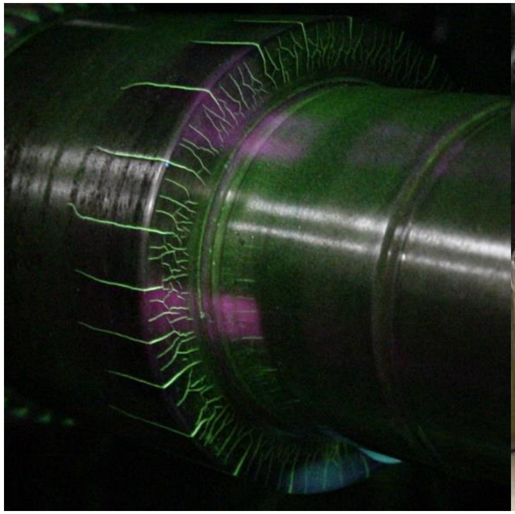
# Non-Destructive Evaluation (NDE)

Chapter 5

# Magnetic Particle Testing




*Mohamad Fathi GHANAMEH*

# Magnetic Particle Inspection (MT/MPI)

- MT is a test method for the detection of surface and near surface defects in ferromagnetic materials.
- Magnetic field induced in component
- Defects disrupt the magnetic flux causing “flux leakage”.
- Flux leakage can be detected by applying ferromagnetic particles

# Advantages of MT

- Can detect both surface and near sub-surface defects.
- Can inspect parts with irregular shapes easily.
- Precleaning of components is not as critical as it is for some other inspection methods. Most contaminants within a flaw will not hinder flaw detectability.
- Fast method of inspection and indications are visible directly on the specimen surface.
- Considered low cost compared to many other NDT methods.
- Is a very portable inspection method especially when used with battery powered equipment.

# Limitations of MT

- Cannot inspect non-ferrous materials such as aluminum, magnesium or most stainless steels.
- Inspection of large parts may require use of equipment with special power requirements.
- Some parts may require removal of coating or plating to achieve desired inspection sensitivity.
- Limited subsurface discontinuity detection capabilities. Maximum depth sensitivity is approximately 0.6” (under ideal conditions).
- Post cleaning, and post demagnetization is often necessary.
- Alignment between magnetic flux and defect is important

# Introduction to Magnetism

- Some natural materials strongly attract pieces of iron to themselves.
- Such materials were first discovered in the ancient Greek city of Magnesia.
- 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
- Magnetic lines of force can be found in and around the objects.
- A magnetic pole is a point where the a magnetic line of force exits or enters a material.

# Introduction to Magnetism

## *Permeability (μ)*

- Permeability can be defined as the relative ease with which a material may be magnetised.
- It is defined as the ratio of the flux density (B) produced within a material under the influence of an applied field to the applied field strength (H) ($\mu = B/H$).
- Permeability of free space = $\mu_o$
- Relative Permeability ($\mu_r$) = $\mu / \mu_o$

# Introduction to Magnetism

On the basis of their permeability materials can be divided into 3 groups:

- **Diamagnetic:** Permeability slightly below 1, weakly repelled by magnets. (Slightly < 1)

  Examples: Gold, Copper, Water

- **Paramagnetic:** Permeability slightly greater than 1, weakly attracted by magnets. (Slightly > 1)

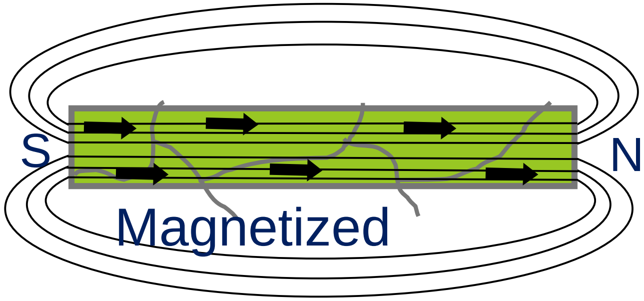
  Examples: Aluminium, Tungsten

- **Ferromagnetic:** Very high permeability, strongly attracted by magnets. (240 +)

  Examples: Iron, Cobalt, Nickel

# Ferromagnetic Materials

- A material is considered ferromagnetic if it can be magnetized. Materials with a significant Iron, nickel or cobalt content are generally ferromagnetic.
- Ferromagnetic materials are made up of many regions in which the magnetic fields of atoms are aligned. These regions are call magnetic domains.
- Magnetic domains point randomly in demagnetized material, but can be aligned using electrical current or an external magnetic field to magnetize the material.

# Ferromagnetic Materials

## ***Hard v Soft Ferromagnetic***

**Soft**

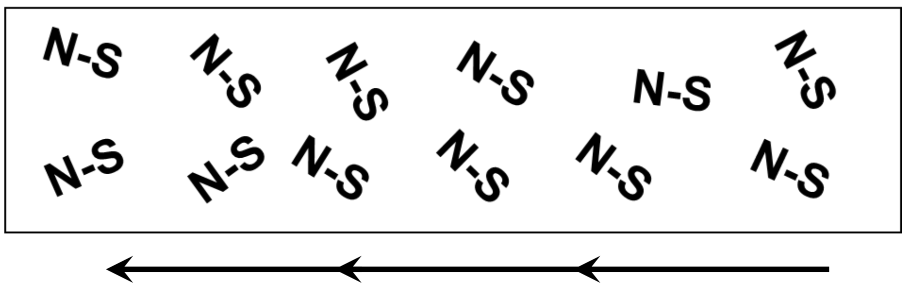
- Typically Low carbon steel
- High permeability
- Easy to magnetise
- Low residual magnetism

**Hard**

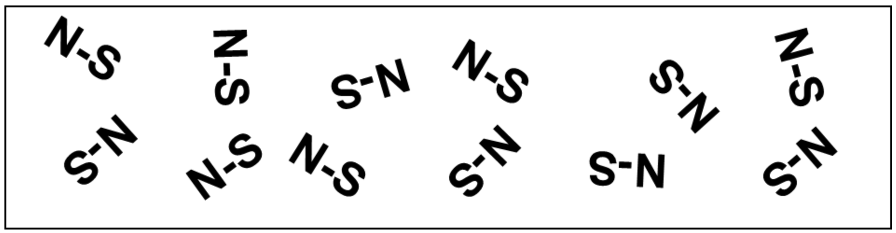
- Typically high carbon steel
- Lower permeability
- More difficult to magnetise
- High levels of residual magnetism

# Magnetic Domain Theory

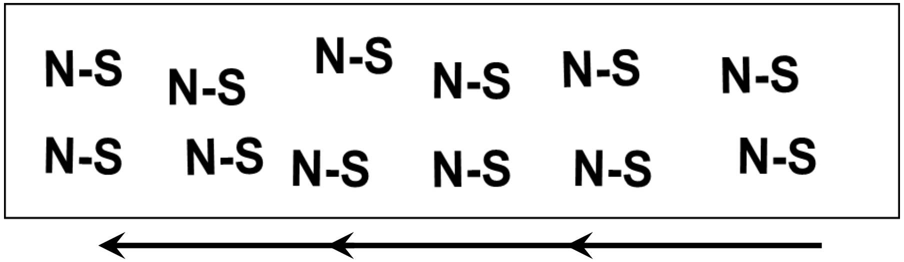
- A domain is a minute internal magnet
- Each domain comprises $10^{15}$ to $10^{20}$ atoms



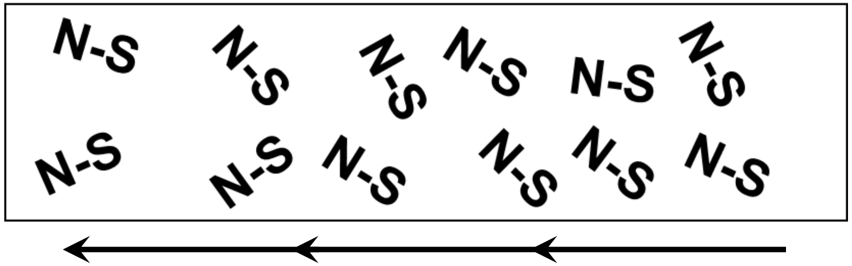

Magnetized state Domains orientated in external magnetic field




Unmagnetized state Domains randomly orientated



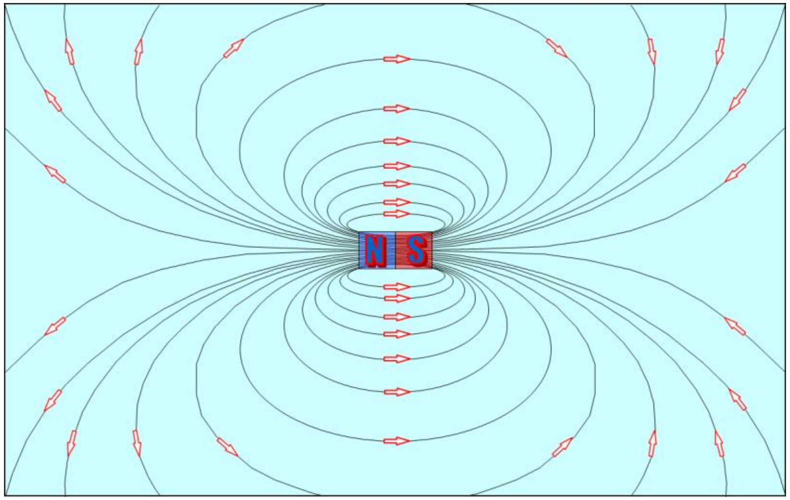

Saturated state All domains orientated in strong external field



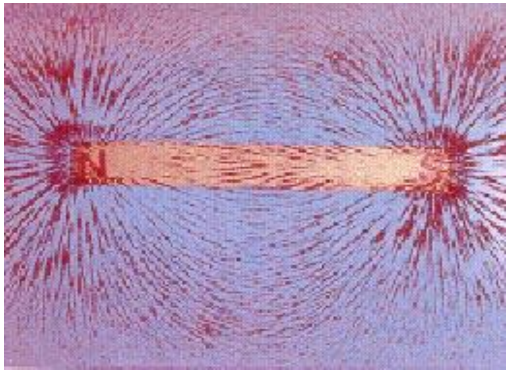

Residual state domains orientated after external magnetic field

# Lines of Flux

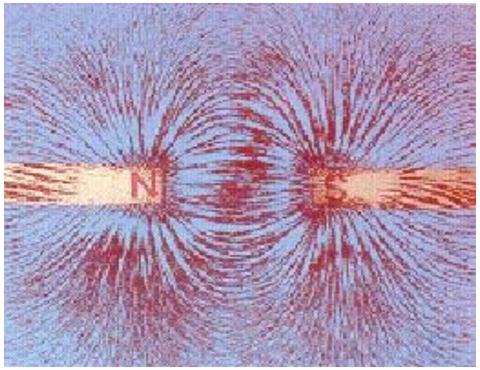
- By convention they flow from North to South outside and South to North inside
- They form closed loops
- They never cross
- They follow path of least resistance
- Flux density is the number of lines of flux passing through a unit area.
- Field strength is highest where flux density is highest.



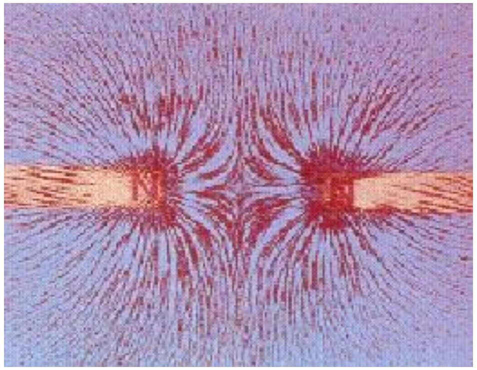
# Lines of Flux




Magnetic lines of force around a bar magnet



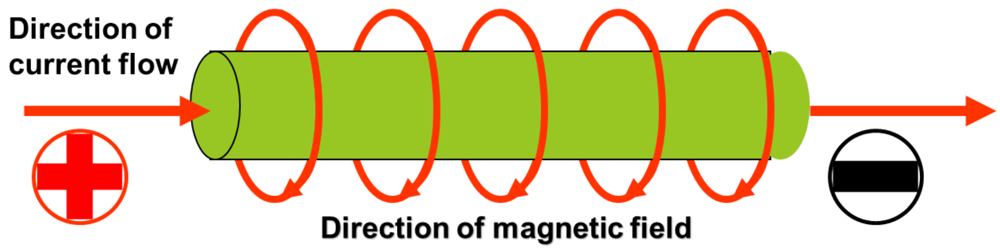

Opposite poles attracting

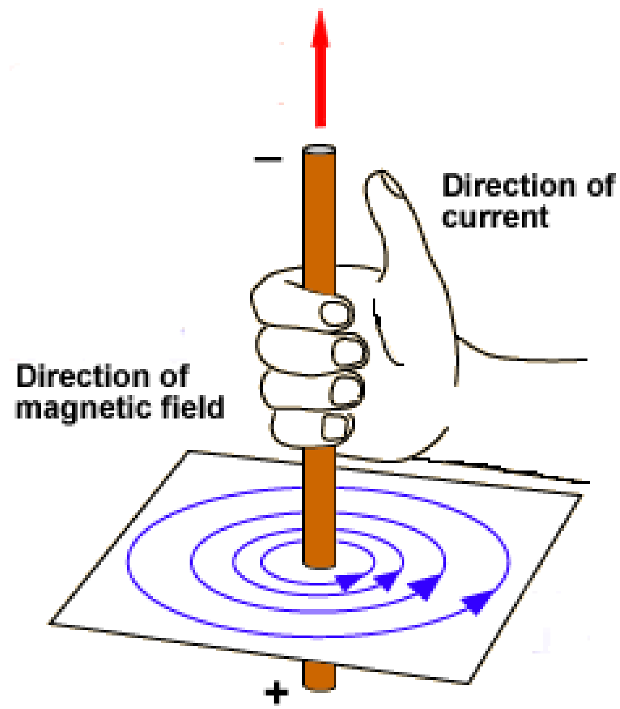



Similar poles repelling

# Electromagnetism

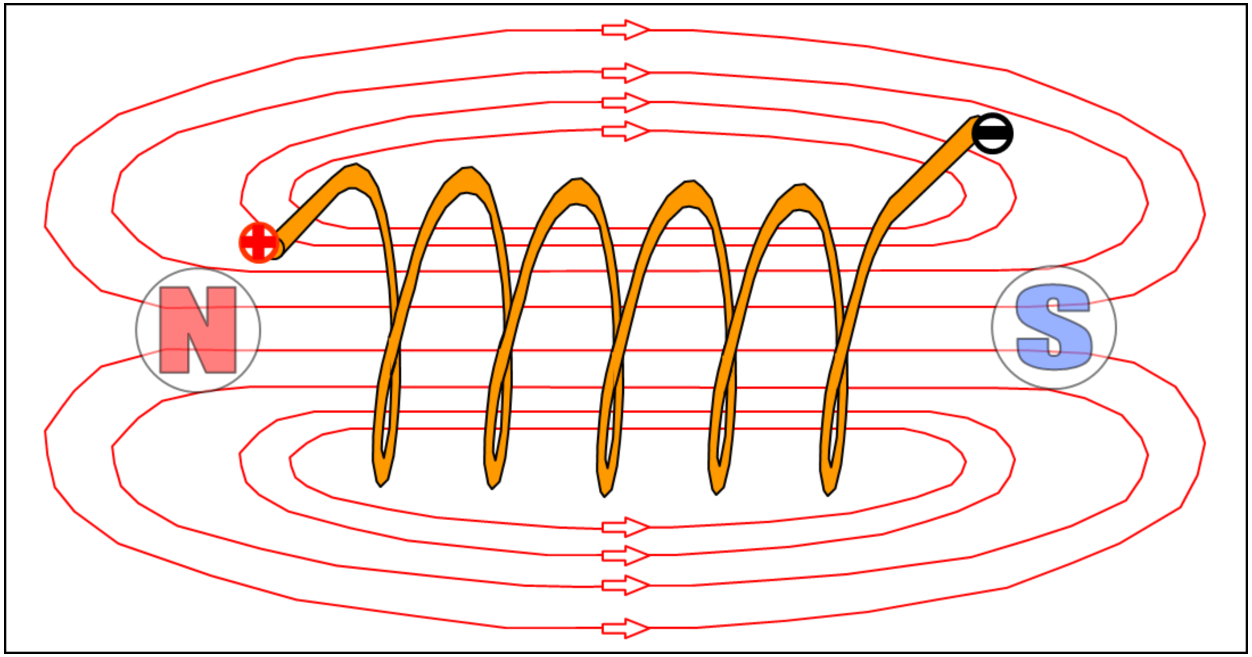
- A current flows through a conductor and sets up a magnetic field around it
- Field is at 90$^{o}$ to the direction of the electrical current



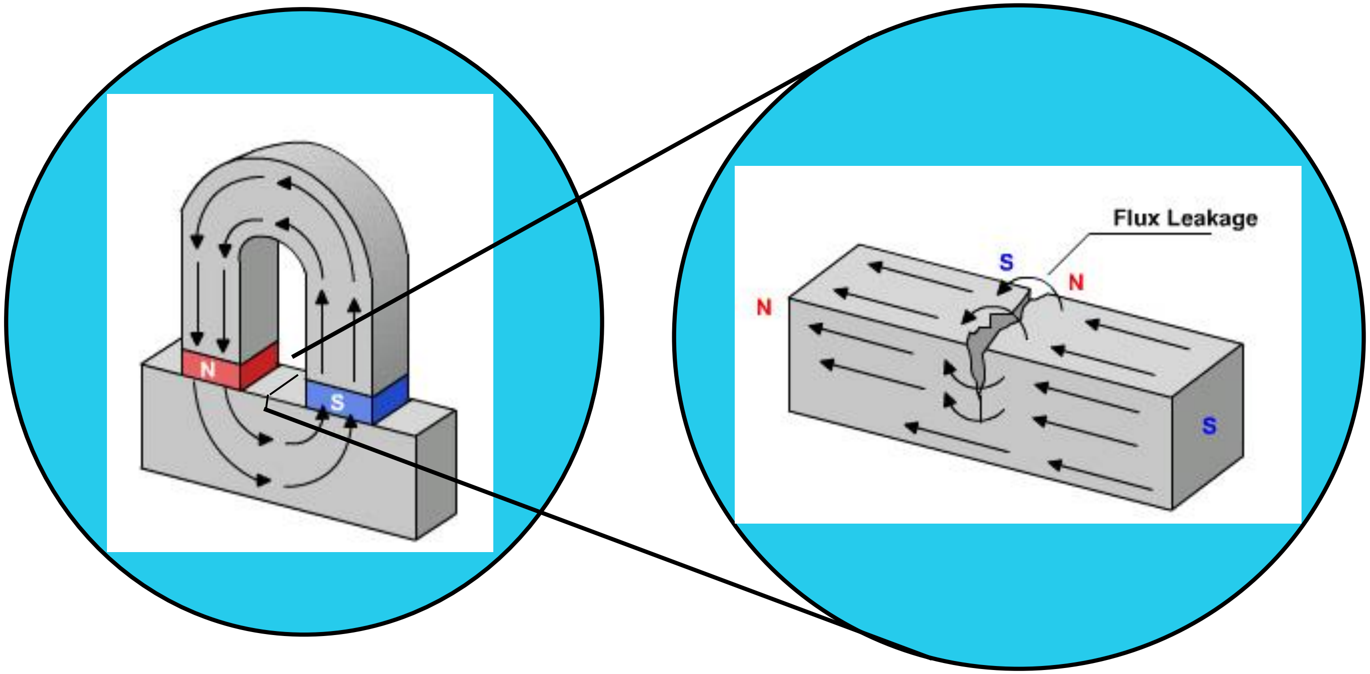
# Coil Magnetization

Changes circular field into longitudinal
Increases the strength of the field



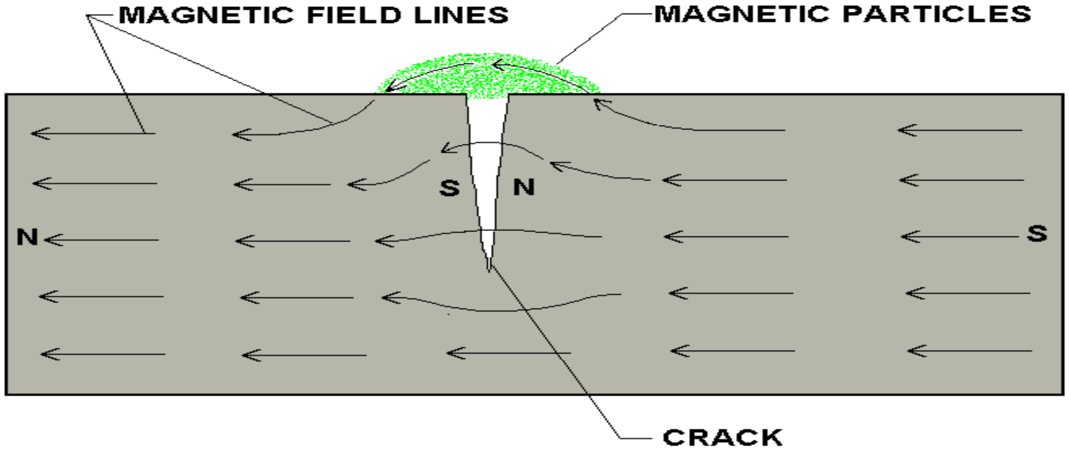
# How Does MPI Work?

A ferromagnetic test specimen is magnetized with a strong magnetic field created by a magnet or special equipment. If the specimen has a discontinuity, the discontinuity will interrupt the magnetic field flowing through the specimen and a leakage field will occur.



# How Does Work?

Finely milled iron particles coated with a dye pigment are applied to the test specimen. These particles are attracted to leakage fields and will cluster to form an indication directly over the discontinuity. This indication can be visually detected under proper lighting conditions.



# Visibility of Flux Leakage

Depends on:

- Depth of defect
- Orientation of defect shape of defect
- Size of defect
- Permeability of material
- Applied Field Strength
- Contrast

# Indications

Relevant Indications: Indications due to discontinuities or flaws

Non-Relevant Indications: Indications due to flux leakage from design features

Spurious Indications: Indications due incorrect inspection procedures

# Basic Procedure

**Basic steps involved:**

1. **Component pre-cleaning**

2. **Introduction of magnetic field**

3. **Application of magnetic media**

4. **Interpretation of magnetic particle indications**

# Pre-cleaning

When inspecting a test part with the magnetic particle method it is essential for the particles to have an unimpeded path for migration to both strong and weak leakage fields alike. The part's surface should be clean and dry before inspection.

Contaminants such as oil, grease, or scale may not only prevent articles from being attracted to leakage fields, they may also interfere with interpretation of indications.

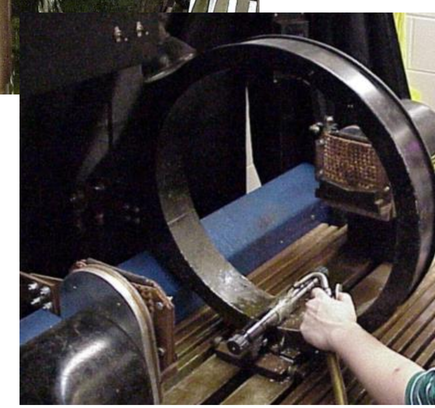
# Introduction of the Magnetic Field

The required magnetic field can be introduced into a component in a number of different ways.

1. Using a permanent magnet or an electromagnet that contacts the test piece

2. Flowing an electrical current through the specimen

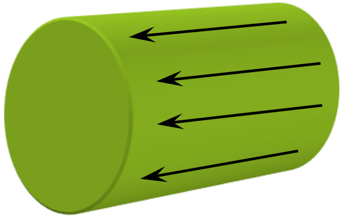
3. Flowing an electrical current through a coil of wire around the part or through a central conductor running near the part.



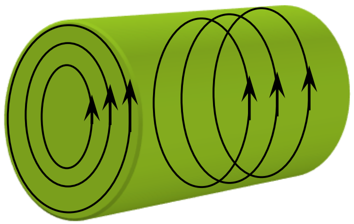
# Direction of the Magnetic Field

Two general types of magnetic fields (longitudinal and circular) may be established within the specimen. The type of magnetic field established is determined by the method used to magnetize the specimen.

- A longitudinal magnetic field has magnetic lines of force that run parallel to the long axis of the part.

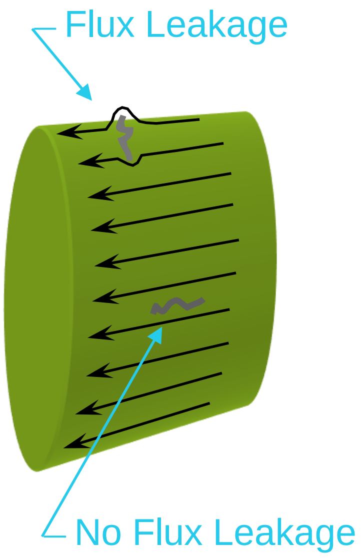


- A circular magnetic field has magnetic lines of force that run circumferentially around the perimeter of a part.



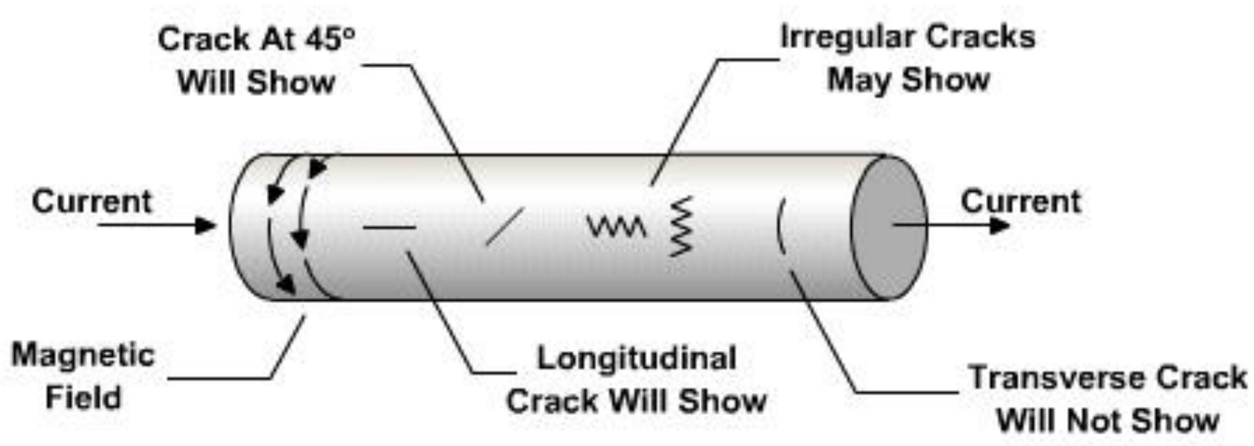
# Importance of Magnetic Field Direction

Being able to magnetize the part in two directions is important because the best detection of defects occurs when the lines of magnetic force are established at right angles to the longest dimension of the defect. This orientation creates the largest disruption of the magnetic field within the part and the greatest flux leakage at the surface of the part. An orientation of 45 to 90 degrees between the magnetic field and the defect is necessary to form an indication.



# Importance of Magnetic Field Direction

Since defects may occur in various and unknown directions, each part is normally magnetized in two directions at right angles to each other.

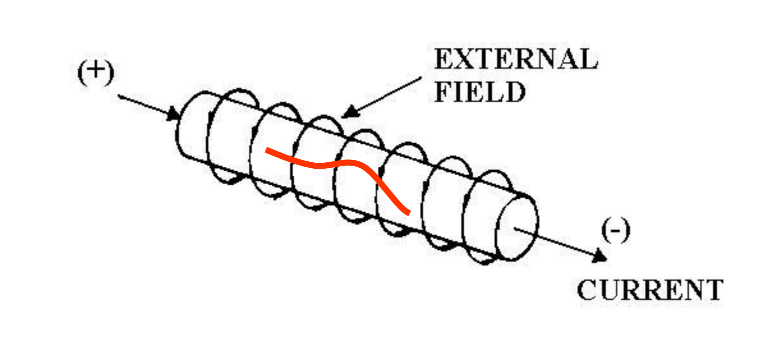


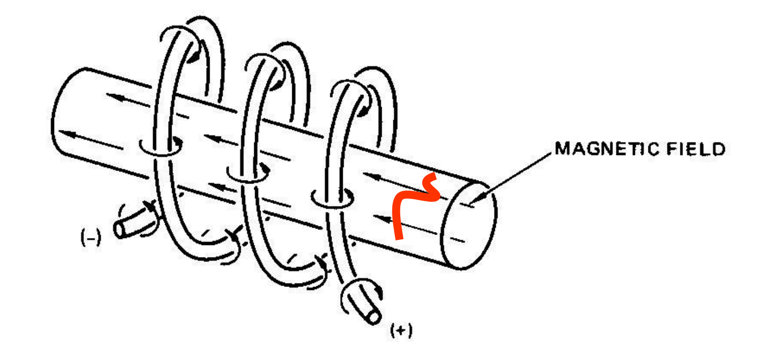
# Importance of Magnetic Field Direction

## Question

?

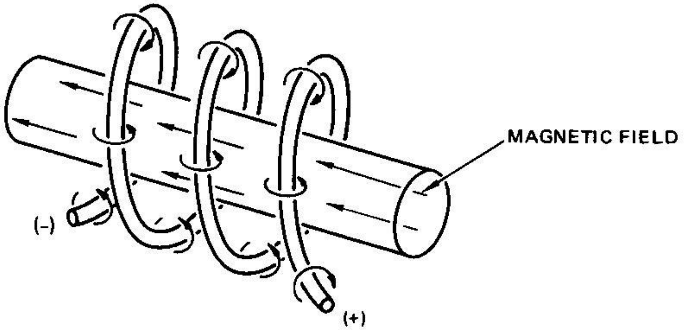
**From the previous slide regarding the optimum test sensitivity, which kinds of defect are easily found in the images below?**



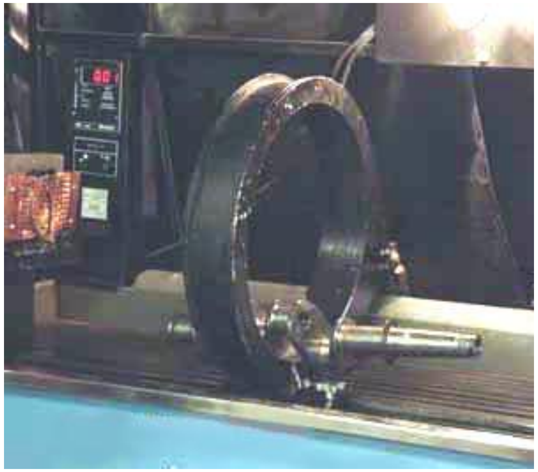



# Producing a Longitudinal Field

## ***Using a Coil***




A longitudinal magnetic field is usually established by placing the part near the inside or a coil's annulus. This produces magnetic lines of force that are parallel to the long axis of the test part.



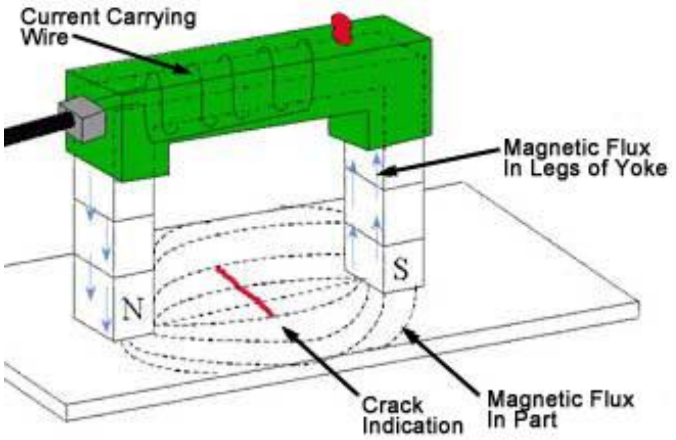
**Coil on Wet Horizontal Inspection Unit**

**Portable Coil**

# Producing a Longitudinal Field

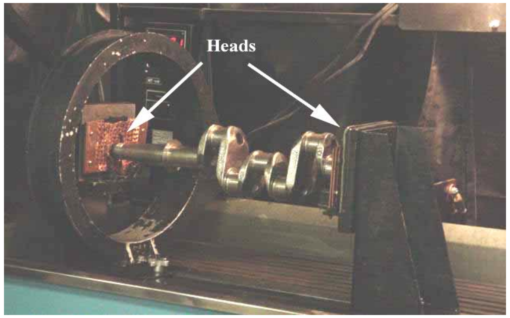
## ***Using Permanent or Electromagnetic Magnets***

Permanent magnets and electromagnetic yokes are also often used to produce a longitudinal magnetic field. The magnetic lines of force run from one pole to the other, and the poles are positioned such that any flaws present run normal to these lines of force.

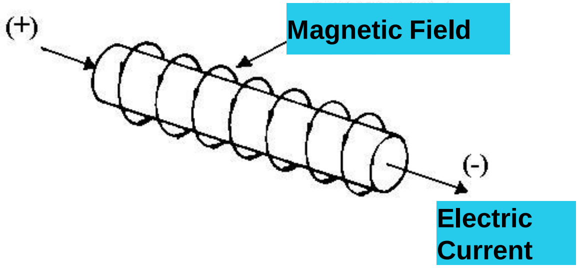



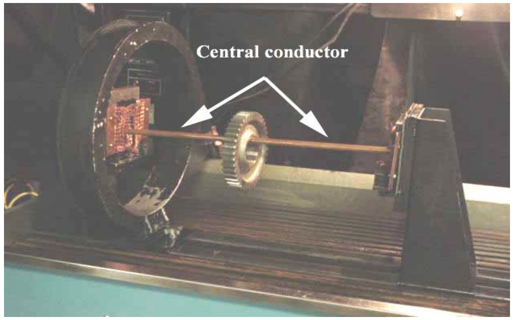
# Circular Magnetic Fields

Circular magnetic fields are produced by passing current through the part or by placing the part in a strong circular magnet field.




A headshot on a wet horizontal test unit and the use of prods are several common methods of injecting current in a part to produce a circular magnetic field. Placing parts on a central conductors carrying high current is another way to produce the field.

# Equipment

***Portable***

- Permanent magnet
- Electromagnet
- Prods
- Flexible coil
- Flexible cable
- Clamps and leeches

***Fixed***

- Current flow
- Magnetic flow
- Threader Bar
- Rigid coil
- Induced current

# Permanent Magnet

Advantages

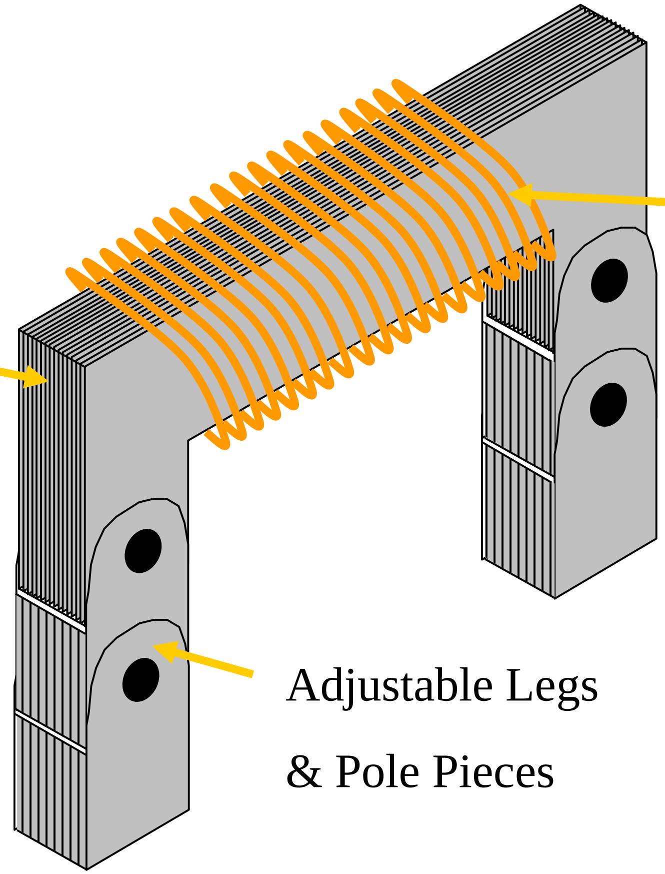
- No power supply
- No electrical contact problems
- Inexpensive
- No damage to test piece
- Lightweight

Disadvantages

- Direct field only
- Deteriorate over time
- No control over field strength
- Poles attract detecting media
- Tiring to use

# Electromagnets

Maximum sensitivity for defects orientated at 90º to a line drawn between the poles



# Electromagnets

Advantages

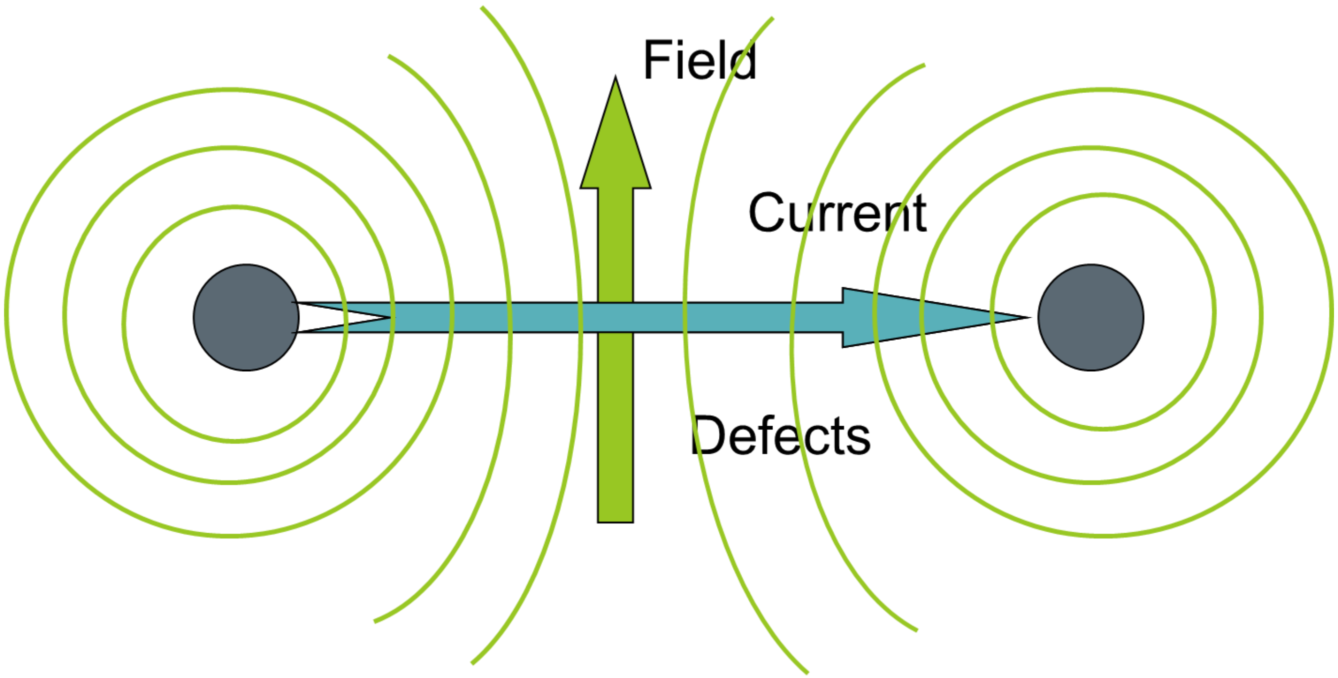
- AC,DC or rectified
- Controllable field strength
- No harm to test piece
- Can be used to demagnetise
- Easily removed

Disadvantages

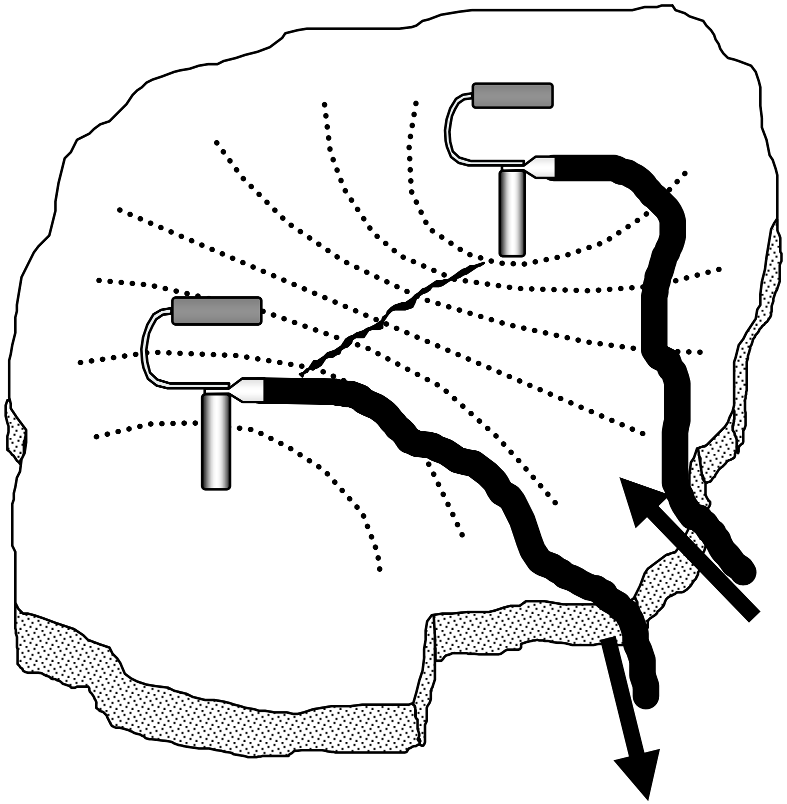
- Power supply required
- Longitudinal field only
- Electrical hazard
- Poles attract particles
- Legs must have area contact

# Prods

- Current passed between 2 contacts.
- Defects detected parallel to contacts



# PROD METHOD



# Prods

Advantages

- AC,DC or rectified
- Controllable field strength
- No poles attract particles
- Control of amperage

Disadvantages

- Arcing / damage to work piece
- Transformer required
- Current can be switched on without creating field
- Good contact required
- 2 man operation

# Flexible Cable

- Flexible, current carrying cable
- Used as
  - Adjacent cable
  - Threading cable
  - Flexible coil

# Flexible Cable

Advantages

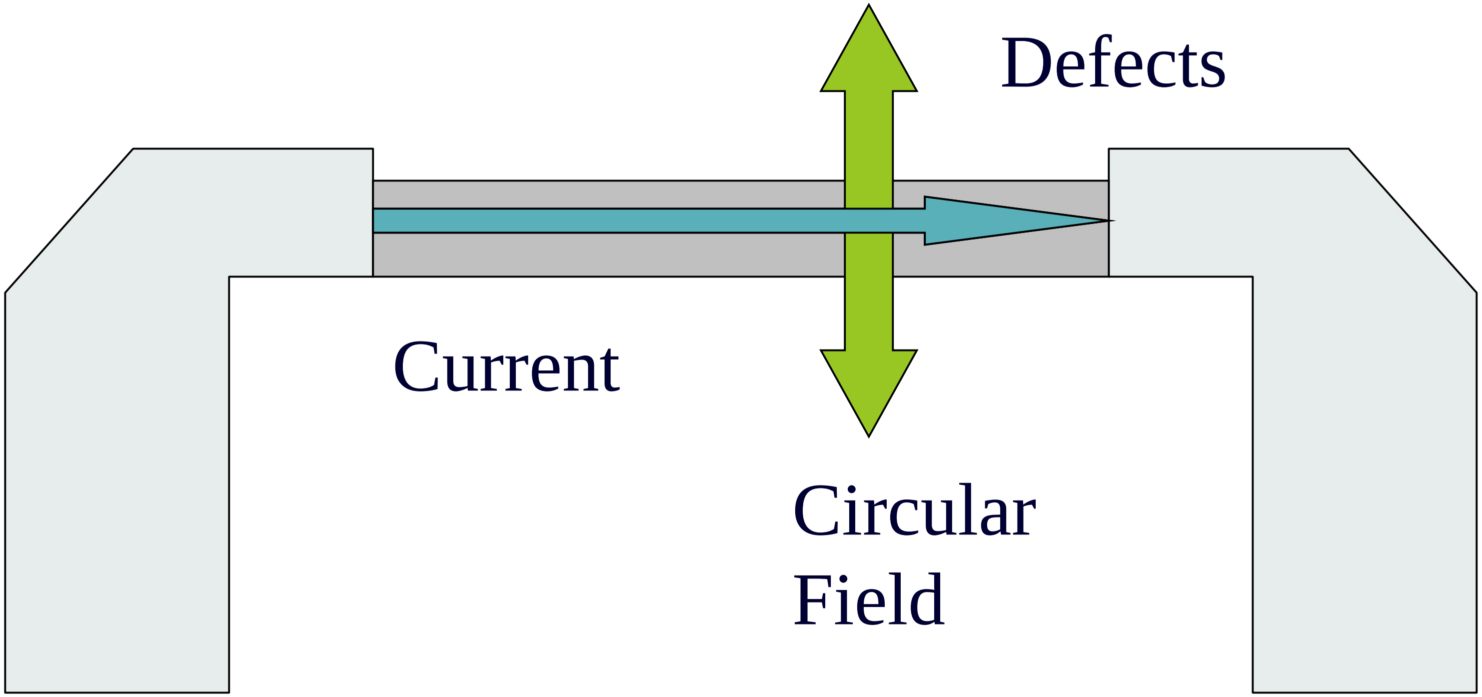
- Simple to operate
- No danger of burning
- AC,DC or rectified
- Current adjustable

Disadvantages

- Difficult to keep cables in place
- High currents required
- Transformer required

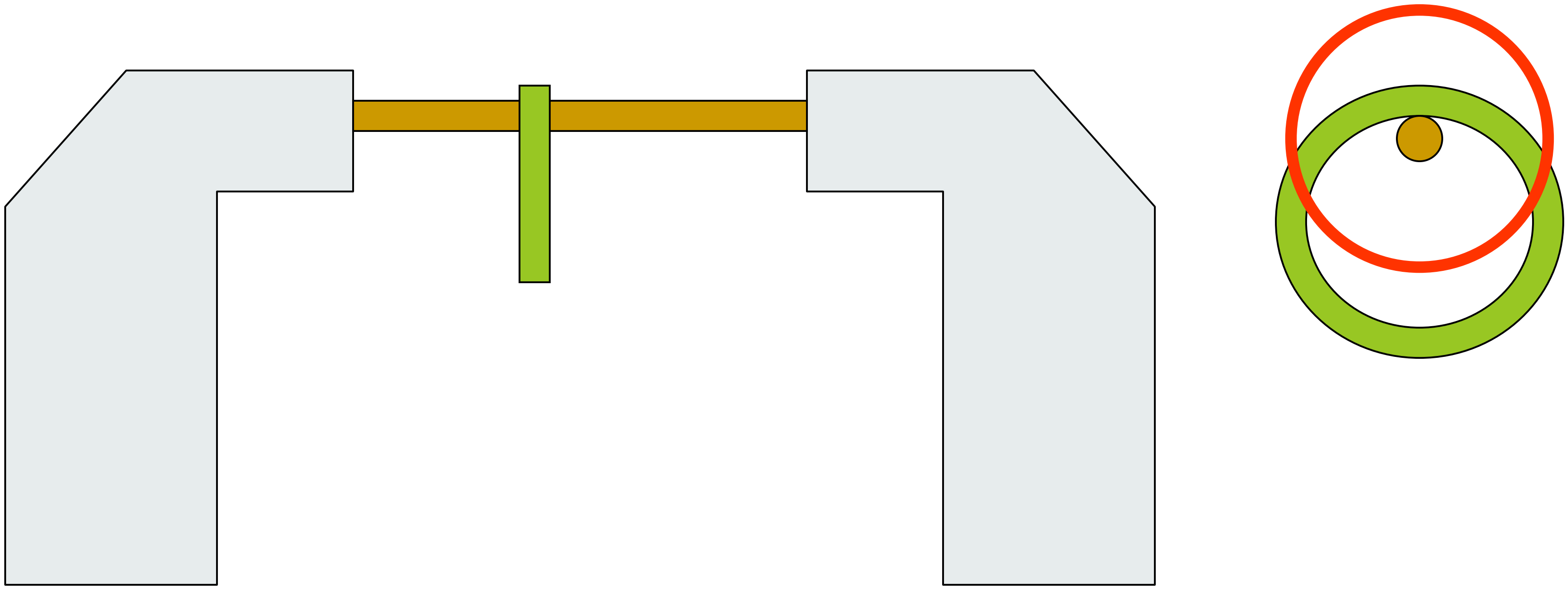
# Current Flow

Current passed through sample



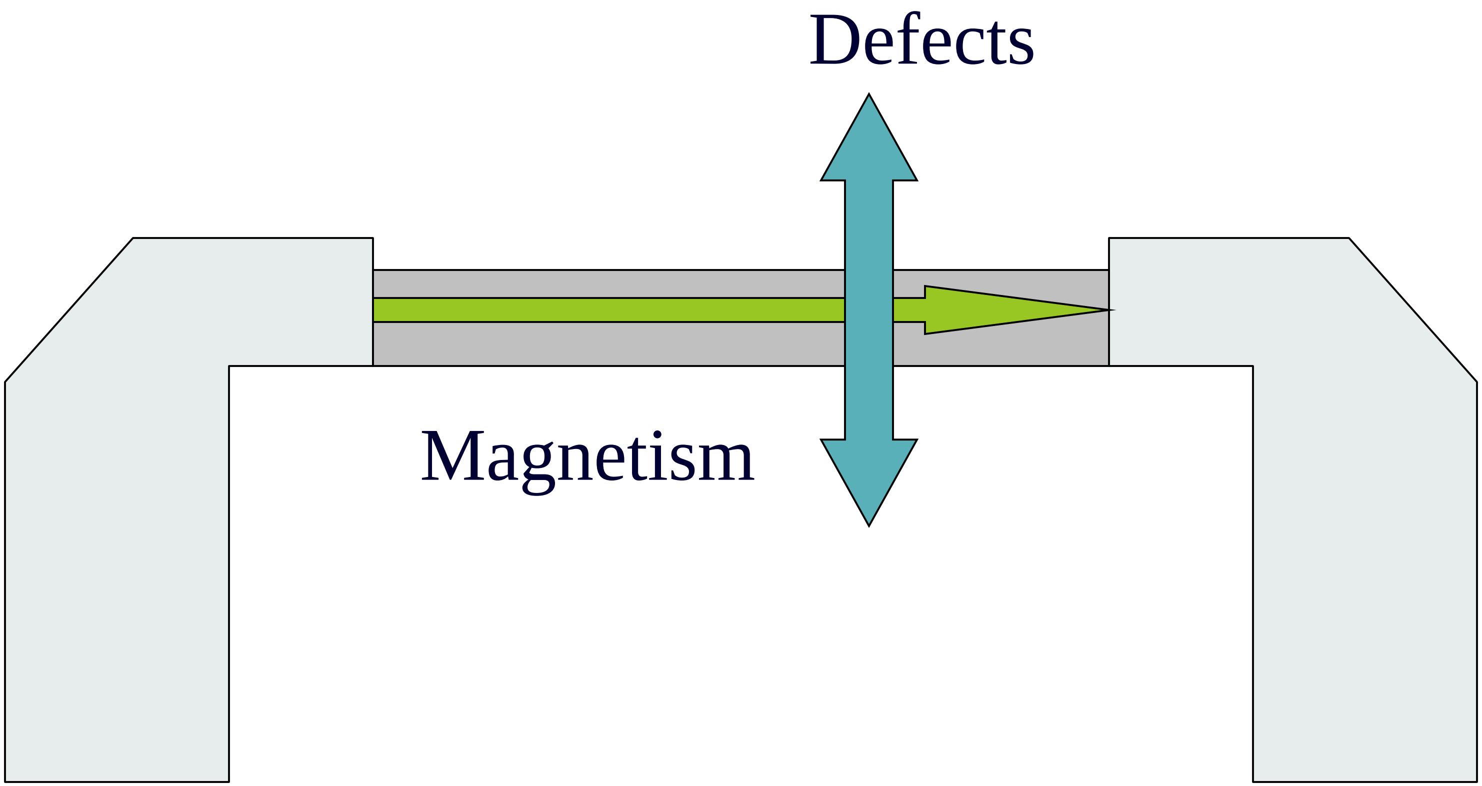
# Threading Bar

- Current passed through brass bar placed between heads of bench unit
- Circular field generated around bar
- Sample hung from bar

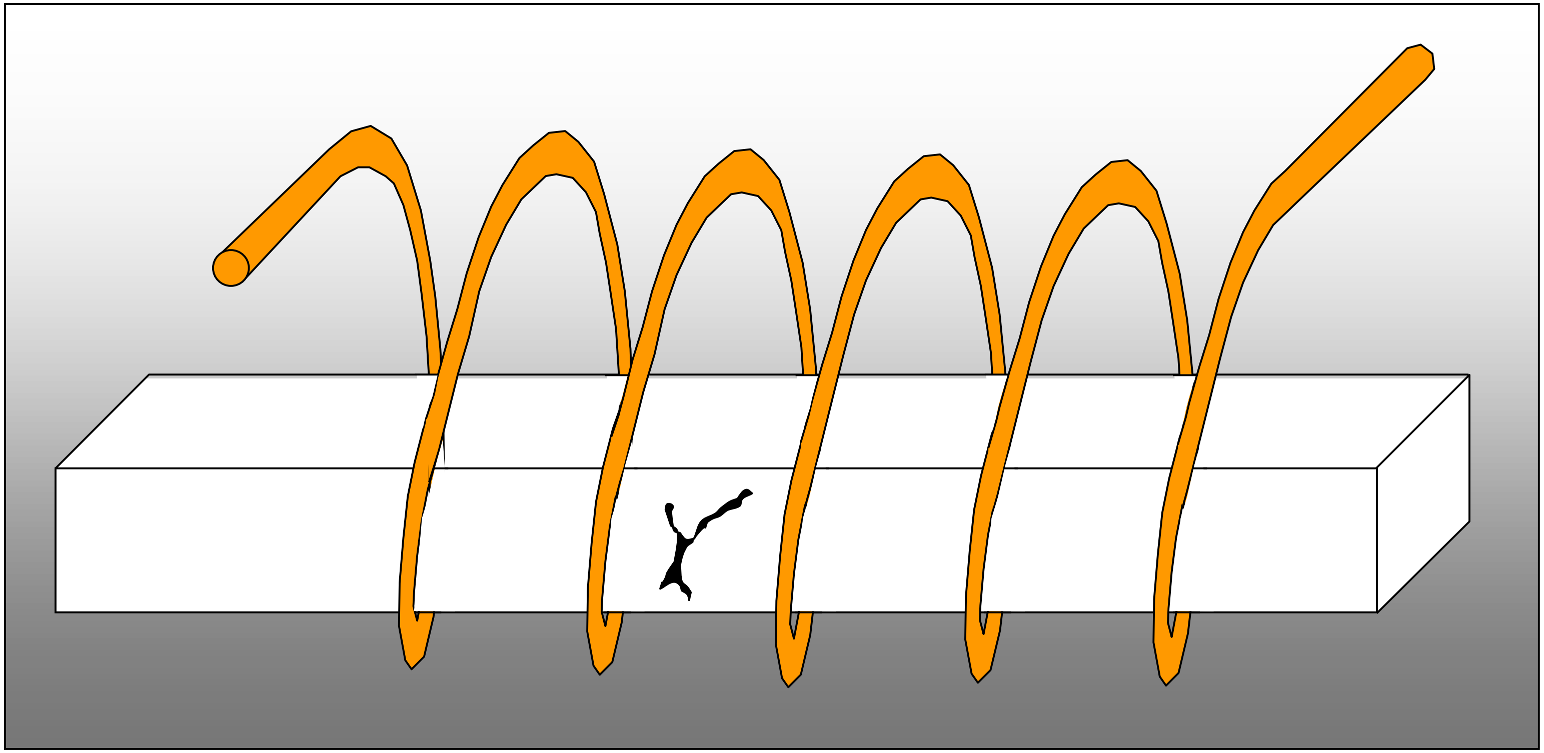


# Magnetic Flow

Magnetism passed through sample



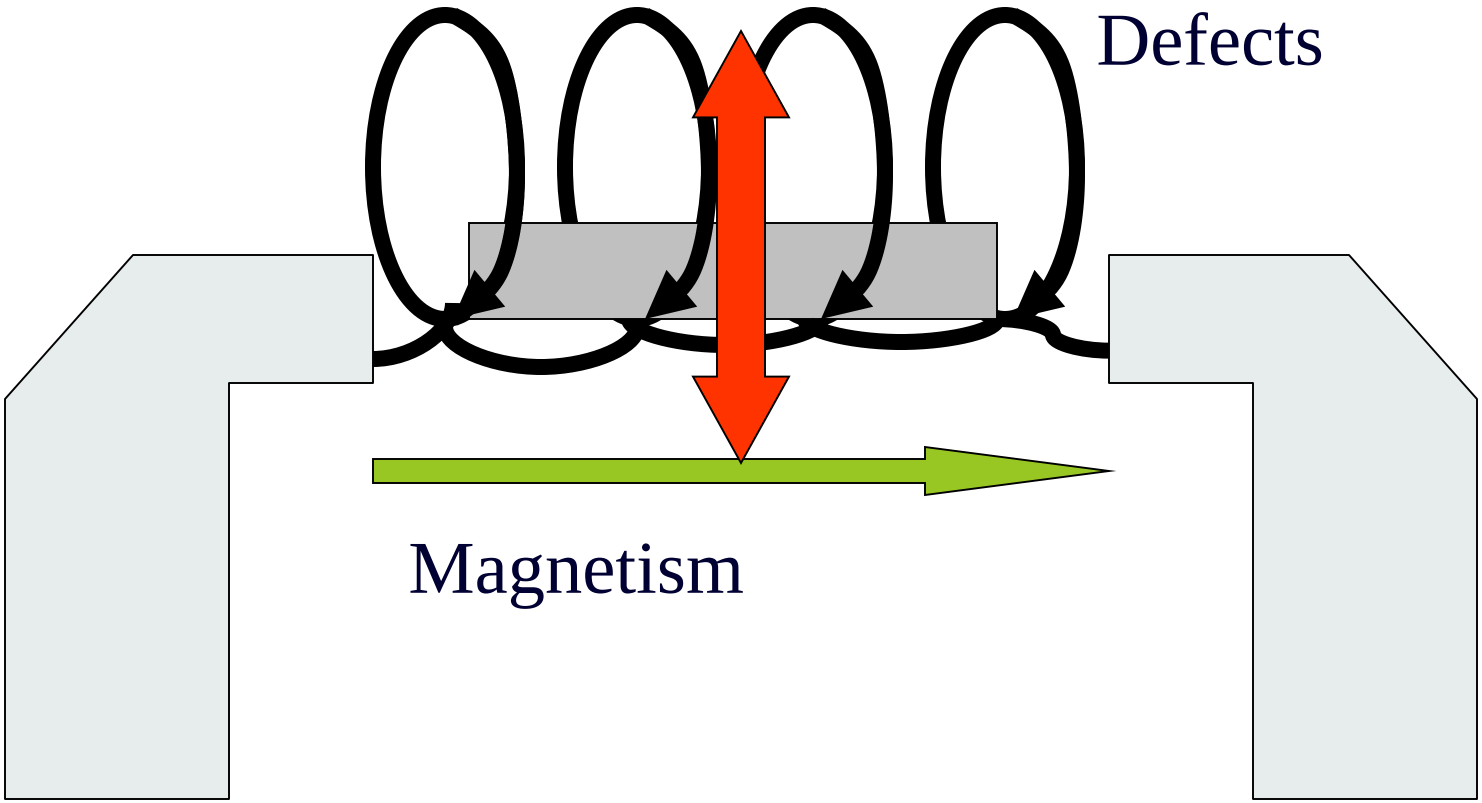
# Coil Magnetisation



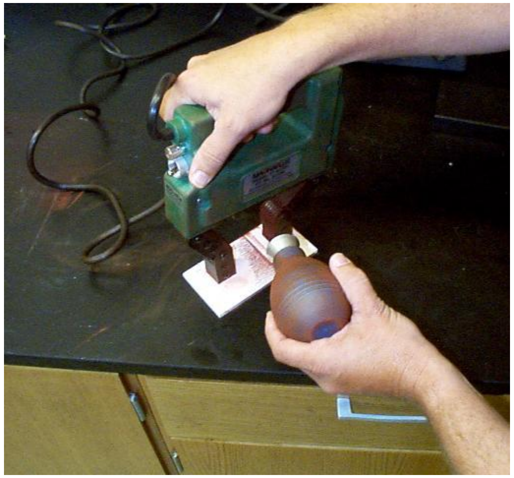
- Changes circular field into longitudinal
- Increases the strength of the field

# Rigid Coil

Current passed through coil to generate a longitudinal field



# Application of Magnetic Media



***Wet Versus Dry***

MPI can be performed using either dry particles, or particles suspended in a liquid.

- With the dry method, the particles are lightly dusted on to the surface.
- With the wet method, the part is flooded with a solution carrying the particles.

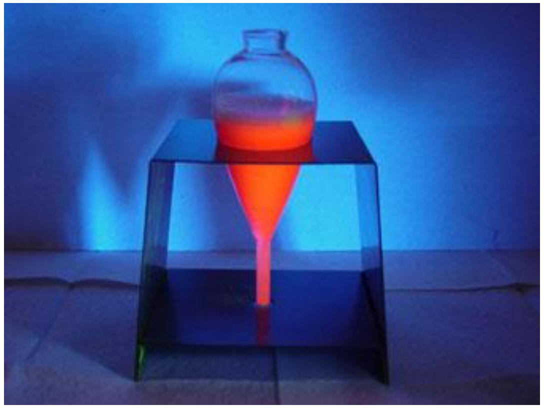
The dry method is more portable. The wet method is generally more sensitive since the liquid carrier gives the magnetic particles additional mobility.

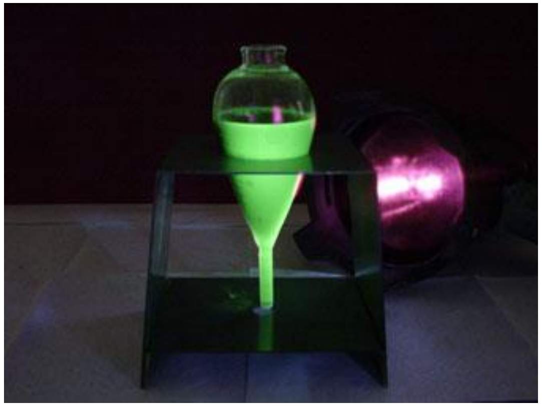
# Dry Magnetic Particles

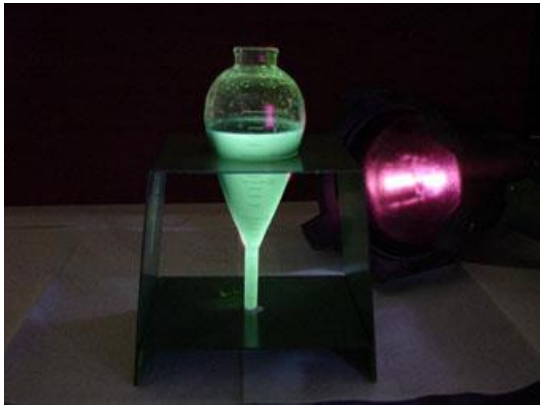
Magnetic particles come in a variety of colors. A color that produces a high level of contrast against the background should be used.

# 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.







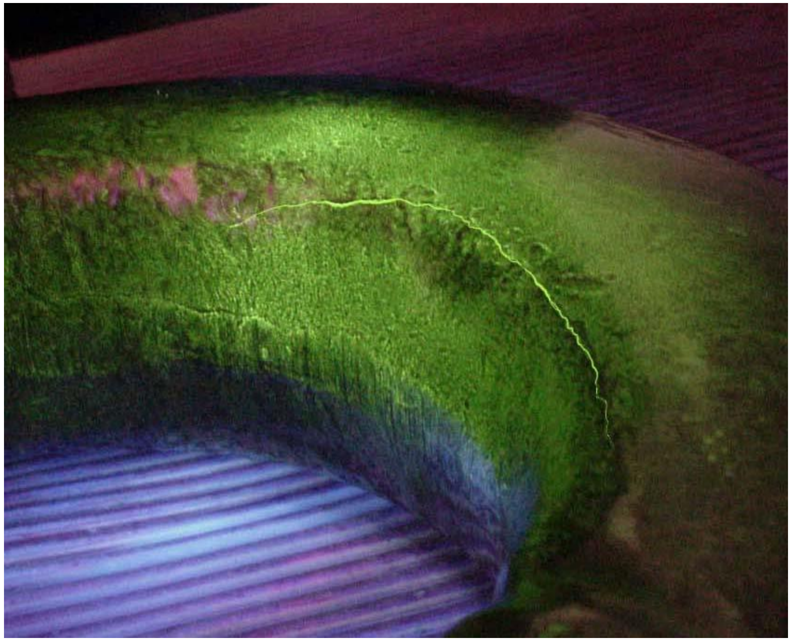
# Interpretation of Indications

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.

# Magnetic particle inspection examples

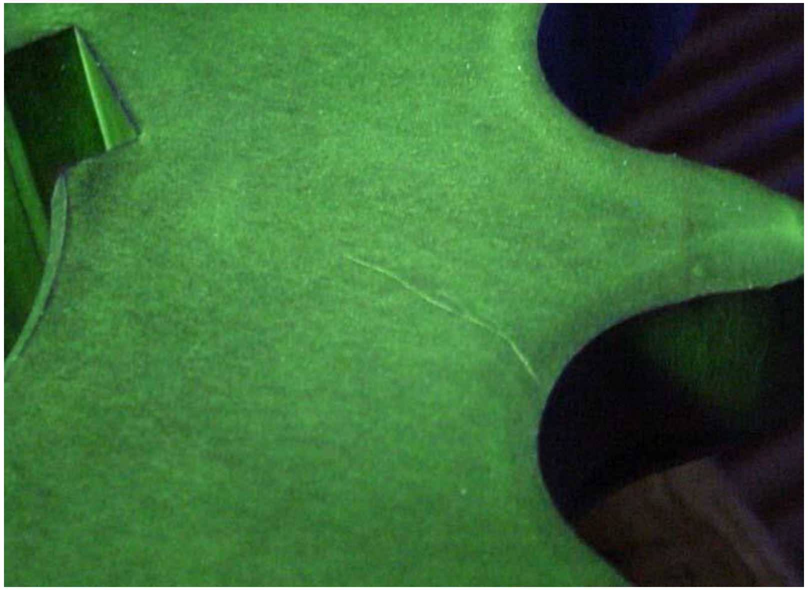
## *Crane Hook with Service Induced Crack*



Fluorescent, Wet Particle Method

# Magnetic particle inspection examples

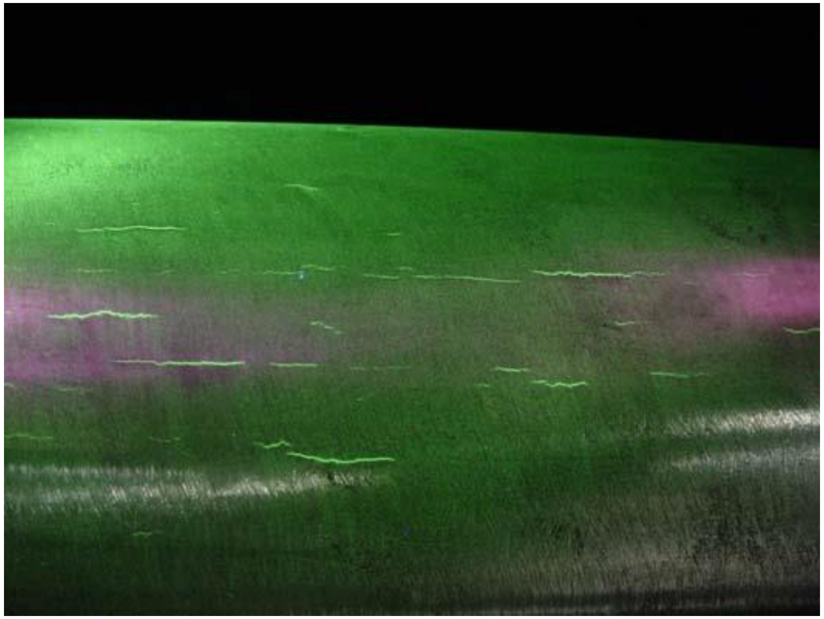
***Gear with Service Induced Crack***

Fluorescent, Wet Particle Method

# Magnetic particle inspection examples

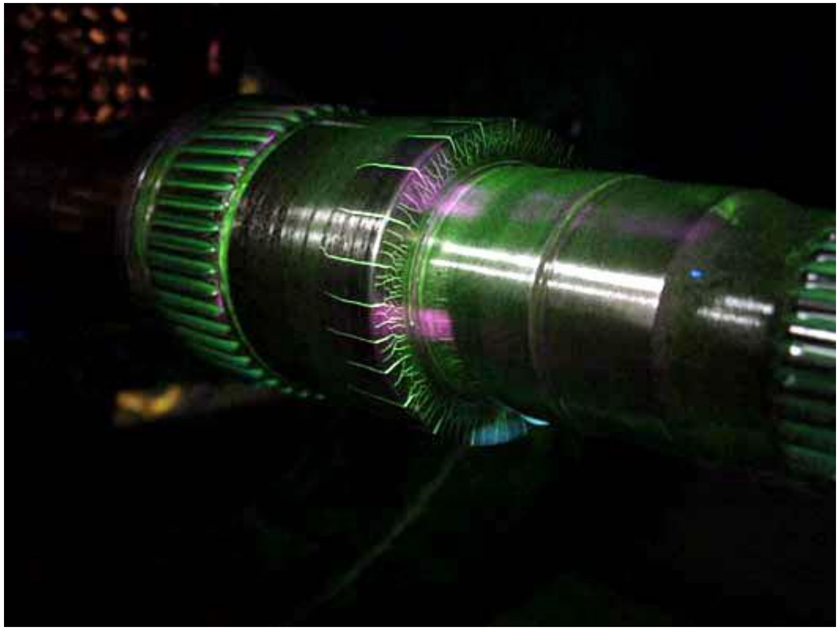
***Drive Shaft with Heat Treatment Induced Cracks***



Fluorescent, Wet Particle Method

# Magnetic particle inspection examples

***Splined Shaft with Service Induced Cracks***



Fluorescent, Wet Particle Method

# Magnetic particle inspection examples

***Threaded Shaft with Service Induced Crack***

Fluorescent, Wet Particle Method

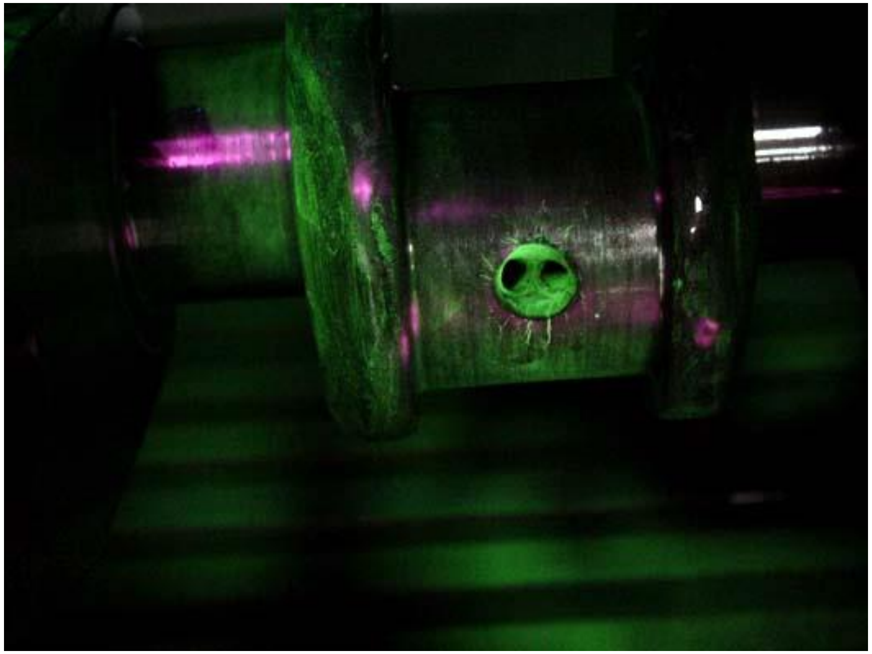
# Magnetic particle inspection examples

## ***Large Bolt with Service Induced Crack***

Fluorescent, Wet Particle Method

# Magnetic particle inspection examples

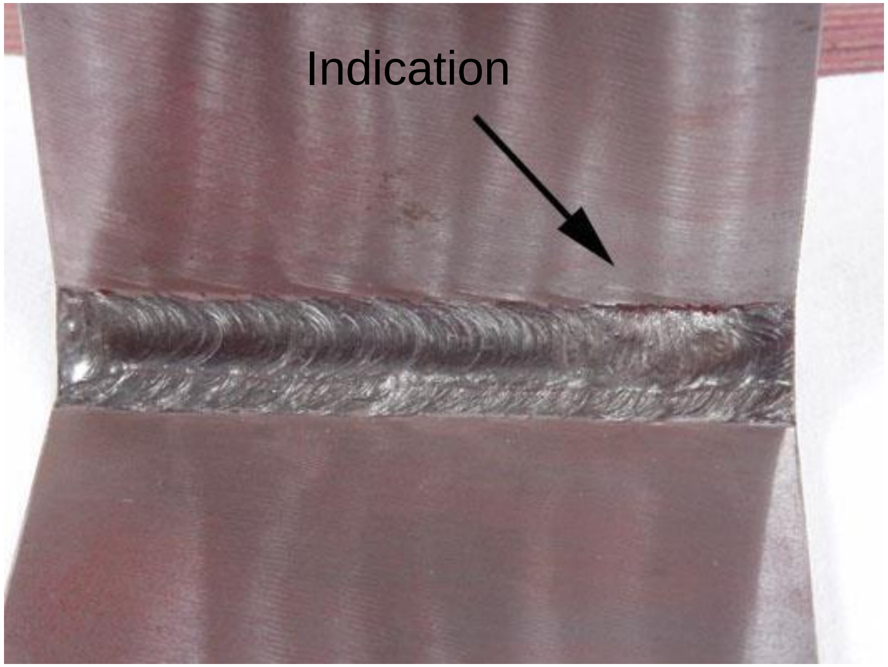
***Crank Shaft with Service Induced Crack Near Lube Hole***



Fluorescent, Wet Particle Method

# Magnetic particle inspection examples

## ***Lack of Fusion in SMAW Weld***

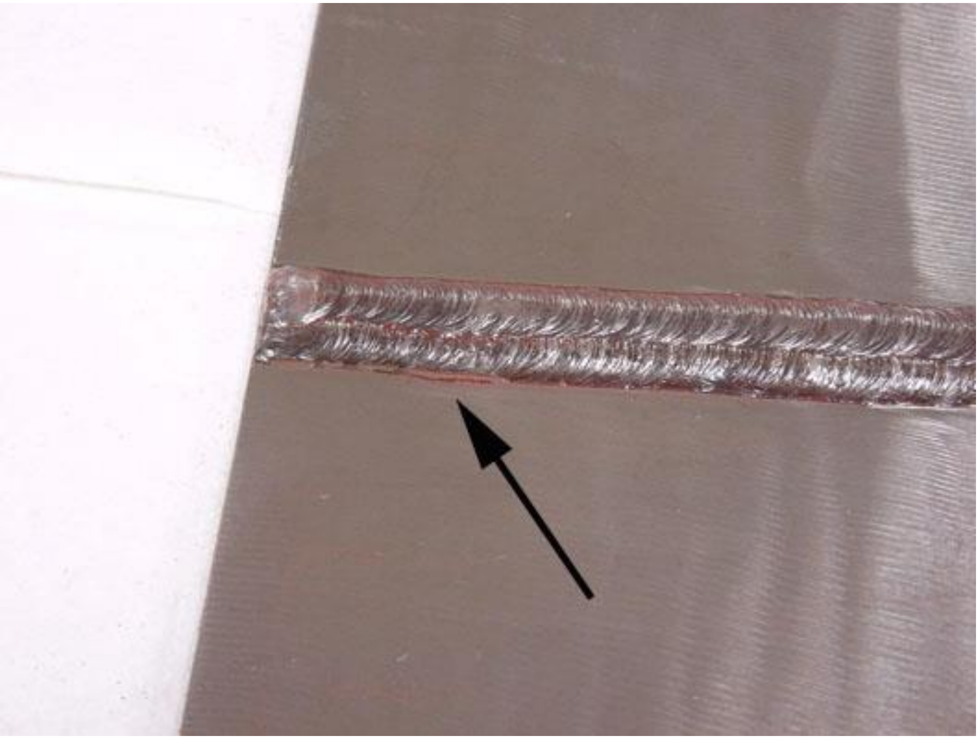



Visible, Dry Powder Method

*SMAW : Shielded metal arc welding*

# Magnetic particle inspection examples

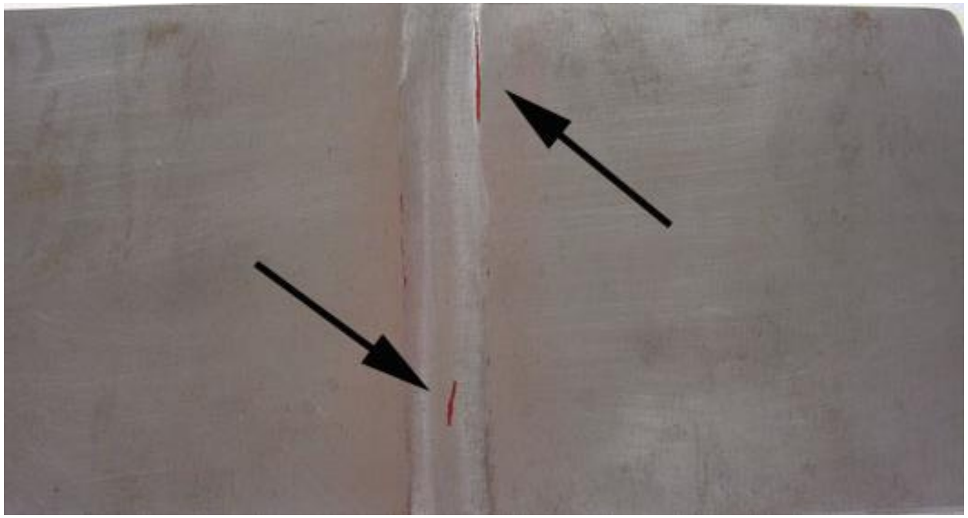
## ***Toe Crack in SMAW Weld***



Visible, Dry Powder Method

# Magnetic particle inspection examples

***Throat and Toe Cracks in Partially Ground Weld***



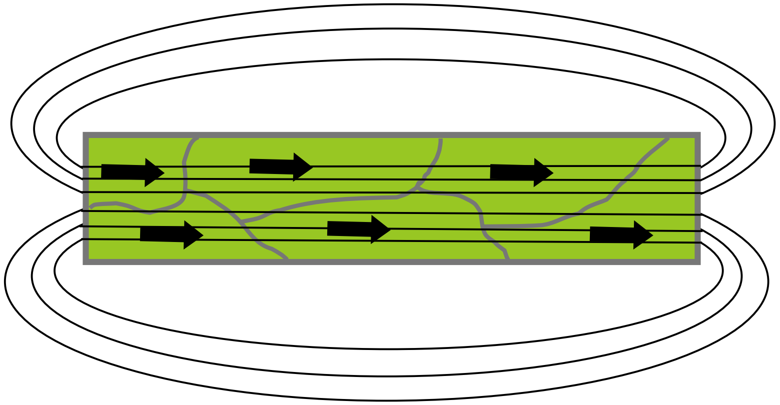
Visible, Dry Powder Method

# Demagnetization

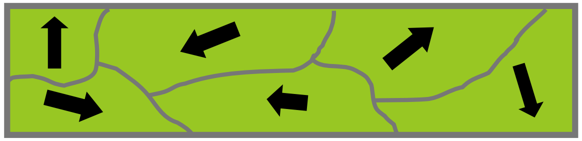
- Parts inspected by the magnetic particle method may sometimes have an objectionable residual magnetic field that may interfere with subsequent manufacturing operations or service of the component.
- Possible reasons for demagnetization include:
  - May interfere with welding and/or machining operations
  - 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

- 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**

# Flux Indicators

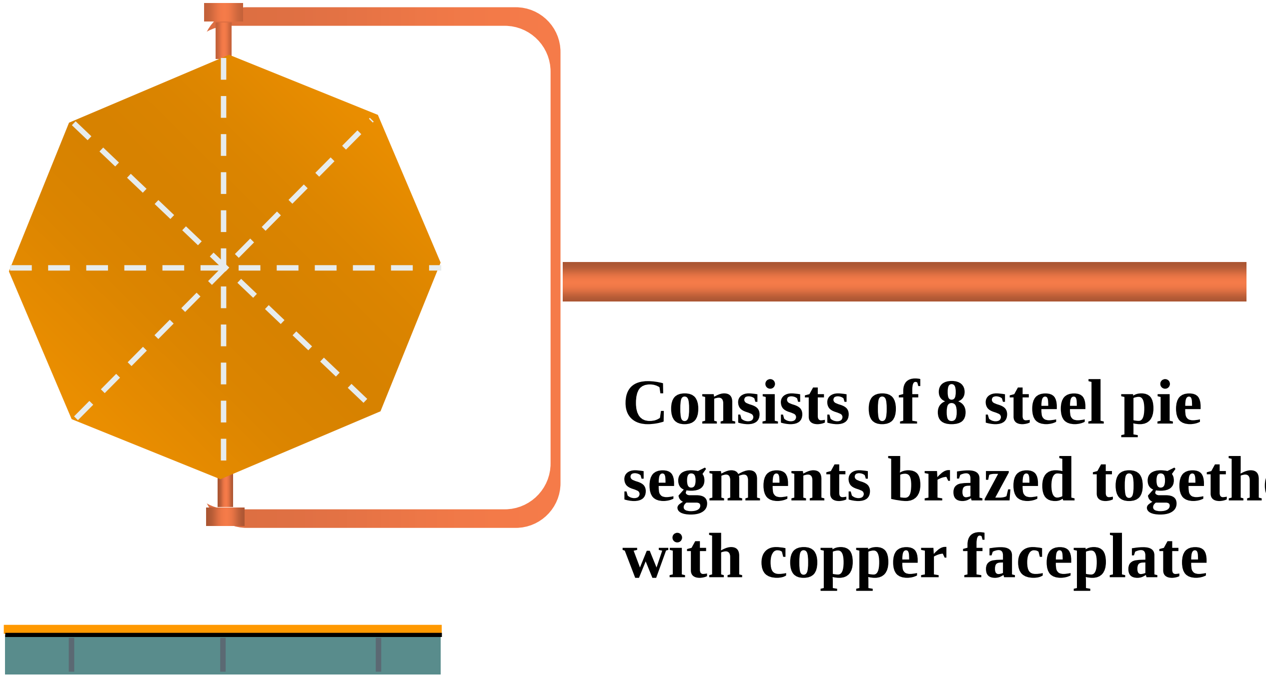
**Check for adequate flux density and correct orientation with Flux Indicators.**

(Do not use with permanent magnets or DC electromagnets.)

- **ASME**
- **Berthold penetrameter**
- **Burmah castrol strips**

# Flux Indicators

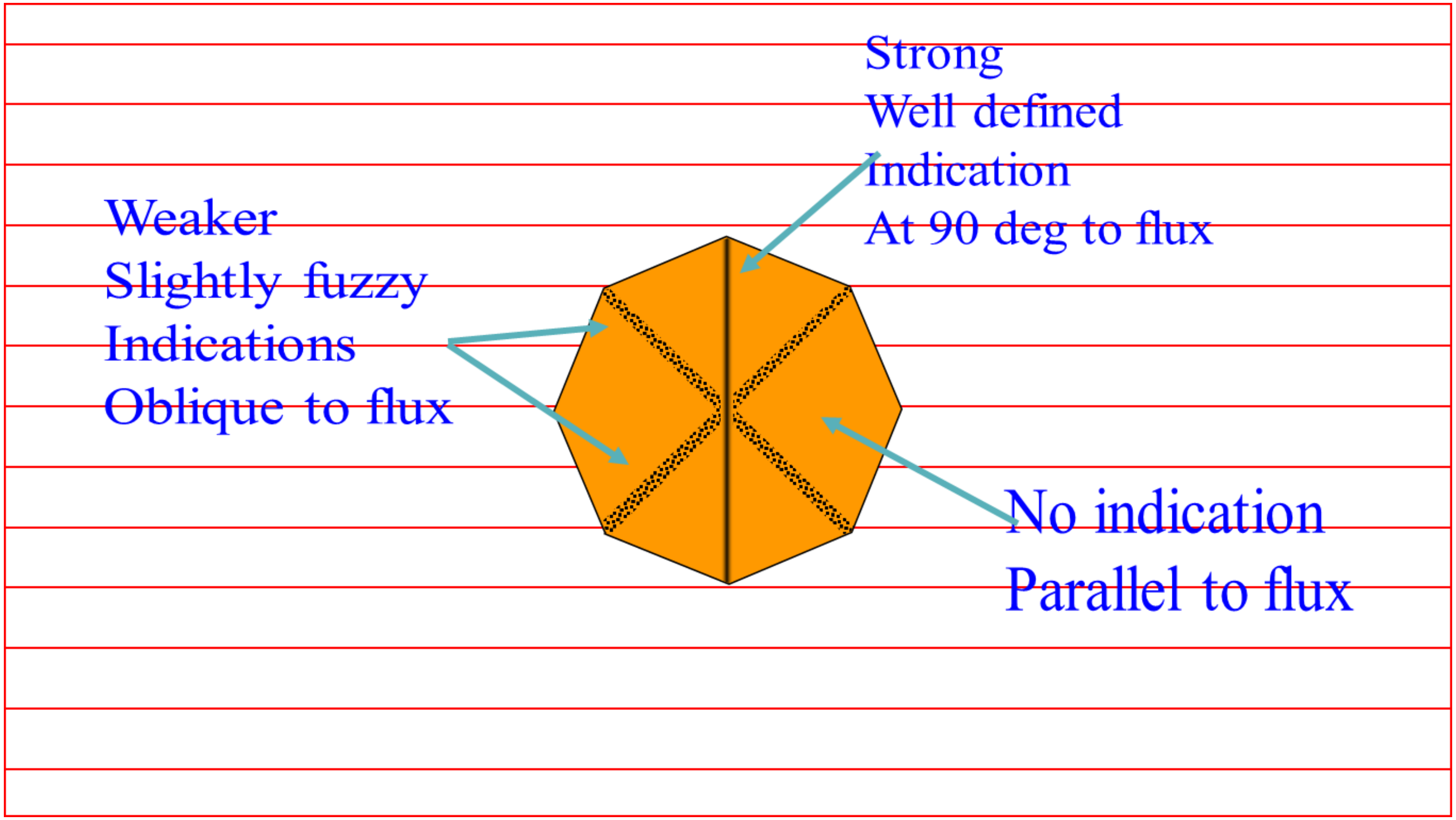
ASME V magnetic flux indicator



**Consists of 8 steel pie segments brazed together with copper faceplate**

# Flux Indicators

ASME V magnetic flux indicator



# Glossary of Terms

- **Black Light:** ultraviolet light which is filtered to produce a wavelength of approximately 365 nanometers. Black light will cause certain materials to fluoresce.
- **Central conductor:** an electrically conductive bar usually made of copper used to introduce a circular magnetic field in to a test specimen.
- **Coil:** an electrical conductor such a copper wire or cable that is wrapped in several or many loops that are brought close to one another to form a strong longitudinal magnetic field.
- **Discontinuity:** an interruption in the structure of the material such as a crack.

# Glossary of Terms

- **Ferromagnetic:** a material such as iron, nickel and cobalt or one of it's alloys that is strongly attracted to a magnetic field.
- **Heads:** electrical contact pads on a wet horizontal magnetic particle inspection machine. The part to be inspected is clamped and held in place between the heads and shot of current is sent through the part from the heads to create a circular magnetic field in the part.
- **Leakage field:** a disruption in the magnetic field. This disruption must extend to the surface of the part for particles to be attracted.
- **Non-relevant indications:** indications produced due to some intended design feature of a specimen such a keyways, splines or press fits.

# Glossary of Terms

- **Prods:** two electrodes usually made of copper or aluminum that are used to introduce current in to a test part. This current in turn creates a circular magnetic field where each prod touches the part. (Similar in principal to a welding electrode and ground clamp).
- **Relevant indications:** indications produced from something other than a design feature of a test specimen. Cracks, stringers, or laps are examples of relevant indications.
- **Suspension:** a bath created by mixing particles with either oil or water.
- **Yoke:** a horseshoe magnet used to create a longitudinal magnetic field. Yokes may be made from permanent magnets or electromagnets.

# Glossary of Terms

- **Magnetic field** Region in which magnetic forces exist
- **Flux Density:** Magnetic flux per unit area (measured in Tesla)
- **Flux:** Total number of lines existing in a magnetic circuit