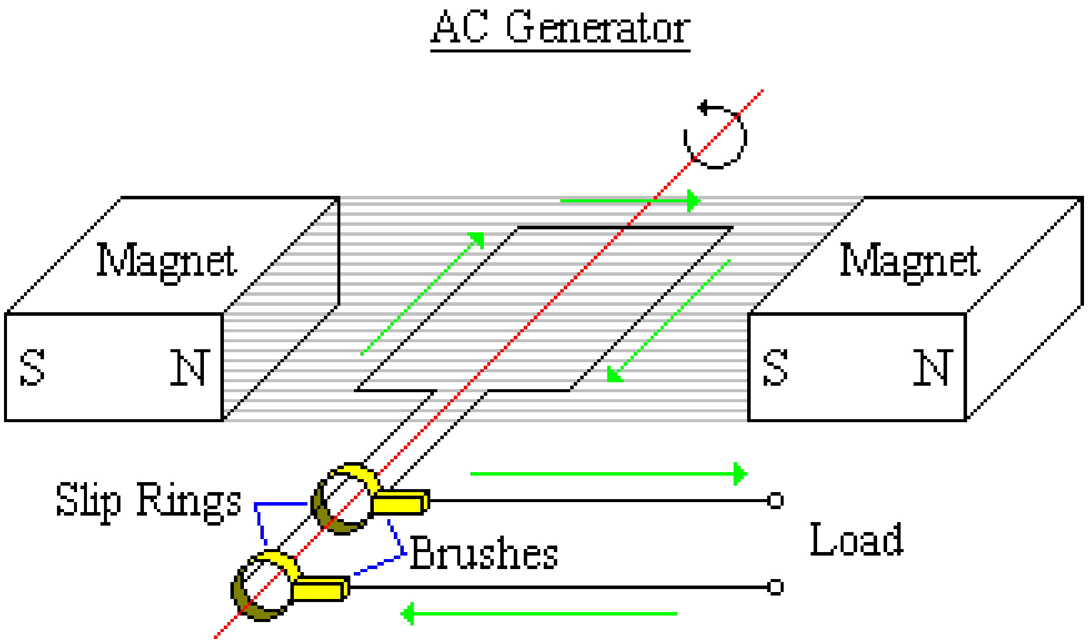
***<u>Magnetic Flow:</u>*** To make the component of a magnetic circuit by effectively using it as the bridge of a permanent or electromagnet.



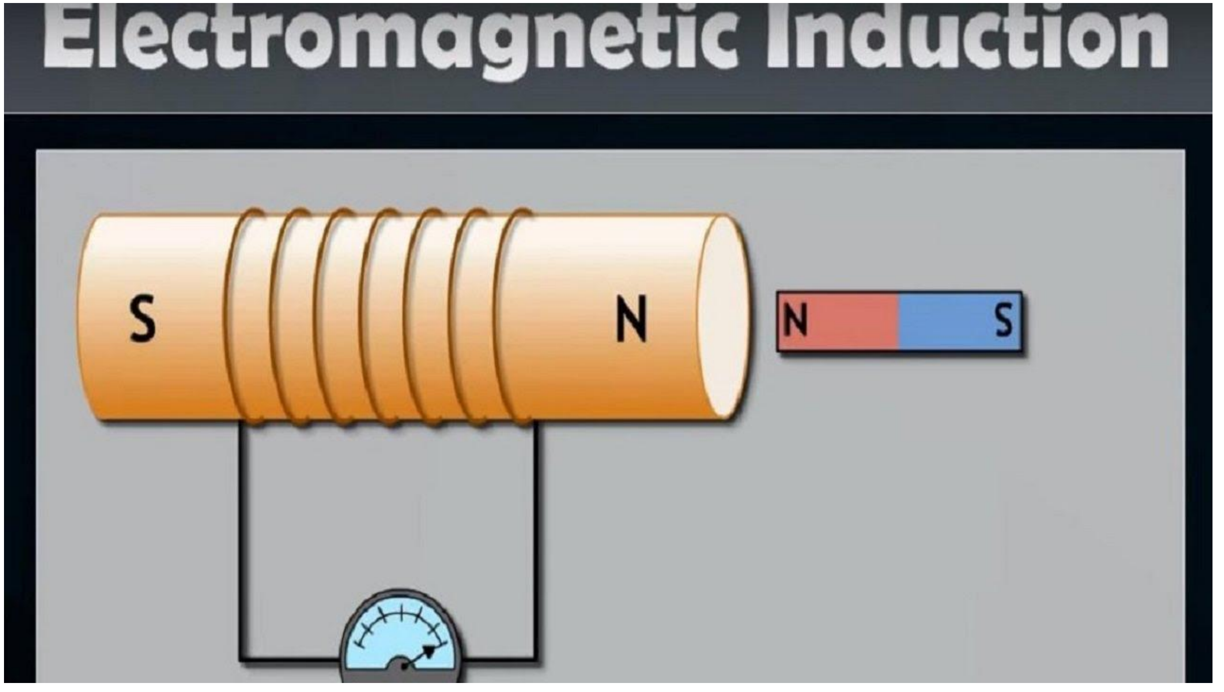
***Current flow:*** To pass an electric current through the specimen, b roadly along the direction and through the region in which cracks are to be expected.



***Induced current flow:*** Used for ring specimens, by effectively making them the secondary of a main transformer. This method has no application to weld inspection.

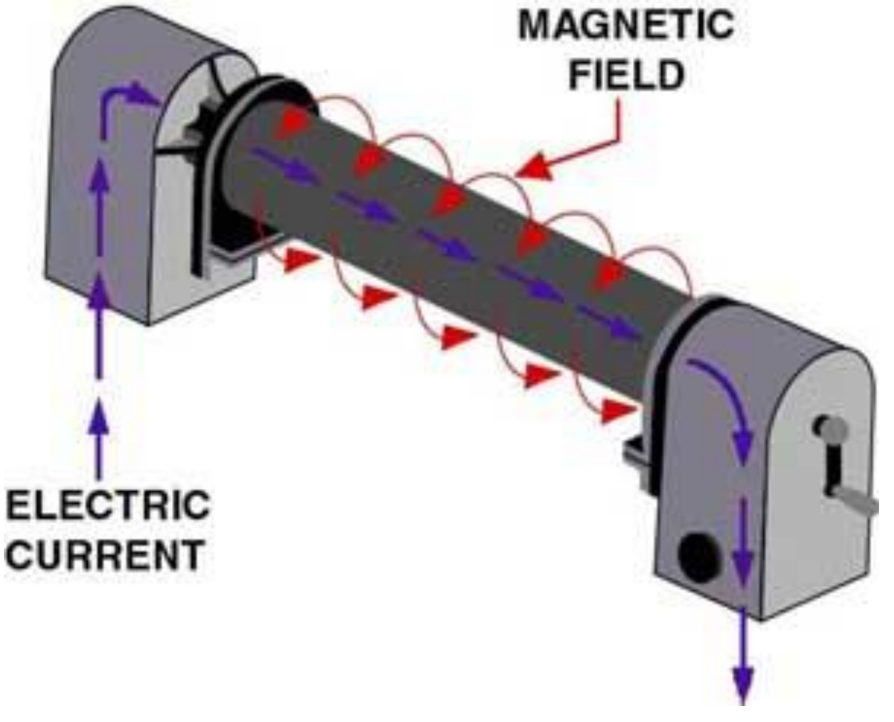


***Electromagnetic Induction:*** To pass an electric current through a conductor which is threaded through a hollow specimen or placed adjacent to or wrapped around it.



# Magnetization Techniques

1. Head Shot Technique:



# 2.Coil Shot Technique

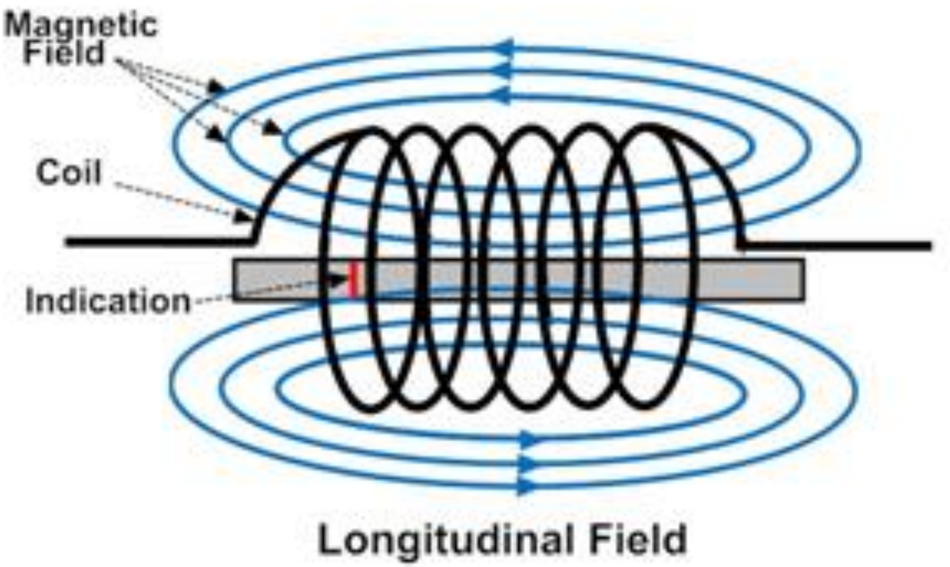
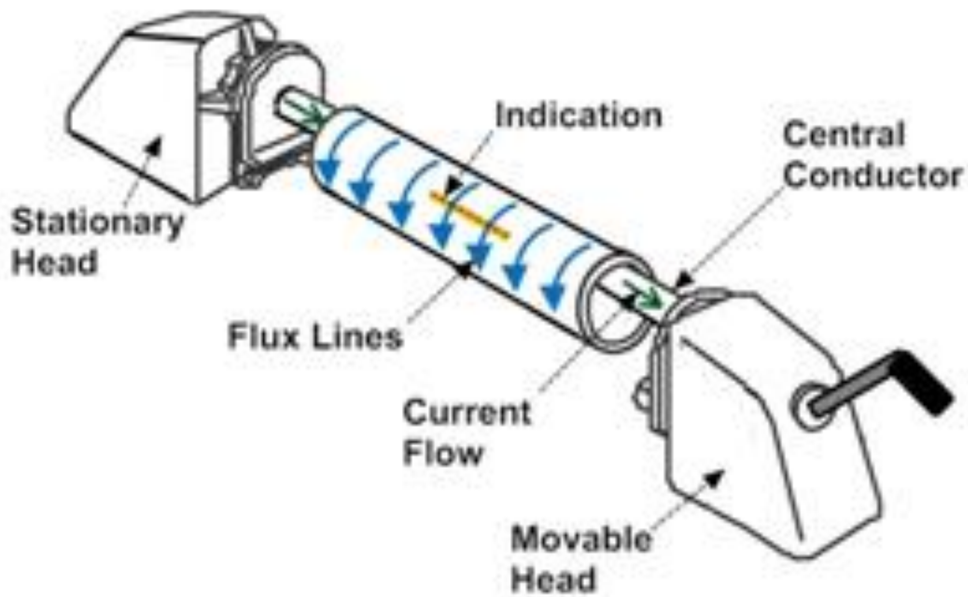



Figure 4

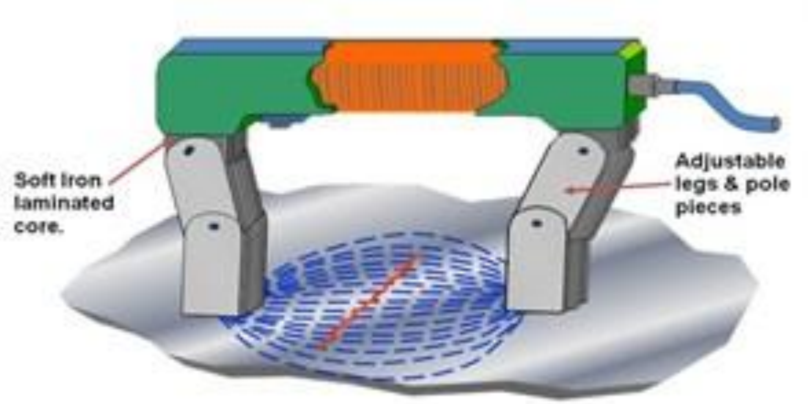
# 3. Central Conductor Technique




Central Conductor

Figure 6

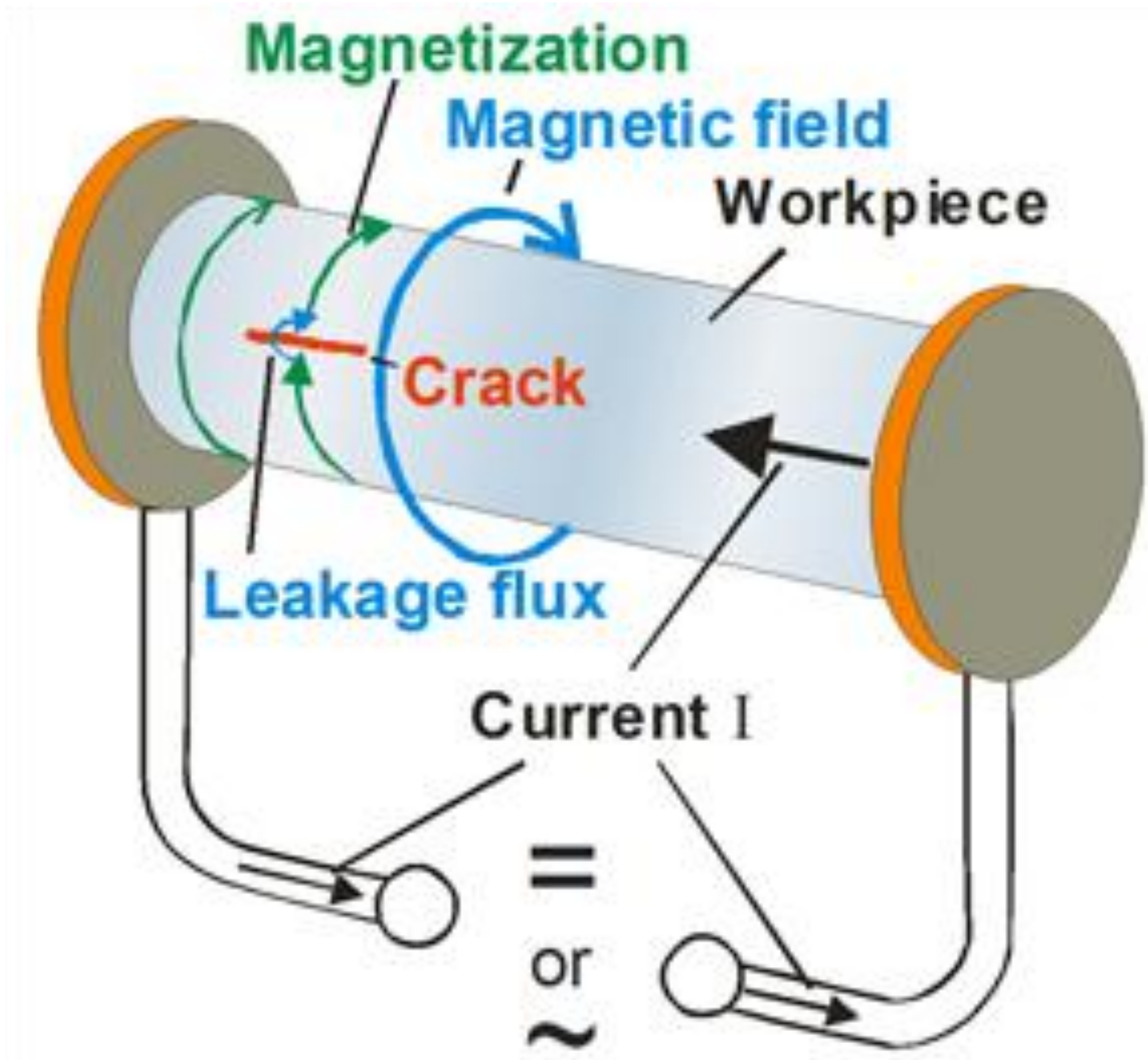
# 4 Magnetisation Using yoke:




# Direct Method of Magnetization

The direct method of magnetization is also called as current flow method, the magnetizing current flows through the part, thereby, completing the electric circuit. The magnetic field formed during this method as at right angles to the direction of current flow. Thu s we can locate the defect at right angles to the applied magnetic f ield direction Eg: Head Shot technique.

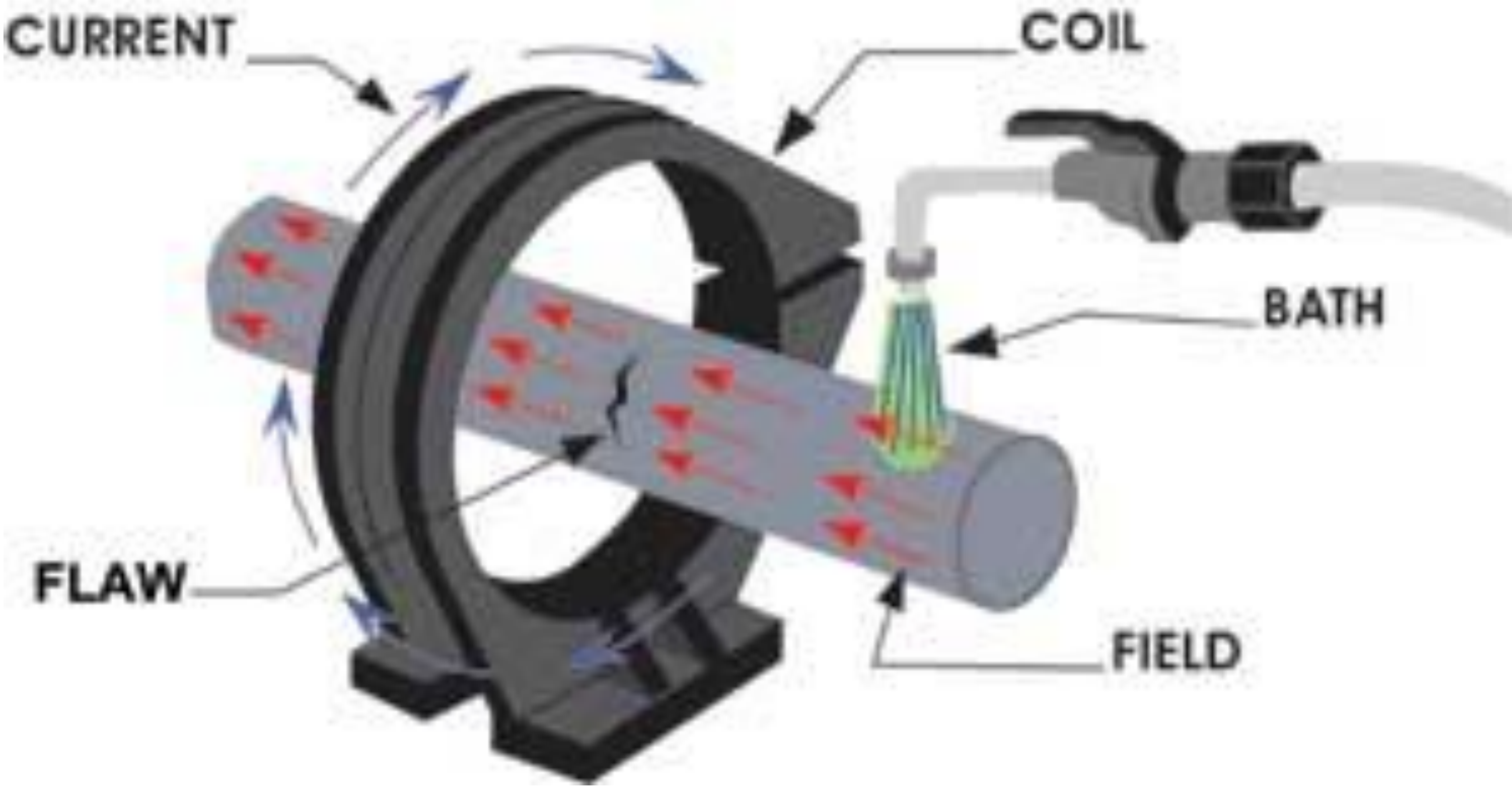
Limitations: In direct method, the head can cause a burn in the a p art if the high current is passing through a small contact area. To a void this, the contact faces on the heads should be flexible and th e tips of the prods should have a low melting point in order to spr ead the thermal load.


Magnetization
Magnetic field
Workpiece
Crack
Leakage flux
Current I
=
or
~

# Indirect Method of Magnetization

The indirect method of magnetization is also called as magnetic flow method. In  this method the test part becomes a part of the magnetic circuit, thus bridging the part between the poles of a permanent magnet.

The main advantages of the indirect techniques is that the risk of arc burning of critical components does not exists. Also, the use of permanent magnet or electromagnet can be vary convenient for inspections in continuous locations


CURRENT
COIL
BATH
FLAW
FIELD

# Continuous Testing of MPI

Continuous testing of MPI can be broadly classifieds in to two types. They are

1Dry Continuous

2.Wet Continuous

1.Dry Continuous

The term dry' means that the MP are applied in fine particle form. The term co ntinuous means that the magnetic particles are applied while the current is till f lowing onto it.

In this technique, the dry particles are applied when the magnetic forces is on. The particle application must cease before the current flow cease. The use of d ry particle is for detecting slightly sub surfaces discontinuities, since the particl es have higher permeability compared to the particle in wet inspection.

Only Advantages of using dry particles is that their mobility which relatively p oor when used with DC Current.

# Dry Magnetic Particles

Magnetic particles come in a variety of colors.  A color that produces a high level of contrast against the background should be used.


DNDT

2.Wet continuous

The term wet means that the particles applied are suspended in a liquid carrier. The Liquid carrier such as Kerosene, other petroleum distillates or water contai ning specially formulated additives can be used during wet suspension.

Compared to the dry particles, the suspended particles are generally lower per meability which makes this technique lass favourable for the direction of slight ly subsurface discontinuities.

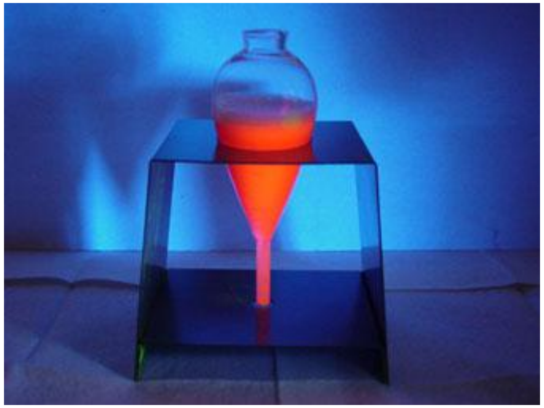
Advantages are

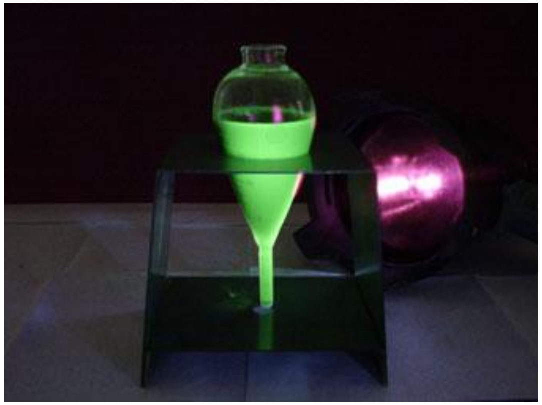
i) The improved mobility of the particles makes the technique very suitable

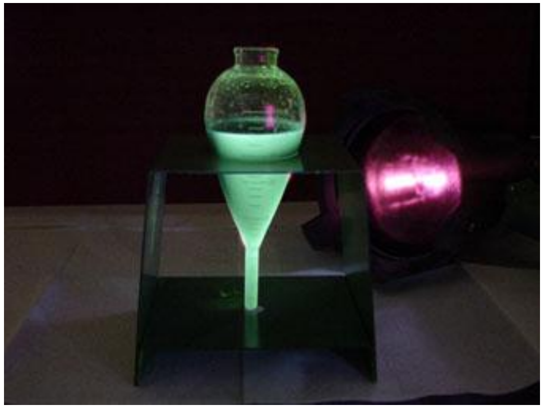
ii) The suspension will adhere to the complex shapes better than dry particles.

# Wet Magnetic Particles

**Wet particles are typically supplied as visible or fluorescent. Visible particles are viewed under normal white light and fluorescent particles are viewed under black light.**







# Advantages and Limitations of Different Liquid carriers

1. Kerosene and Petroleum distillates

Advantages:

•Help to lubricate parts

•Do not constitute the corrosion source

Limitations:

•They are more expensive

•Produce health problems

2. Water

Advantages:

•They are inexpensive

•No health Issues

Limitations

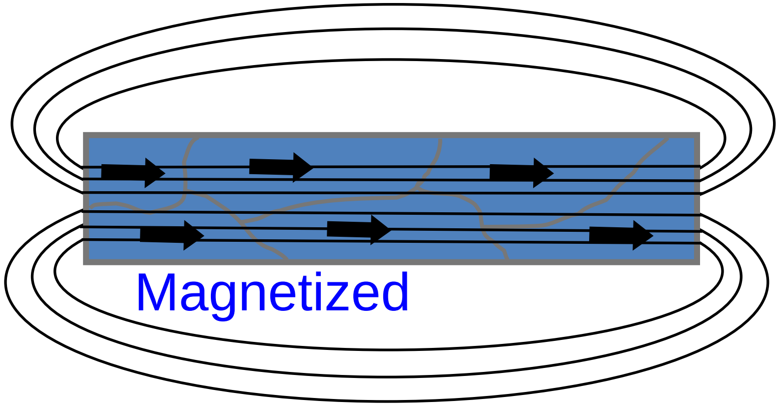
•Constitute Corrosion

# Demagnetization

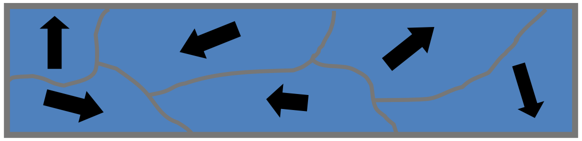
- Parts inspected by the magnetic particle method may sometimes have an objectionable residual magnetic field that may interfere with subsequent manufacturing operations or service of the component.
- Possible reasons for demagnetization include:
  - May interfere with welding and/or machining operations
  - Can effect gauges that are sensitive to magnetic fields if placed in close proximity.
  - Abrasive particles may adhere to components surface and cause and increase in wear to engines components, gears, bearings etc.

# Demagnetization (Cont.)

- Demagnetization requires that the residual magnetic field is reversed and reduced by the inspector.
- This process will scramble the magnetic domains and reduce the strength of the residual field to an acceptable level.



Magnetized



Demagnetized

# Residual Techniques of MPI

Similar to continuous testing methods, the residual techniques of MPI also be c lassified in to two types

1.Dry residual

The term “residual means that, the material has sufficient retentivity to allow a pplications of the magnetic particles after the current has ceased.

Advantages

Suitable for low sensitivity materials

Multiple parts can be magnetized simultaneously

Limitations

Subsurface discontinuities are difficult to detect

2. Wet Residual

In this techniques uses the suspended particles where the suspension is applied after the magnetizing force has been stopped

# System Sensitivity

Many fine cracks of size less than .02mm deep can be located using the sensitivity of MPI.

It not only involves crack detection, but also allow us to locate wide range of defects like

- Detecting segregations, Macro inclusions
- Marks generated using stamping operations
- Laps in the threaded section

Sensitivity depends on the type of current used

AC Magnetization suitable for Surface defects, but not for subsurface

- DC magnetization is good for subsurface defects
- Half wave DC give superior penetration than straight DC

# Checking Devices in MPI

In order to maintain consistency and control during MPI, checkin g devices have to use. Commonly used are

***i)Settling test:*** Is also called as suspension concentration test. The purpose is to assure that the proper concentration of particles is b eing maintained in the liquid carrier

***ii)Ketos ring:*** The ketos ring is a device made of tool steel and is designed to show the effectiveness of the MPI and the relative pe netration based on the number of holes that display indications

***iii)Field indicator:*** Field indicator is used to check the presence o f residual magnetism on the system

# Interpretation of Indications

After applying the magnetic field, indications that form must interpreted. This process requires that the inspector distinguish between relevant and non-relevant indications.

The following series of images depict relevant indications produced from a variety of components inspected with the magnetic particle method.

# Indications

Indications may be classify as

***i) False Indications***

False indications can be produced due to improper handling, use of excessively high magnetizing currents, inadequate precleaning of the parts to remove oil , Grease, corrosion products and other s urface contaminants.

***ii) Non Relevant Indications***

Non-relevant indications are the result of flux leakage due to the geometrical changes of the test object

Eg;- Thread roots , Gear teeth etc.

***iii) Relevant Indications***

Relevant indications are produced by flux leakages due to discont inuities in the part

# Advantages of Magnetic Particle Inspection (MPI)

- It is quick and relatively uncomplicated
- Indications are produced directly on the surface of the part and c onstitute a visual representation of the flaw.
- It shows surface and near surface defects, and these are the most serious ones as they concentrate stresses
- The method can be adapted for site or workshop use
- Large or small objects can be examined
- Minimal surface preparation (*no need for paint removal) Advant ages*
- High sensitivity (*small discontinuities can be detected)*.
- Indications are produced directly on the surface of the part and c onstitute a visual representation of the flaw.

# Disadvantages of Magnetic Particle Inspection

- It is restricted to ferromagnetic materials - usually iron and steel, an d cannot be used on austenitic stainless steel
- Only surface and near surface defects can be detected.
- Most methods need a supply of electricity
- It is sometimes unclear whether the magnetic field is sufficiently str ong to give good indications
- The method cannot be used if a thick paint coating is present
- Spurious, or non-relevant indications, are probable, and thus interpre tation is a skilled task
- Some of the paints and particle suspension fluids can give a fume or fire problem, particularly in a confined space
- Relatively small area can be inspected at a time.
- Only materials with a relatively nonporous surface can be inspected.
- The inspector must have direct access to the surface being inspected.