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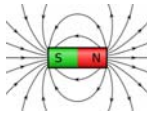
Advanced Electromagnetic Nondestructive Testing and Evaluation (NDT&E) ---MFL

• **Yong Li**

3/7/2017 ENDE 


Magnetism

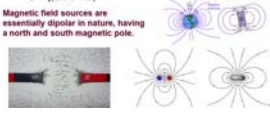
Magnetism is a class of physical phenomena that are mediated by **magnetic fields**, **Electric currents** and **the magnetic moments of elementary particles** give rise to a magnetic field, which acts on other currents and magnetic moments.





Sources of magnetism:

- > **Electric current** (Electron magnetic moment).
- > **Spin magnetic moments of elementary particles.** (The magnetic moments of the nuclei of atoms are typically thousands of times smaller than the electrons' magnetic moments, so they are negligible in the context of the magnetization of materials.)

Magnetic field
 Magnetic fields can be produced by moving electric charges and the intrinsic magnetic moments of elementary particles associated with a fundamental quantum property, their spin.
 $F = q(\mathbf{E} + \mathbf{v} \times \mathbf{B})$
 Magnetic field sources are essentially dipolar in nature, having a north and south magnetic pole.



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H-field and B-field


The magnetic field can be defined in several equivalent ways based on the effects it has on its environment.

B-field: the magnetic field is defined by the force it exerts on a moving charged particle.

$$\mathbf{F} = q(\mathbf{E} + \mathbf{v} \times \mathbf{B})$$

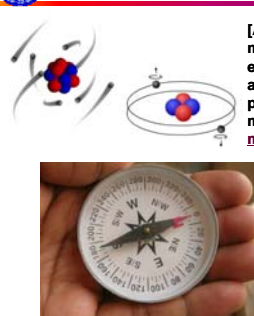
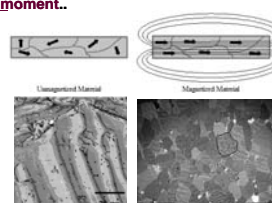
H-field: there is a quantity H , which is also sometimes called the magnetic field. In a vacuum, B and H are proportional to each other, with the multiplicative constant depending on the physical units. Inside a material they are different (H and $B \rightarrow$ inside and outside of magnetic materials).

$$\bar{B} = \mu_0(\bar{H} + \bar{M})$$

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Magnetisation

[Atoms] Electrons (in pairs) are in constant motion around the nucleus, carry a negative electrical charge and produce a magnetic field as they move through space. A magnetic field is produced whenever an electrical charge is in motion. The strength of this field is called the **magnetic moment**.

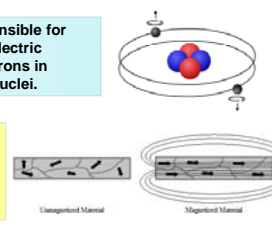
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Magnetisation

Magnetisation (magnetic polarization) is the vector field that expresses the density of permanent or induced magnetic dipole moments in a magnetic material.

The origin of the magnetic moments responsible for magnetization can be either microscopic electric currents resulting from the motion of electrons in atoms, or the spin of the electrons or the nuclei.

Net magnetization results from the response of a material to an external magnetic field, together with any unbalanced magnetic dipole moments that may be inherent in the material itself.



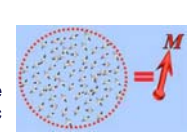
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Magnetisation

$$\vec{B} = \mu_0(\vec{H} + \vec{M})$$

- ❖ Diamagnetic materials (e.g. gold) have a weak, negative susceptibility to magnetic fields.
- ❖ Paramagnetic materials (e.g. lithium) have a small, positive susceptibility to magnetic fields.
- ❖ Ferromagnetic materials (e.g. steel) have a large, positive susceptibility to an external magnetic field.

$$\vec{M} = \chi_m \vec{H}$$

$$\vec{B} = \mu_0(\vec{H} + \vec{M}) \Rightarrow \mu_0(\vec{H} + \vec{M}) = \mu_0(1 + \chi)\vec{H} = \mu_r \mu_0 \vec{H} = \mu \vec{H}$$


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Initial magnetisation, Saturation

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BH loop/curve, Hysteresis

A great deal of information can be learned about the magnetic properties of a material by studying its 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.

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Magnetic Particle Inspection (MPI)

“This method is used for the detection of surface and near-surface flaws in **ferromagnetic materials** and is primarily used for crack detection. The specimen is **magnetised** either locally or overall, and if the material is sound the magnetic flux is predominantly inside the material. If, however, there is a surface-breaking flaw, the magnetic field is distorted, causing **local magnetic flux leakage** around the flaw. This leakage flux is displayed by covering the surface with very fine **iron particles** applied either dry or suspended in a liquid. The particles accumulate at the regions of flux leakage, producing a build-up which can be seen visually even when the crack opening is very narrow. Thus, a crack is indicated as a line of iron powder particles on the surface.”

---BNDT

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Basic principles of MPI

If the magnet is cracked, a north and south pole will form at each edge of the crack. The magnetic field exits the north pole and re-enters at the south pole. The magnetic field spreads out when it encounters the small air gap created by the crack because the air cannot support as much magnetic field per unit volume as the magnet can. When the field spreads out, it appears to leak out of the material and, thus is called a **flux leakage field**.

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Fringing field and Leakage field

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Magnetic Flux Leakage (MFL)

“As with MPI, the ferromagnetic specimen is magnetised, and depending upon the level of induced flux density, magnetic flux leakage due to both near- and far-surface flaws is detected by a **Hall effect element**, which is traversed over the surface of the specimen. Unlike MPI, the method is not limited to surface-breaking or near-surface flaws, but actually becomes increasingly sensitive to **far-surface flaws** with increasing levels of magnetisation.”

— BINDT

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Principles of MFL

The diagram illustrates the principles of Magnetic Flux Leakage (MFL). It shows a cross-section of a pipe with an internal coil and a magnet. Magnetic flux is applied to the pipe. In the presence of a defect, the magnetic flux leaks out of the pipe, creating a leakage field. The diagram compares a narrow defect and a wide defect, showing how the leakage field distribution changes. A graph plots the leakage field (A/T) against distance, showing a peak for a narrow defect and a broader peak for a wide defect.

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Principles of MFL

The diagram illustrates the principles of Magnetic Flux Leakage (MFL). It shows a cross-section of a pipe with an external magnet and sensors. Magnetic flux is applied to the pipe. In the presence of a defect, the magnetic flux leaks out of the pipe, creating a leakage field. The diagram compares an external defect and an internal defect, showing how the leakage field distribution changes. A graph plots the leakage field (A/T) against distance, showing a peak for an external defect and a broader peak for an internal defect.

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Magnetic field measurement

The diagram illustrates magnetic field measurement. It shows a cross-section of a pipe with a field sensor and a coil sensor. The field sensor measures the axial field, and the coil sensor measures the radial field. The diagram shows the field distribution and the output signals for both sensors. A graph plots the field sensor output (Axial Field) against distance, showing a peak for a defect.

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Factors influencing leakage field

- Strength of external field (80% saturation)
- Location of defects
- Ratio of defect depth to defect width
- Defect orientation
- Specimen coating
- Materials and condition of specimens

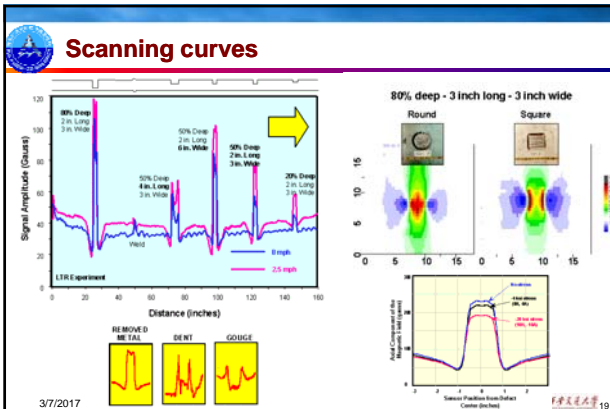
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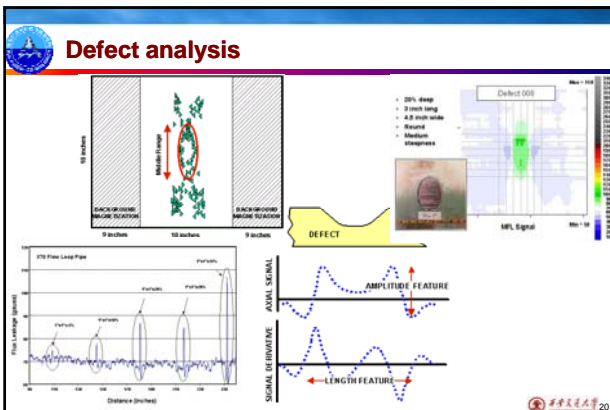
Scanning curves

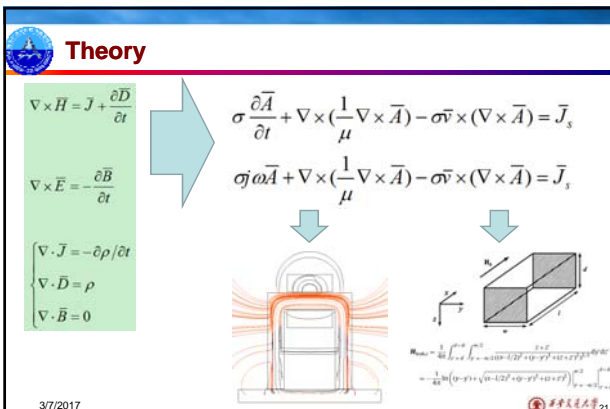
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Scanning curves

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Finite Element Modelling --- 3D MFL

$\nabla \times \vec{H} = 0$
 $\vec{B} = \mu_0 \mu_r \vec{H}$

$\vec{H} = -\nabla V_m$

The diagram shows a 3D model of a rectangular specimen with a surface defect. The defect is a rectangular notch on the top surface. The specimen is placed on a base. The magnetic field distribution is visualized in four plots, showing the field lines around the defect. The plots are labeled with H_x and H_y components.

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Finite Element Modelling --- Dynamic MFL

The diagram illustrates a dynamic MFL system. It includes a ferrite core with a coil wound around it. A specimen is placed between the poles of the core. The dimensions of the core and specimen are given: 10mm, 20mm, 1mm, and 10mm. The current density J is shown in two plots, with a color scale ranging from 0.0000e+000 to 2.0702e+007 A/m². A sensor array is also shown. A graph on the right shows the current density over time.

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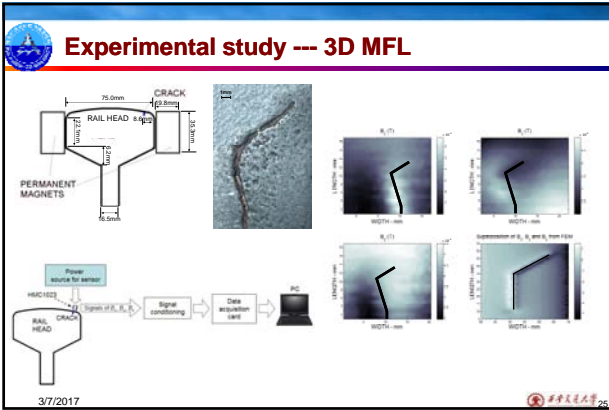
MFL system

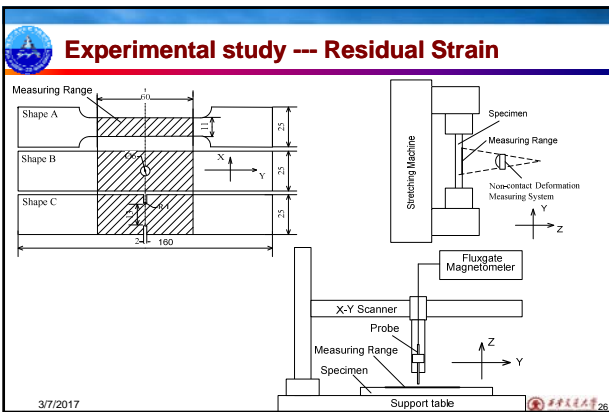
Magnetiser + Sensing element + Scanner

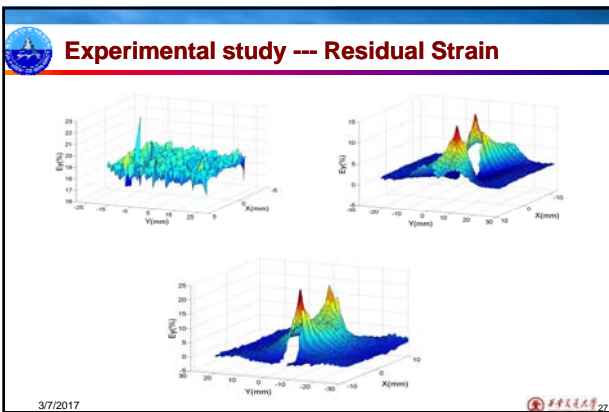
The block diagram shows the MFL system components: Power source for sensor, HMC1023, RAIL CRACK HEAD, Signal conditioning, Data acquisition card, and PC. The signal flow is: Power source for sensor → HMC1023 → Signals of B_x, B_y → Signal conditioning → Data acquisition card → PC.

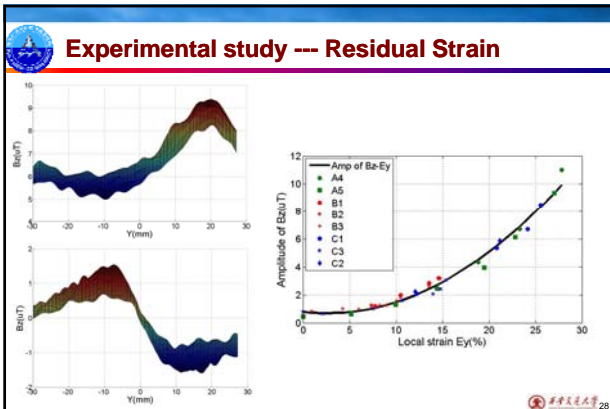
Magnetiser: Permanent magnets or Electromagnets
Sensing element: Hall devices, GMR, AMR, etc.

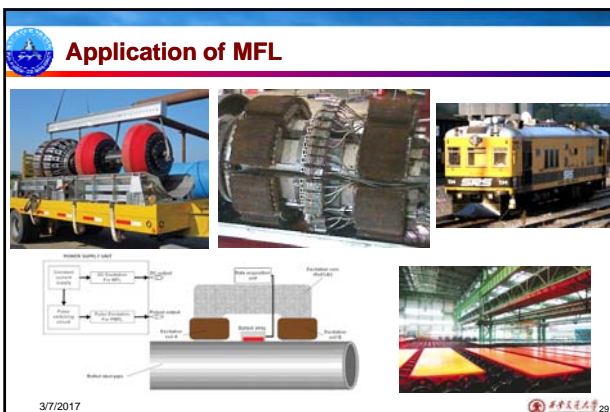
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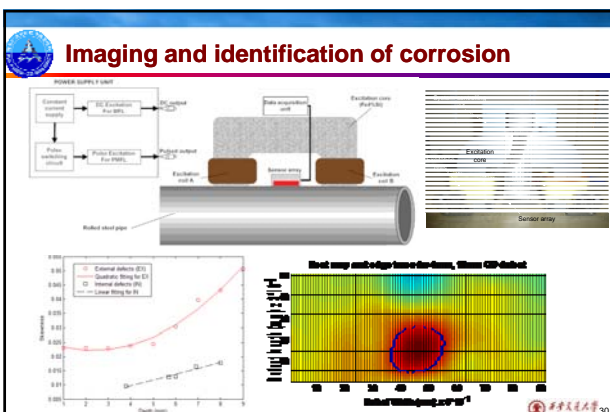












Thank you!
and Any Questions?



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