Les journées COFREND 2026

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OCEA

Electromagnetic Characterization Tools for Steels

Multi-modal probe and AI for the non-destructive evaluation of steel

PROJECT France 2030 — BPI France

PARTNERS CMPhy • ELyTMaX (CNRS / INSA Lyon / Tohoku Univ.) • Serprotronics

Why OCEA?

Anticipating degradation, rather than observing the defect

THE CHALLENGE

The surface microstructure contains the precursor signs of future failures

This is where the variations heralding degradation can be read — long before a crack appears.

THE GAP

Conventional NDT detects defects — not their causes

Ultrasound, eddy currents, penetrant testing: excellent for an established crack. Insensitive to the microstructural changes that precede it.

From healthy microstructure to macroscopic defect

✓

STAGE 1

Healthy material

Initial state

Homogeneous microstructure — organized grains, low dislocations, controlled stresses.

!

STAGE 2

Invisible embrittlement

← OCEA acts here

Grain reorientation, dislocation accumulation, local phase transformations under stress or chemical variations.

X

STAGE 3

Macroscopic defect

Too late

Crack, spalling, burn — detectable by UT, EC or penetrant testing. The part must be repaired or scrapped.

Evolution over time / under mechanical or chemical loading

OCEA — a new NDT approach to detect the magnetic signature of the microstructure, before the defect becomes visible

The situation

Current electromagnetic NDT methods are reaching their limits

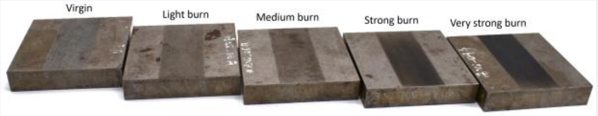
Limitations of existing systems

Unidirectional excitation

The 3MA and Rollscan systems rely on a U-shaped yoke that explores only one direction at a time.

Limited magnetic information

Difficulty separating correlated effects: stress vs hardness vs texture vs phases.



Costly calibration

Heavy experimental campaigns for each application, results that generalize poorly.

Single-physics probes

One probe per method (EC, MBN, ultrasound)
— multiplying the measurement passes.

Industrial challenges

Residual stresses

Essential to control on critical parts (aerospace, automotive, energy).

Characterization of chemical and mechanical treatments

Carburizing, nitriding, induction: effective depth, hardness, profile.

Detection of grinding burns, micro-cracking

Effect of grinding and machining on parts— critical defect.

In-line monitoring, contactless measurements

100% in-production inspection without damage or disassembly.

OCEA addresses these challenges through a multi-modal, multi-mode approach instrumented with AI

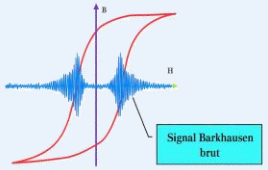
OCEA at a glance

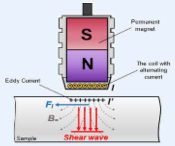
An integrated hardware and software platform for next-generation magnetic NDT

OCEA combines, in a single probe, four electromagnetic NDT techniques under three excitation modes, with dedicated software, complemented by AI processing that extracts indicators and correlates them

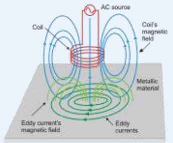
M U L T I - P H Y S I C S

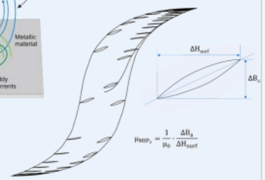
4 integrated methods





- **Incremental Magnetic Permeability MIP**
- **Barkhausen Noise MBN**
- **Eddy Currents EC**
- **Ultrasound EMAT board**





- **➔ All within a single multi-pole probe.**

M U L T I - M O D E

3 excitations

Uni-axial, biaxial and rotational — access to the 90° and 180° domain-wall mechanisms.

I N S T R U M E N T A T I O N

Multi-channel rack

8 synchronous channels, 1 MHz, integrated lock-in, dedicated analog filters.

I N T E L L I G E N C E

Embedded AI

More than 10 physical indicators per measurement, supervised regression models.

Project approach

1 Capture

Synchronous multi-channel acquisition on the part

2 Extraction

Computation of physically interpretable indicators

3 Learning AI

Models trained on calibrated specimens

4 Model-based estimation

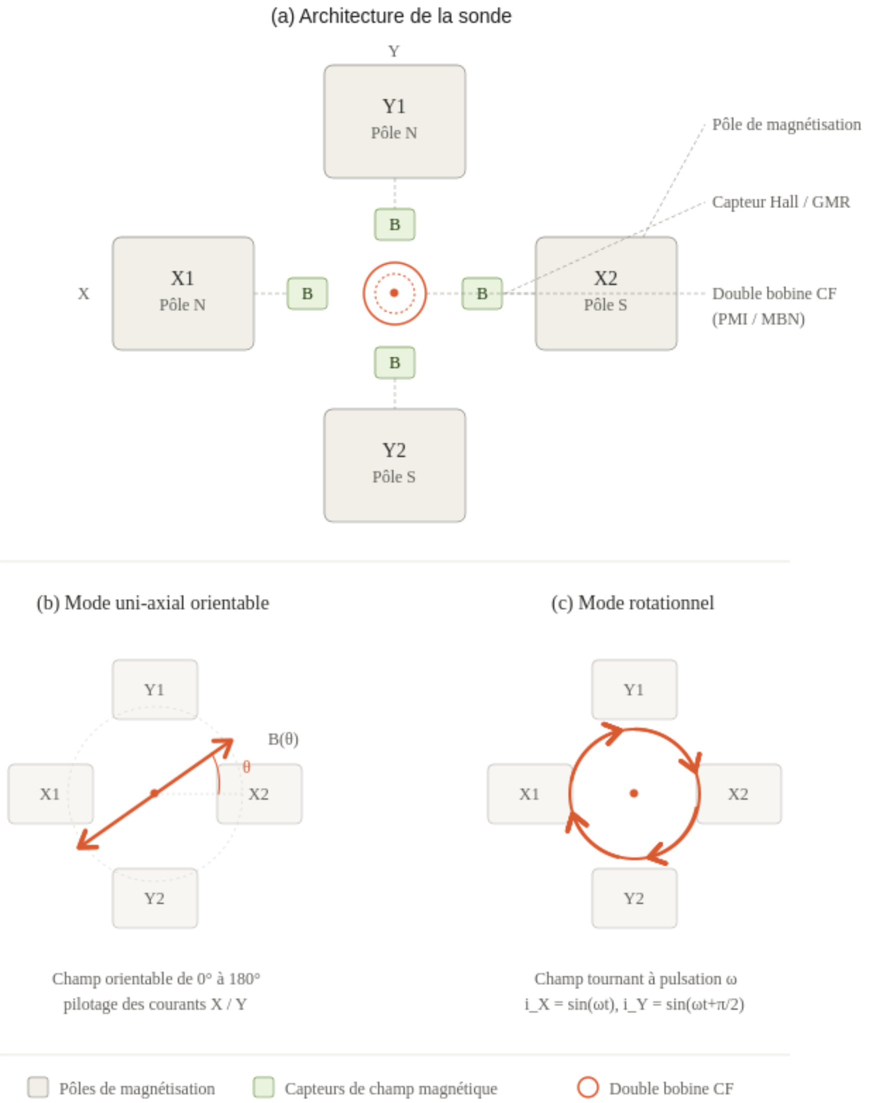
Real-time quantitative estimation with the developed reference database

Diagnostic support

From acquisition to decision: a complete integrated chain

The OCEA probe

Multi-pole architecture integrating 4 NDT techniques



Technical specifications

ARCHITECTURE	4-pole yoke X1, X2, Y1, Y2 Magnetic field DC or AC (0.05 to 200 Hz)
EXCITATION	0 to 20 kA/m at the part surface
SENSORS	4 magnetic field sensors (Hall effect or GMR array) + emitter/receiver EC coil set
EC FREQUENCY	1 kHz to 100 kHz (adjustable skin depth)
MBN	Low-noise preamp + 10–500 kHz band-pass filter
EMAT	Integrated HF coils under DC bias

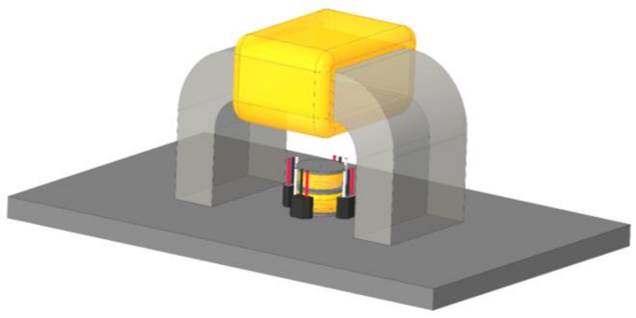
Principle

- A single inductor generates the uniaxial, biaxial or rotating field
- The Hall sensors or GMR array measure the effective field H_XY at the surface
- The EC coil measures the permeability and the Barkhausen noise,
- The EMAT uses the DC bias and generates a wave mechanical within the material

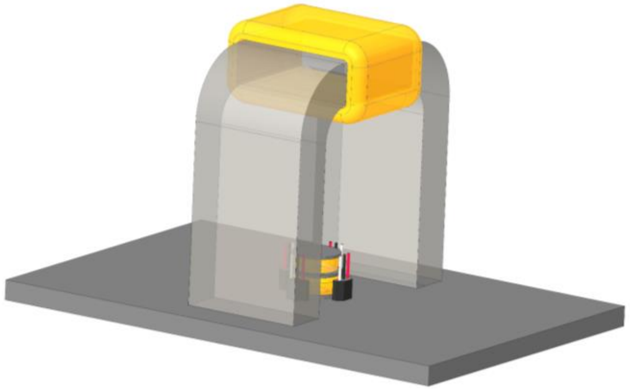
The 3 excitation modes

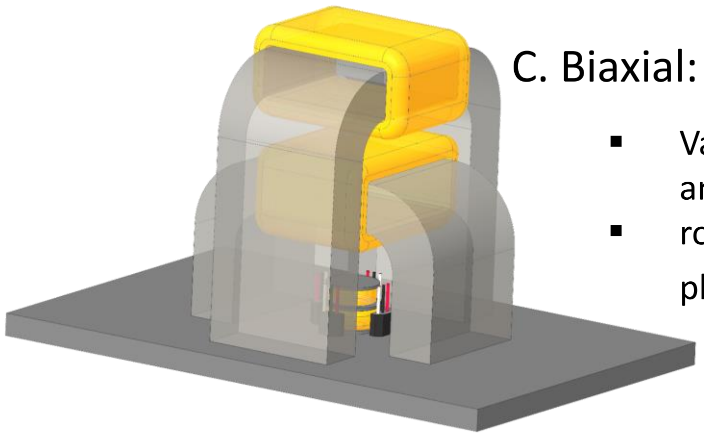
Choosing the field trajectory to explore the magnetic microstructure

A. Uniaxial: parallel axis



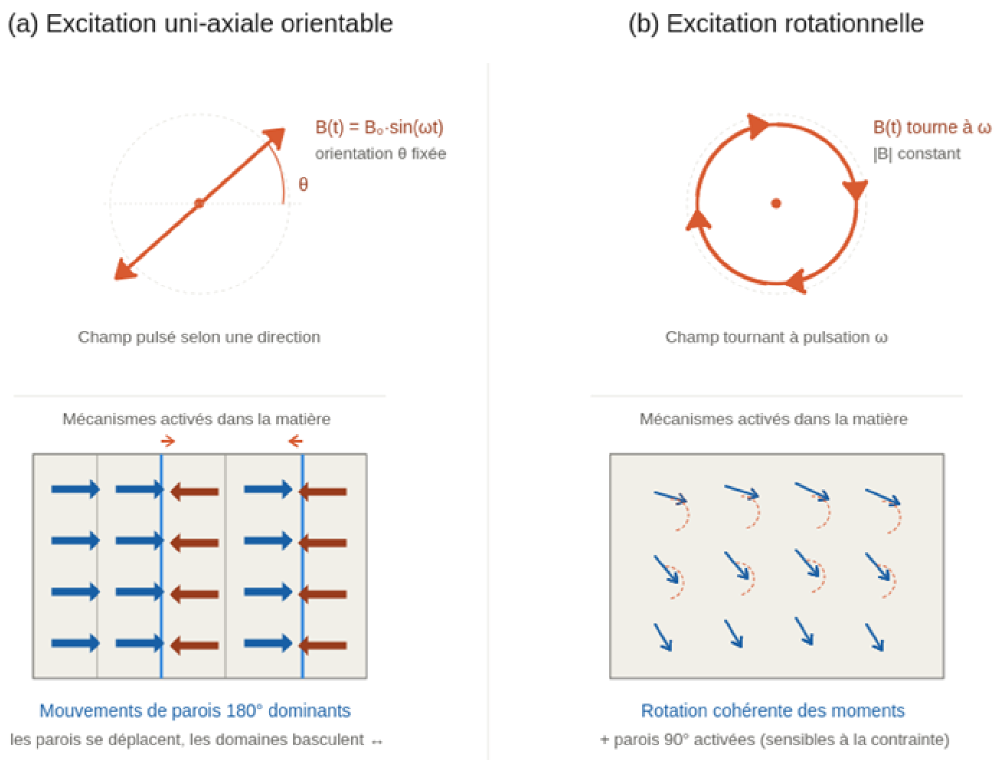
B. Uniaxial: perpendicular axis





C. Biaxial:

- Variable phase shift or amplitude
- rotating field (90-degree phase shift)



UNIAXIAL

Configurable axis

Dominant 180° wall movements

BIAXIAL

Elliptical trajectory of the magnetic field

Multidirectional exploration

ROTATIONAL

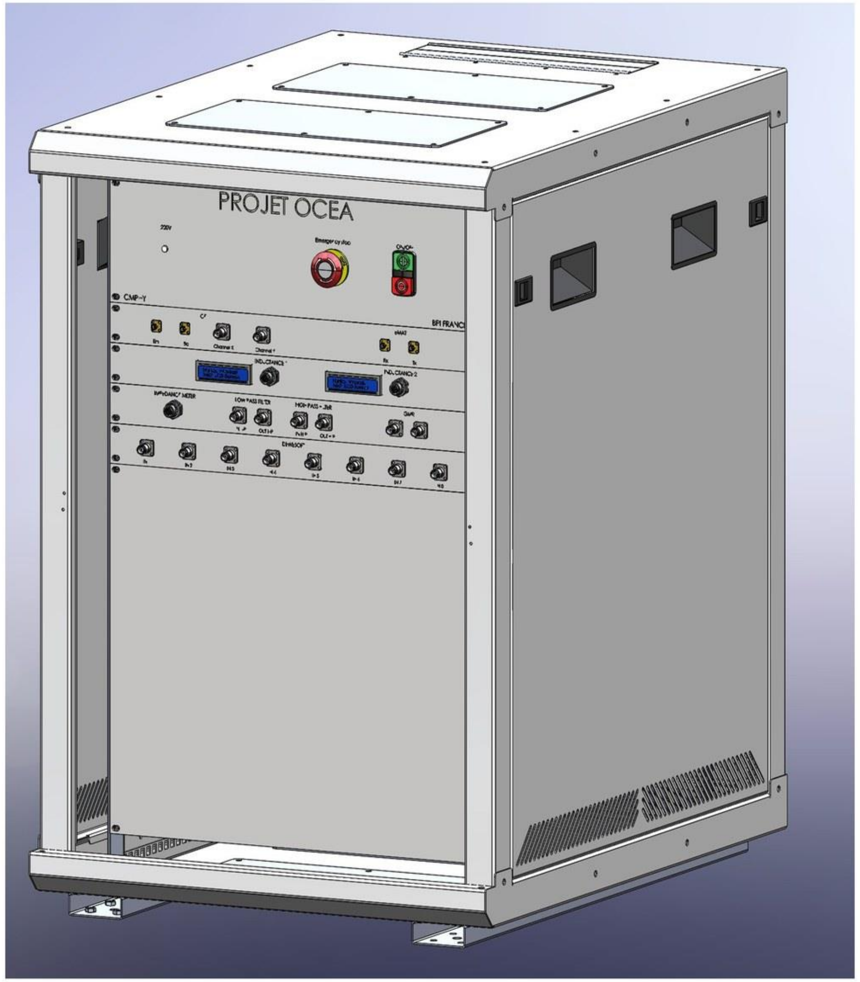
Field rotating at 90°

Activation of 90° walls and coherent rotation

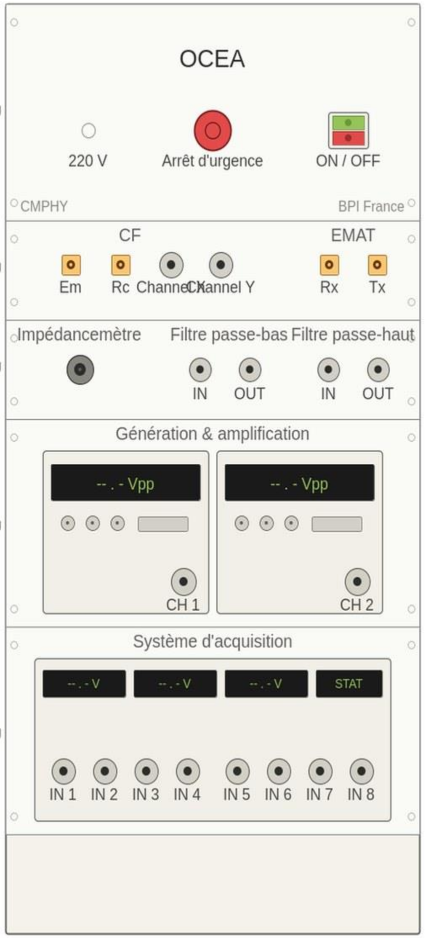
The measurement rack

Dedicated multi-channel hardware architecture

(a) Vue intégrée



(b) Vue schématique



Main components

1. **Generators**
   Dual coherent AFG: phase-shiftable X and Y signals (0–360°)
2. **Amplifiers**
   2 high-power AC amplifiers for the excitation coils
3. **Integrated lock-in**
   Synchronous detection Re(V) / Im(V) on the EC carrier
4. **Ultrasound Ultrasound EMAT board**
   Pulse 0–400 V / operating in pulse-echo or separate emitter + receiver mode
5. **Preamp + MBN filters**
   Analog conditioning of the Barkhausen noise
6. **Acquisition**
   8 synchronous channels, up to 1 MHz, 24 bits
7. **Control**
   Embedded PC, dedicated HMI, execution of the AI models

MIP — Incremental magnetic permeability

Principle and characteristic signature

Principle

Superposition of a high-frequency AC field on a quasi-static DC field.

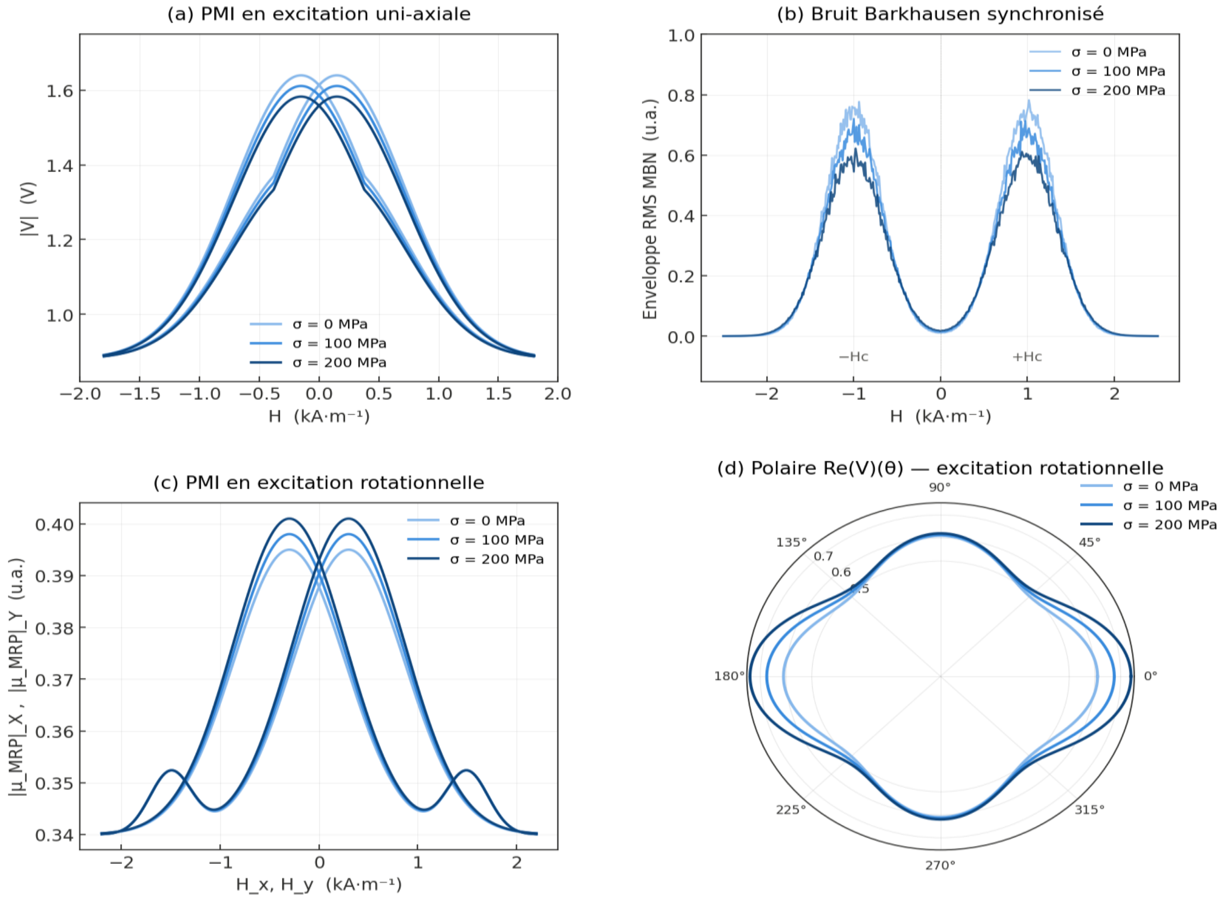
The ratio ΔB/ΔH measured in the eddy-current coil gives access to the incremental permeability μ_MIP at each point of the magnetization cycle.

Sensitive to:

- Dislocation density
- Grain size
- Hard phases (martensite, carbides)
- Residual stresses

MIP signature

Characteristic “butterfly” shape in uniaxial — two domes crossing in biaxial



MBN — Barkhausen magnetic noise

Activity at the polarity reversals of the cycle

Principle

When the magnetizing field reverses, the domain walls cross the pinning sites in discrete jumps.

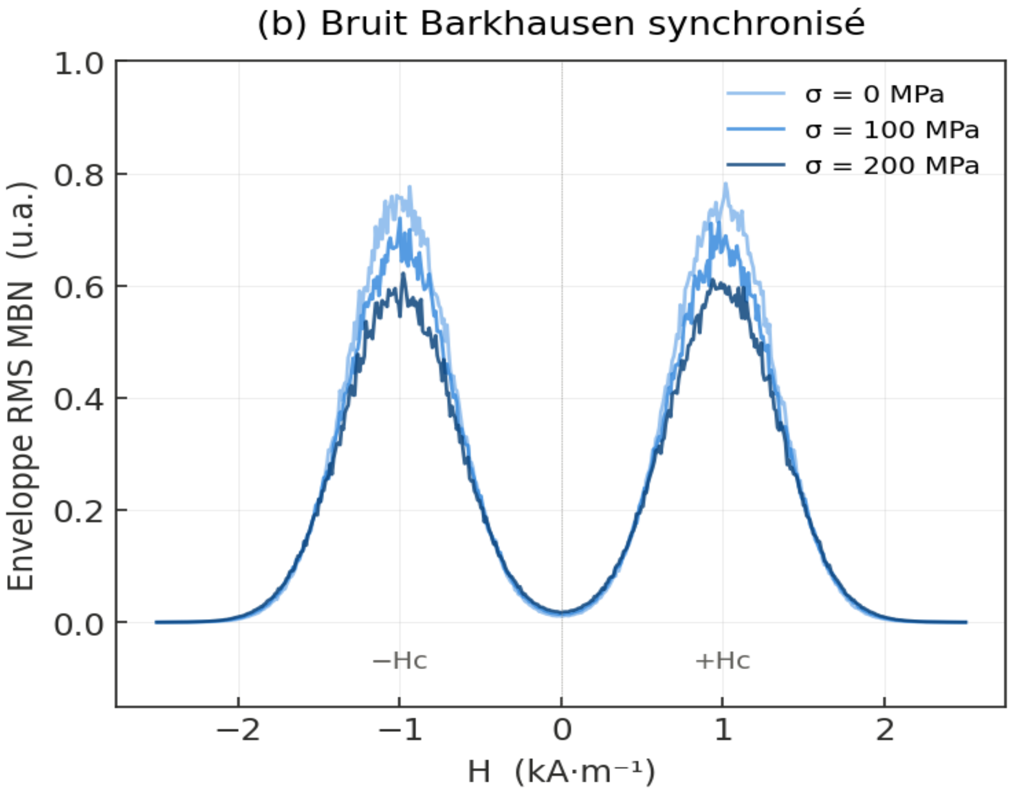
These jumps induce HF electromagnetic pulses (10–500 kHz) captured by a dedicated coil of the OCEA probe.

Extracted indicators:

- Peak amplitude Vpp
- Integrated spectral energy
- Burst position ±Hc
- Harmonic content

RMS envelope of the MBN signal

Two activity bursts centered on ±Hc — high sensitivity to stress



Multi-frequency impedance plane

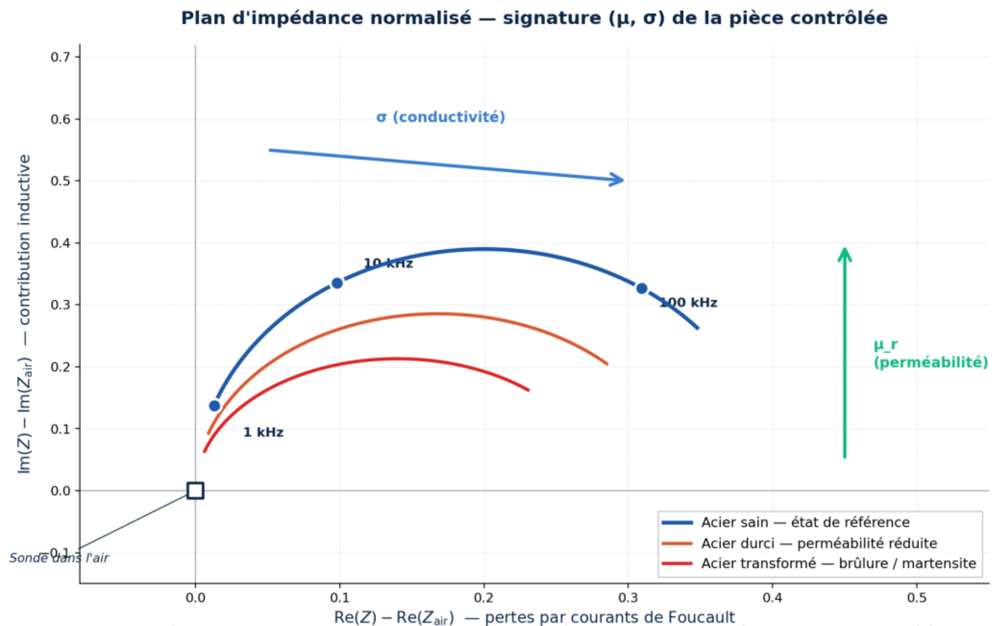
Multi-depth probing by skin effect

Principle

Frequency sweep of the EC coil between 1 and 100 kHz, with or without a superimposed DC field.

Each frequency probes a given depth δ:

$$\delta = 1 / \sqrt{\pi f \mu \sigma}$$



Le balayage de la fréquence (1 → 100 kHz) trace la signature complète ; toute évolution microstructurale écarte la trajectoire de la référence

Skin effect

100 kHz — δ surface

10 kHz — δ medium

1 kHz — δ deep

Steel part

Indicators extracted from the impedance plane

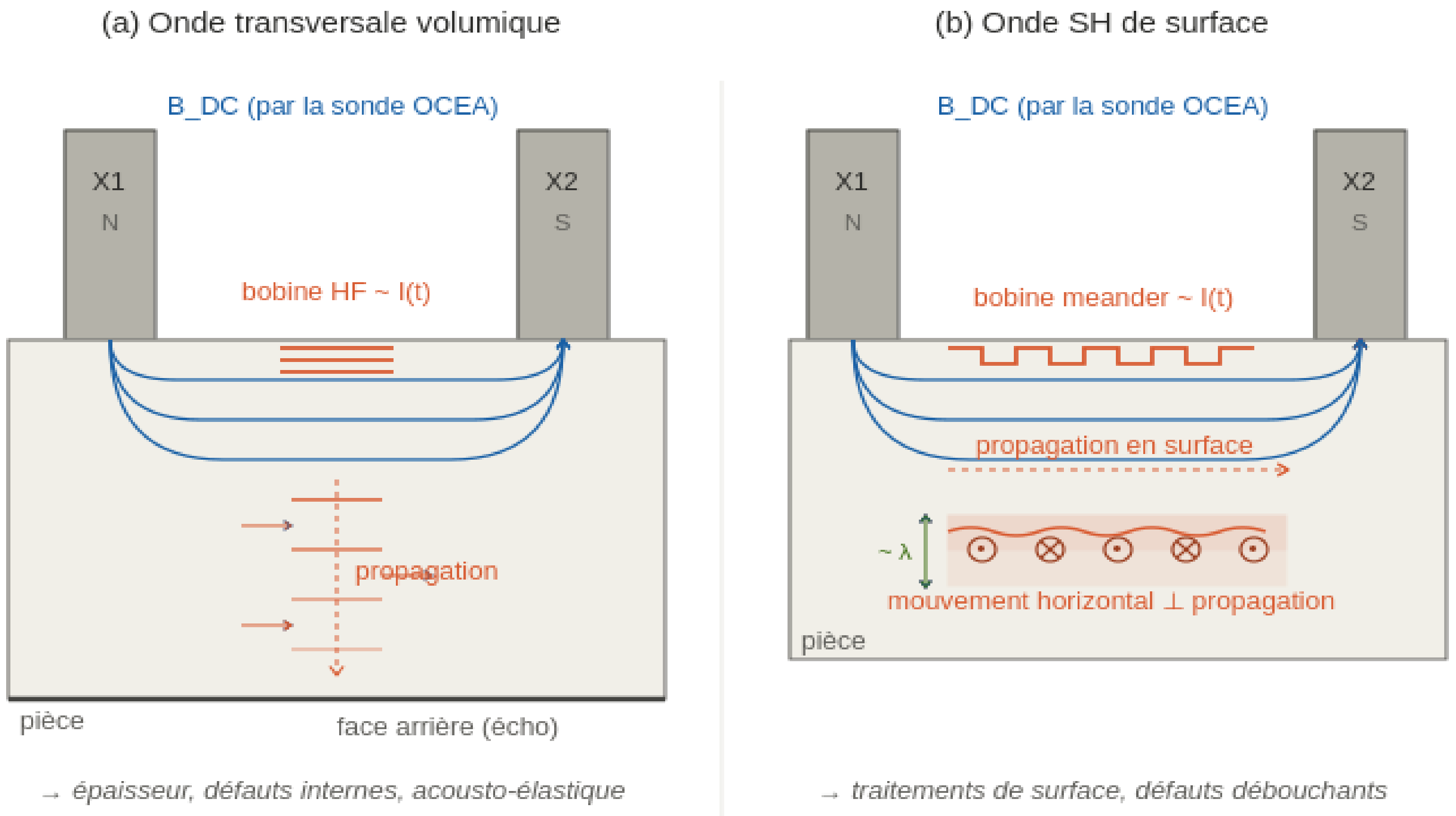
- Full trajectory Re(Z) / Im(Z)
- Local slope of the trajectory
- Characteristic cutoff frequencies
- Distance to the reference curve

CMPhy Mesures Physiques
ElytMaX

EMAT — Contactless ultrasonic waves

Direct generation by electromagnetic coupling

The OCEA probe uses its own DC bias to generate ultrasonic waves without contact or couplant — an innovation compared to conventional EMATs with NdFeB permanent magnets.



3 extracted indicators

Time of flight

Velocity → stress (acousto-elastic effect)

Amplitude

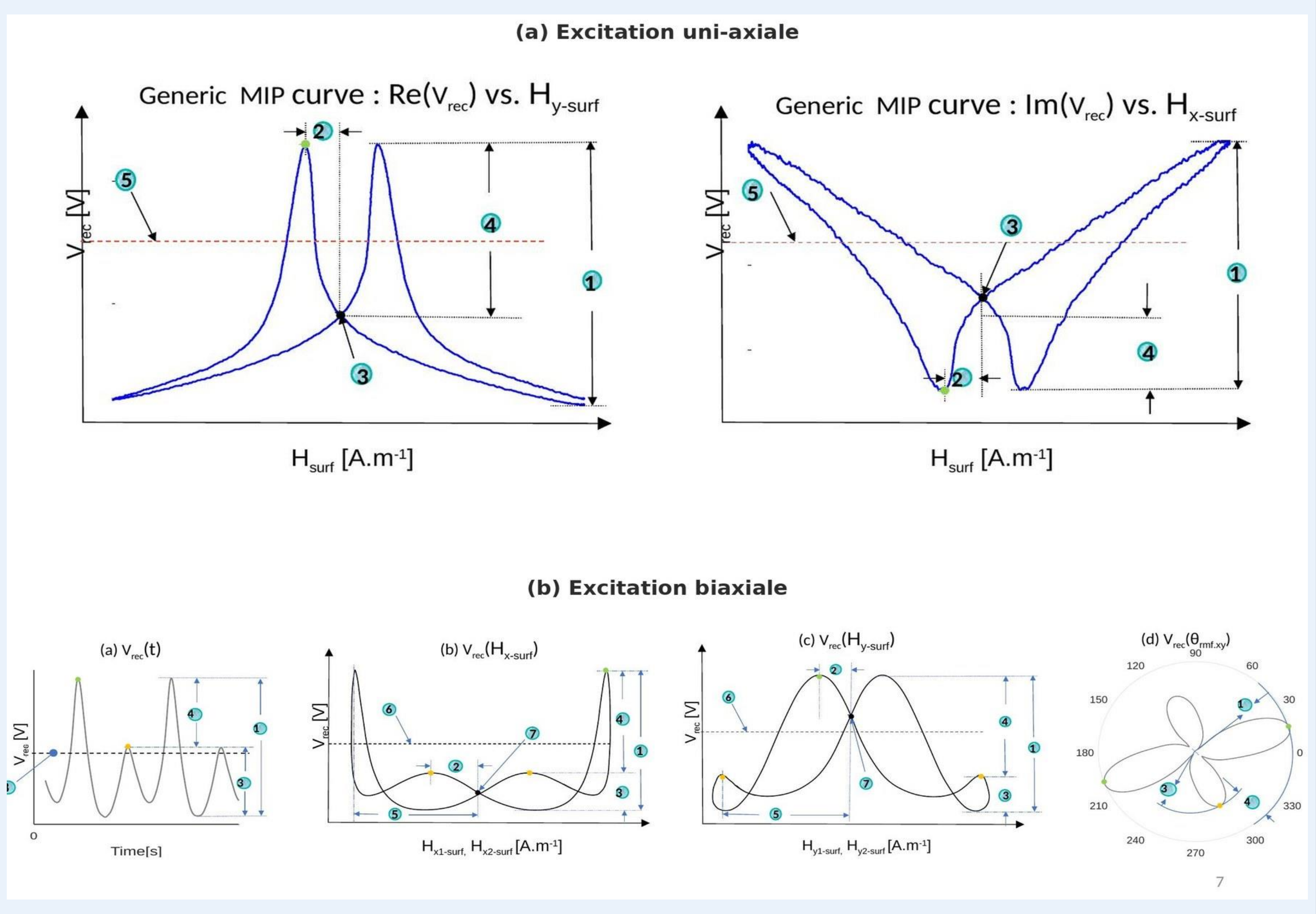
Attenuation → microstructure and defects

FFT

Dispersion and spectral signature

Extracted indicators

Scalar quantities readable directly from the magnetic signatures



The 9 indicators

FROM UNI-AXIAL

1. Δ(V_rec) — peak-to-peak amplitude
2. Coercive point H_c
3. Remanence rem(V_rec)
4. Mean(V_rec) — mean value
5. pk2 − min(V_rec)

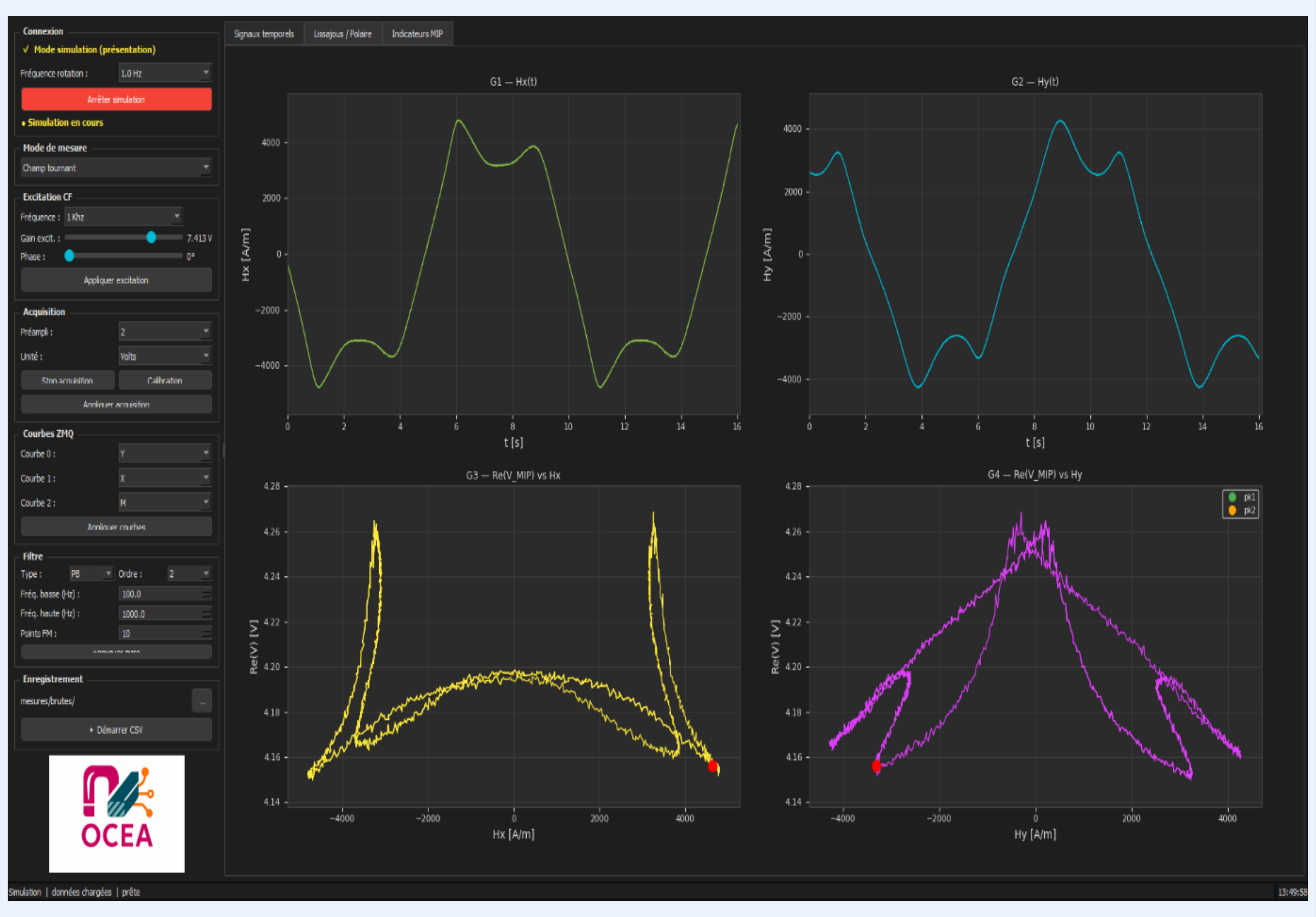
REQUIRE BIAXIAL

6. max(pk1 − pk2)
7. pk1 − rem(V_rec)
8. pk2 − rem(V_rec)
9. H_surf at pk2

9 readable scalar indicators, physically interpretable, automatically extracted

OCEA software

A unified interface for multi-modal acquisition, visualization and analysis



Key features

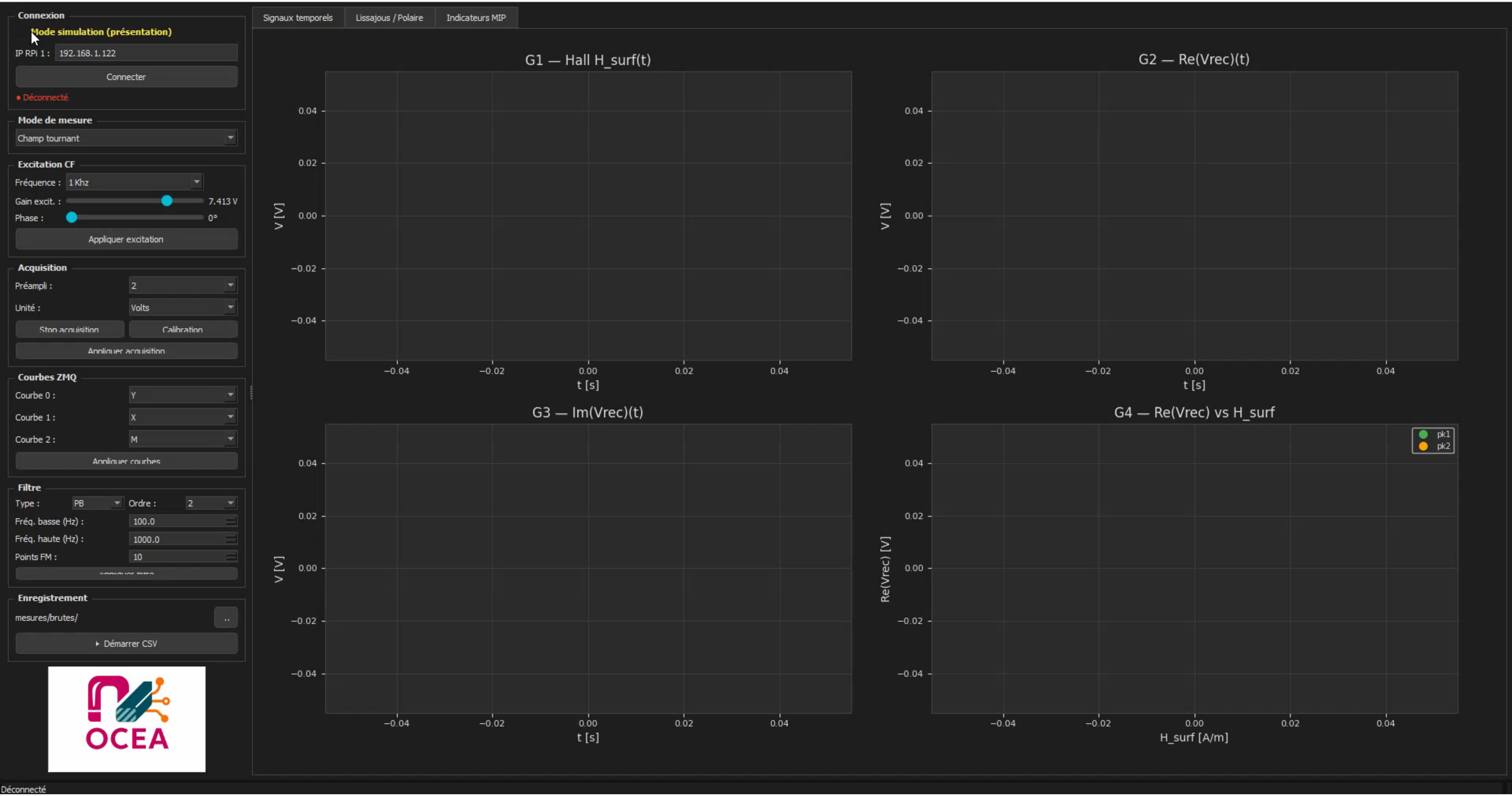
CONTROL & ACQUISITION

1. Configuration of the excitation modes
2. EC settings: frequency, gain, phase
3. 8 synchronous channel acquisition
4. Analog & digital filtering
5. CSV recording / raw export

VISUALIZATION & ANALYSIS

6. Time-domain signals H_X / H_Y
7. Real-time MIP signatures
8. Lissajous, polar view, indicators
9. Interoperable with Python / MATLAB

An open software platform, from hardware control to signature analysis



Connexion
Mode simulation (présentation)
IP RPi 1 : 192.168.1.122
Connecter
• Déconnecté
Mode de mesure
Champ tournant
Excitation CF
Fréquence : 1 Khz
Gain excit. : 7.413 V
Phase : 0°
Appliquer excitation
Acquisition
Préampli : 2
Unité : Volts
Stop acquisition
Calibration
Appliquer acquisition
Courbes ZMQ
Courbe 0 : Y
Courbe 1 : X
Courbe 2 : M
Appliquer courbes
Filtre
Type : PB
Ordre : 2
Fréq. basse (Hz) : 100.0
Fréq. haute (Hz) : 1000.0
Points FM : 10
Enregistrement
mesures/brutes/
Démarrer CSV
OCEA
Signaux temporels
Lissajous / Polaire
Indicateurs MIP
G1 — Hall H_surf(t)
G2 — Re(Vrec)(t)
G3 — Im(Vrec)(t)
G4 — Re(Vrec) vs H_surf
V [V]
Re(Vrec) [V]
t [s]
H_surf [A/m]
pk1
pk2
Déconnecté

Learning approach

A complete chain, from acquisition to quantitative decision

The OCEA AI relies on the prior extraction of physical indicators before any statistical model, to preserve interpretability.

1 — Acquisition
8 synchronous channels • 1 MHz • Impedance measurement with frequency sweep • T-wave and GW velocity

2 — Conditioning
Lock-in • Filtering • FFT

3 — Indicators
Indicators base × configuration type (Uniaxial, Biaxial, Rotational)
Impedance plane / A-Scan

4 — Model AI
Statistical methods • Decision trees • Convolutional neural networks (CNN)

5 — Decision
Quantitative estimation of the target properties
Stress • Hardness • Treatment depth • Micro-cracking

Models evaluated — from simple to complex

Complexity ↑ — *Required data ↑*

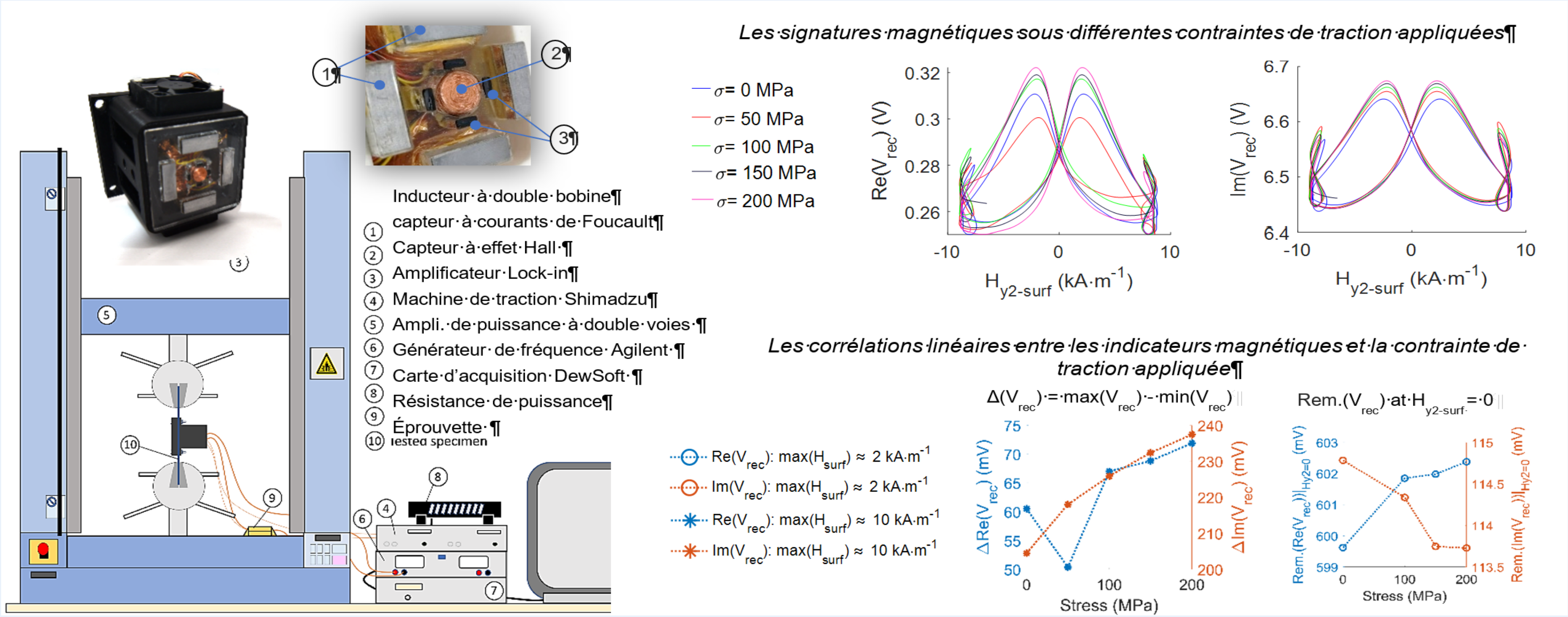
1 TO START
Penalized regression
Ridge, Lasso
The simplest and most transparent. Helps identify the indicators that really matter.

2 WHEN NON-LINEAR
Decision trees
Random forest, gradient boosting
Captures non-linear relationships and remains robust on little data.

3 WITH LARGE VOLUMES
Lightweight networks
Supervised deep learning
Maximum power. Reserved for cases where the accumulated data volume allows it.

Application case — Residual stresses

Rotational measurement on a specimen under tensile loading



PROTOCOL

Tension 0 → 200 MPa

Steel specimen loaded in 50 MPa steps, low-frequency rotational mode.

OBSERVATION

Evolving signatures

The Re and Im curves deform monotonically and reproducibly with stress.

RESULT

Linear correlations

Several MIP indicators vary linearly with stress — calibration is possible.

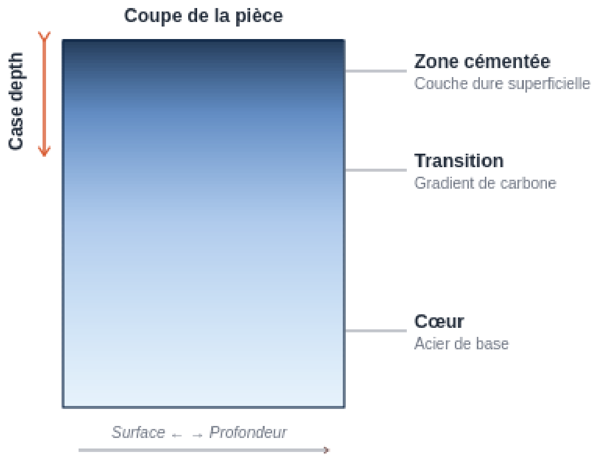
The magnetic signature evolves with stress — the basis for a quantitative non-destructive measurement

Other application cases

Three families of targeted industrial challenges

HARDNESS & TREATMENTS

Carburizing, nitriding, induction



Effective depth of the treated layer and hardness profile from the multi-frequency MIP indicators.

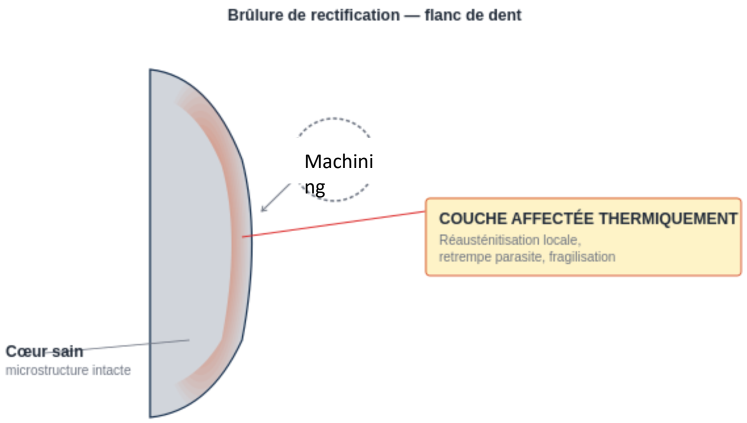
Target depth 0.5 – 4 mm

Destructive reference

XRD, Vickers microhardness

GRINDING BURNS

Transmission parts



Défaut critique sur les pièces de transmission (engrenages aéronautiques)

Detection of thermally affected surface layers — a critical defect for aerospace gears.

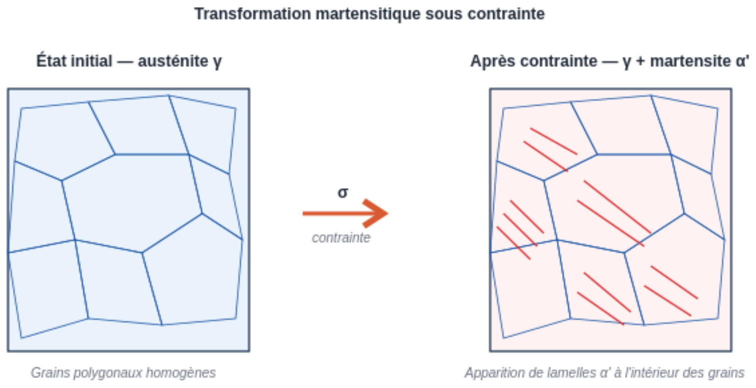
Target sensitivity ≈ 50 µm

Destructive reference

Nital chemical etching

MARTENSITE & PHASES

Austenitic steels



Aciers austénitiques (AISI 304/316) — transformation invisible en surface

Estimation of the martensitic transformation rate under mechanical loading (AISI 304L, cryogenic structures).

Target range 0 – 30% vol

Destructive reference

SEM, EBSD

A unified approach to characterize, non-destructively, the microstructural changes related to the process or to service

Roadmap

France 2030 timeline — from prototype to industrialization

2024 — Launch
Specifications and probe architecture

2025 — Prototype A
First functional 4-pole transducer

2026 — Prototype B
Multi-mode validation and complete rack

2027 — Prototype C
Training datasets and operational AI

2028 — Industrialization
Transfer and first industrial deployments

Three structuring areas

Area 1 — Hardware platform — Multi-pole probe + integrated measurement rack

Area 2 — Multi-methods — MIP, MBN, multi-frequency EC, EMAT

Area 3 — AI platform — Indicators, models, industrial validation

What if you became an OCEA partner?

Standards, industrial specimens, field feedback — your application cases enrich the training database.

DEMONSTRATION

On-site presentation of the OCEA probe and rack, with tests on your reference parts.

EVALUATION

Customized feasibility study to assess the relevance for your industrial application.

CO-DEVELOPMENT

Adaptation of the acquisition chain and the models to your specific constraints.

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