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[RELIABILITY] [TECHNOLOGY]

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[INDEPENDENT]

[CAN DO]

**USIMINAS**
**TRAINING PLAMAT –MM -8M**
**DECEMBER 2021**

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# TRAINING PLAMAT –MM -8M
CONTENT

- Agenda
- Introduction – Hardspots
- Hardware
- Measurement Approach
- Software

# TRAINING PLAMAT –MM -8M

## AGENDA

| Date | Start / End | Description | Group |
|---|---|---|---|
| Mo., Dec. 6th | 9 am / 1 pm | - Introduction,<br>- Overview Hardware<br>- Measurement Approach<br>- Software and Procedures | All |
| Tu., Dec 7th | 8 am / 1 pm | - Starting the system<br>- Referencing and teaching<br>- Conducting a measurement<br>- Scan procedure<br>- Reporting<br>- Maintaining the system | Group 1 |
| We., Dec 8th | 9 am / 1 pm | | Group 2 |
| Th., Dec 9th | 8 am / 1 pm | | Group 3 |
| Fr., Dec 10th | 8 am / 12 pm | - Open questions<br>- Way forward<br>- Wrap up | All |

# TRAINING PLAMAT –MM -8M

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# TRAINING PLAMAT –MM -8M
## INTRODUCTION - HARDSPOT

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- Various threads compromise the integrity of steel structures (e.g. pipelines, platforms, heavy plates, …) during their lifespan

- Besides cracking and metal loss, e.g. due to corrosion, changes in steel properties also play a crucial role during the lifetime of an asset

- Localized variations in material properties are a direct result of changes in both the electromagnetic (magnetization) and mechanical configuration (displacement in lattice structure): metallurgical changes in microstructure

- Areas with locally increased steel hardness are referred to as hard spots

- Improper quenching or cold work during manufacturing as well as carbon enrichment or a sour environment (hydrogen sulfide) promote hard spots

# TRAINING PLAMAT –MM -8M

## INTRODUCTION - HARDSPOT MECHANISMS

Different Hardening mechanisms are identified:

- Martensitic microstructure (quenching)
- Carbon enrichment
- Change of grain size
- Bainitic microstructure

=> Process optimization of steel production

Requirements as in 2019 for hardspot detection:

- Detection thresholds :
  - minimum Hard Spot dimensions: length x width = 20 x 20mm .
  - Minimum surface hardness: 250 HV
  - Hardening depth ~1mm
- Max scan velocity: 1m/s

# TRAINING PLAMAT –MM -8M

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# TRAINING PLAMAT –MM -8M
## HARDWARE - OVERVIEW

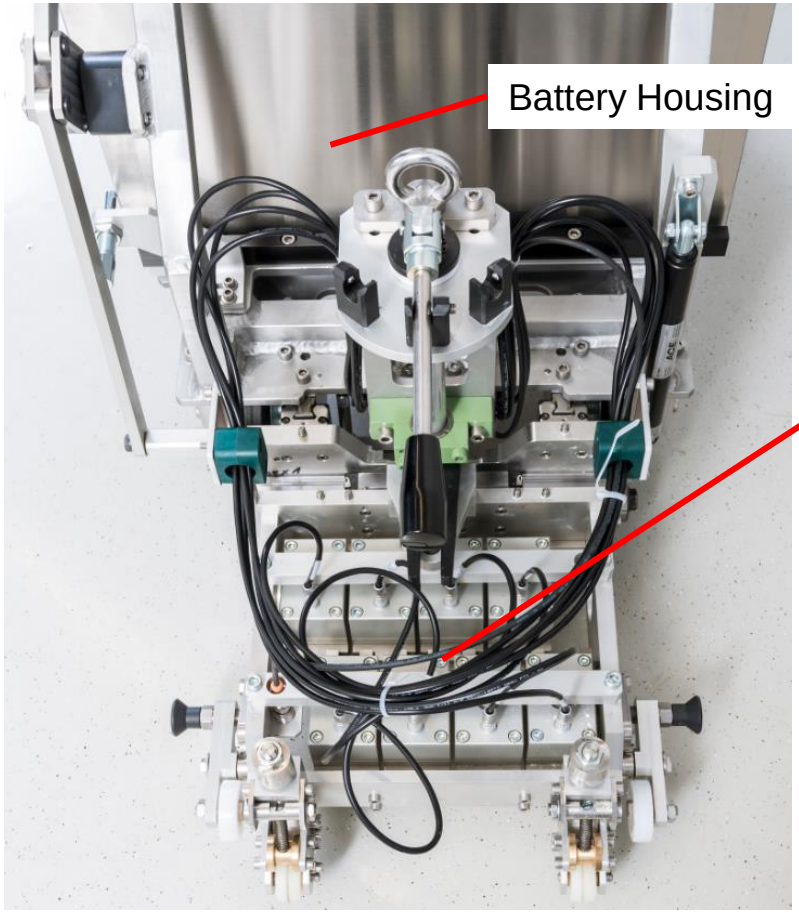

| Pos. | Description | | Pos. | Description |
|---|---|---|---|---|
| 1 | Crane eye | | 7 | Encoder (here: covered) |
| 2 | Gas brake | | 8 | Battery |
| 3 | Transversal adjustment | | 9 | Electronics |
| 4 | Chalk marking | | 10 | Lifting handle |
| 5 | Inspection unit with 8 probes | | 11 | Notebook |
| 6 | Guide rollers | | | |

# TRAINING PLAMAT –MM -8M
## HARDWARE - OVERVIEW

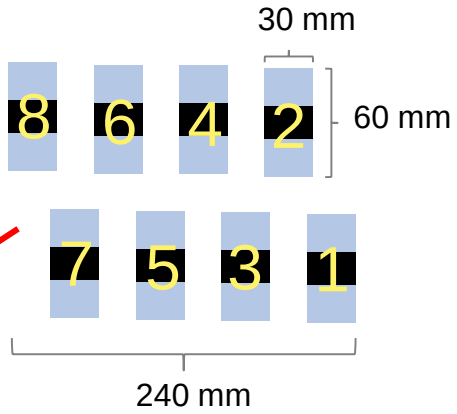

| Pos. | Description | | Pos. | Description |
|---|---|---|---|---|
| 1 | Shaft | | 6 | Rolling ledge |
| 2 | Socket | | 7 | Snapping bolt |
| 3 | Rail system | | 8 | Clamping piece |
| 4 | Bearing (here: covered) | | 9 | Snapping piece |
| 5 | Wheels | | | |

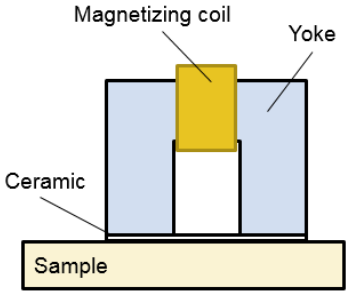
Weight approx. 90 kg

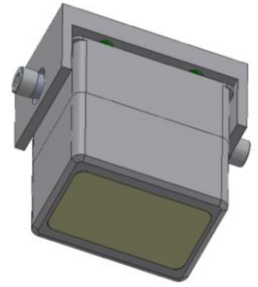
# TRAINING PLAMAT –MM -8M
## HARDWARE – SENSOR UNIT




**Probe Configuration**

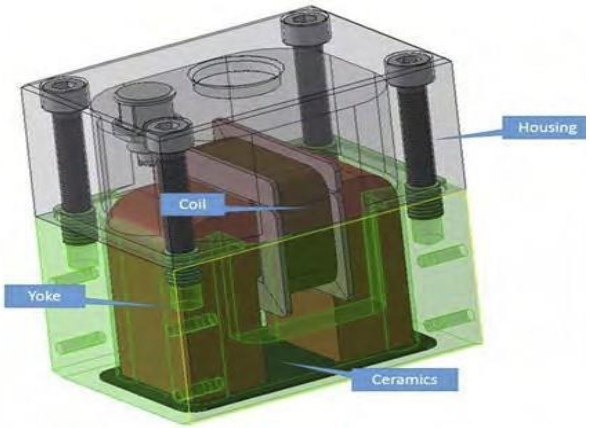


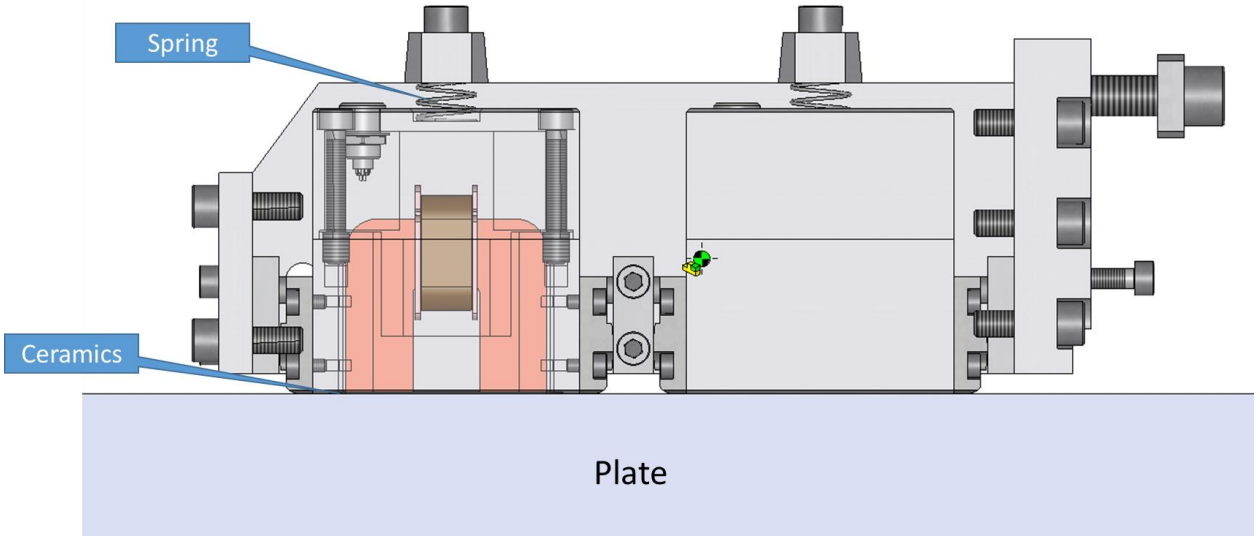



- flexible sensor suspension for contour following
- no lift-off between sensor and plate

# TRAINING PLAMAT –MM -8M
## HARDWARE – SENSOR UNIT



# TRAINING PLAMAT –MM -8M
## HARDWARE – SENSOR UNIT

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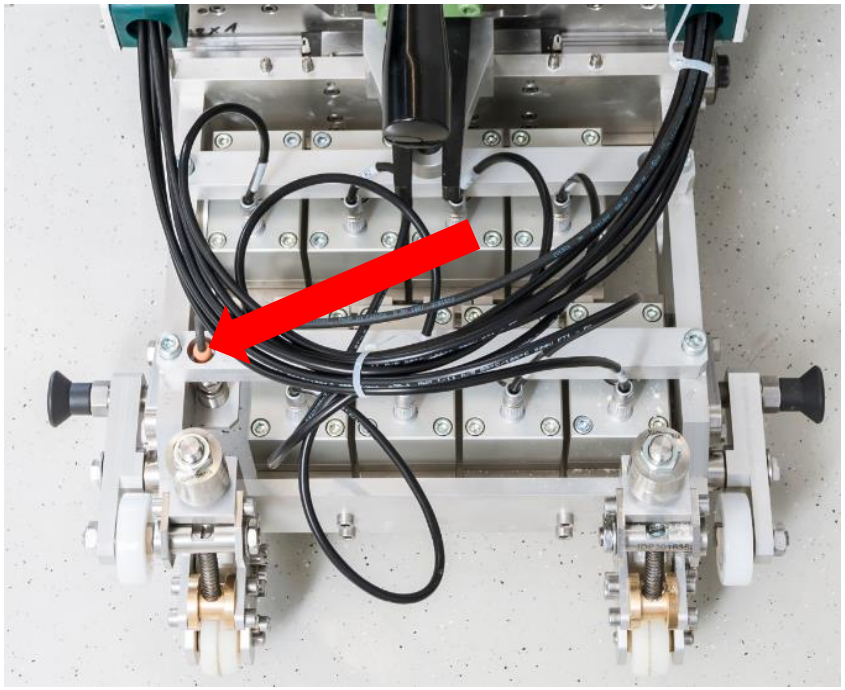
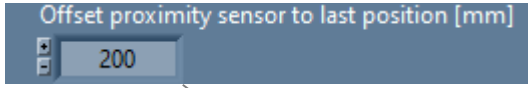
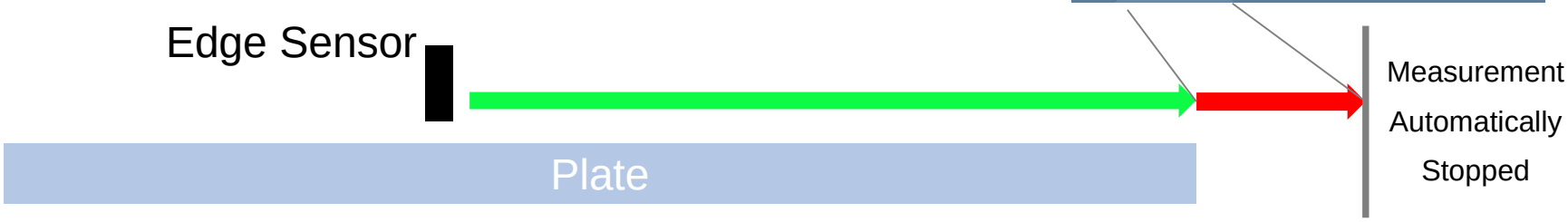
- Additional proximity sensor for detecting the plate transversal edge
- Two states:

- Measurement automatically stops beyond plate edge
- Important for scanning procedure

In expert setting:



# TRAINING PLAMAT –MM -8M
## HARDWARE – POWER SUPPLY: BATTERY

- 24 VDC LithiumIon Batteries
- Max dim. 250 x 225 x 500 mm (H x W x D)

# TRAINING PLAMAT –MM -8M
## HARDWARE – POWER SUPPLY: MAINS


- Instead of battery: ACDC Converter
- Converts local voltage to 24 VDC

# TRAINING PLAMAT –MM -8M

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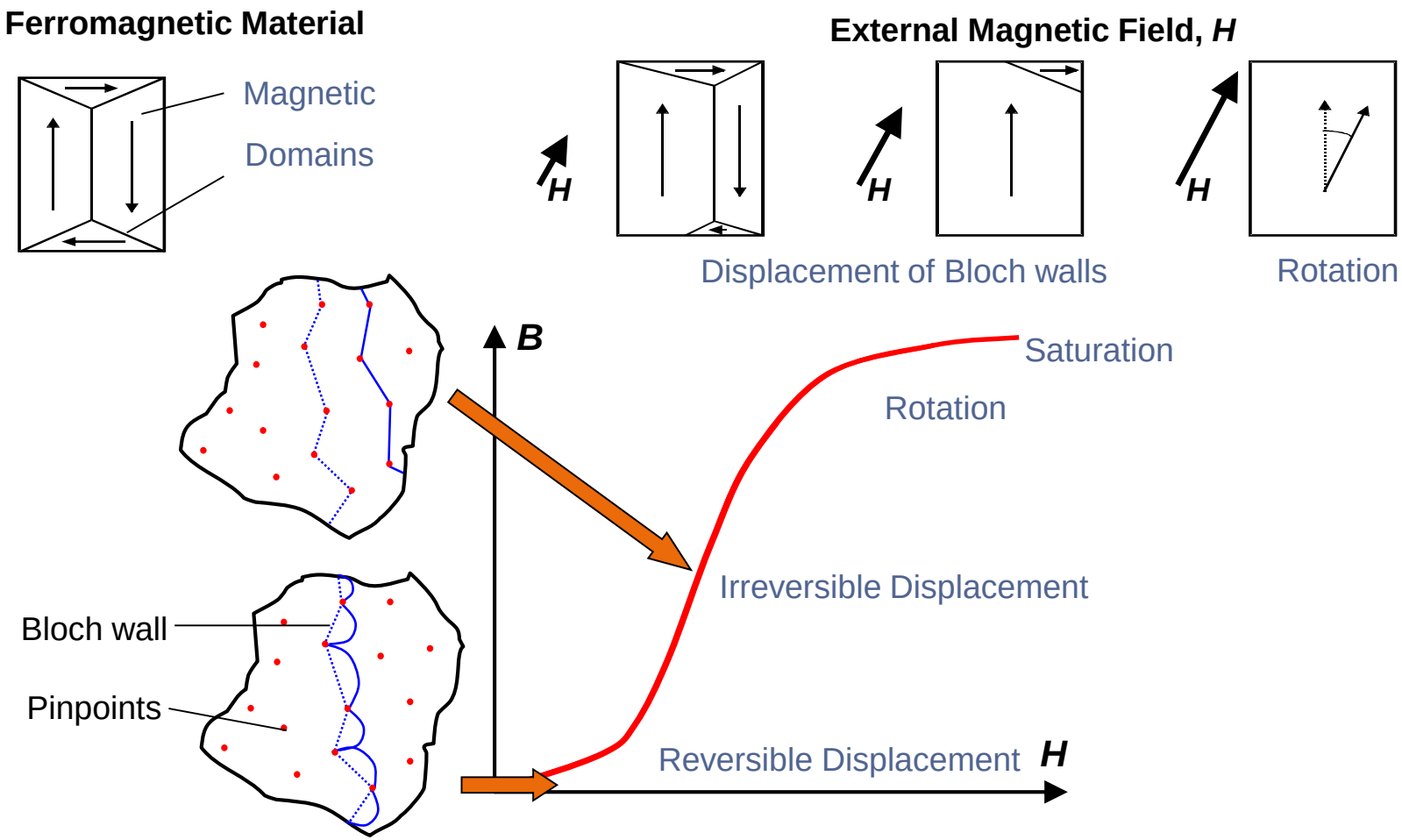
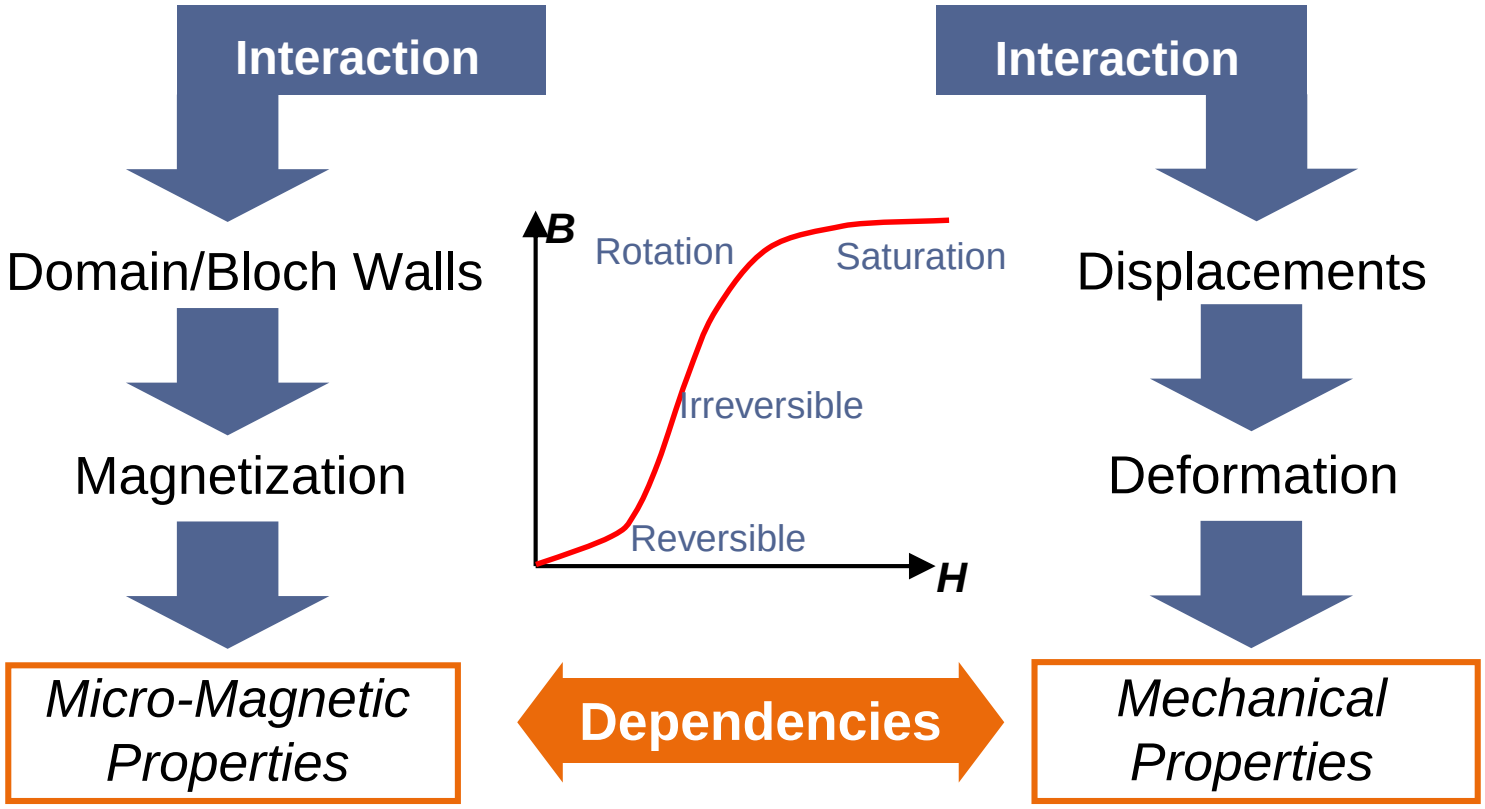
# MEASUREMENT APPROACH – BASICS: HYSTERESIS



# MEASUREMENT APPROACH – BASICS: HYSTERESIS

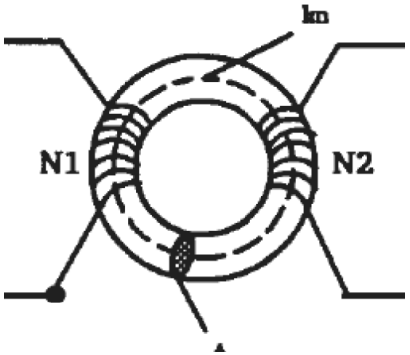
Fundamental methodology for material characterization

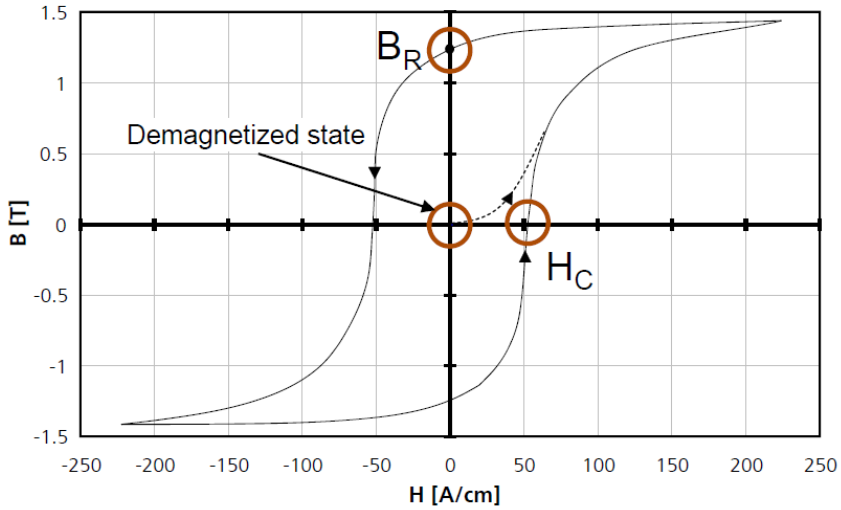


# TRAINING PLAMAT –MM -8M

## MEASUREMENT APPROACH – BASICS: HYSTERESIS

- Hysteresis: non-linear response to applied Magnetic field $H$
- Hysteresis curve depends on:
  - Chemical composition
  - Size and shape
  - Measuring frequency and amplitude
  - Stress
  - Hardness
- Characteristic features like remanent flux $B_R$ or coercive field $H_C$ usefull for material property determination



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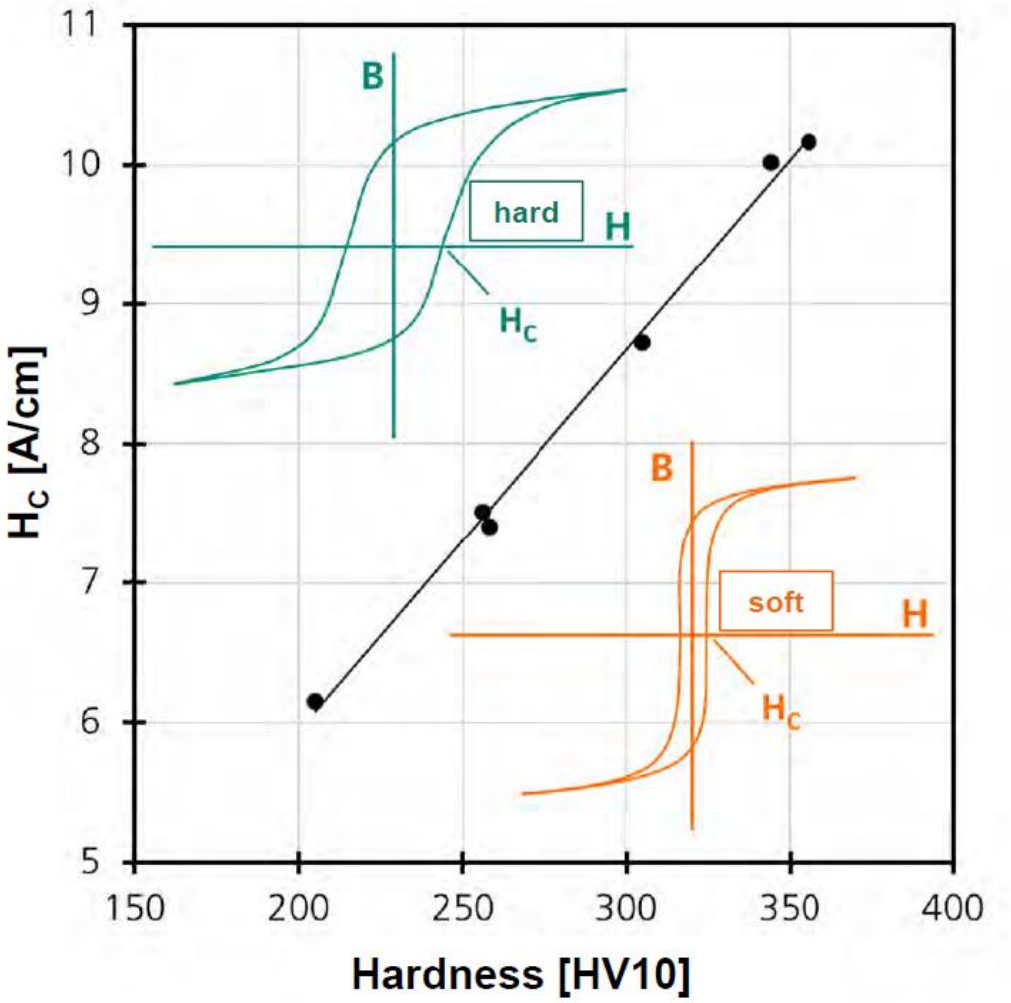
# MEASUREMENT APPROACH – BASICS: HYSTERESIS

- Magnetic hard material show wider hysteresis curves
- Correlation between magnetic and mechanic hardness often found
- Defects in crystal structure hinder mechanical movement and magnetic domain wall movement
- BUT: measured slowly on specific geometries



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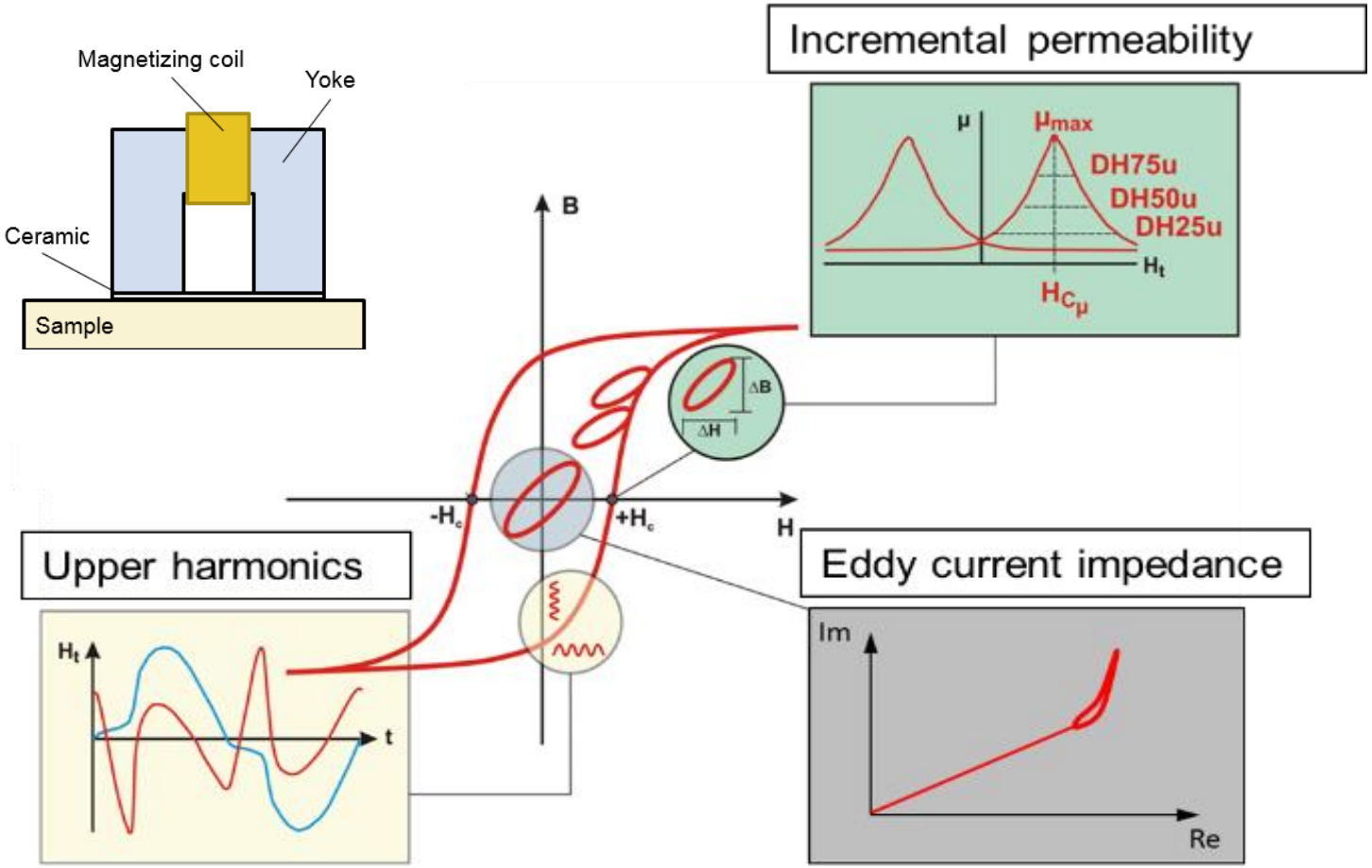
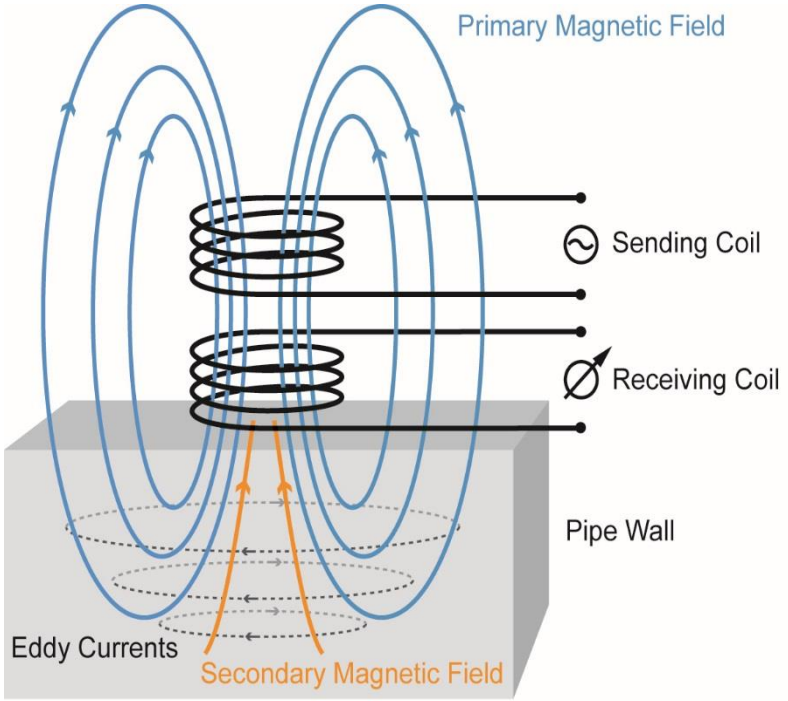
Fundamental methodology for material characterization



# MEASUREMENT APPROACH – EDDY CURRENT

- Eddy Currents (ECs) are generated in conductive specimen by an alternating current in a coil system. Mutual inductance between coils and specimen trigger the signal
- Material properties (mag. Permeability, conductivity) determine the EC distribution inside the steel
- Density of EC in steel decreases with depth
- For standard carbon steel, ECs in sub-mm range of the surface only
- ECs are sensitive to changes in material properties!!!

=> Excellent candidate for superficial hardspots



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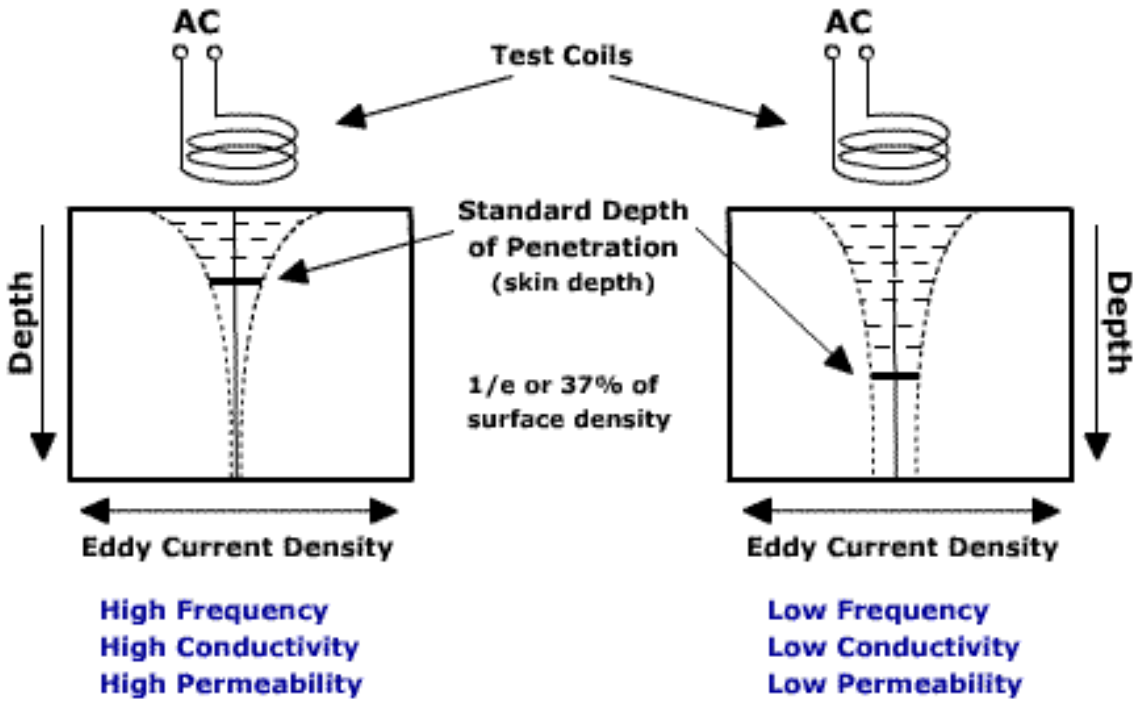
ECs penetration depth in conductor is limited by Skin Effect

Skin Depth: $\delta \sim 1/\sqrt{f\mu\sigma}$

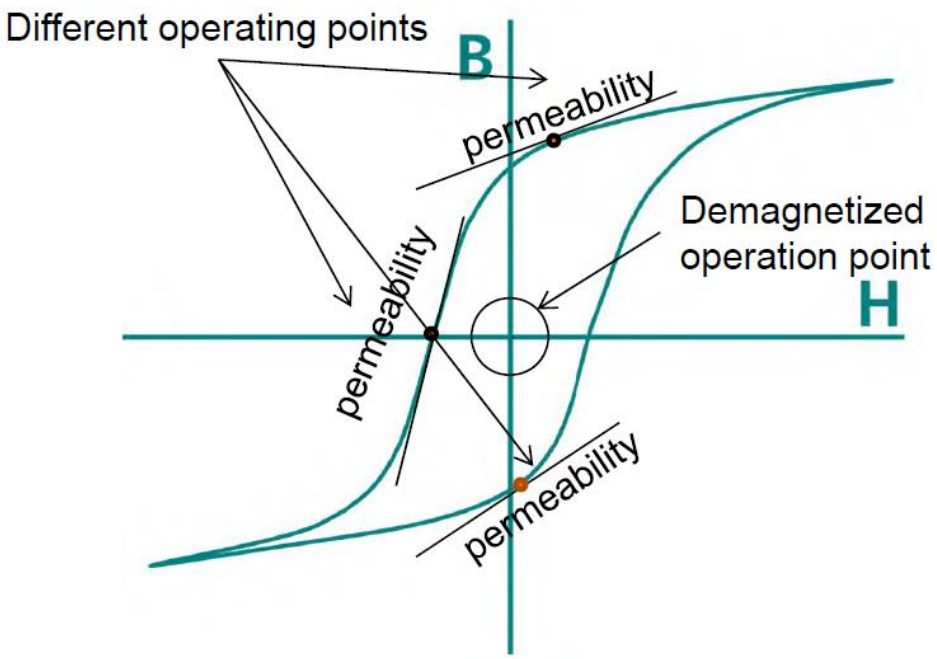
- $f$ AC frequency
- $\mu$ Magnetic permeability
- $\sigma$ Conductivity

Eddy current density decreases with depth.



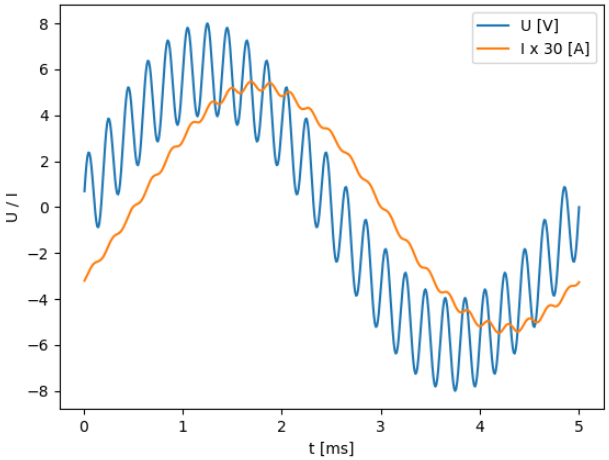
# TRAINING PLAMAT –MM -8M
## MEASUREMENT APPROACH – 3MA

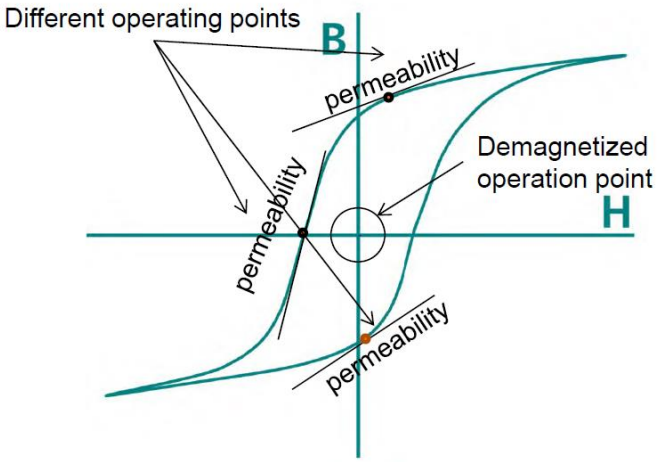
- Idea of 3MA: Measure permeability by Eddy Current at different operating points/magnetization fields $H$
- Analyze different features with 3MA:
  - Eddy current
  - Incremental Permeability
  - Upper harmonics



# TRAINING PLAMAT –MM -8M
## MEASUREMENT APPROACH – 3MA

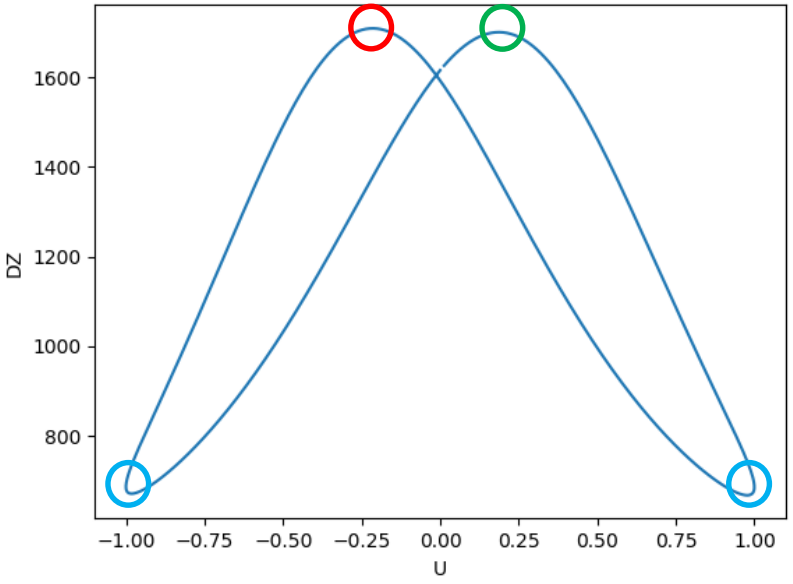
- Sensor’s coil excited by voltage
- Current measured and further analyzed
- Excitation consists of two frequencies:
  - Lower magnetization frequency $f_{\mathrm{mag}} \sim 125$ Hz to operating point on hysteresis curve
  - Higher eddy current frequency $f_{\mathrm{EC}} \sim 3125$ Hz to measure impedance and incremental permeabilit
- From these data 21 parameters are extracted:
  - Amplitude of magnetization voltage
  - Amplitude of magnetization current
  - Klirr factor of magnetization current
  - …

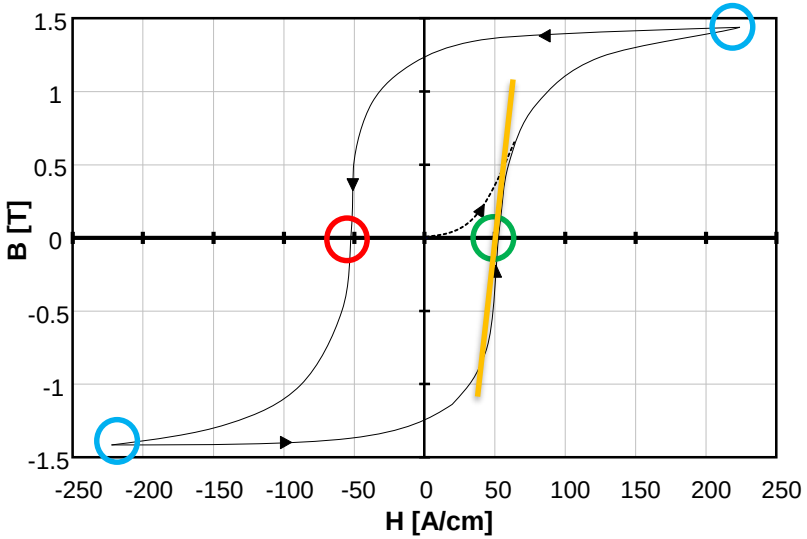


# TRAINING PLAMAT –MM -8M
## MEASUREMENT APPROACH – 3MA

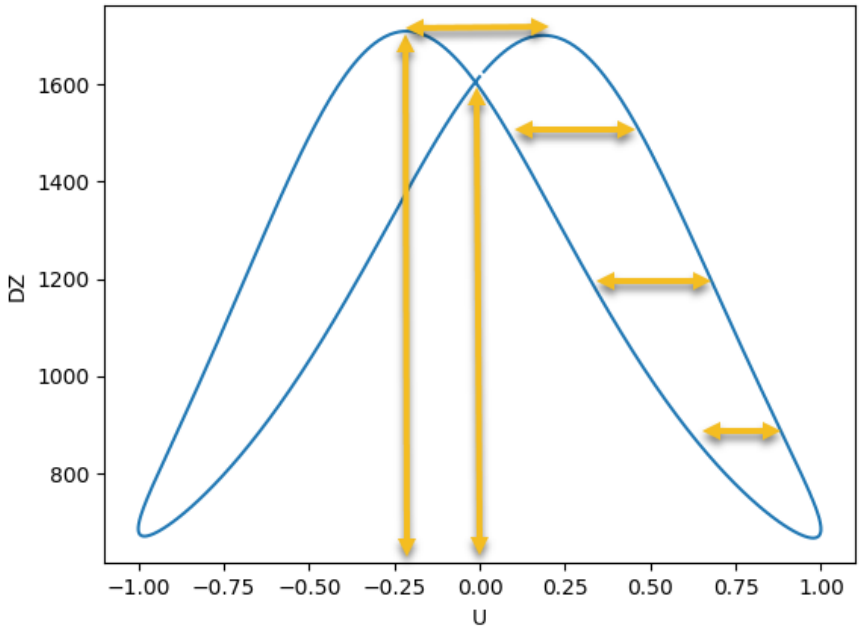
- Demodulate eddy current signal to get incremental permeability as a function of driving voltage
- For every period of fast signal: one complex impedance ➔ one loop after a magnetization wavelength
- Can be interpreted as the derivative of the hysteresis curve



# TRAINING PLAMAT –MM -8M
## MEASUREMENT APPROACH – 3MA

- Demodulate eddy current signal to get incremental permeability as a function of driving voltage
- For every period of fast signal: one compl impedance ➔ one loop after a magnetization wavelength
- Can be interpreted as the derivative of the hysteresis curve
- Extract some further parameters



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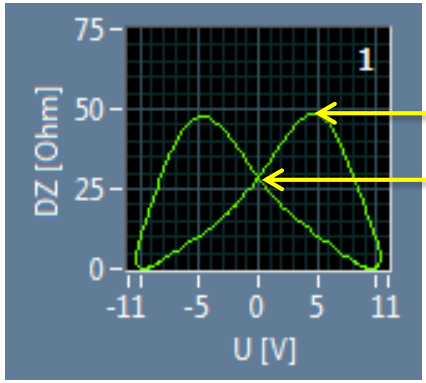
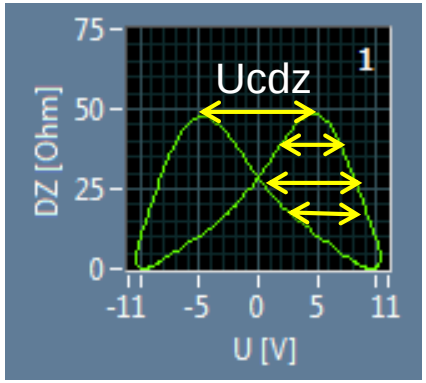
## Incremental Permeability

DZmax [Ohm]: Maximum of incremental permeability
DZmean [Ohm]: Averaged incremental permability
DZr [Ohm]: Incremental permeability at the remnant point
Ucdz [V]: Voltage at maximum incremental permability
DU75dz [V]: curve-widening at 75% signal peak
DU50dz [V]: curve-widening at 50% signal peak
DU25dz [V]: curve-widening at 25% signal peak
Rem [%]: asymmetry of the incremental permability curve



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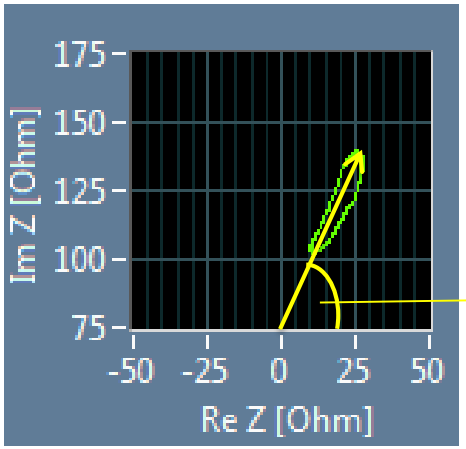
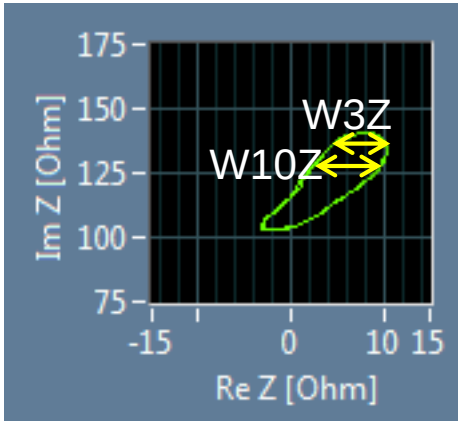
## Eddy Current

Zmax [Ohm]: Maximum magnitude of the impedance
Zmin [Ohm]: Minimum magnitude of the impedance
Zmean [Ohm]: Averaged magnitude of the impedance
Phizmax [rad]: Maximum phase of the impedance
Phizmin [rad]: Minimum phase of the impedance
Phizmean [rad]: Averaged phase of the impedance
W3Z [Ohm]: 3% widening of the eddy current loop
W10Z [Ohm]: 10% widening of the eddy current loop



**TRAINING PLAMAT –MM -8M**

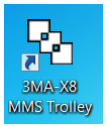
MEASUREMENT APPROACH – 3MA PARAMETERS

Parameter recommended
for running the system:

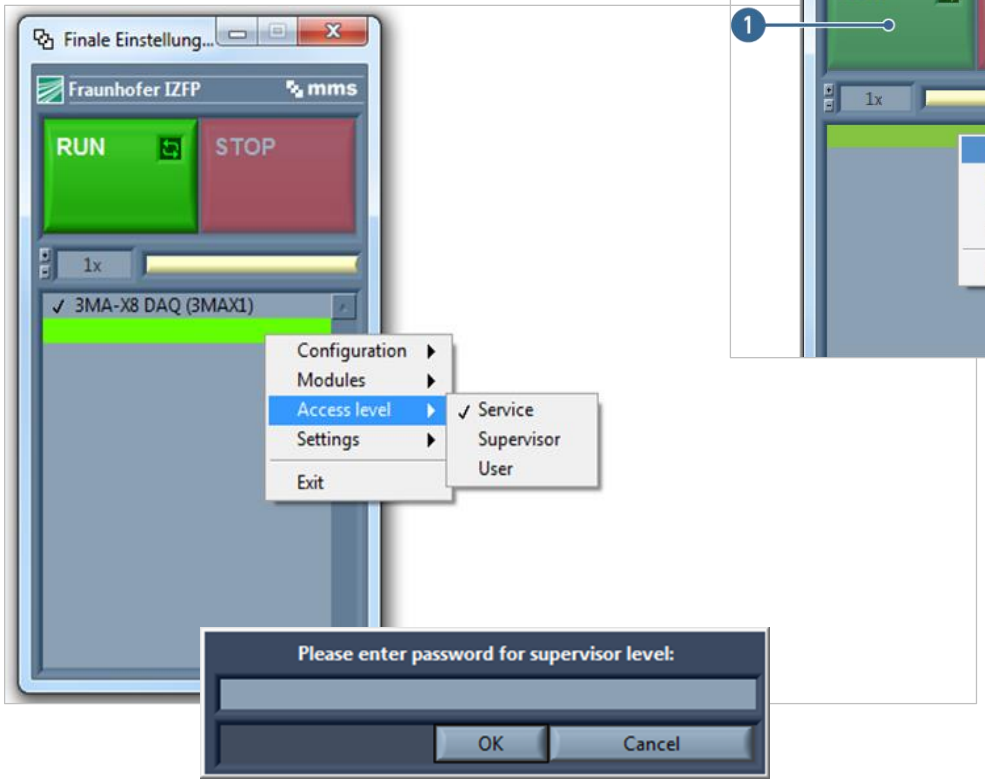
# TRAINING PLAMAT –MM -8M

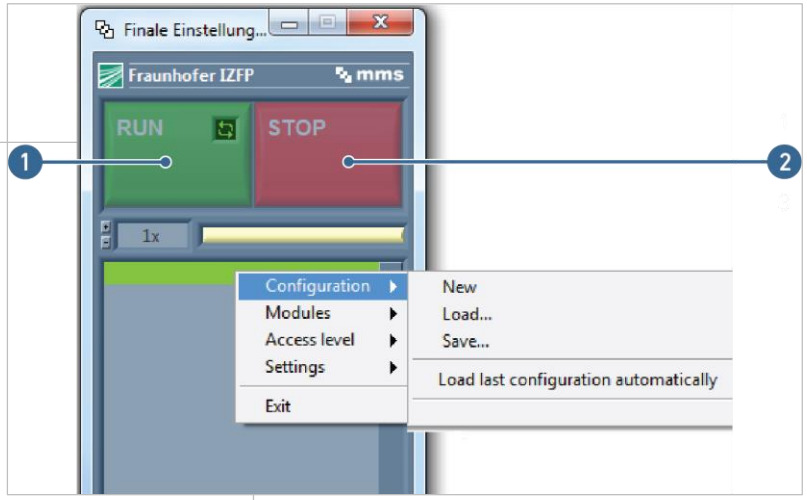
BREAK

# TRAINING PLAMAT –MM -8M
## SOFTWARE

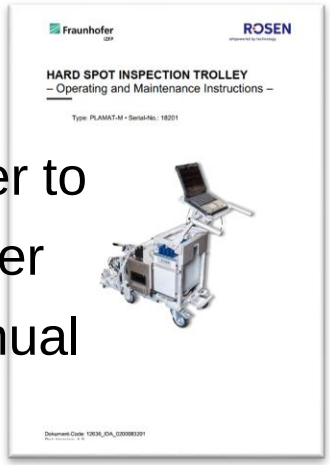
Press 

on desktop




Refer to user manual



# TRAINING PLAMAT –MM -8M
## EQUALIZATION

Equalization, i.e, …

… adjustment of all channels over homogeneous reference steel plate or a therefrom defined “golden” standard area

… with the goal to minimize individual tolerances in each channel

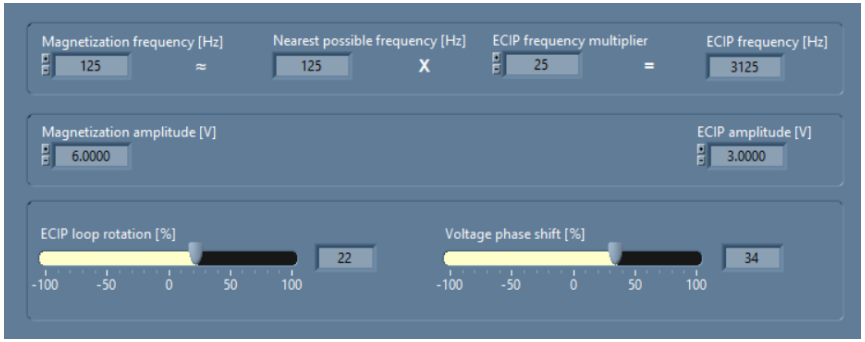
… so that all channels provide similar and comparable signal level

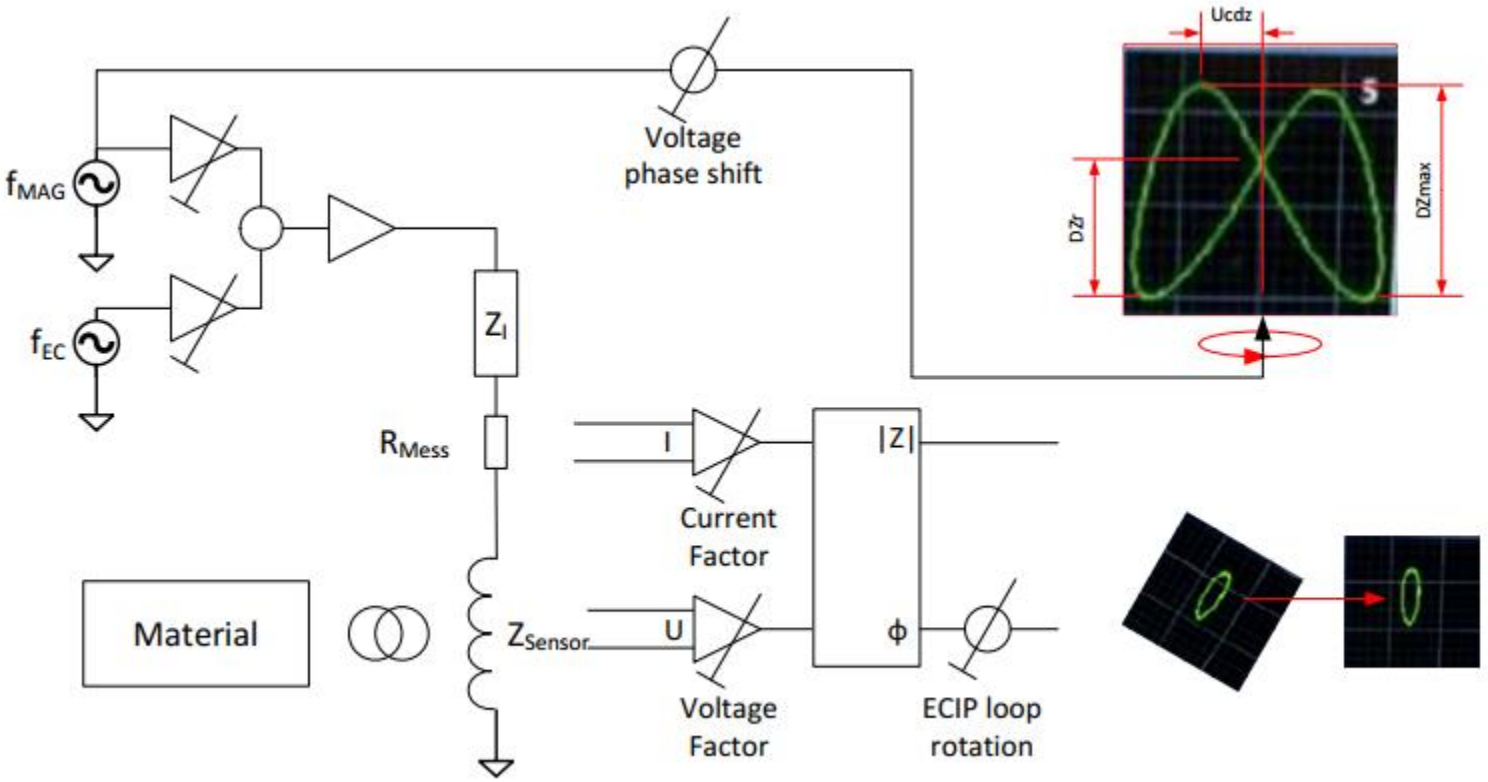
Important parameter:

- Current factor
- ECIP loop rotation
- Voltage Phase Shift

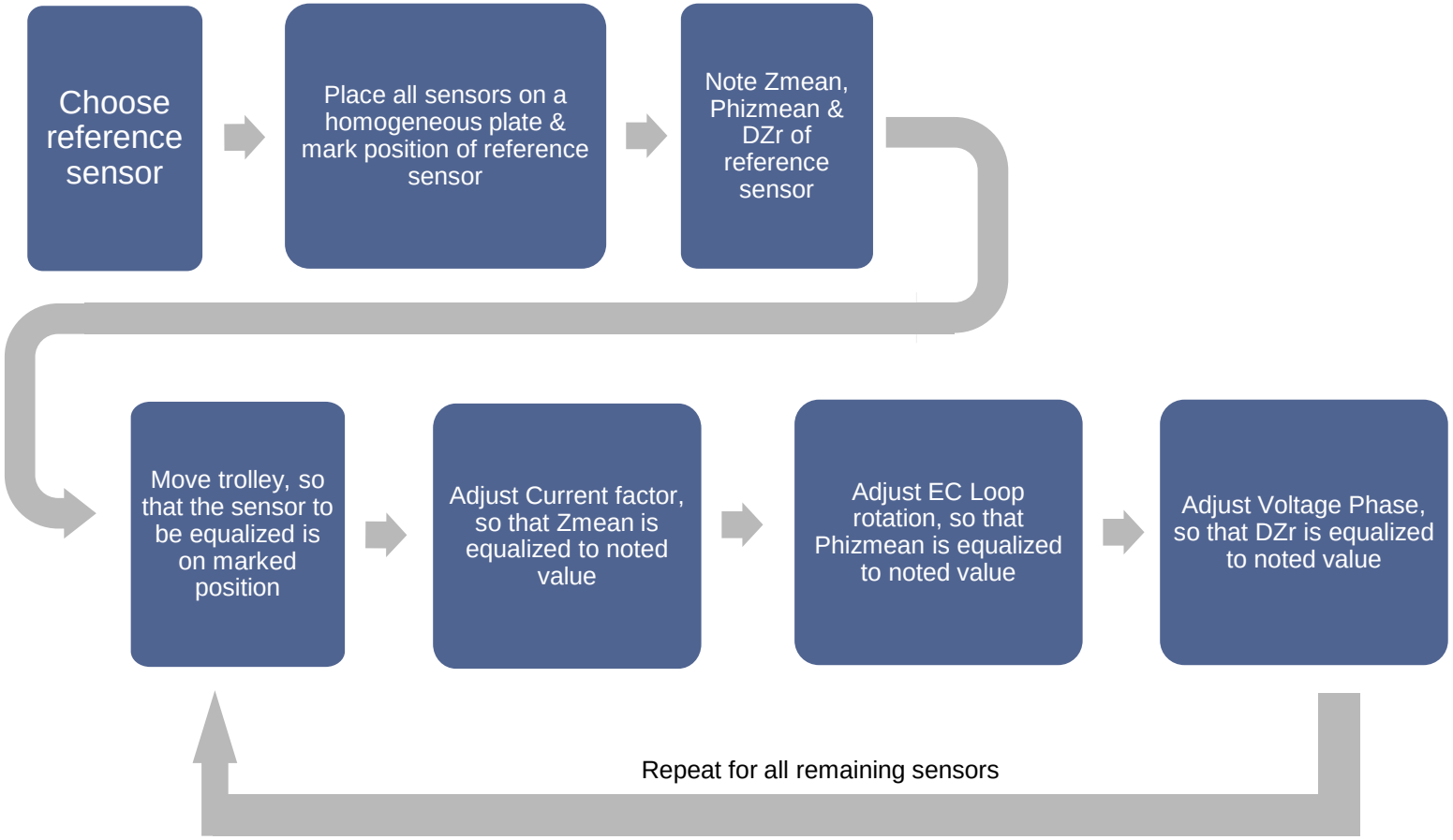
# TRAINING PLAMAT –MM -8M
## EQUALIZATION

Fine adjustment is conducted after first adjustment.



# TRAINING PLAMAT –MM -8M
## EQUALIZATION



# TRAINING PLAMAT –MM -8M
## REFERENCING/TEACHING

### Potential influences:

- Mill scale
- Residual magnetization (remanence due to e.g. lifting magnets)
- Residual stress

### Calibration for each influence, steel grade and their combinations:

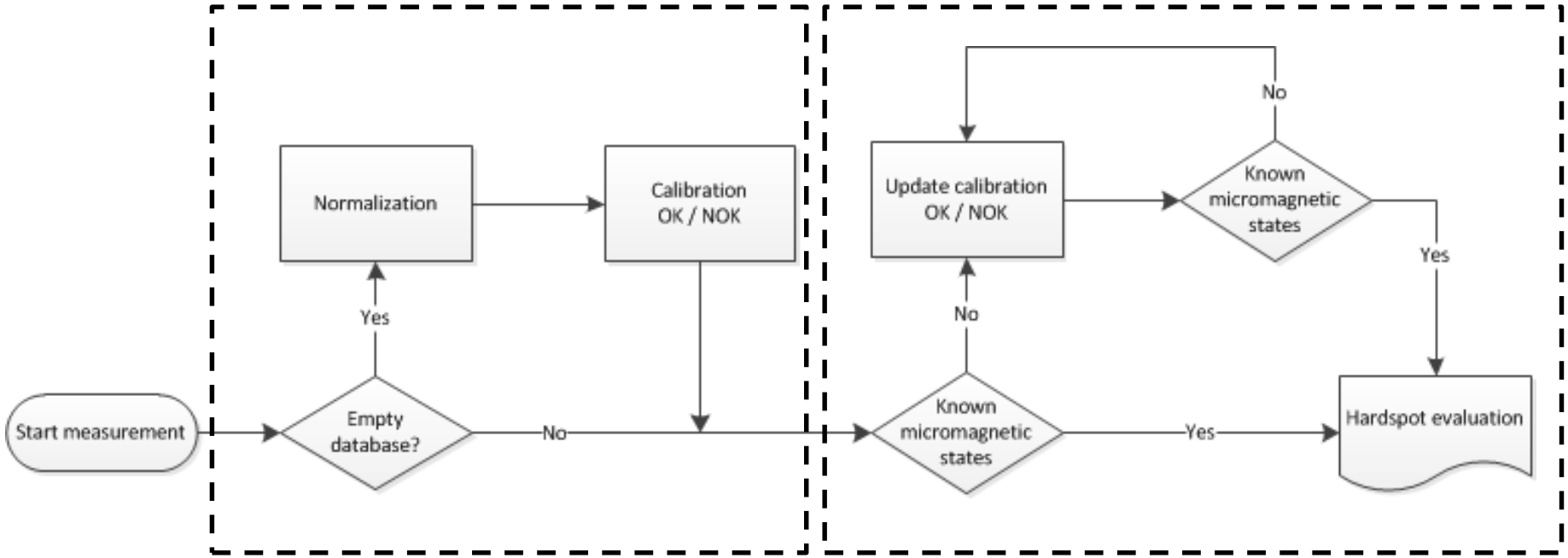
- Different microstructures and hardening depths: ferrite, perlite, bainite,…
- Huge variety of reference plates for matching different scenarios

- Approach is machine learning classification algorithm (supervised classification)
- Mobile hardness testing (Leeb, UCI) as absolute reference
- Calibration is updated and extended if unknown states are measured
- Classification by nearest-neighbors algorithm (euclidean distance)

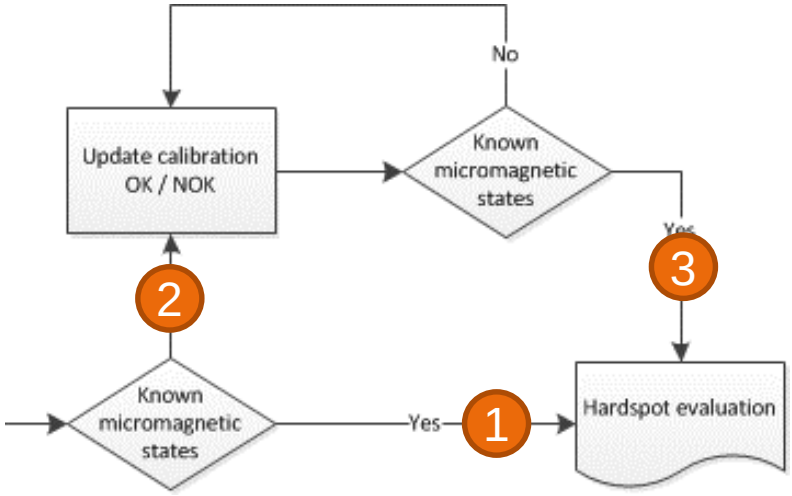
# TRAINING PLAMAT –MM -8M
REFERENCING/TEACHING

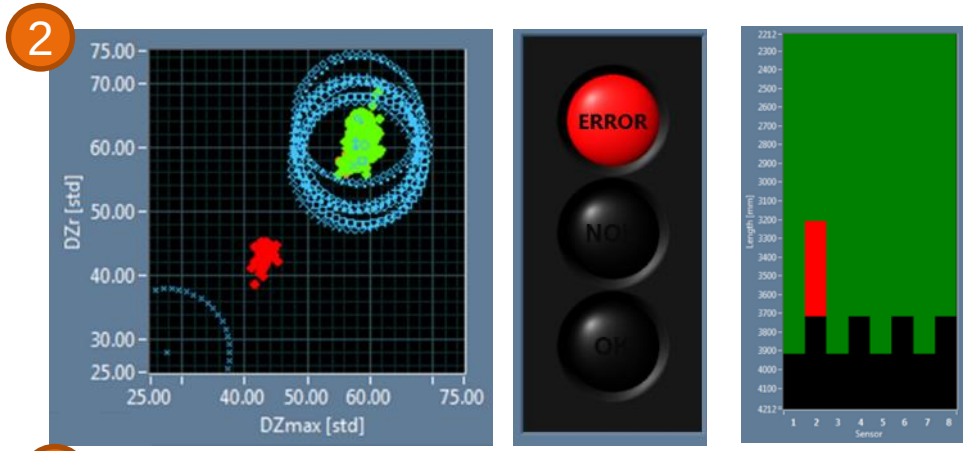
Initial operation:
Prior actual measurement

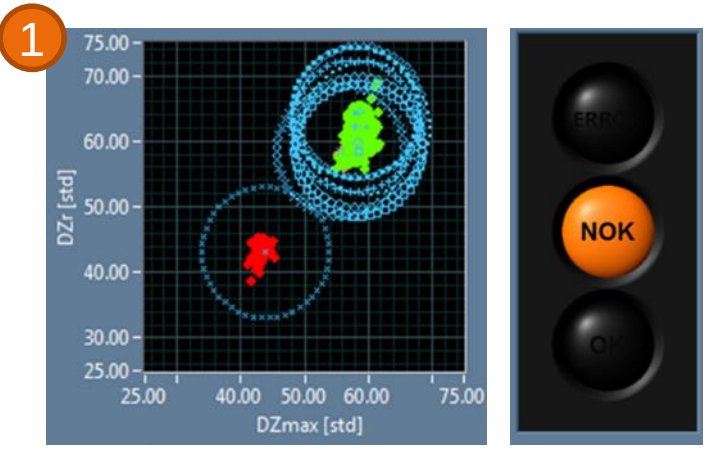
After initial operation:
during actual measurement



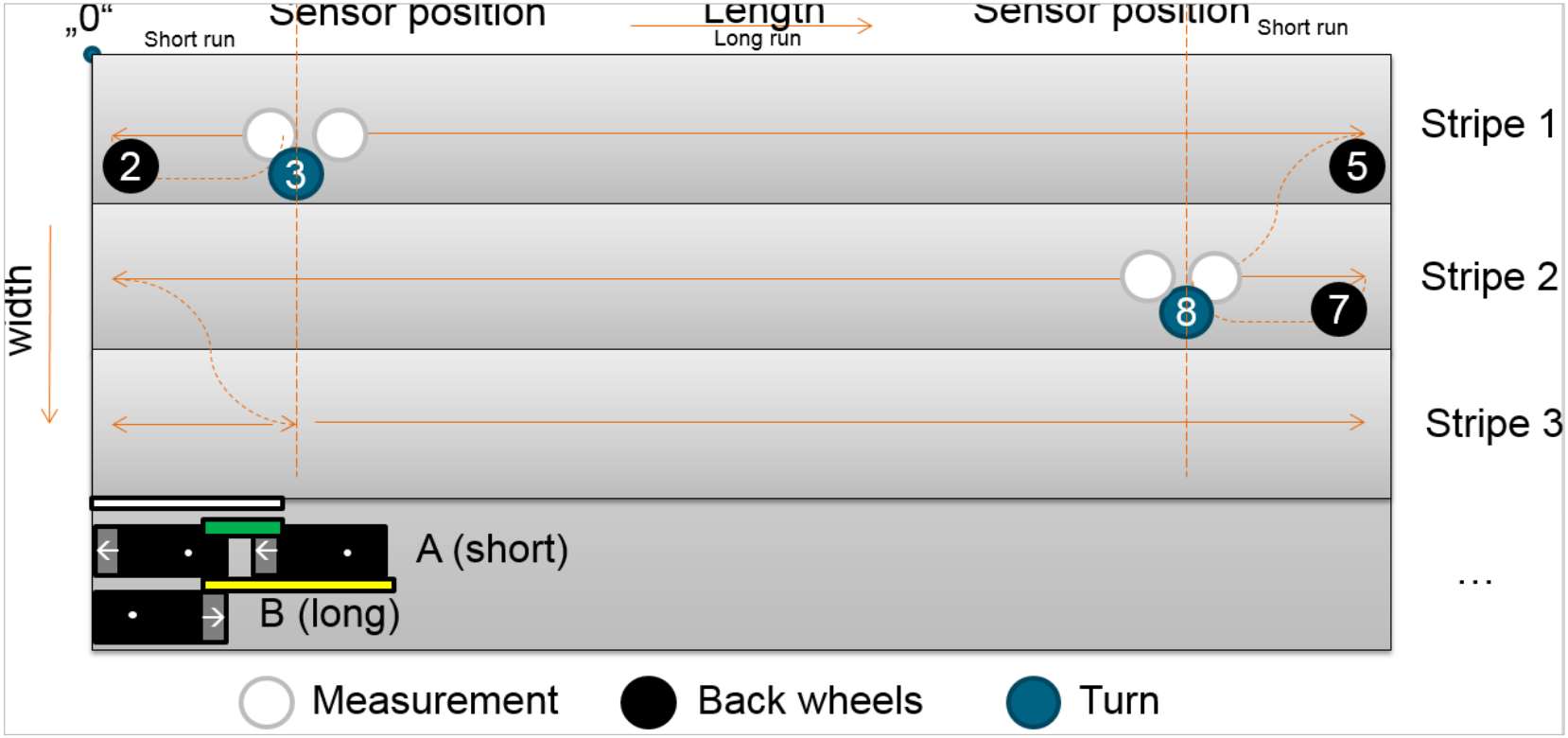
# TRAINING PLAMAT –MM -8M
## REFERNCING/TEACHING



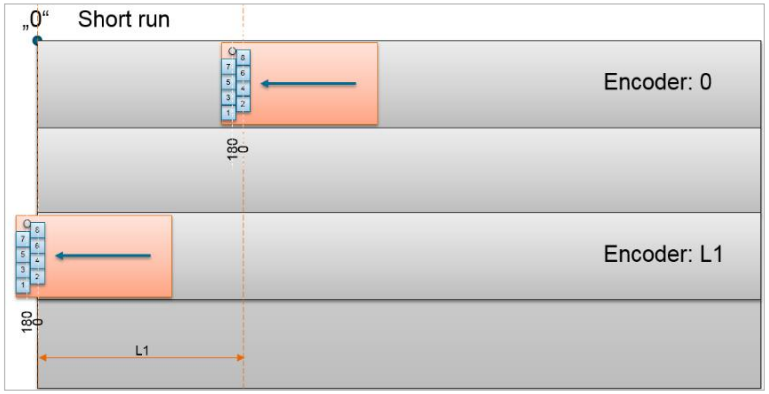



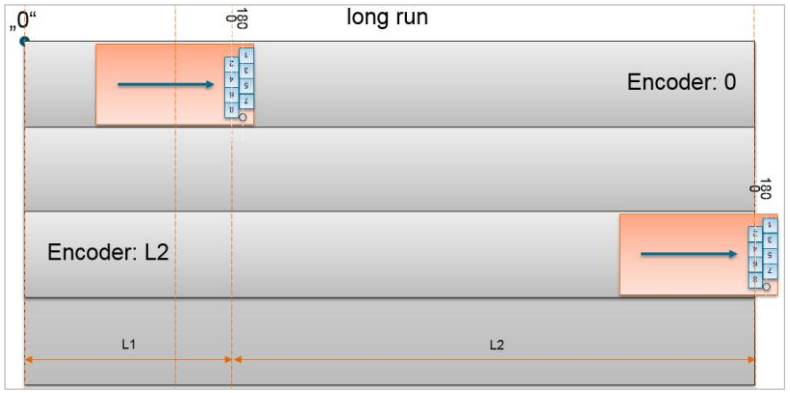
# TRAINING PLAMAT –MM -8M
## SCANNING PROCEDURE

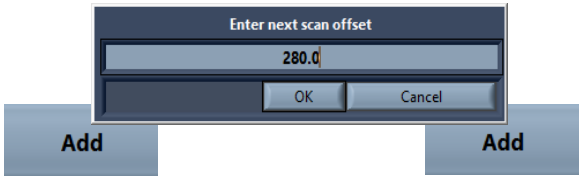


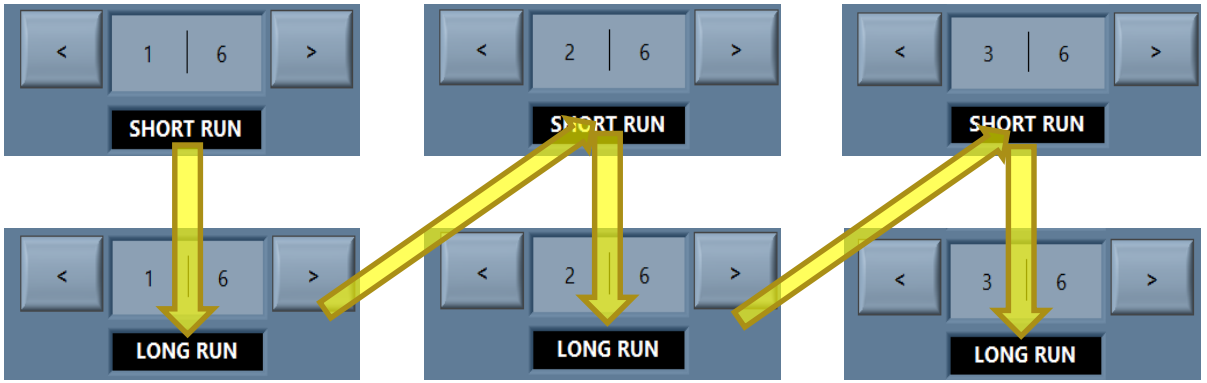

Width of last stripe varies from others

# TRAINING PLAMAT –MM -8M
## SCANNING PROCEDURE




Lane 1 Lane 2 Lane 3

# THANK YOU

Thank you for your attention