Three-Dimensional Finite Element Modeling of Magnetic Flux Leakage Technique for Detection of Defects in Carbon Steel Plates

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Outline of Presentation

# Non Destructive Testing (NDT)?

Definition: Testing or inspection of materials / components / structures without destroying or impairing their intended use is Non Destructive Testing (NDT)

Two types of material testing:

- ✓ Destructive (stress-strain, creep, fatigue etc.)

- ✓ Non-destructive (ultrasonic, eddy current, X-radiography, magnetic particle etc.)

Component can be used as-it-is, after NDT

Generic NDT System
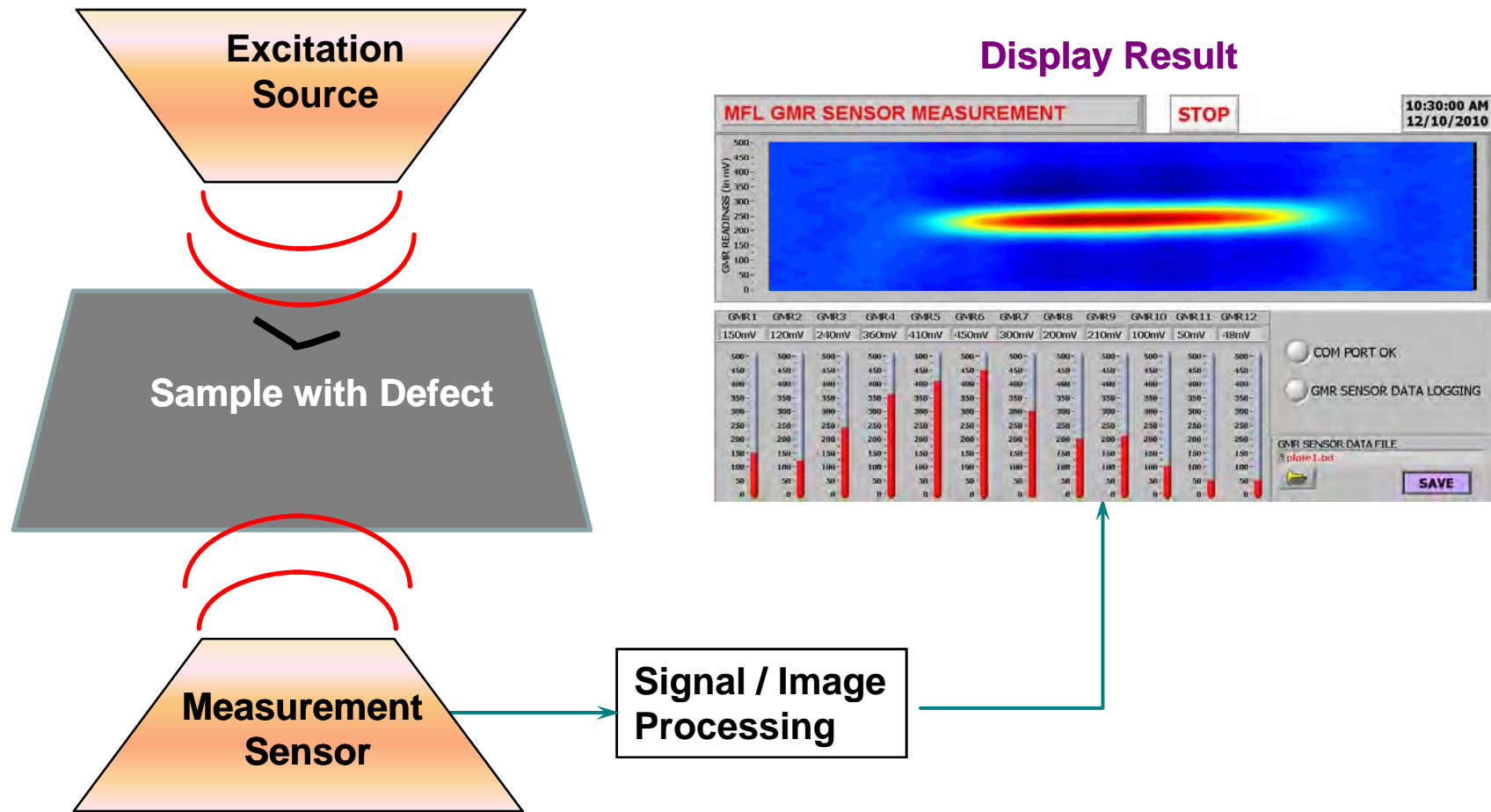
Every NDT technique is based on physical principles and nearly all forms of energy is utilized in NDT

Various NDT Techniques

- ➢ **Visual**
- ➢ **Ultrasonic**
- ➢ **Magnetic Particle**
- ➢ **Magnetic Flux Leakage**
- ➢ **Eddy Current**
- ➢ **Radiography**
- ➢ **Acoustic Emission**
- ➢ **Infrared Thermography**

✓**More than 50 NDT techniques are available today for detection of defects in materials, components and structures.**

✓**Selection of technique is very important depending on the material, capability, access and cost.**

Magnetic Flux Leakage Technique - Principle

Widely preferred nondestructive detection of defects in ferromagnetic materials.

Principle:

When a ferromagnetic material is magnetized, the magnetic flux lines are confined within the material.

When the material has any defect, the magnetic flux lines bend around the defect and, a part of flux lines leak out of the surface. This leakage flux is detected by magnetic sensors and used to estimate the shape and size of the defect.

Normal

Tangential
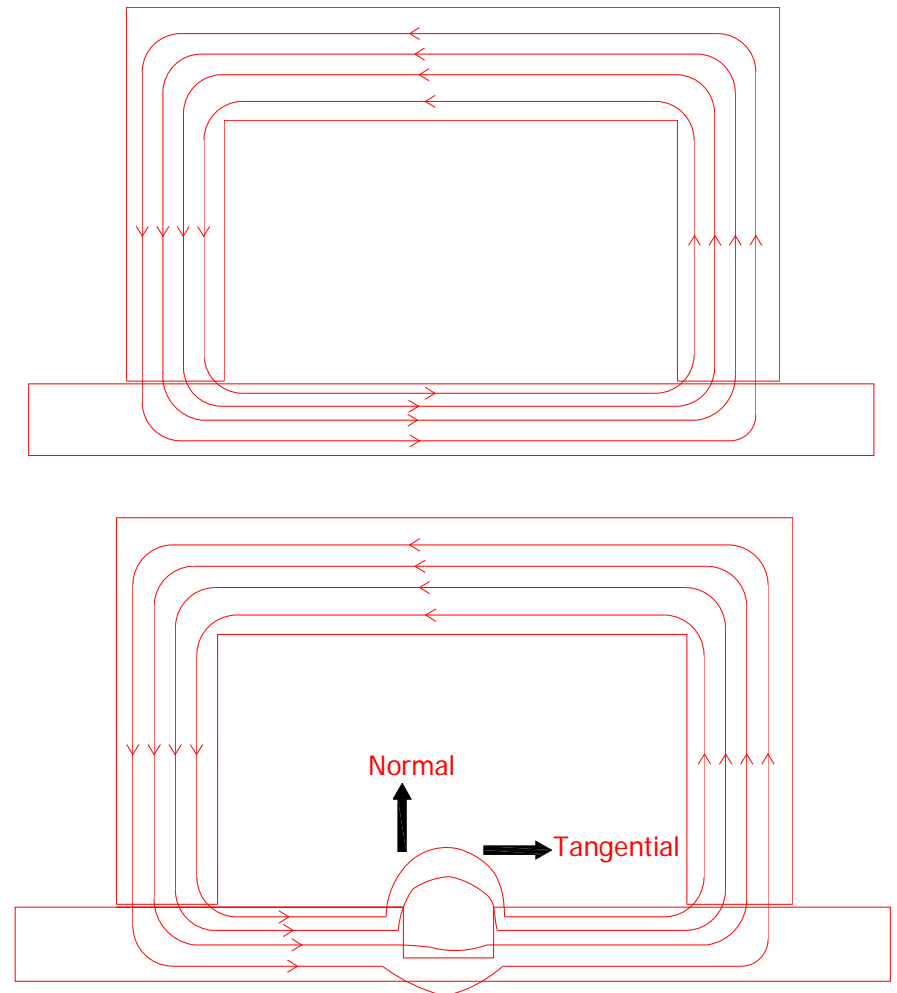
MFL Technique - Features

Field Detection Sensors:

- Inductive coils (pick-up coils)
- Hall probes (semi conductor)
- Giant Magneto-resistive (GMR) sensors
- Giant Magneto-impedance (GMI) sensors

MFL technique detects and sizes surface and sub-surface defects.

Applications:

- ❖ Inspection of oil and gas pipelines using Pipe Inspection Gauges (PIGs)
- ❖ Corrosion detection in storage tanks, damages in wire ropes and rail tracks
- ❖ Automated testing of axi-symmetric components in production-line.

MFL Inspection of Pipes
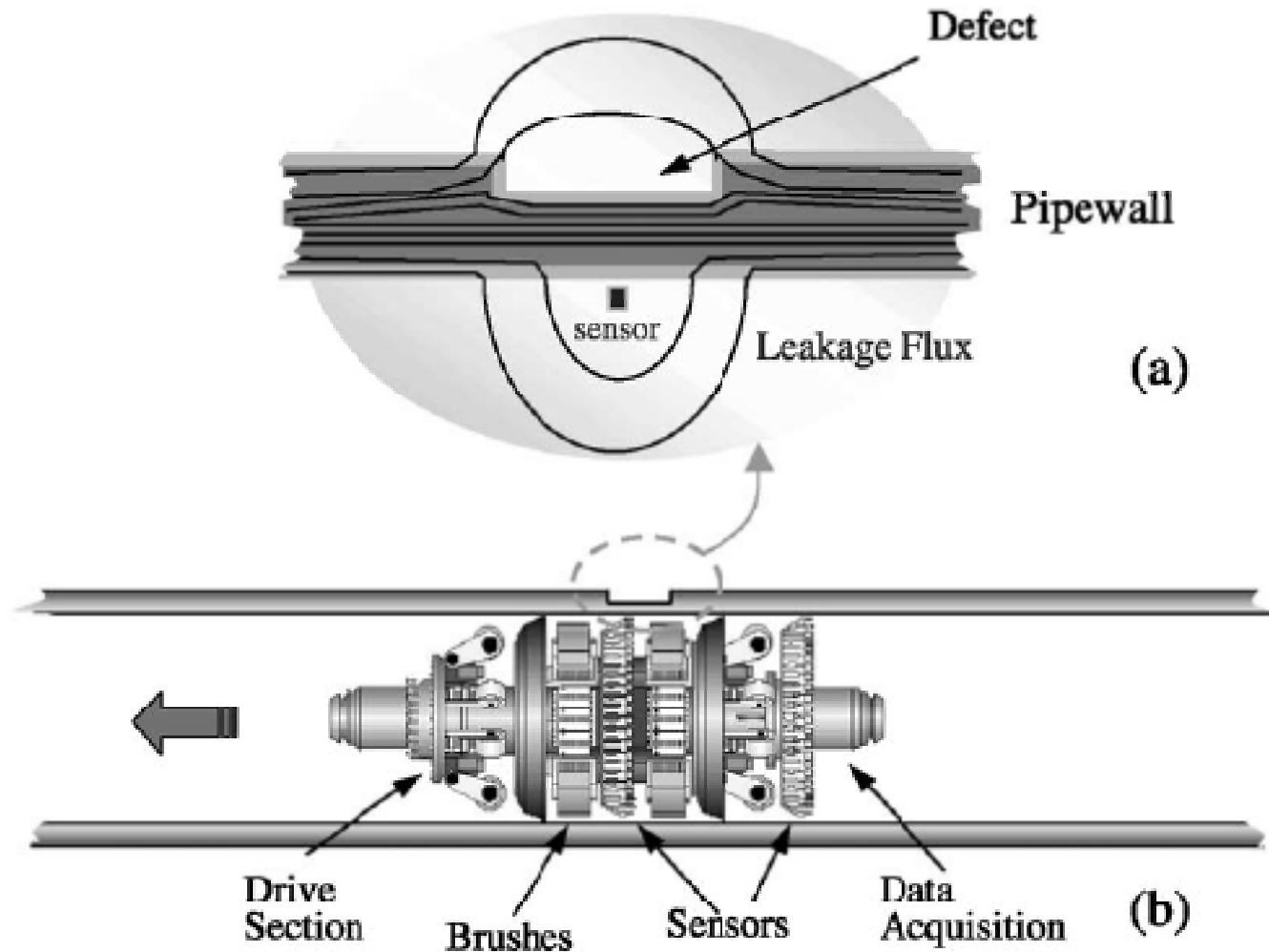
Inspection using Pipe Inspection Gauge (PIG)- Automated expert system for data analysis, interpretation and decision making
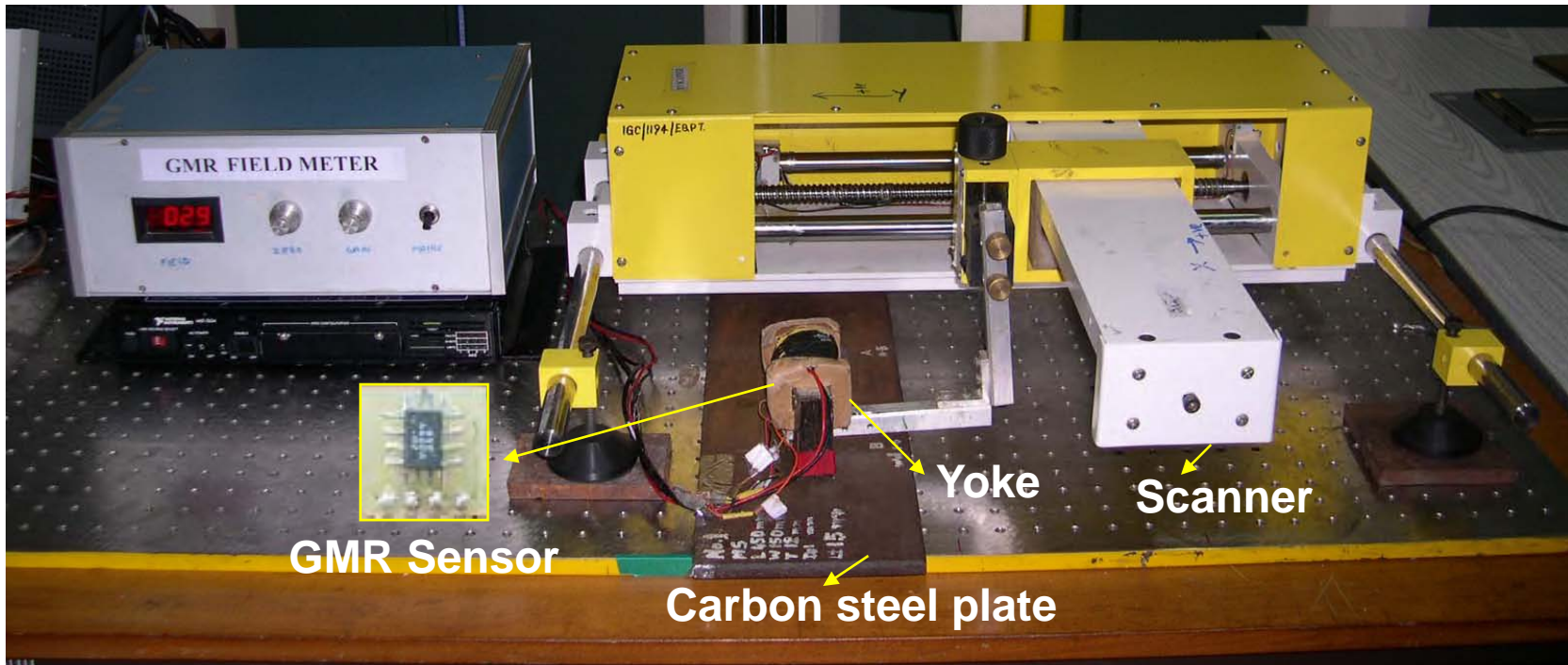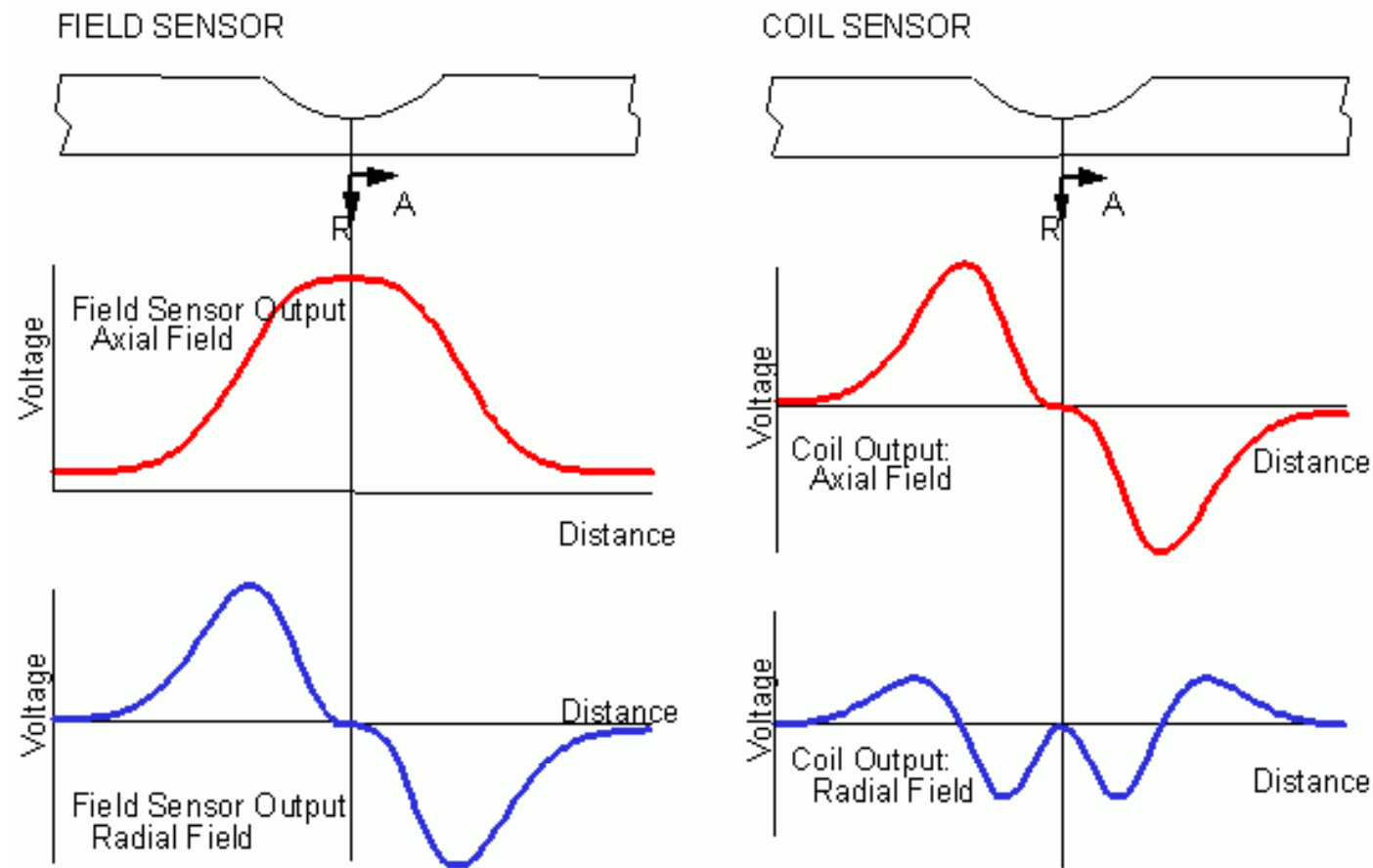
Typical MFL experimental setup

Labels in image: GMR FIELD METER, GMR Sensor, Yoke, Scanner, Carbon steel plate

Important Aspects:

- proper magnetization of material
- detection of leakage flux using a suitable sensor
- processing raw data to enhance SNR and
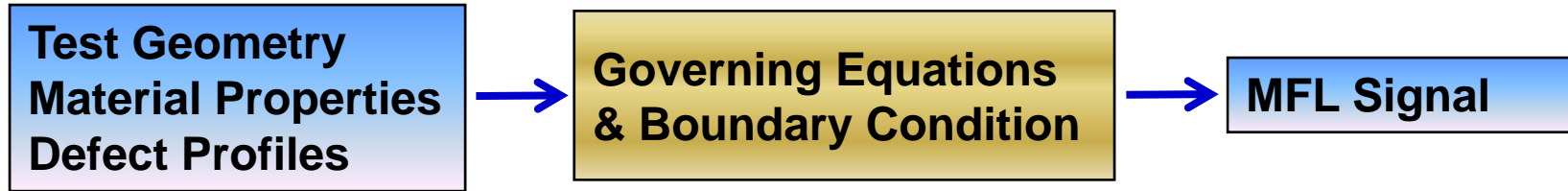- interpretation of test results

Defect-free region

Leakage flux

Defect region

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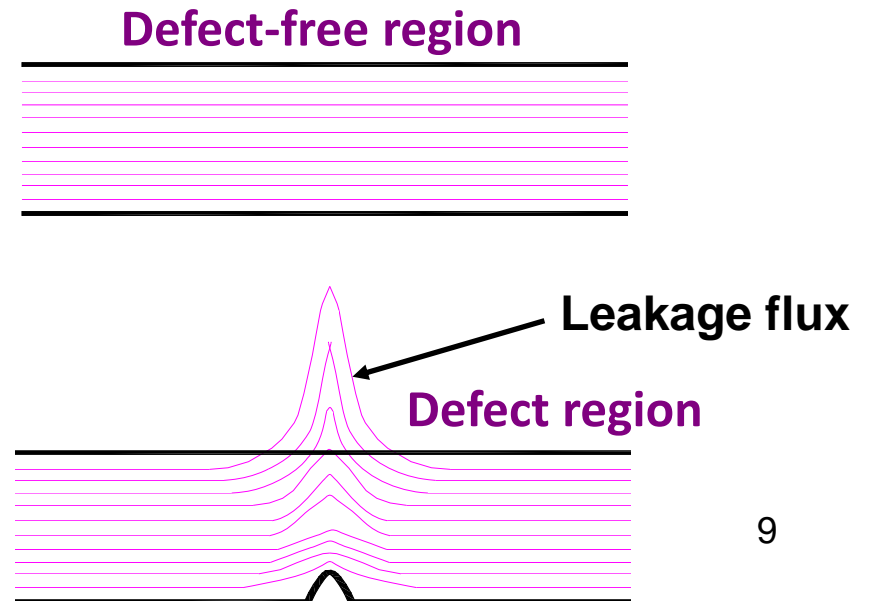
Field Sensor vs. Coil Sensor

➢ **Coils measure the rate of change of a magnetic field**
➢ **Hall & GMRs measure the actual magnetic field**
➢ **Speed of testing influences the measured output**

MFL Modeling

| Test Geometry Material Properties Defect Profiles | → | Governing Equations & Boundary Condition | → | MFL Signal |

Purpose of modeling:

❑ **Visualization of field/defect interactions**

❑ **Optimization of sensor/system design**

❑ **Parametric studies**

❑ **Generation of defect signatures for training database**

❑ **Better understanding and effective utilization of MFL technique**

Methods of MFL Modeling

- <u>**Analytical method:**</u>
  - Defects are assumed as magnetic dipoles
  - MFL signals are calculated from the magnetic field of the magnetic dipoles
    - Offer closed form solution
    - Good for simple geometries

- <u>**Numerical method:**</u>
  - Finite difference
  - Finite element (FE)
  - Boundary element
    - Can handle complicated geometries
    - Usually require intensive computer resources

FE method is capable of modeling of nonlinear problems and irregular geometries which are difficult to be modeled analytically.

Finite Element (FE) Method

- **Procedure:**
  - **Create geometry**
  - **Generate mesh (discretize solution domain)**
  - **Select basis function**
  - **Formulate matrix equation**
  - **Impose boundary conditions**
  - **Solve matrix equation**
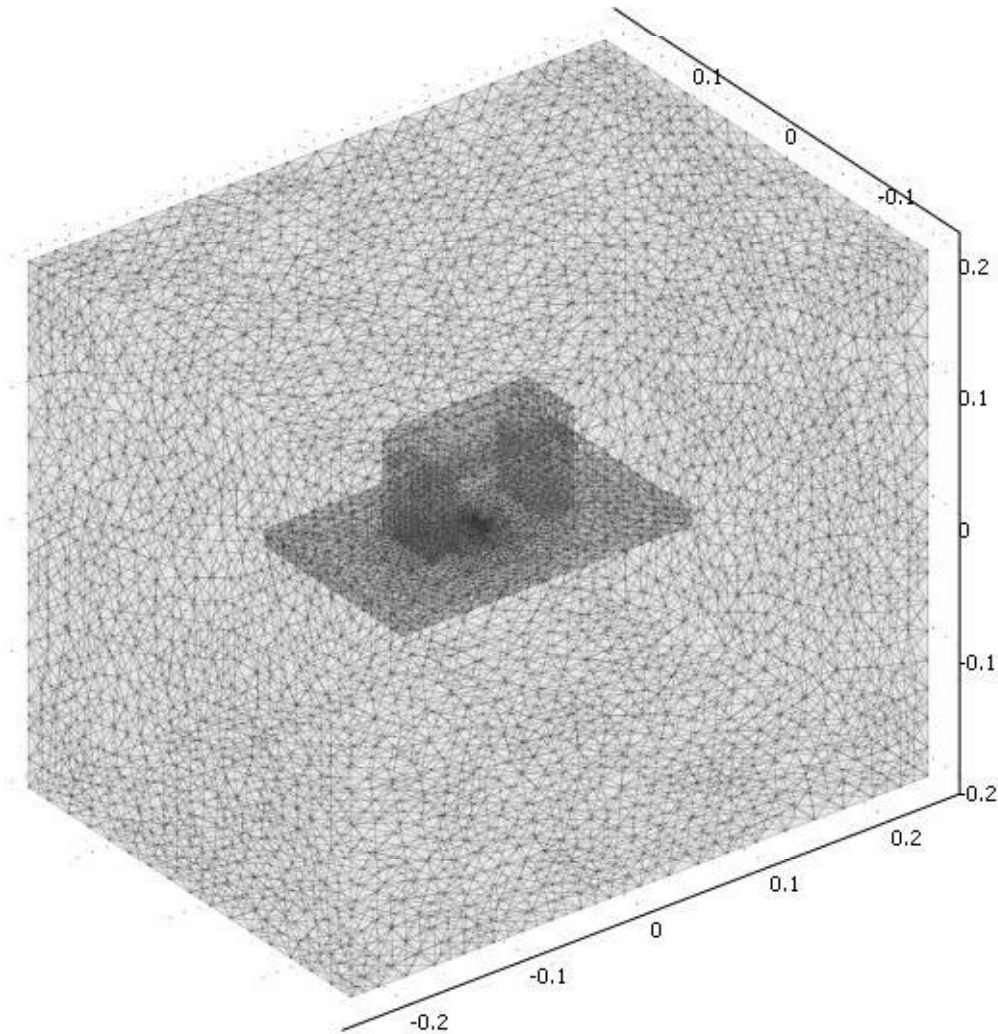 - **Post-processing**

3D MFL FE Modeling
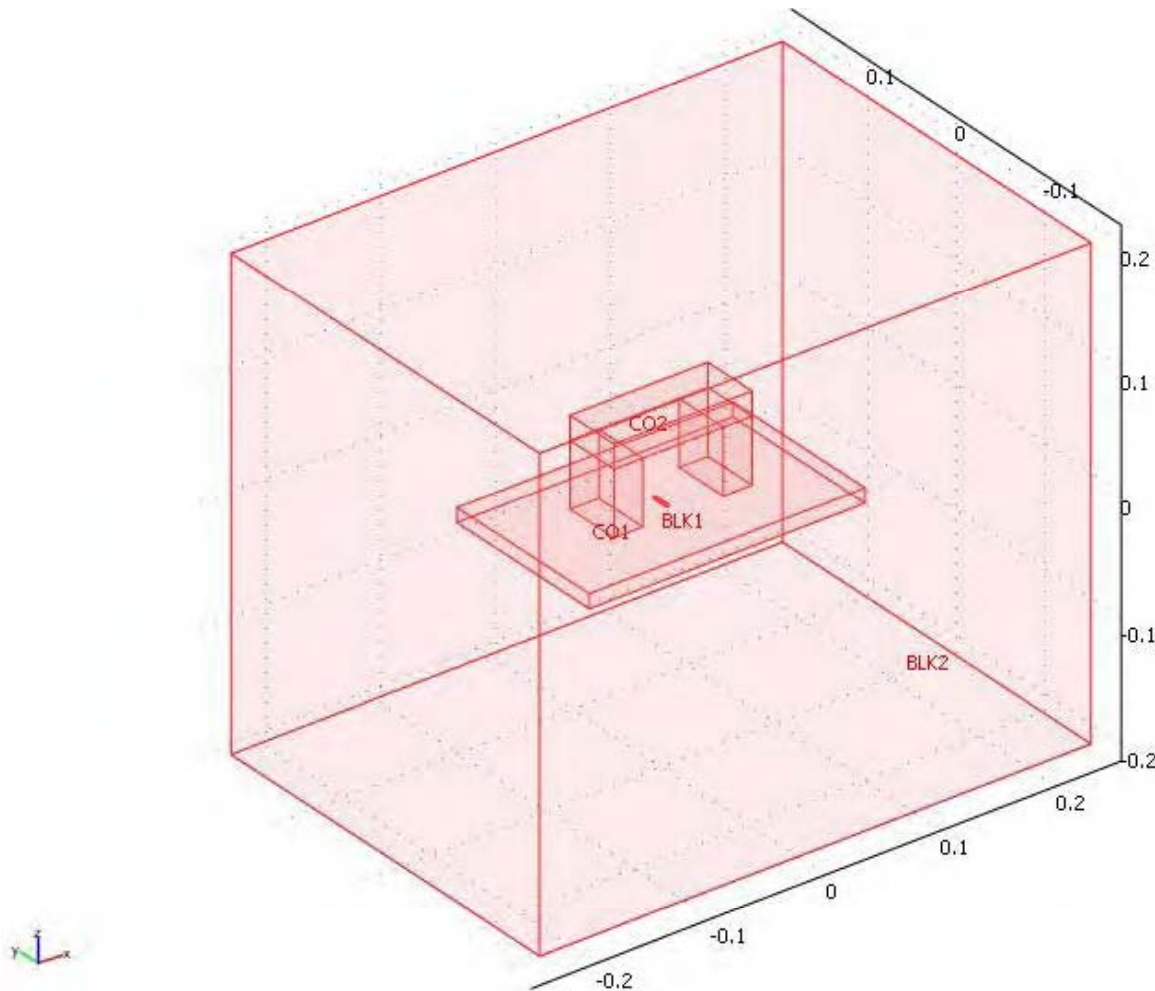
Dimension:
Permanent magnet:
Length 90 mm, cross-sectional area 55 x 50 mm^2, leg spacing 70 mm
Carbon steel plate:
Length 240 mm, breadth 150 mm, thickness 12 mm) with 15 mm long slot

Mesh Structure of 3D MFL Modeling

COMSOL 3.4 multiphysics software
Magnet: M = 100000 A/m
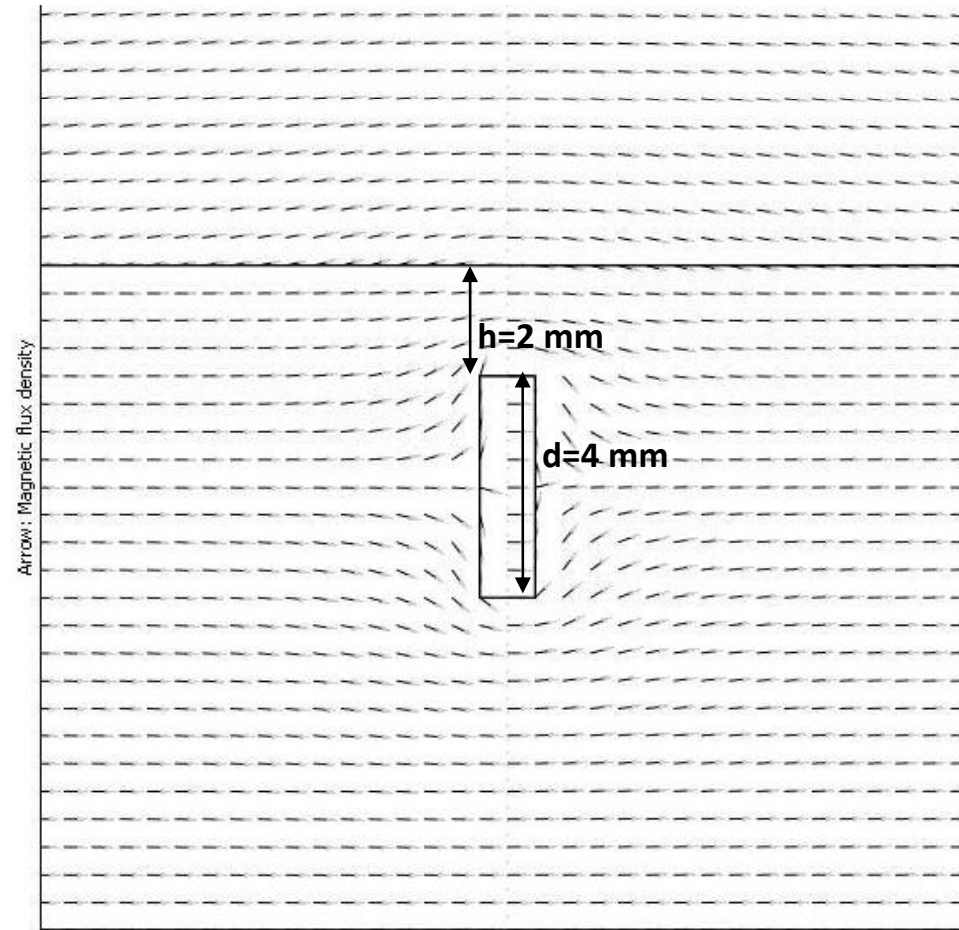**Carbon steel plate: μ_r = 100**
Mesh: 214984 tetrahedral elements
Solution time : 2 hours in dual core 64 bit processor workstation
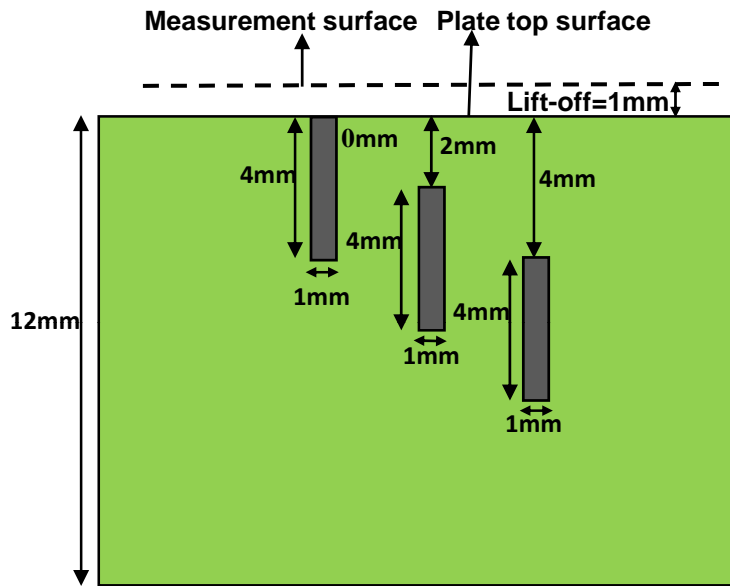**The following equation is solved using FE method:**

$$\nabla \times \left(\mu_0^{-1} \mu_r^{-1} \nabla \times A \right) = J$$

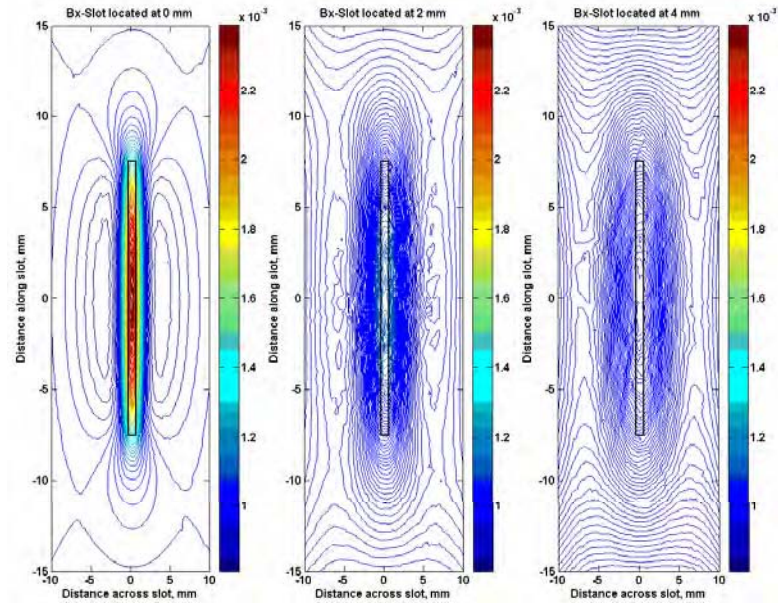# Arrow plot for a 4 mm deep sub-surface slot located at 2 mm below plate surface

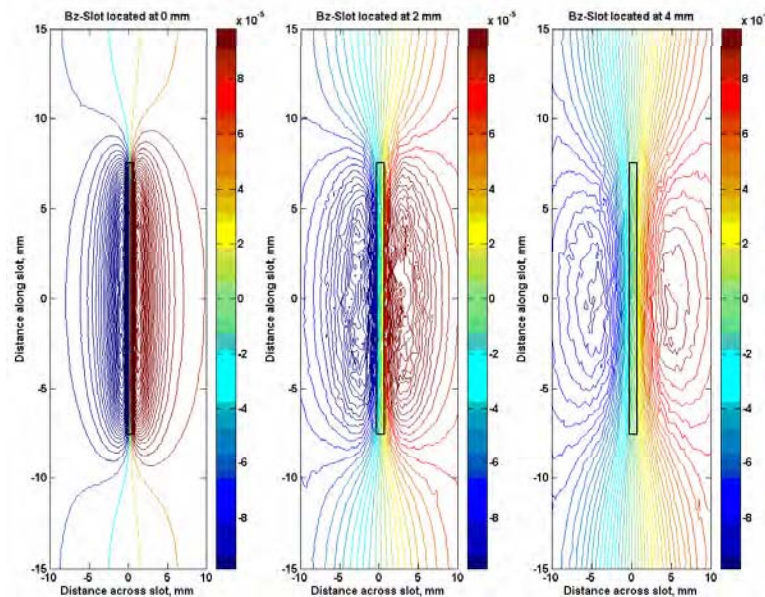**Sub-surface defects are difficult to simulate experimentally**

Effect of Defect Location

Measurement surface   Plate top surface

Lift-off=1mm

0mm

4mm

2mm

4mm

4mm

4mm

1mm

1mm

1mm

12mm

B_x component

B_z component

Intensity of leakage fields decreases with the increase in defect location below the surface while the lateral spread of fields increases
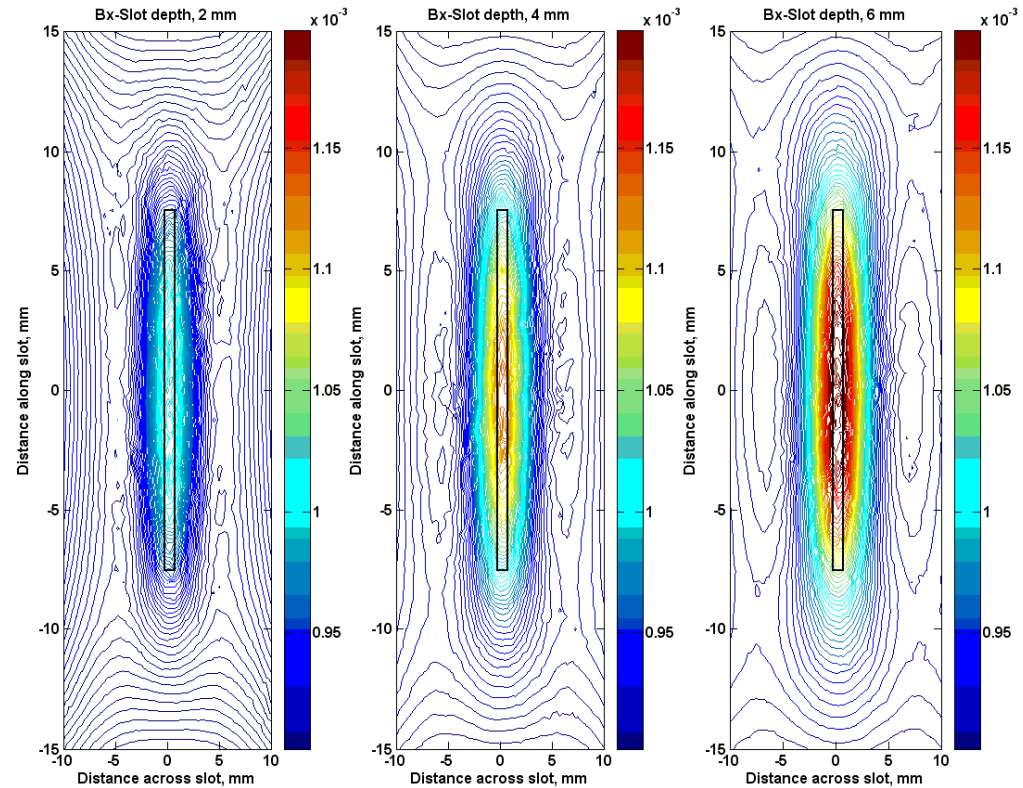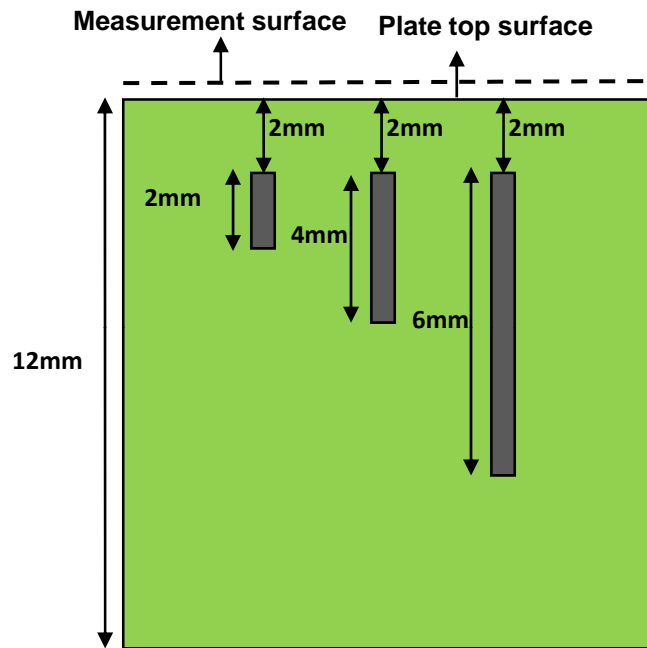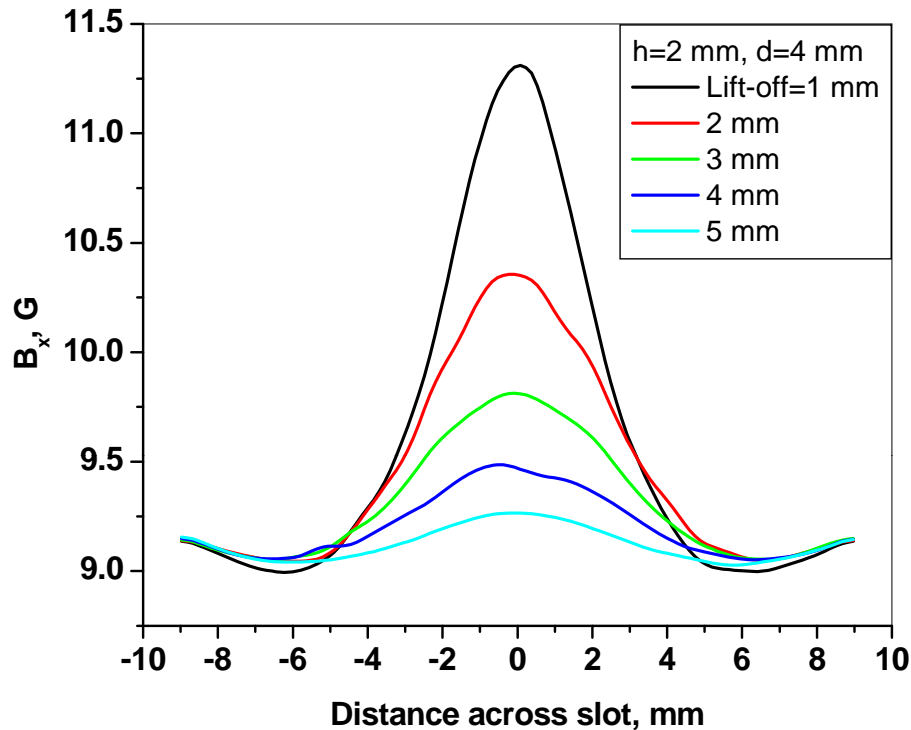
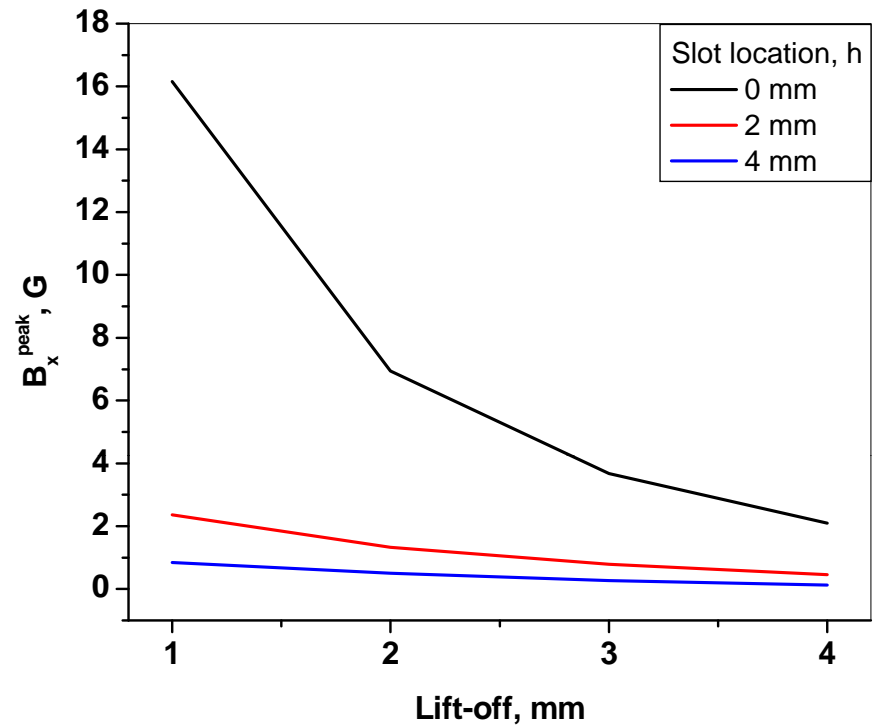17

Effect of Defect Depth

Intensity as well as lateral spread of leakage fields for the same slot location increase with the increase in slot depth

Effect of Lift-off

MFL signals for a 4 mm deep sub-surface slot for different lift-offs

MFL signal peak amplitudes for a 4 mm deep slot as a function of lift-off

MFL signal amplitude decreases with the increase in lift-off. The decrease of signal amplitude is more prominent for the surface slot as compared to sub-surface slots.

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Summary

- Three-dimensional FE modeling has been performed to study the detectability of sub-surface defects in MFL technique .

- The Intensity of leakage fields decreases with the increase in defect location while the lateral spread of fields increases.

- The intensity as well as lateral spread of leakage fields increase with the increase in defect depth.

- MFL signal amplitude decreases with the increase in lift-off and it is more prominent for the surface defects as compared to sub-surface defects.

- Features such as peak amplitudes, full width at half maximum (FWHM), slope, etc. extracted from the model predicted signals may be useful for characterisation of defects.

THANK YOU