Magnetic Particle Inspection

TWI

Magnetism

- Some natural materials strongly attract pieces of iron to themselves.
- Such materials were first discovered in the ancient Greek city of Magnesia.
- Magnets were utilised in navigation.
- Oersted found a link between electricity and magnetism.
- Faraday proved that electrical and magnetic energy could be interchanged.

Magnetic Particle Inspection
(MT or 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

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 (μ)

- On the basis of their permeability materials can be divided into 3 groups:
- Diamagnetic
- Paramagnetic
- Ferromagnetic

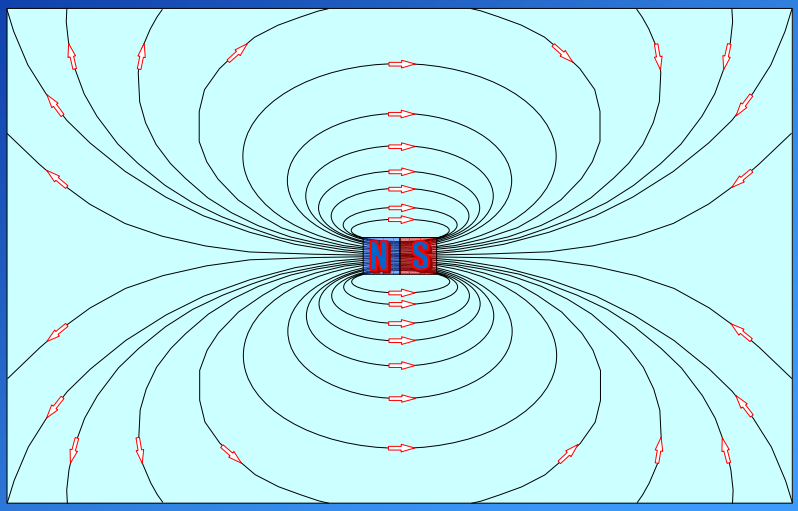
Permeability (μ)

Diamagnetic: Permeability slightly below 1, weakly repelled by magnets.
Examples: Gold, Copper, Water

- Paramagnetic: Permeability slightly greater than 1, weakly attracted by magnets.
- Examples: Aluminium, Tungsten

Ferromagnetic: Very high permeability, strongly attracted by magnets.
Examples: Iron, Cobalt, Nickel

Lines of Flux



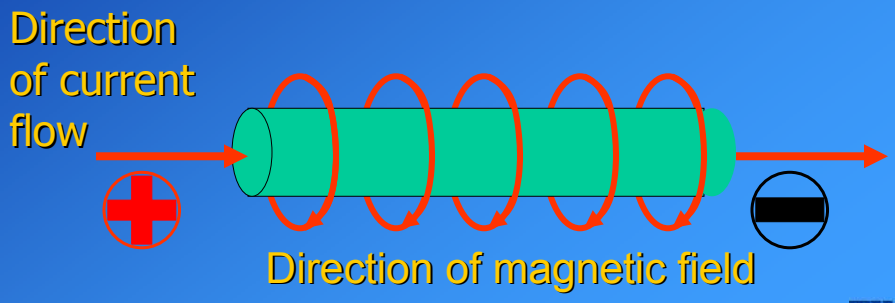
Lines of flux

- 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

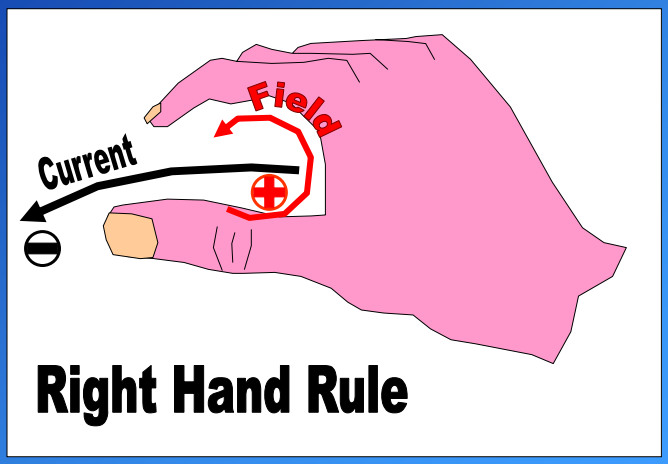
- Flux density is the number of lines of flux passing through a unit area.
- Field strength is highest where where flux density is highest.

Electromagnetism

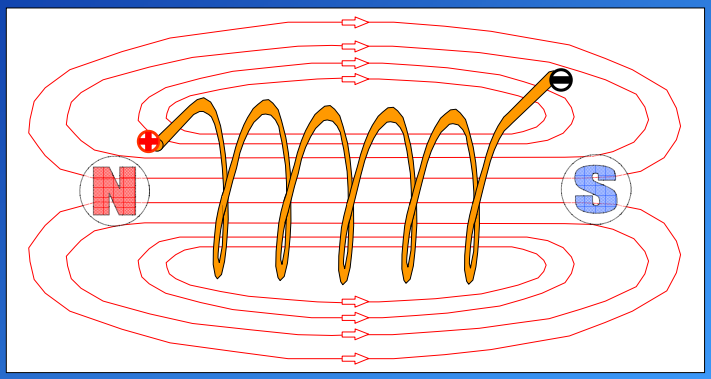
- A current flows through a conductor and sets up a magnetic field around it
- Field is at 90° to the direction of the electrical current



Right Hand Rule



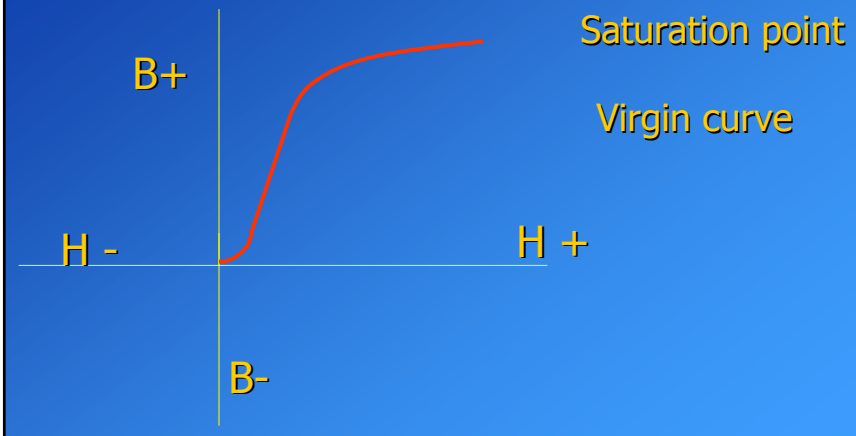
Coil Magnetisation



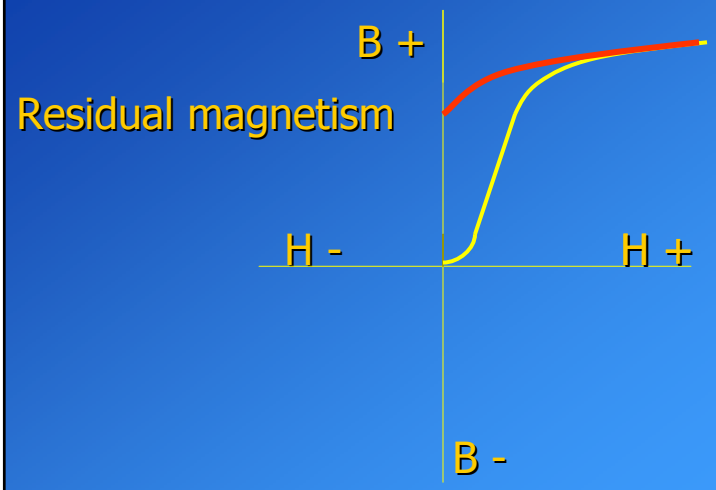
- Changes circular field into longitudinal
- Increases the strength of the field

Hysteresis

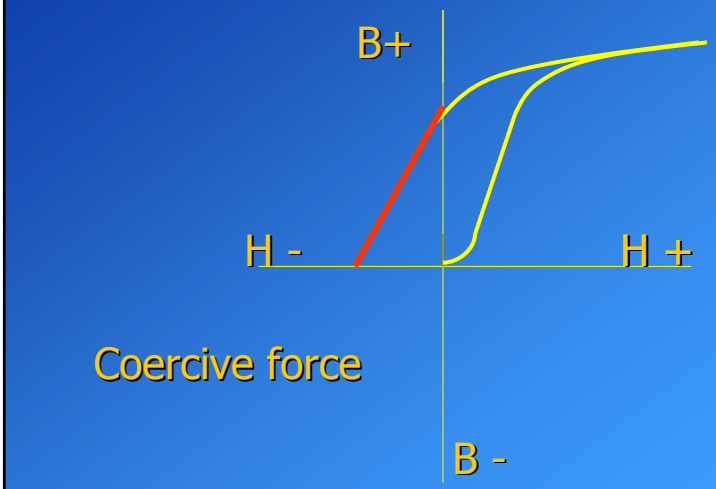
Place an un-magnetised piece of ferromagnetic material within a coil



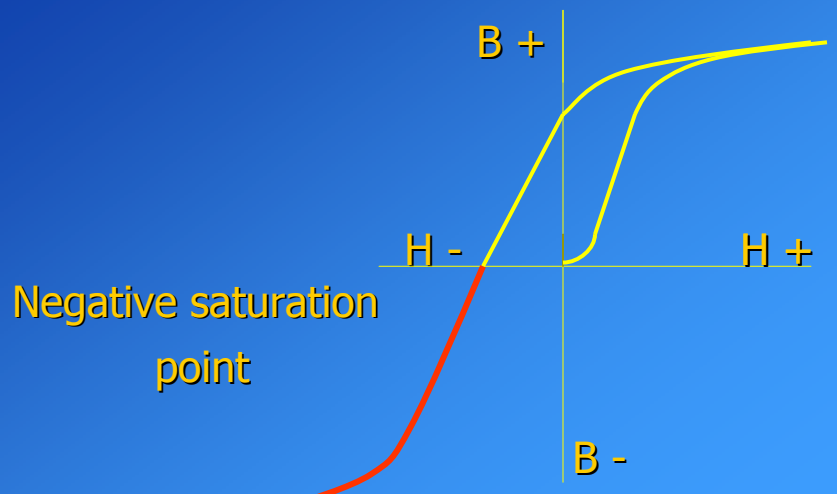
Hysteresis



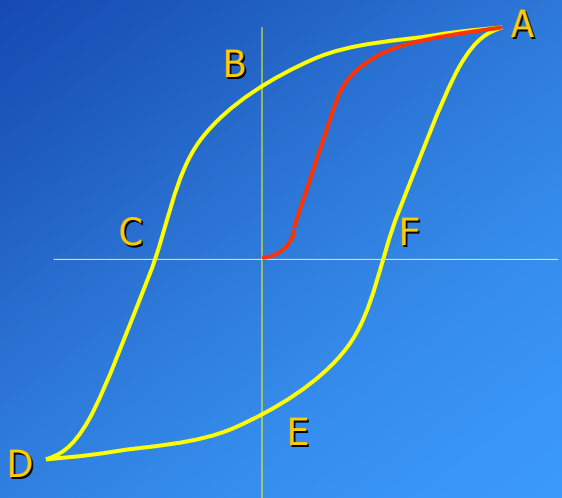
Hysteresis



Hysteresis

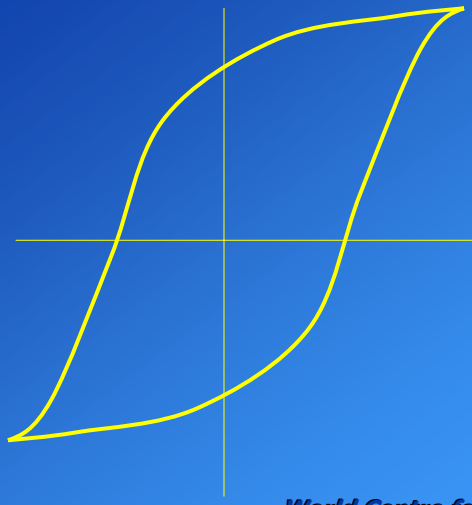


Hysteresis

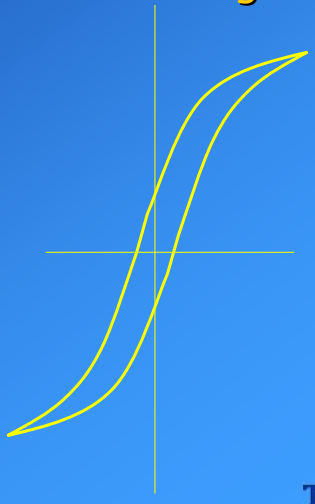


Hysteresis

Hard ferromagnetic



Soft ferromagnetic



Permeability (μ)

- The ease with which a material can be magnetised
- Opposite of reluctance (difficulty with which a material can be magnetised)
- $\mu = B / H$
- Permeability of free space = μ_o
- Relative Permeability (μ_r) = μ / μ_o

Relative Permeability (μ_r)

- Paramagnetics — Slightly > 1
- Diamagnetics — Slightly < 1
- Ferromagnetics — 240 +

Hard v Soft Ferromagnetics

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

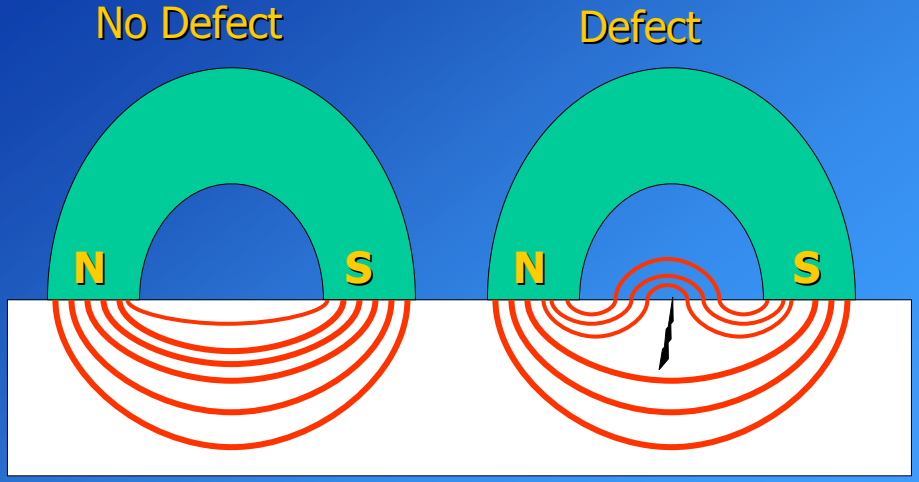
Definitions

- **Magnetic field** — **Region in which magnetic forces exist**

Flux — Total number of lines existing in a magnetic circuit

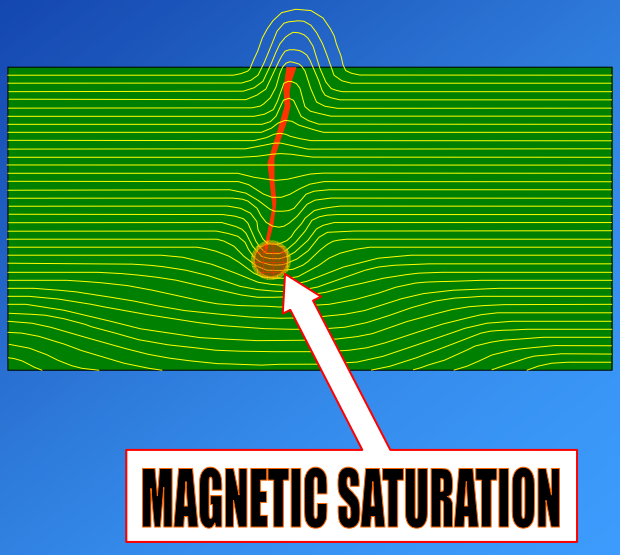
Flux Density — Magnetic flux per unit area (measured in Tesla)

Principle of MPI : Flux Leakage



Lines of flux follow the path of least resistance

LEAKAGE FIELDS



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**

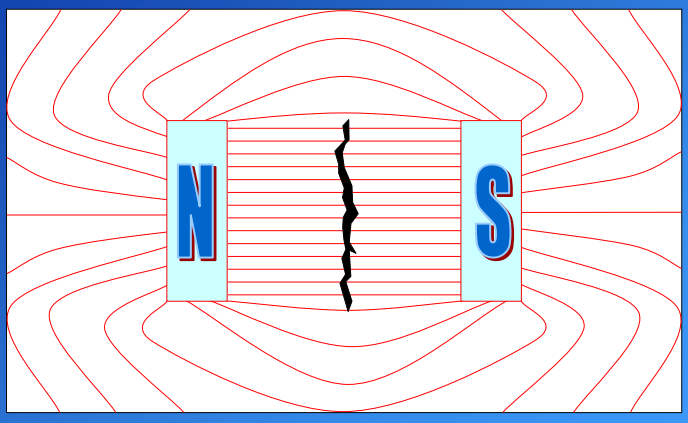
Indications

Relevant Indications - Indications due to discontinuities or flaws

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

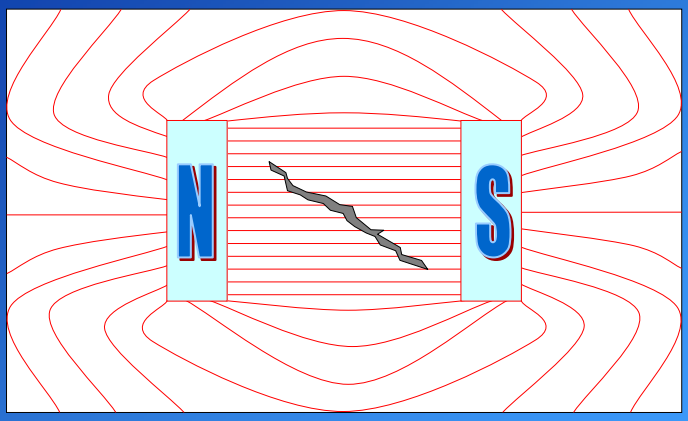
Spurious Indications - Indications due incorrect inspection procedures

Defect Orientation



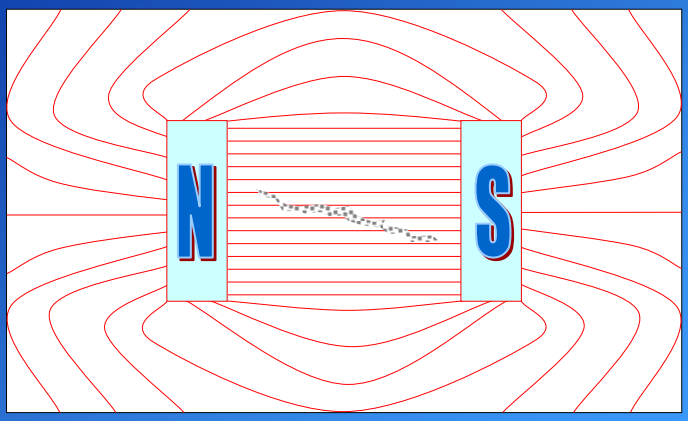
Defect at 90 degrees to flux : maximum indication

Defect Orientation



>30 Degrees to Flux: Acceptable indication

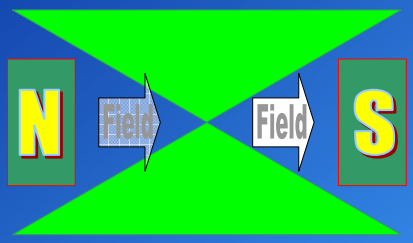
Defect Orientation



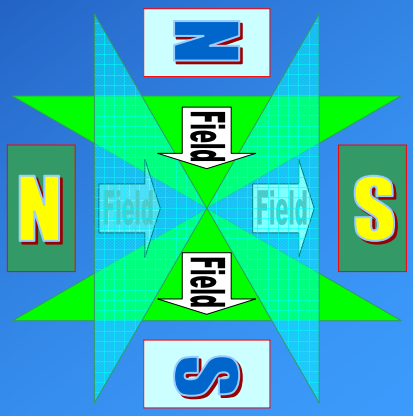
<30 Degrees to Flux : Weak indication

Defect Orientation

Test 1



Test 2



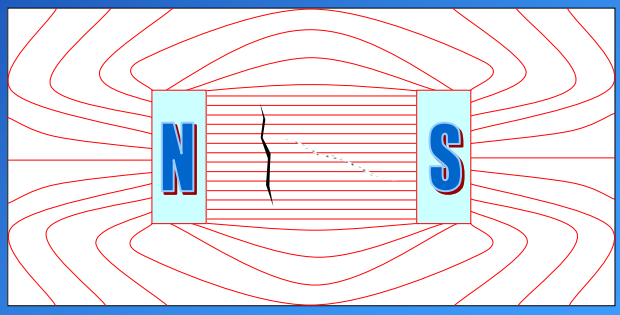
MPI requires 2 tests at 90° to one another

Equipment

Permanent Magnet

Longitudinal field between poles

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



Permanent Magnet

Advantages

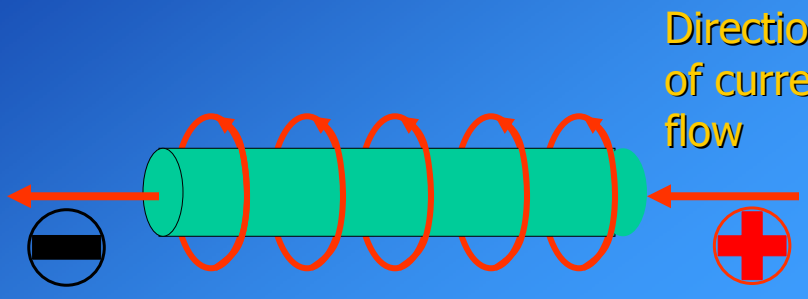
- No power supply
- No electrical contact problems
- Inexpensive
- No damage to test piece
- Lightweight

Disadvantages

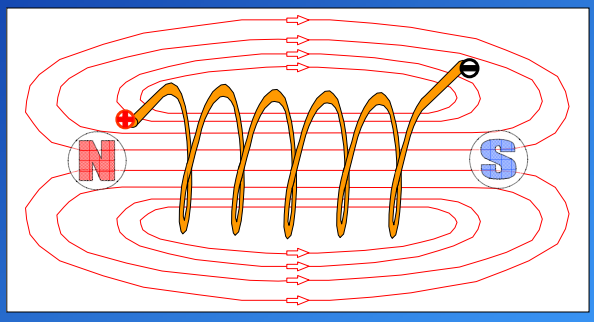
- Direct field only
- Deteriorate over time
- No control over field strength
- Poles attract detecting media
- Tiring to use

Electromagnetism

- A current flows through a conductor and sets up a magnetic field around it
- Field is at 90° to the direction of the electrical current



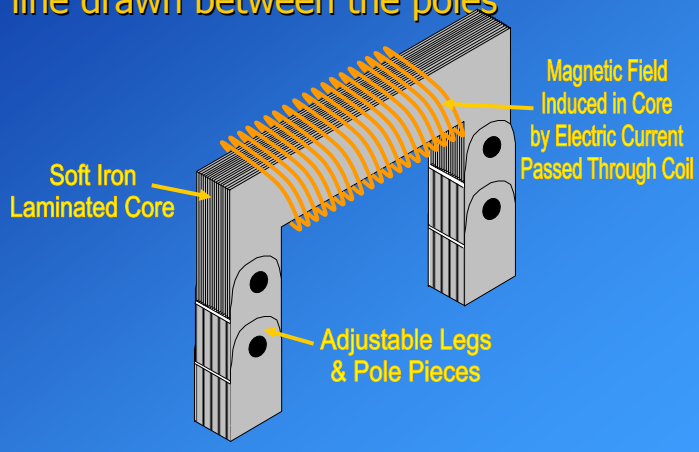
Coil Magnetisation



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

Electromagnets

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



Electromagnets

Advantages

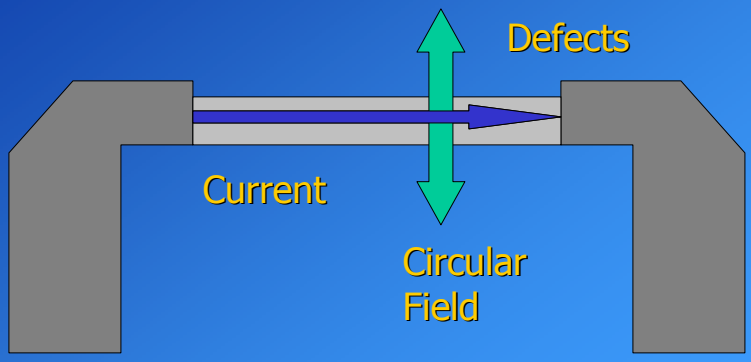
- AC,DC or rectified
- Controllable field strength
- No harm to test piece
- Can be used to demagnetise
- Easily removed

Disadvantages

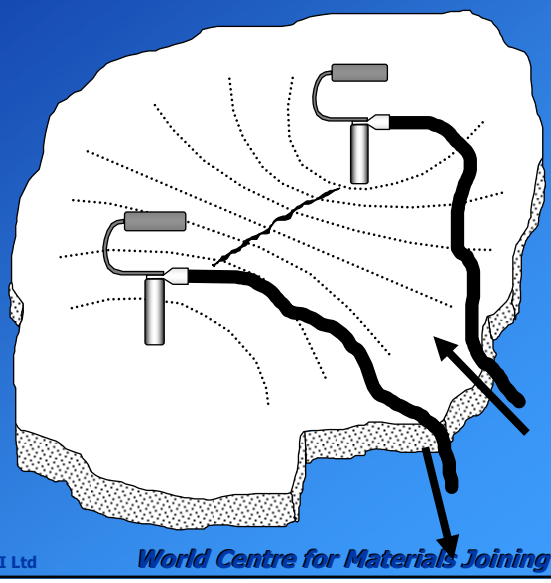
- Power supply required
- Longitudinal field only
- Electrical hazard
- Poles attract particles
- Legs must have area contact

Current Flow

Current passed through sample

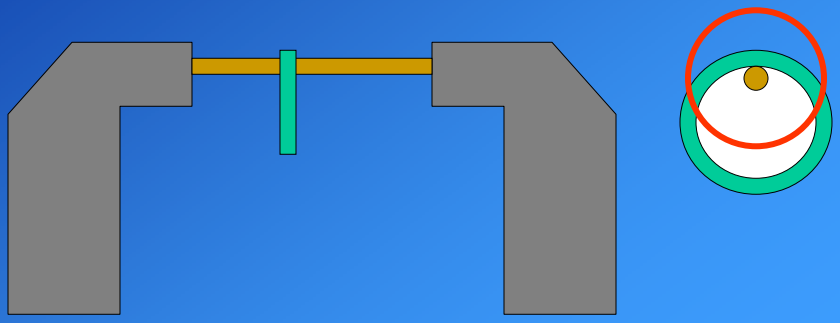


PROD METHOD



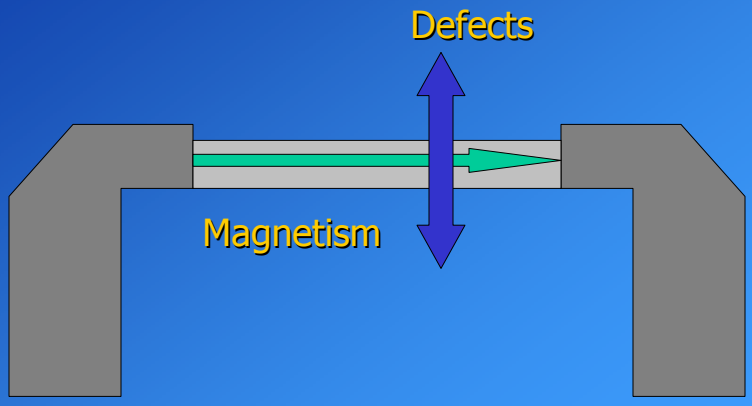
Threading Bar

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

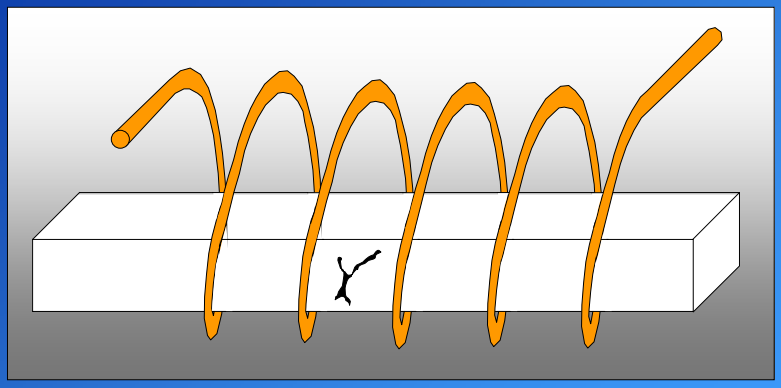


Magnetic Flow

Magnetism passed through sample



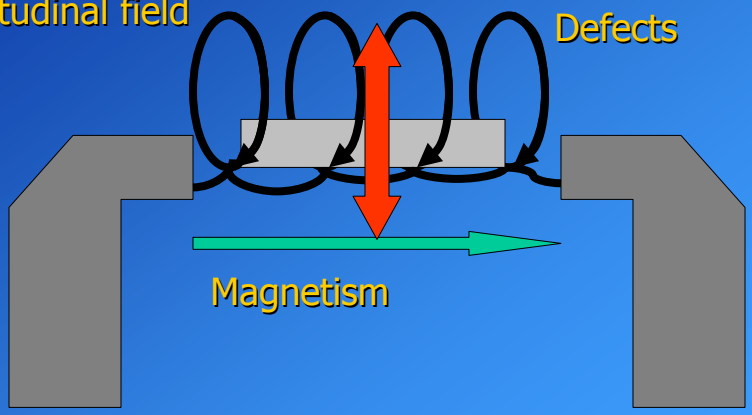
Coil Magnetisation



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

Rigid Coil

Current passed through coil to generate a longitudinal field



MPI Equipment

Portable

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

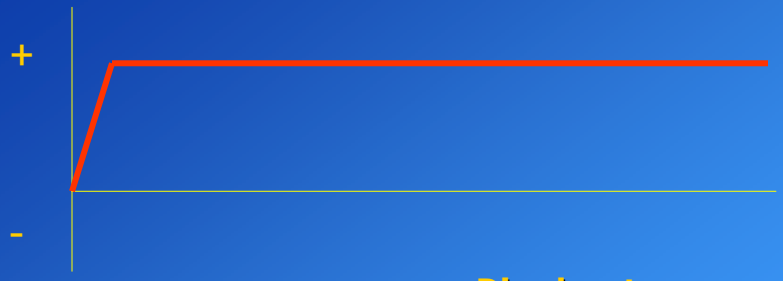
Fixed

Current flow
Magnetic flow
Threader Bar
Rigid coil
Induced current

Current Types

- Direct current (DC)
- Alternating current (AC)
- Half wave rectified current (HWDC or HWRAC)
- Full wave rectified (FWDC or FWRAC)

Direct Current



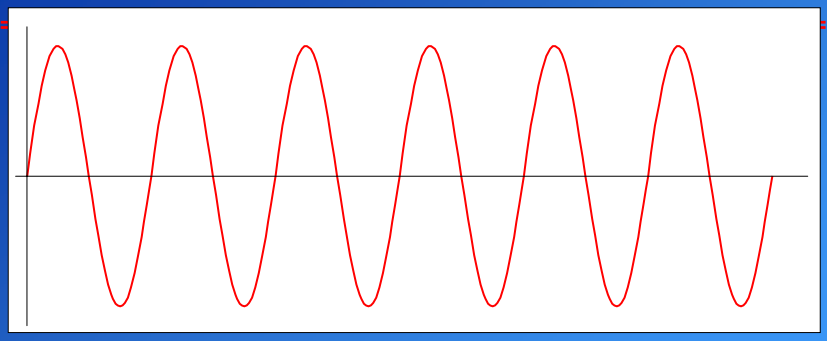
Advantages

- Sub-surface defects
- Availability from batteries

Disadvantages

- No agitation
- Less sensitive to surface defects

Alternating Current



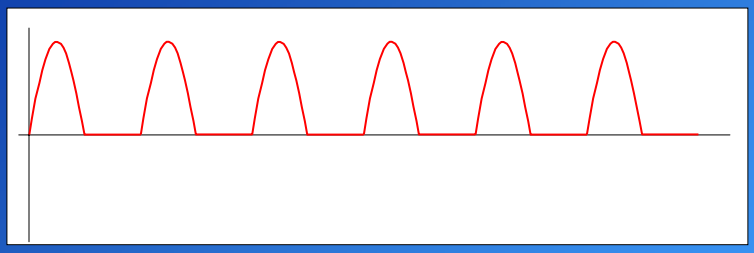
Advantages

- Availability
- Sensitivity to surface defects
- Agitation of particles
- Demagnetisation

Disadvantages

- Will not detect sub-surface defects

Half Wave Rectified Current



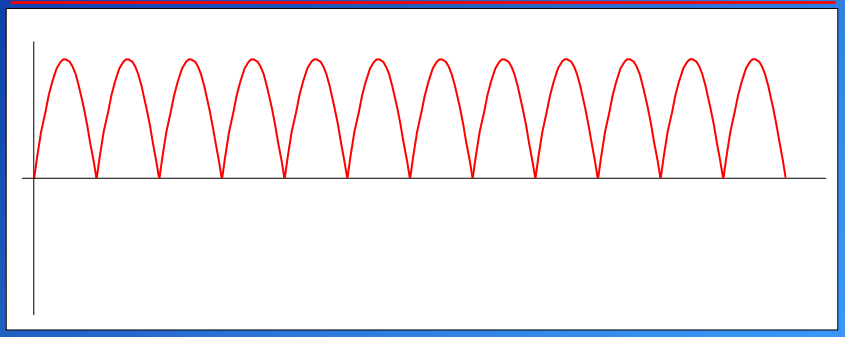
Advantages

- Penetration like DC
- Agitation
- Ease of production
- High flux density for less power

Disadvantages

- Sensitivity to surface defects lower than AC

Full Wave Rectified Current



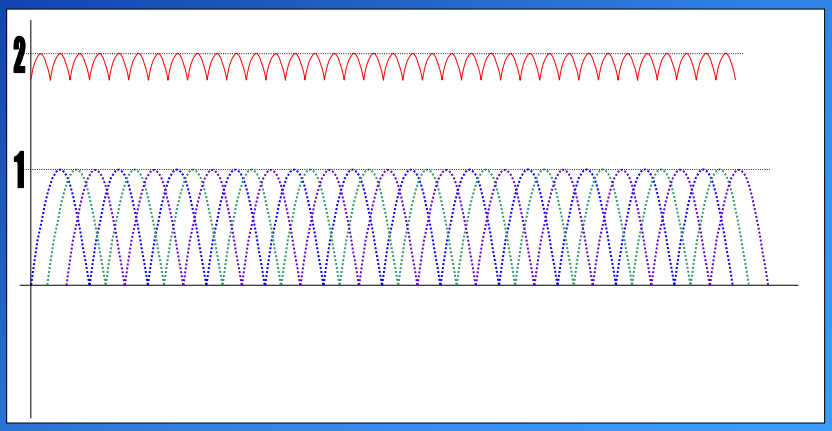
Advantages

- Penetration like DC
- Agitation

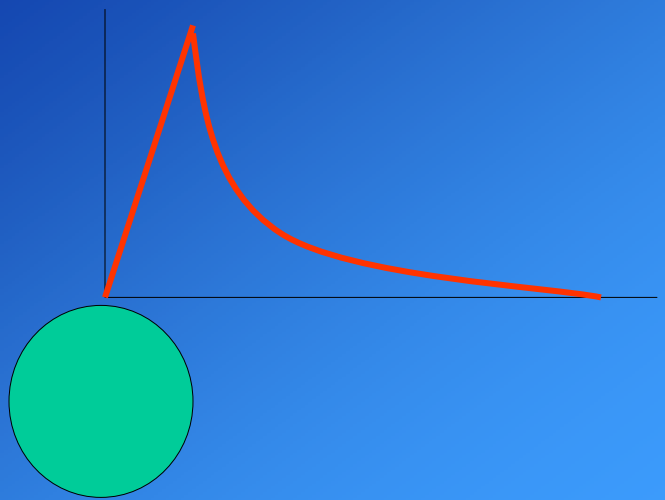
Disadvantages

- Sensitivity to surface defects lower than AC

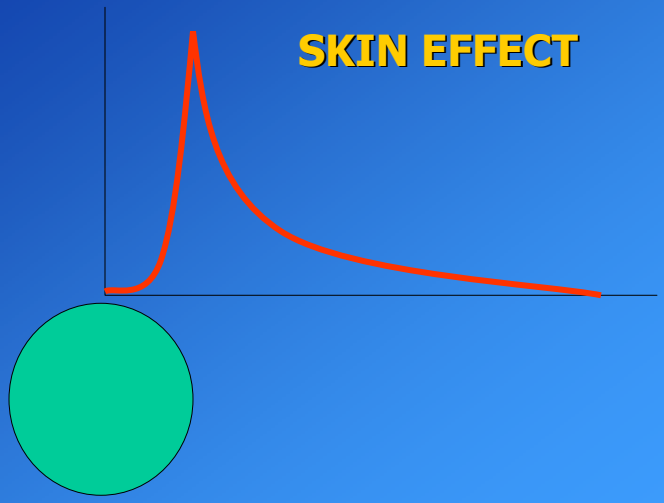
3 - PHASE FW RECTIFIED



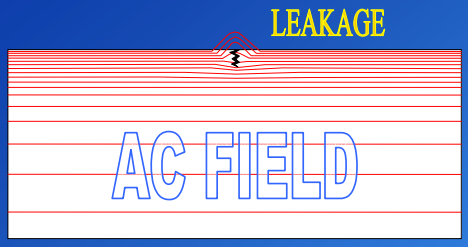
Direct Current: Field distribution

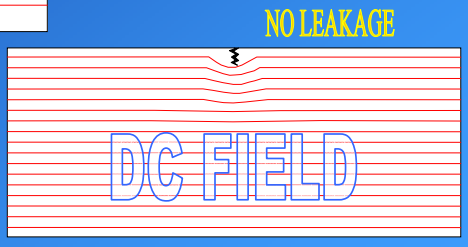


A.C. : Field distribution



SKIN EFFECT



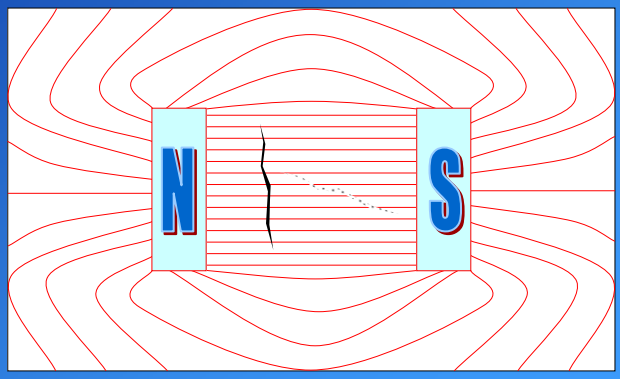


In order to achieve the same sensitivity to shallow defects a DC field must be far more powerful than a corresponding AC field

Permanent Magnet and DC Electromagnet

Use the Lift Test

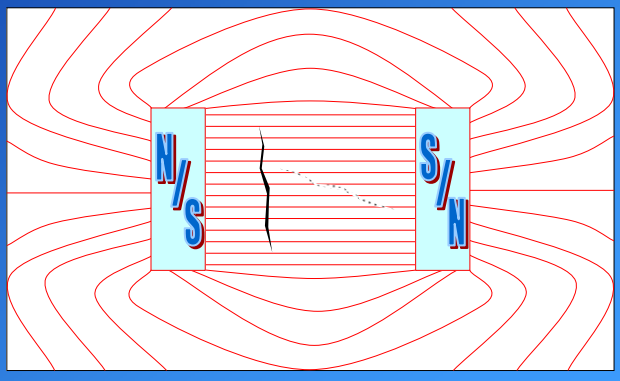
For pole spacing from 75 to 150mm - 18 kg



AC Electromagnets

Use the Lift Test

For pole spacing no more than 300mm - 4.5kg



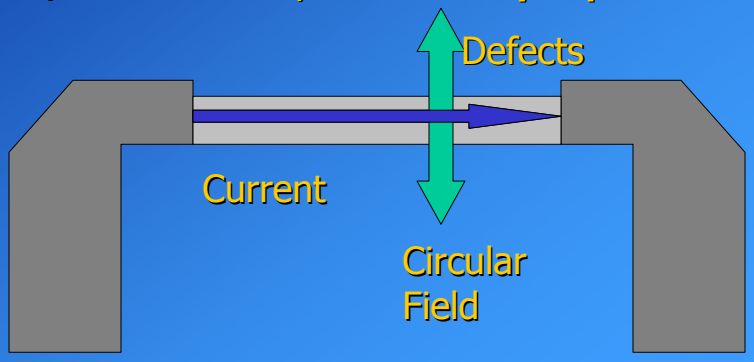
Current Flow

Current passed through sample, typically:

- **7.5 Amps / mm diameter**

or

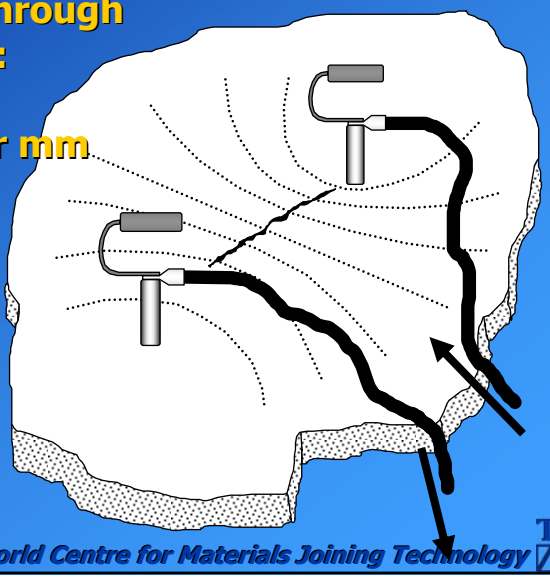
- **2.4 Amps / mm perimeter**
- **For L/D = 1.5 or less, one shot only req'd**



PROD METHOD

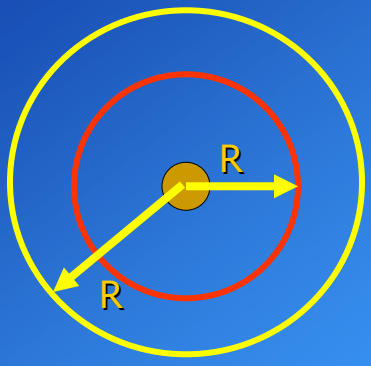
Current passed through sample, typically:

5 Amps (rms) per mm of prod spacing



Threading Bar

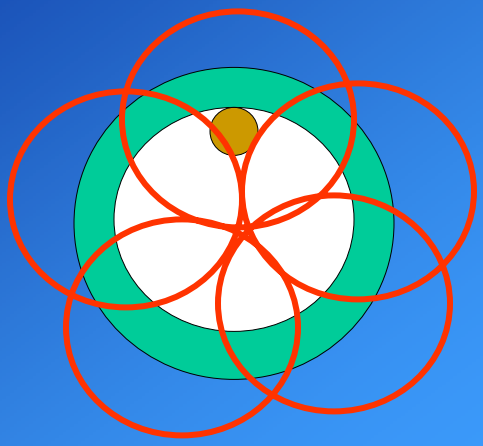
- **R (mm) = I / 15 for General engineering**
- **R (mm) = I / 56 for aerospace**



Increase the current (I) to increase R, the radius of the test zone.
R=I/15 is equivalent to 7.5A per mm of diameter.
R=I/56 is equivalent to 28A per mm of diameter.

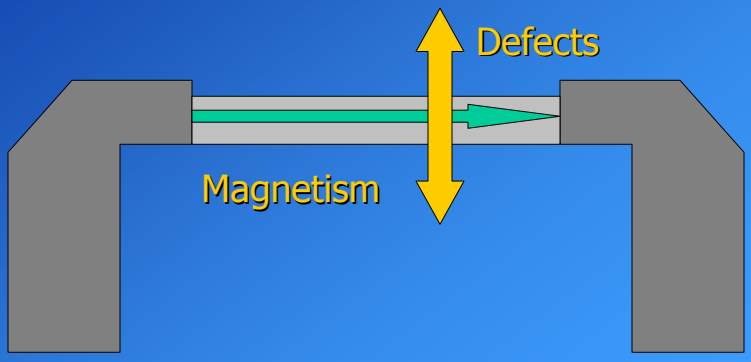
Threading Bar

Component placed within field and rotated for complete coverage



Magnetic Flow

Magnetism passed through sample



Field strength can be assessed using a "flux indicator".

Rigid Coil

$$NI = \frac{K}{L/D} \qquad I = \frac{K}{L/D \times N}$$

- N = Number of turns in coil
- K = 32,000 for DC (typical)
  22,000 for AC or FWR (typical)
  11,000 for HWR (typical)
- L/D = Length / Diameter

Rigid Coil Conditions

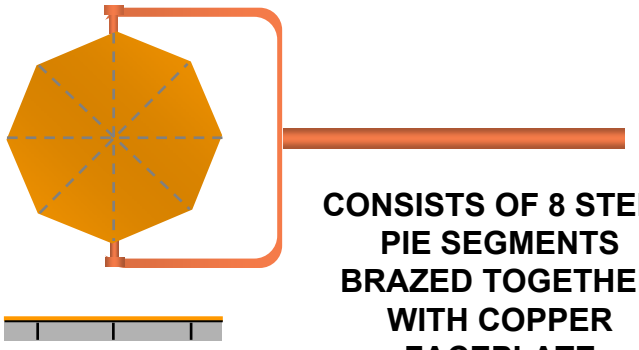
- Cross section of test piece <10% of Coil (the fill factor)
- Test piece must lie against side or bottom
- The test zone is the part of the component which lies within the coil
- L / D must be between 5 and 20

FLUX INDICATORS

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

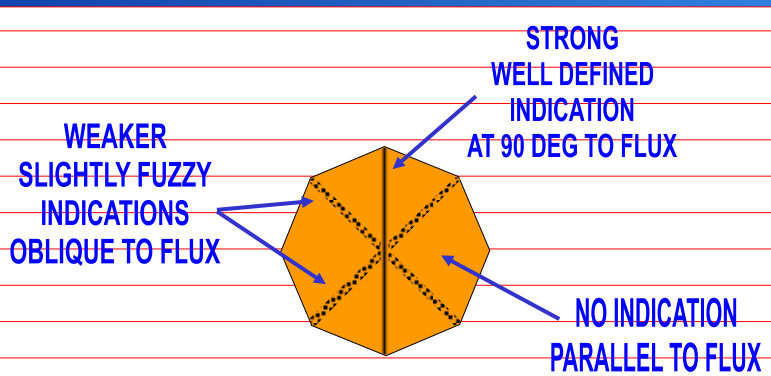
(Do not use with permanent magnets or DC electromagnets.)

ASME V MAGNETIC FLUX INDICATOR



CONSISTS OF 8 STEEL PIE SEGMENTS BRAZED TOGETHER WITH COPPER FACEPLATE

ASME V MAGNETIC FLUX INDICATOR



FLUX INDICATORS - COMMON TYPES

- ASME
- BERTHOLD PENETRAMETER
- BURMAH CASTROL STRIPS

Detecting Media

Dry Magnetic Particles

- Iron powder or magnetic iron oxide (magnetite).
- 5 - 200 microns, rounded and elongated shapes
- Colours vary for contrast against component
- Can be used on hot surfaces
- Poor particle mobility, HWDC best, DC or permanent magnets must never be used
- Greater operator skill required
- Difficult to apply to overhead surfaces especially in field conditions
- Generally less sensitive than wet particles

Wet Magnetic Particles

Magnetic iron oxide (magnetite) or iron powder
0.1 - 100 microns rounded and elongated shapes
Colour contrast or fluorescent
Water or kerosene based
Concentration important
Good particle mobility
Easier to use
More sensitive

Demagnetisation

Demagnetisation

Removal of residual magnetisation

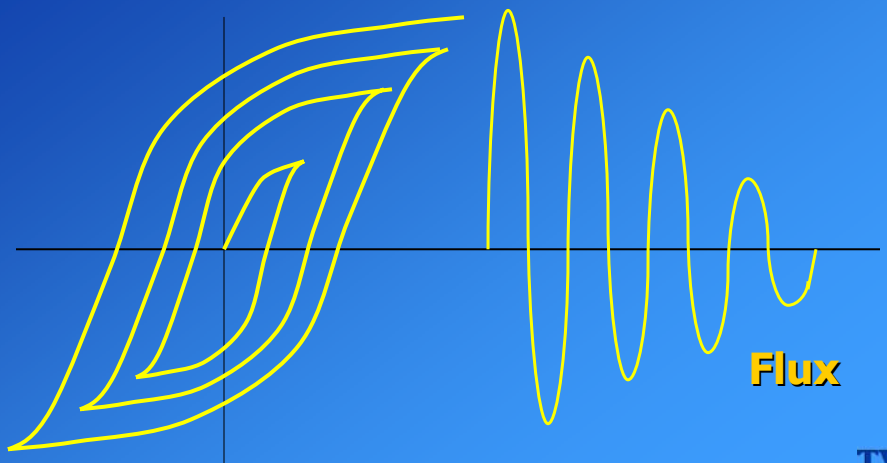
Required for:

- Aircraft parts
- Rotating parts
- Components to be welded,machined or electroplated

Check for removal with Field strength meter (magnetometer)

How to Demagnetise?

- A constantly reversing and reducing magnetic field



Methods of Demagnetisation

- Aperture type coil reversing stepped DC
- Aperture type coil reducing AC
- AC or reversing DC aperture type coil, withdraw component along the coil axis
- AC electromagnet
- Heating to above the Curie point (about 770°C for steel)

MPI Practices

Test Methods

- Continuous or Residual
- Fluorescent or Visible
- Wet or Dry

Continuous or Residual?

Continuous Method

- Detecting media applied immediately prior to & during magnetisation.

Residual

- Detecting media used after the applied field has been removed.
- Requires high retentivity.
- Less sensitive than continuous.
- Useful for components like ball bearings

Fluorescent or Visible?

Fluorescent	Visible
Detecting media dye coated	No special lighting required
More sensitive	Higher concentration of particles
Less tiring for operators	Background paint may be required
Better for batch inspections	

NB All surface defects form indications
But not all indications are caused by defects

Relevant indications…Linear 3:1

Non-relevant indications
Due to flux leakage but arising from design features
Changes in section
Changes in permeability
Grain boundaries
Forging flow lines

Spurious indications
Not due to flux leakage
- Lint
- Scale
- Dirt
- Hairs
- Magnetic writing

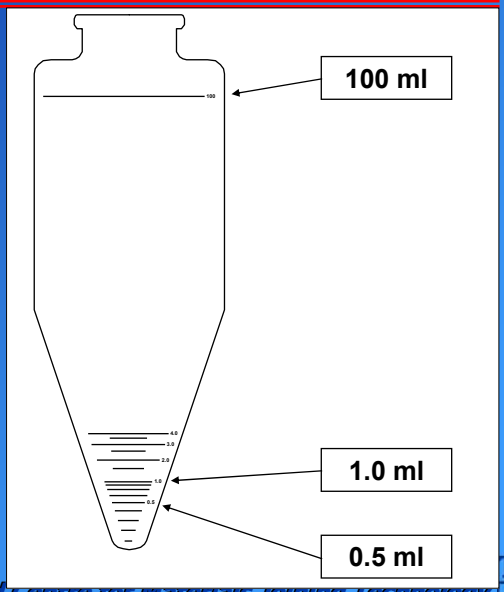
Control and Maintenance Checks

To ensure equipment,ancillaries and materials are up to standard

- Ink
- Lighting conditions
- Magnetising units

Control and Maintenance Checks

- Ink settlement



Ink Settlement Test

Fluorescent Ink
- 0.1 - 0.3 %

Non-Fluorescent Ink
- 1.25 - 3.5 %

Control and Maintenance Checks

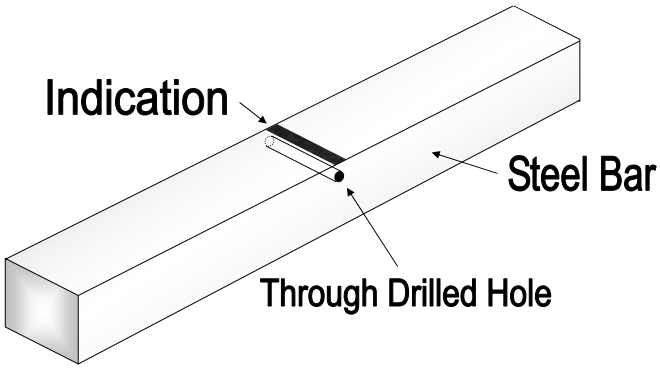
- Ink settlement
- Fluorescent ink check
- Equipment performance check

Equipment Performance Checks

- Current flow test piece
- Magnetic flow test piece
- Cracked component

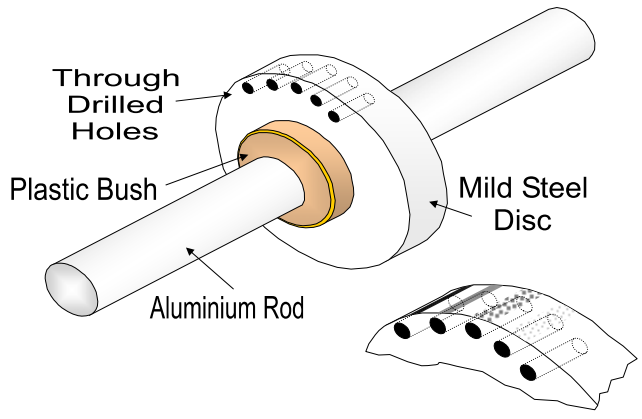
Equipment Performance Checks

Magnetic Flow Test Piece



Equipment Performance Checks

Current Flow Test Piece



Control and Maintenance Checks

- Ink settlement
- Fluorescent ink check
- Equipment performance check
- Viewing efficiency
- Magnetising unit
- Unit tank levels
- Unit ammeters
- Demagnetiser

Control Check Frequency

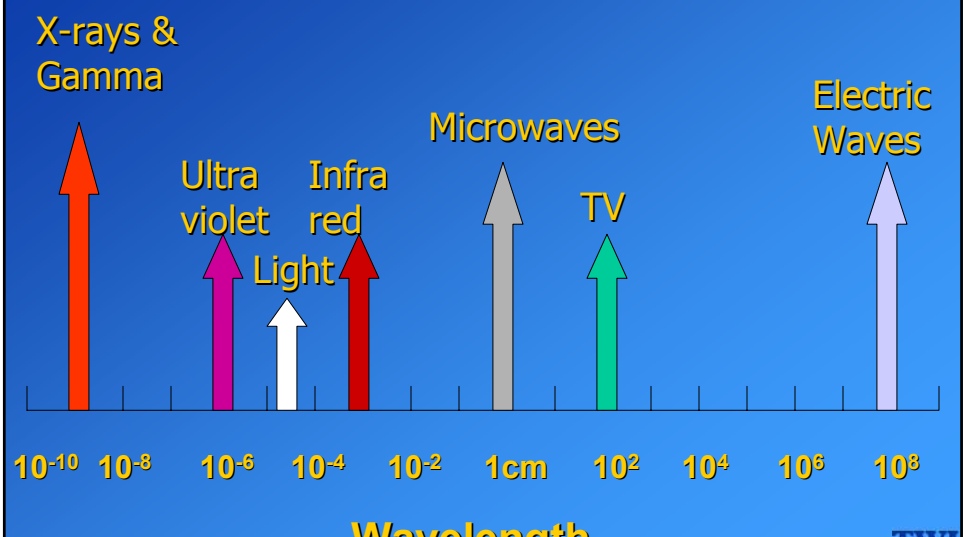
• Settlement test	Daily
• Fluorescent intensity	Weekly
• Test piece	Daily
• Viewing efficiency	Monthly

Maintenance Check Frequency

• Magnetising units	Weekly
• Tank levels	Daily
• UV lamp	Monthly
• Ammeters	6 monthly
• Demagnetiser	6 monthly

UV(A)

Electromagnetic Spectrum



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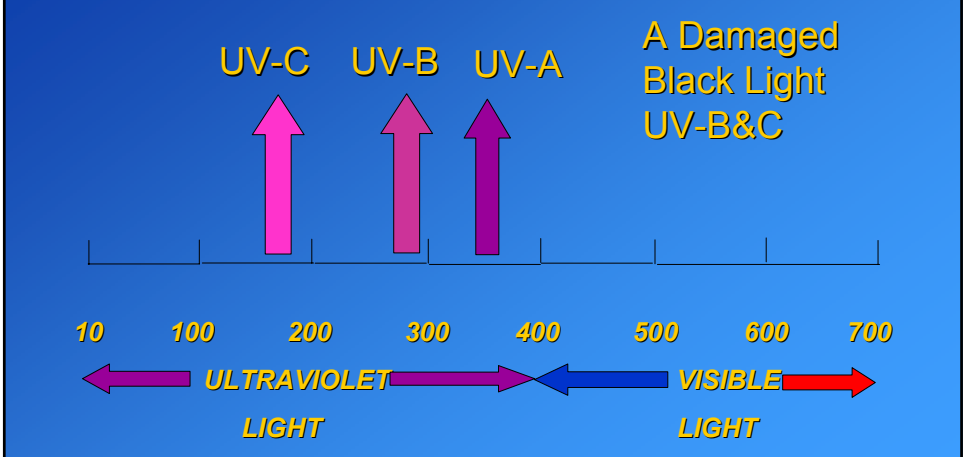
Electromagnetic Spectrum



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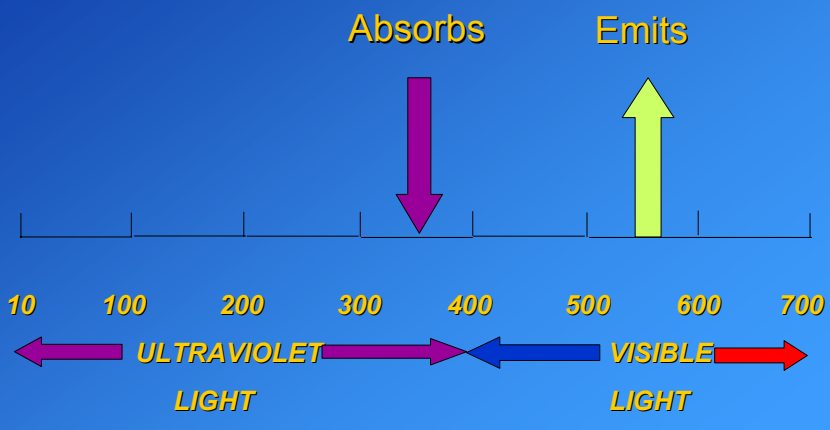
Fluorescence

UV-A Source : Mercury vapour arc lamp + Filter

Precautions

- **Avoid looking directly at the lamp**
- **Do not use if filter is cracked, damaged or incorrectly fitted**

Fluorescence and the Electromagnetic Spectrum



Fluorescent v Colour Contrast

- Fluorescent methods are more sensitive.
- Less operator fatigue with fluorescent.
- Background lacquer is not required.
- Fluorescent properties will degrade if exposed to UV light, acids, alkalis or high temperature.
- Background fluorescence is a problem on rough surfaces.
- Some oils will produce strong background fluorescence.
- Low background light levels are required.

Fluorescent v Colour Contrast

Black Particles **Fluorescent Particles**