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Metrology solutions with diamond quantum sensors

Teratec

KWAN-TEK - Thomas Hingant

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KWAN-TEK: Startup in Quantum Sensing

Founded in April 2020 (Lorient, France)

Metrology solutions based on diamond quantum sensors

Pioneer French SME on diamond quantum sensors

7 Patents

24 staff

- 17 in R&D
- including 5 PhD
- Multiple skills

Recognitions and Partnerships

La French Tech, bpifrance, i-Lab, Photonics Bretagne, Institut Foton, IMT Atlantique, Les Deep Tech, France 2030, La Place Stratégique, LSPM, cnrs, anr, EMC2, Evolen'Up, université Paris-Saclay, Fondation UBS

What can (diamond) quantum sensors bring to the industry?

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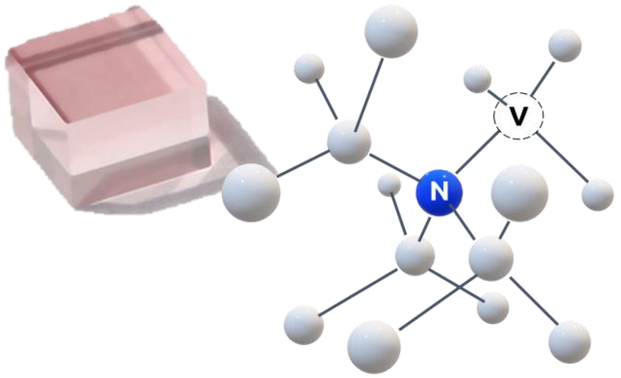
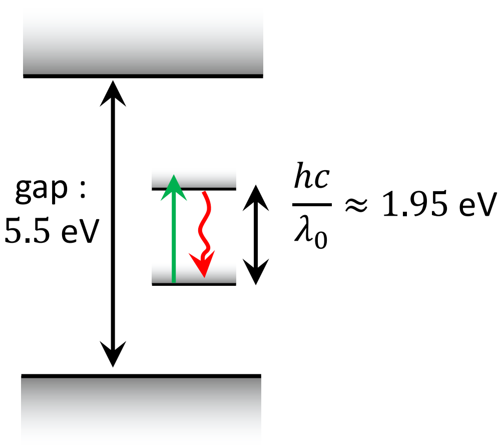
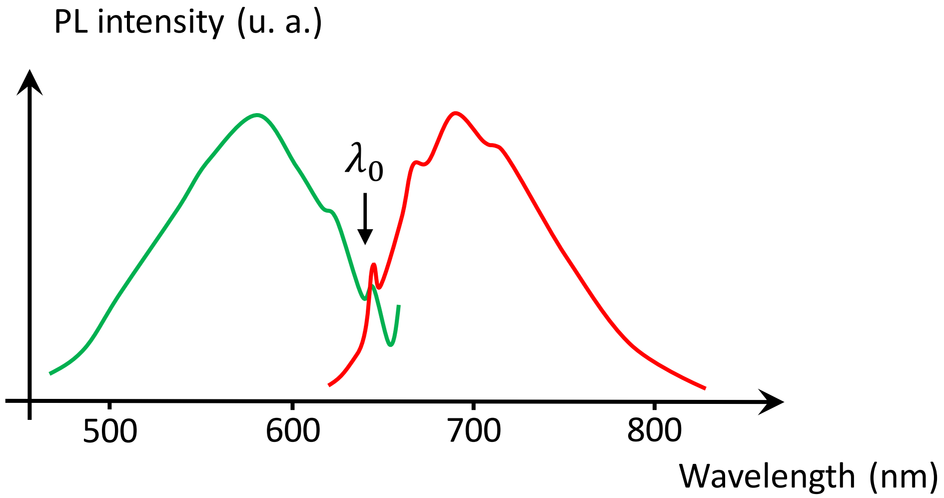
The NV centre in diamond

The NV centre in diamond is an atomic defect, perfectly photostable

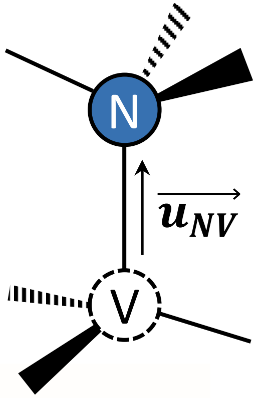


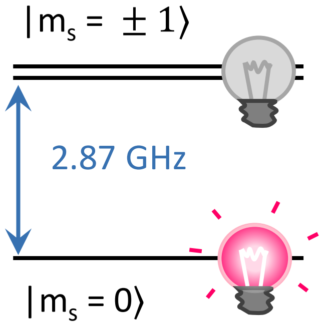
NV : Nitrogen Vacancy





Electronic spin S=1, optically adressable



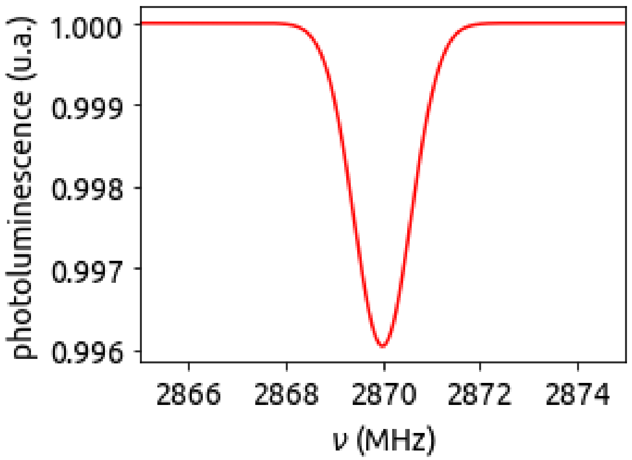


2 key properties:

Under green light excitation

- Initialisation into $|m_s = 0\rangle$
- Optical readout

Optically detected magnetic resonance (ODMR)



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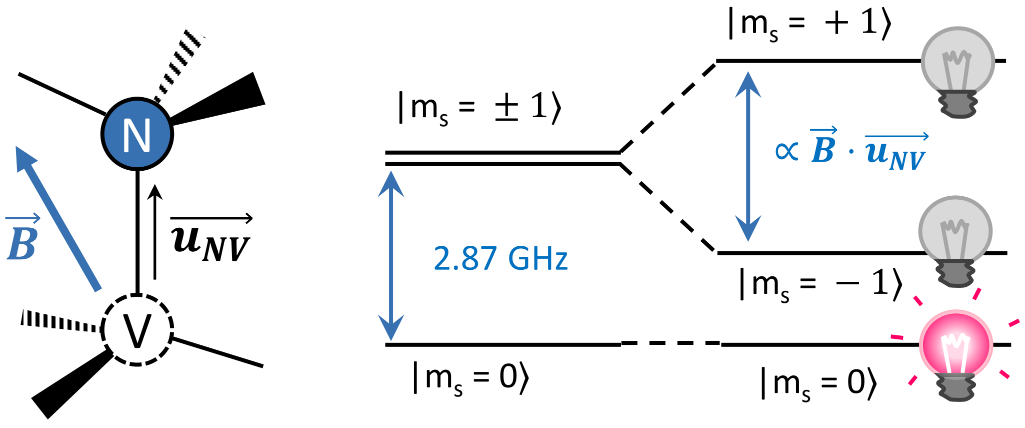
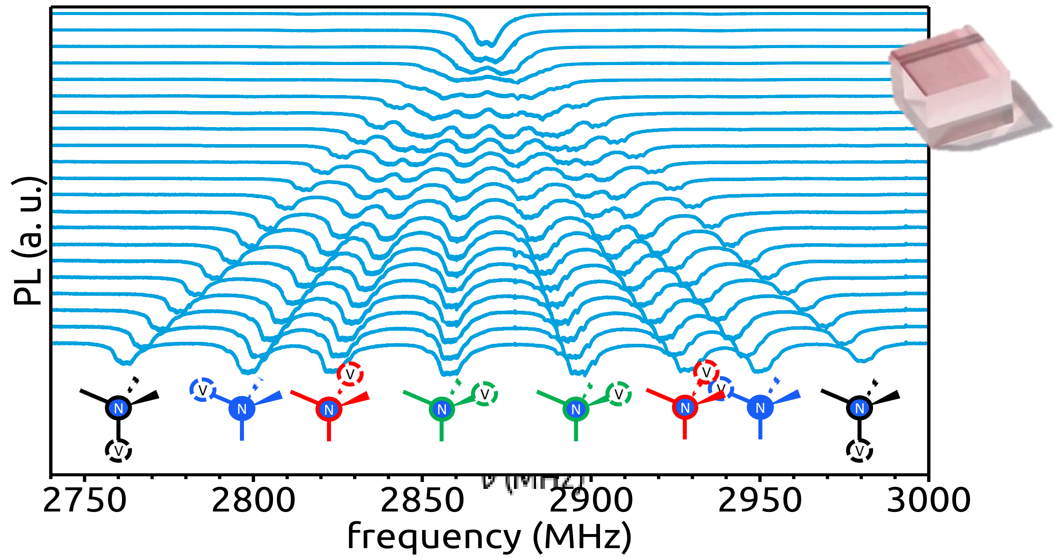
NV magnetometry

With a magnetic field: degeneracy between + 1 and -1 is lifted (Zeeman effect)



Bulk diamond: 4 possible orientations



A bulk diamond is an excellent magnetometer

- High resolution, small size (10 ~ 100 µm)
- Vectorial (3 axes)
- Quantitative and absolute (no calibration)
- High sensitivity (≤ nT/√Hz → 10 pT/√Hz*)
- Robust

for which applications?

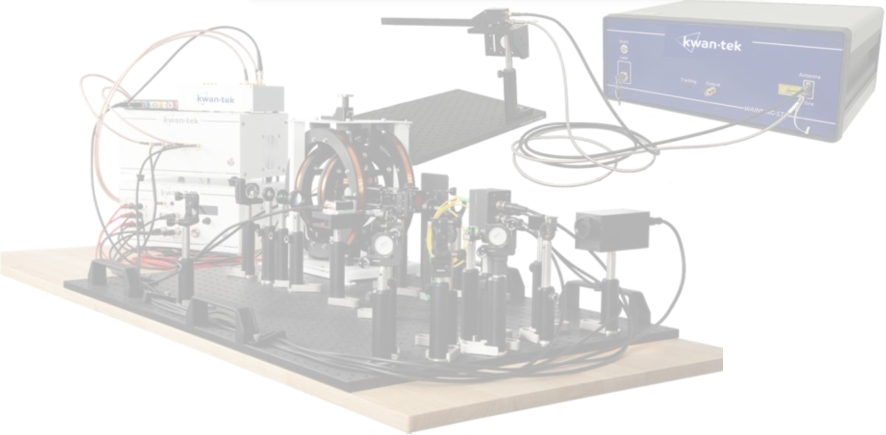
*See for example J. F. Barry, et al. "Optical magnetic detection of single-neuron action potentials using quantum defects in diamond," PNAS (2016).

Development of new applications

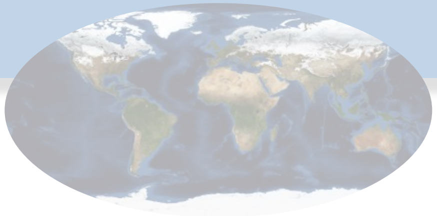
The NV centre is an excellent magnetometer

→ unique combination of resolution – accuracy – integration

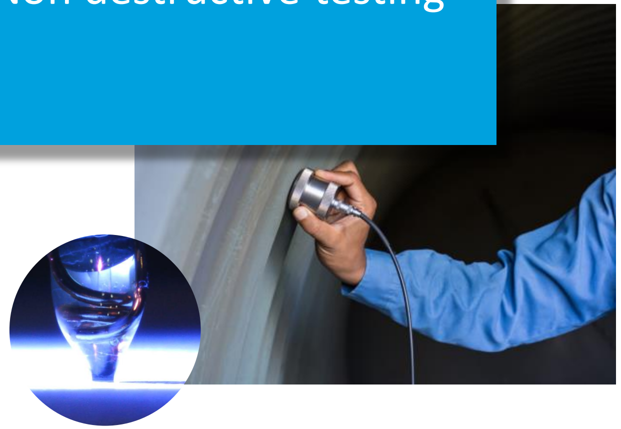
Scientific instrumentation & Teaching



Navigation & détection



Non destructive testing

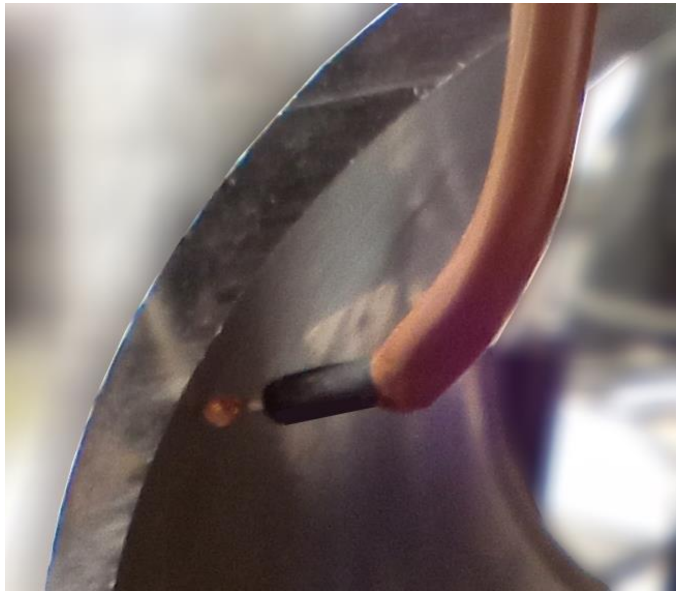


Many techniques already make use of the magnetic field for NDT (magnetoscopy, Eddy current, Barkhausen noise, ...)

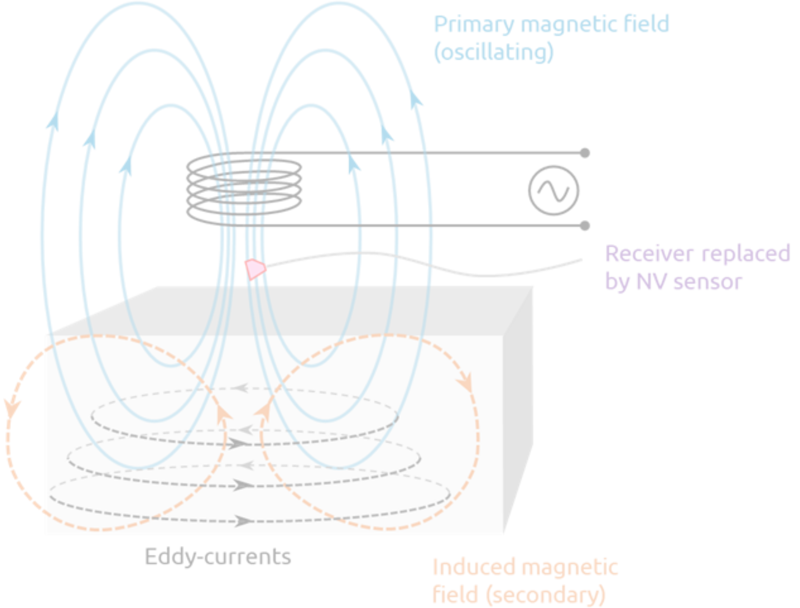
NV sensing for non-destructive testing

Goal: improve magnetic-based detections with NV sensors

DC sensing: e.g. magnetic flux leakage



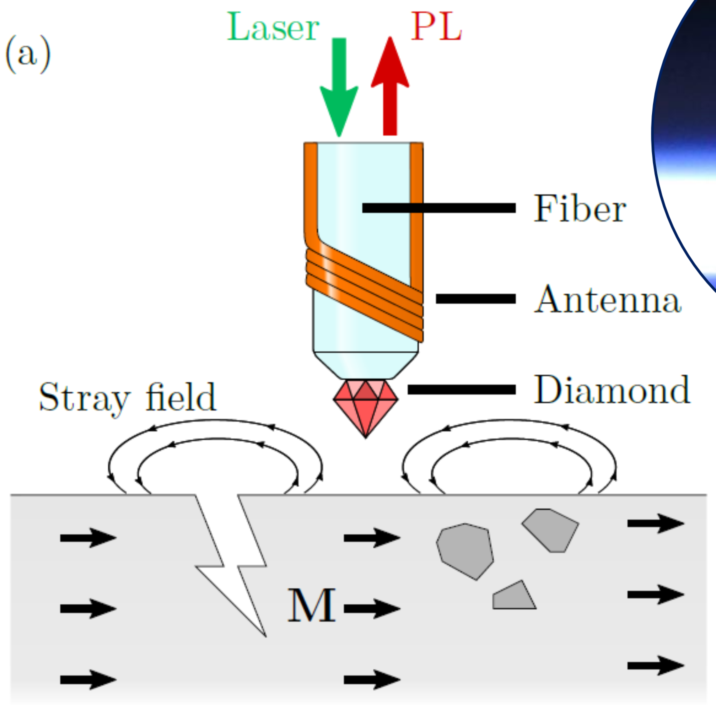
AC sensing: e.g. Eddy currents

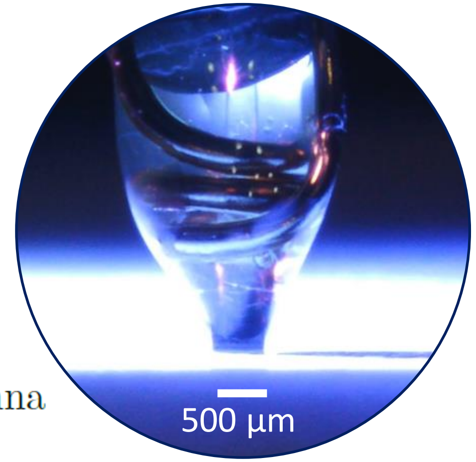


DC Sensing: MFL

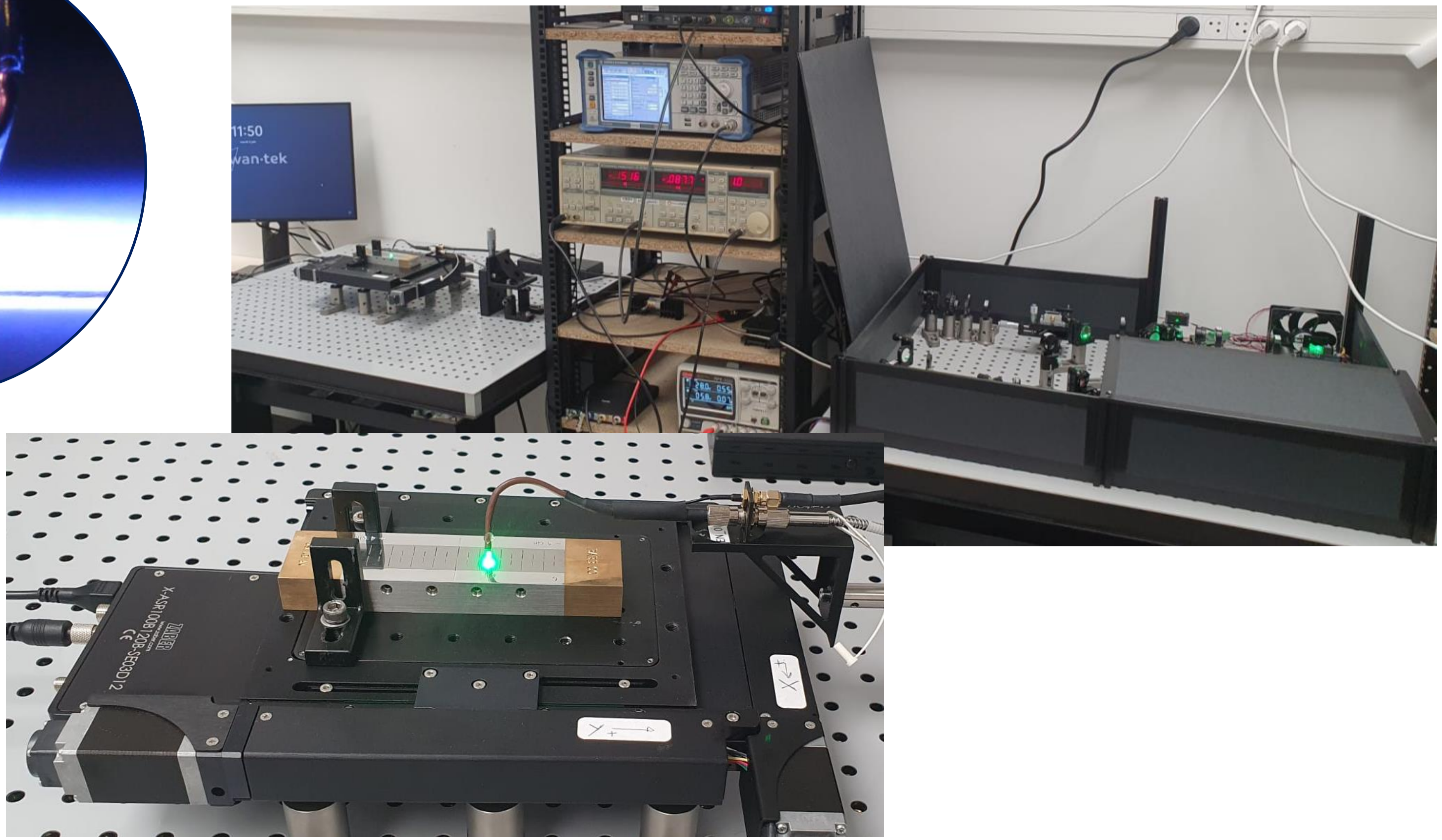
Principle: local defects such as cracks in steel give rise to stray magnetic fields (as soons as $\mathrm{div}(\vec{\boldsymbol{M}}) \neq 0$)

→ Scan a magnetometer close to the part to measure stray fields and detect defects.





Test set-up

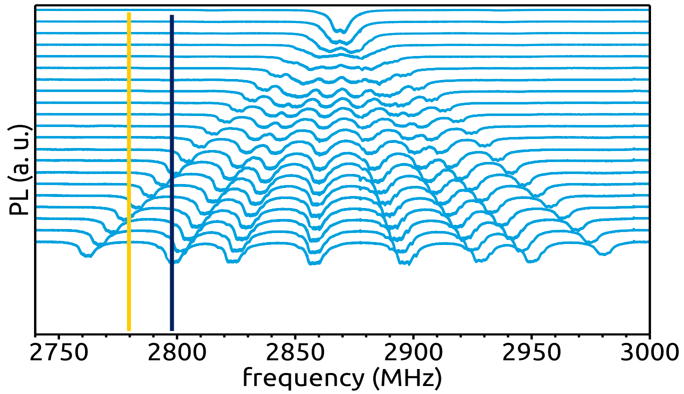


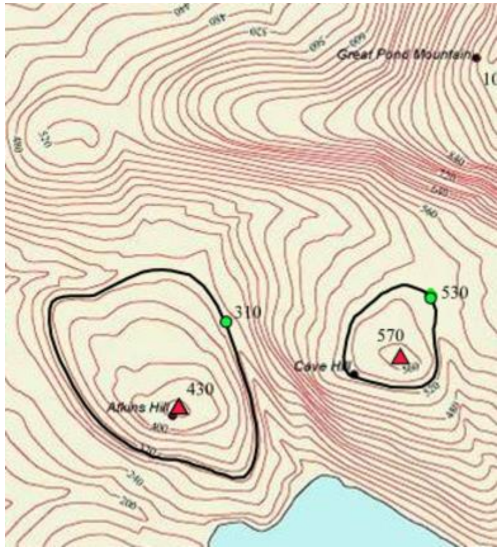
Quick imaging: iso-field (iso-B)

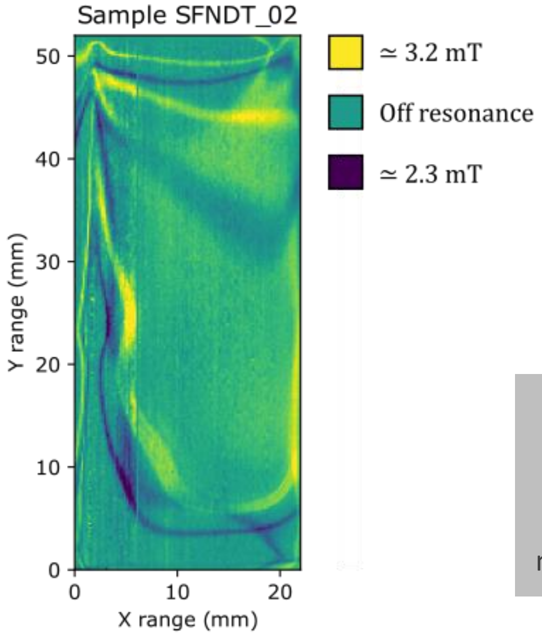
Iso-field maps are obtained by fixing the microwave frequency

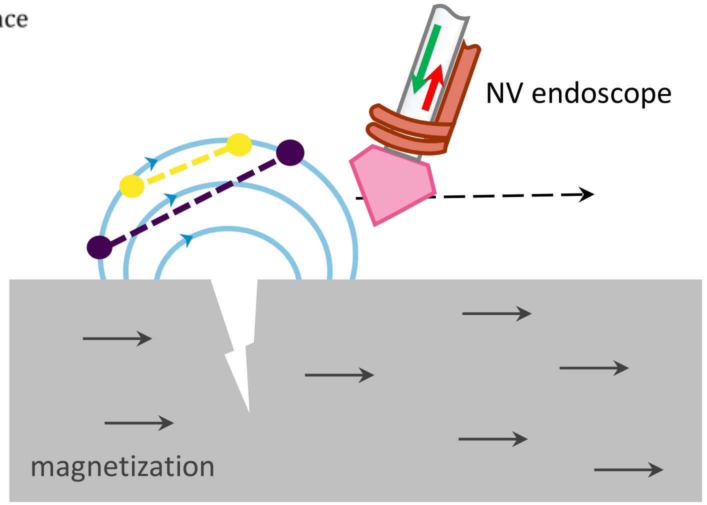
Field contours are observed, corresponding **to a given projection of the magnetic field**

(cf. relief maps)







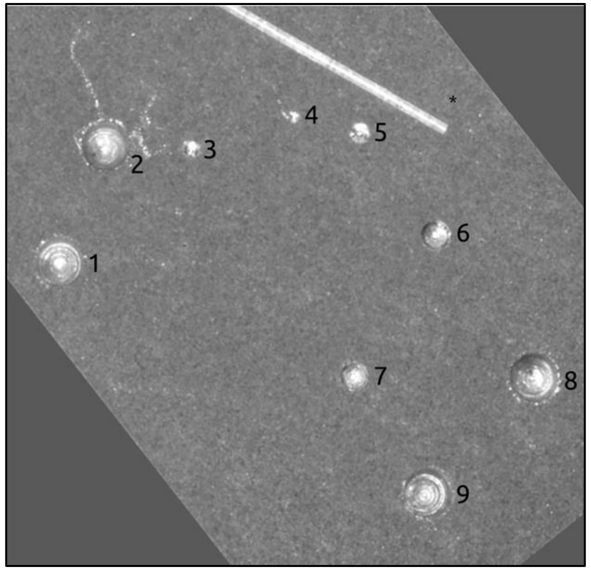


Iso-B maps contains vectorial and quantitative information about the magnetic field

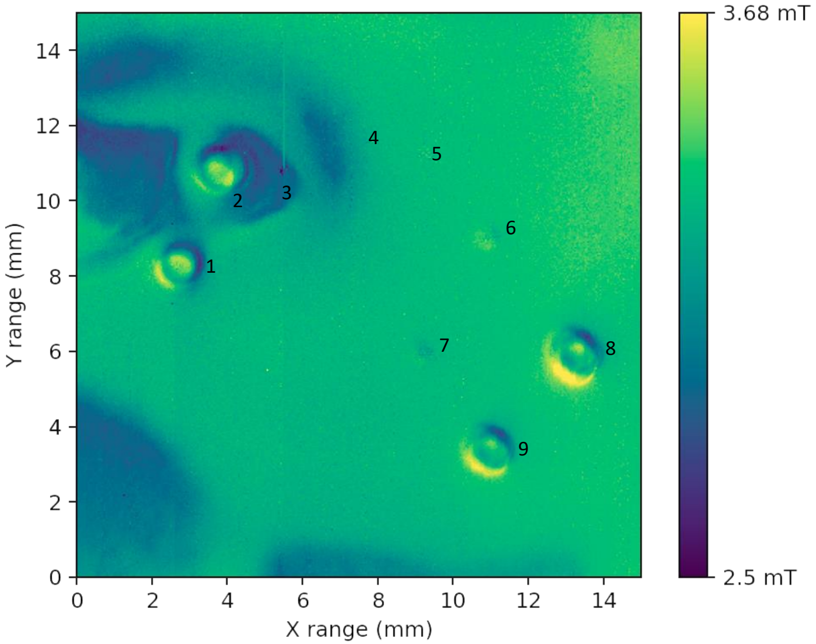
Example of results (1)

Detection and quantification of small defects by magnetic field imaging

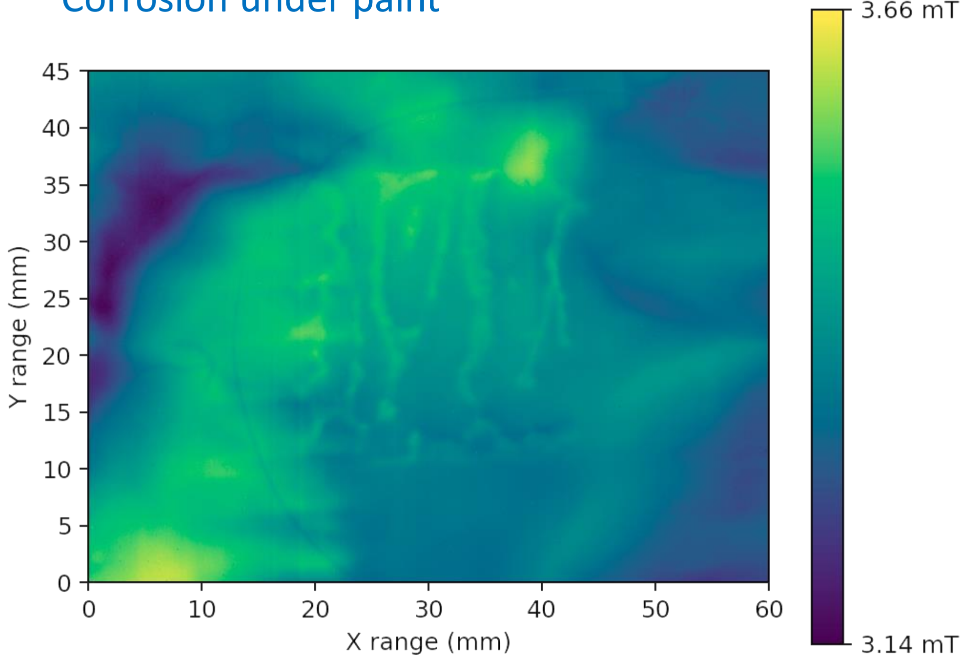
Simulated corrosion pitting in 300M steel



Photographs of the part



Corrosion under paint

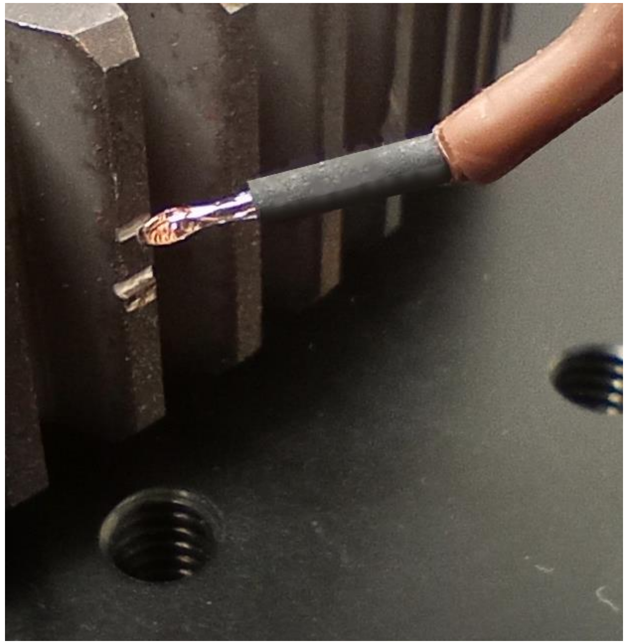


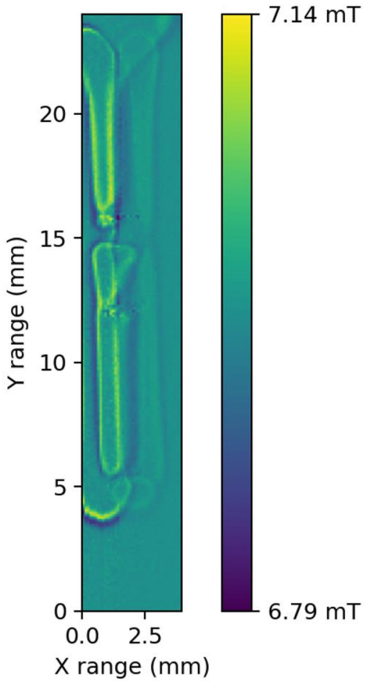
- Holes between 200 µm and 1.4 mm
- Image taken at remanence

Example of results (2)

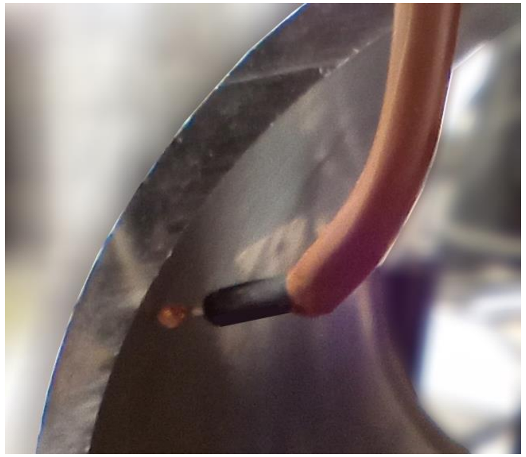
Defect in complex geometries

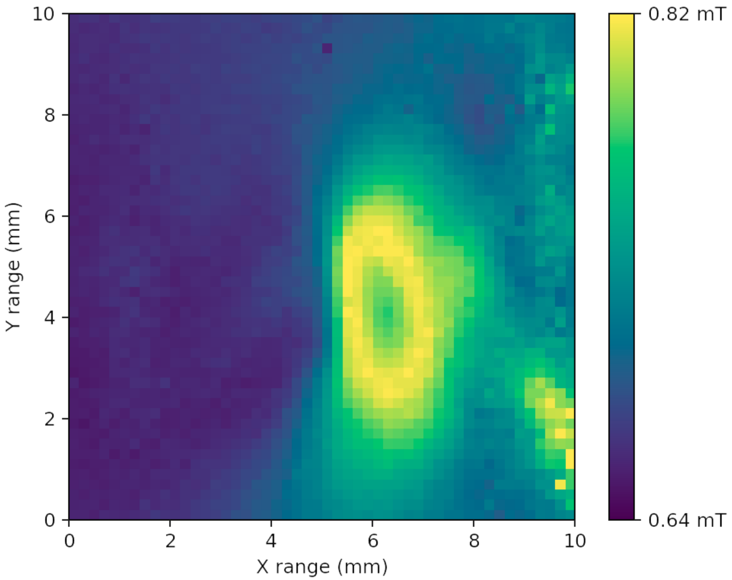
Damaged gear





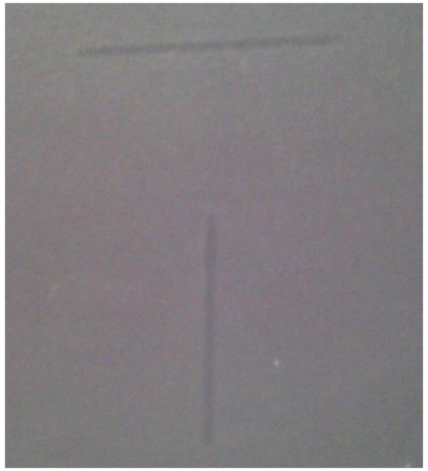
Sub-millimetre hole in a steel tube (300M)





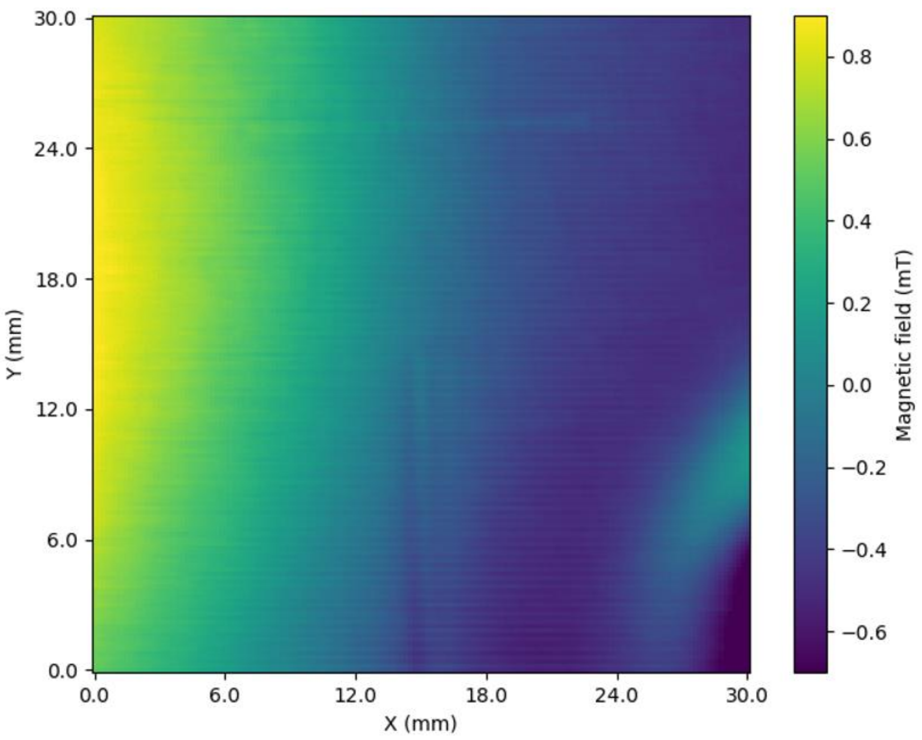
Quick and quantitative maps with resonance tracking

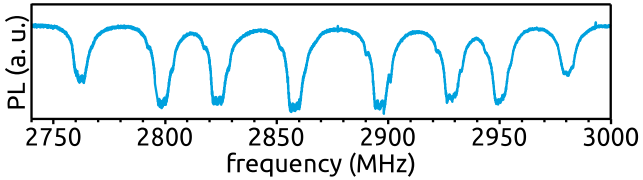
Example: detection of grinding burns in steel



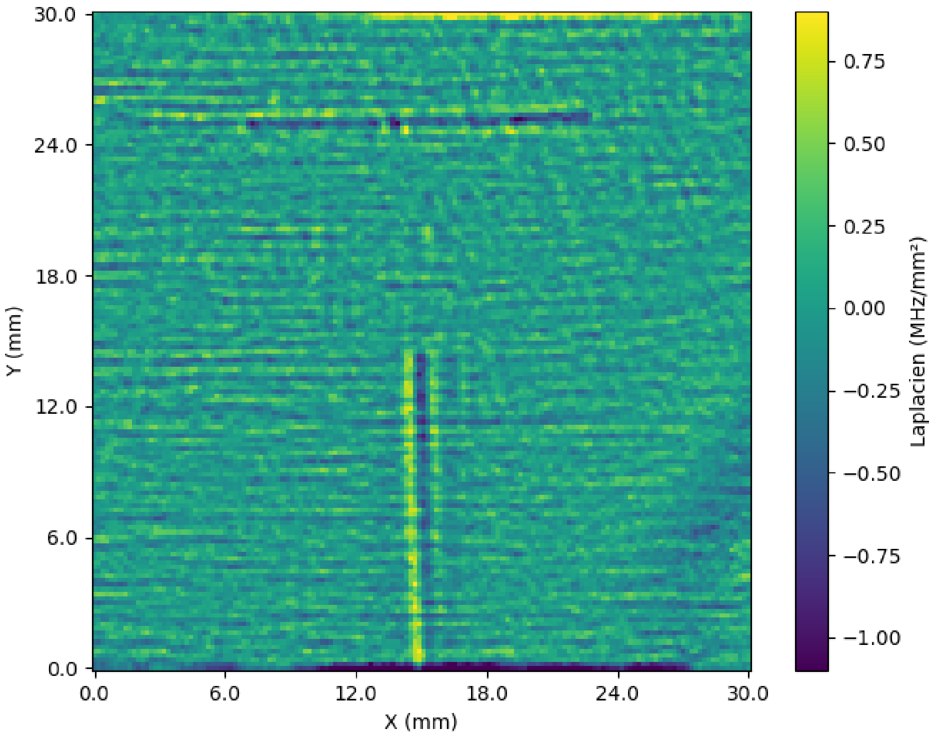
Photograph
(after chemical revelation)

Magnetic map





Spatial derivative

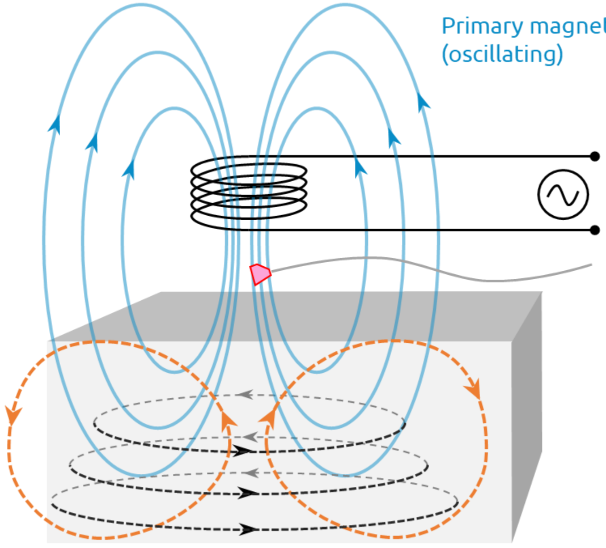


NV sensing for non-destructive testing

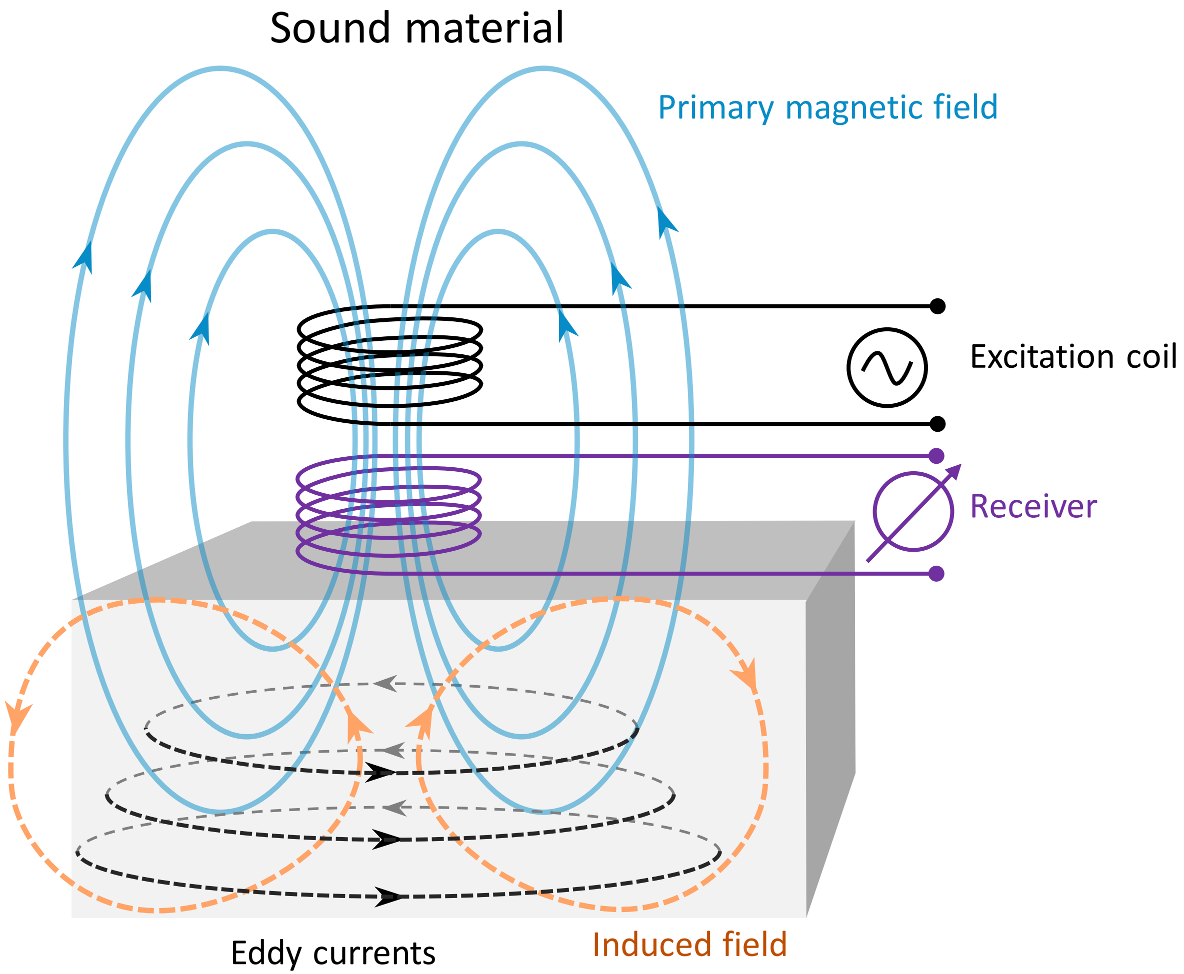
Goal: improve magnetic-based detections with NV sensors

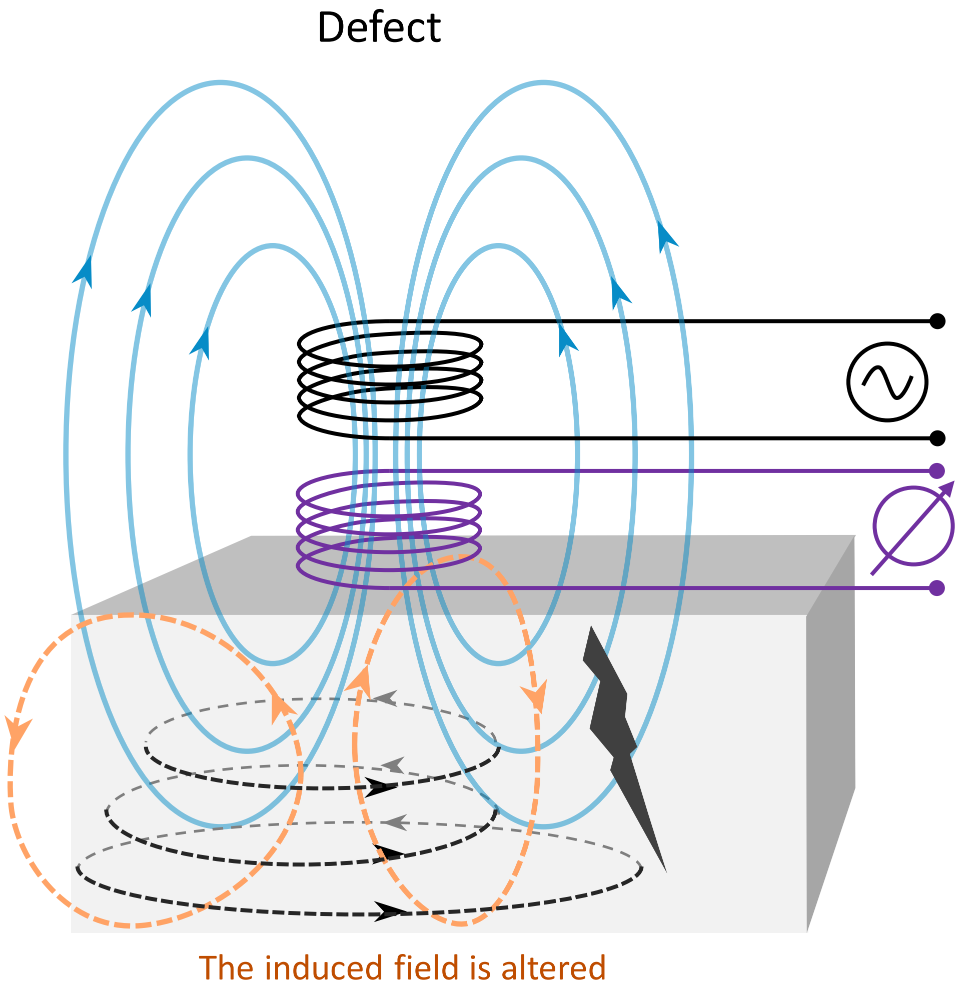
DC sensing: e.g. magnetic flux leakage

AC sensing: e.g. Eddy currents



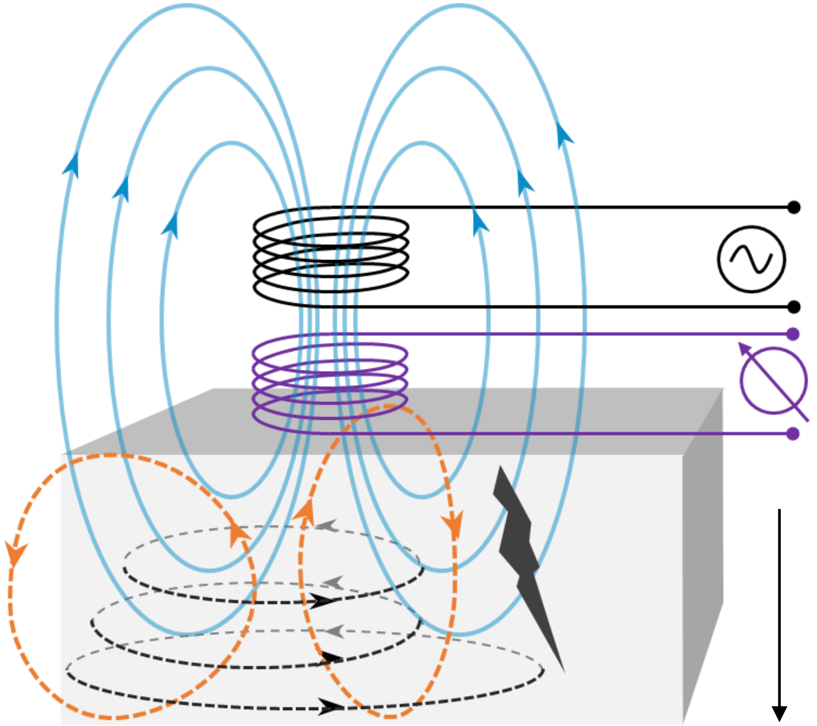
Eddy current testing





Eddy current testing

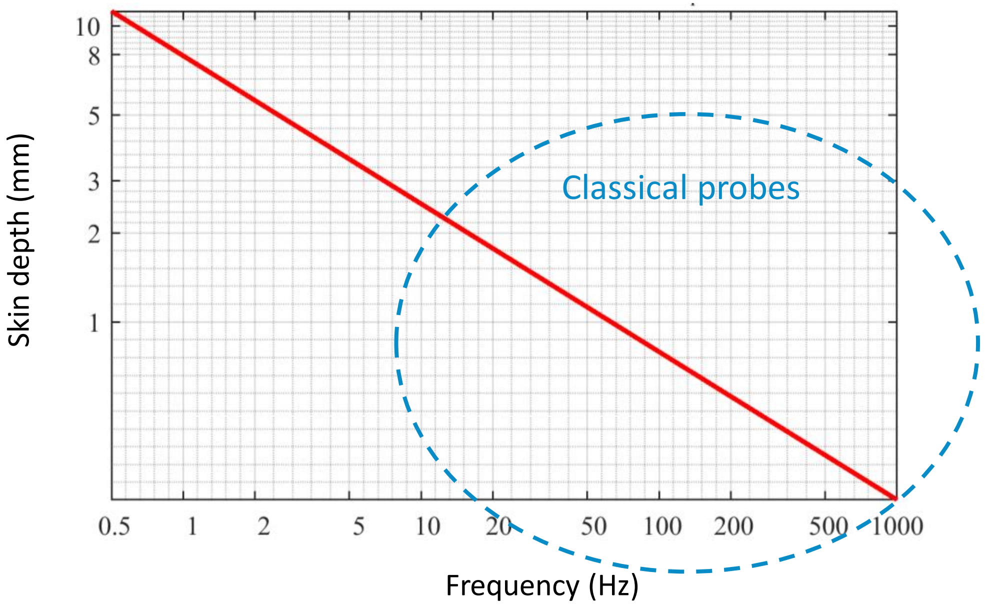
Effect of frequency



Depth of penetration of the magnetic field (skin depth)

Example - 300M steel

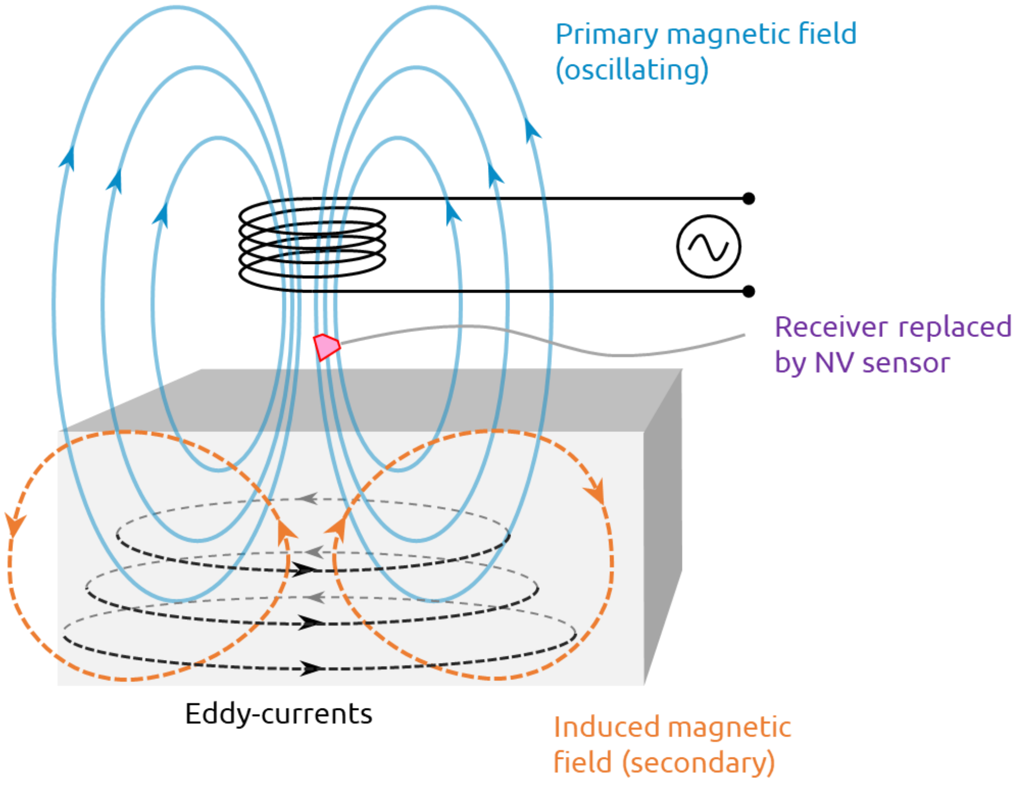
$\sigma = 4 \cdot 10^6$ S/m, $\mu_r = 1000$



Frequency needs to be lower to inspect deeper in metals
→ the induced field is weaker and the noise of classical probes increases (1/f).

NV for eddy current testing

Advantage of NV for eddy currents:



- Improve the resolution (reducing the surface of classical probes reduces the sensitivity).
- Increase measurement depth with lower frequencies

	Classical sensors	NV
Depth in steels	~ 1-3 mm	~ 10 mm
Resolution	~ 1 mm	< 100 µm

Advantages of NV for NDT

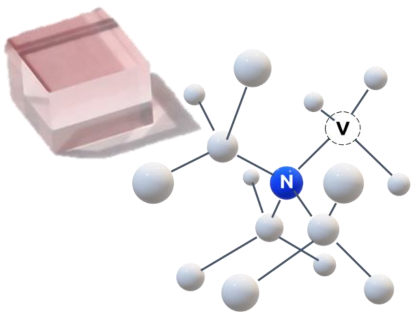
Reliable and efficient

- High sensitivity (< nT/√Hz)
- High resolution (< 10 µm achievable)
- Quantitative and no calibration
- Digital measurement

Easy implementation

- Small probe (sub-mm) for difficult geometries
- Ready-to-use (no coupling fluid, no preparation)
- Detection through paints and coatings

Conclusion – what can quantum sensors bring to the industry?



Diamond quantum sensors push back the limits of classical sensors:

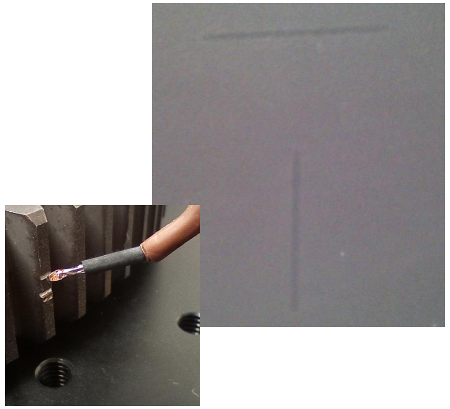
- Better sensitivity vs. resolution
- No calibration
- Easy integration, small size

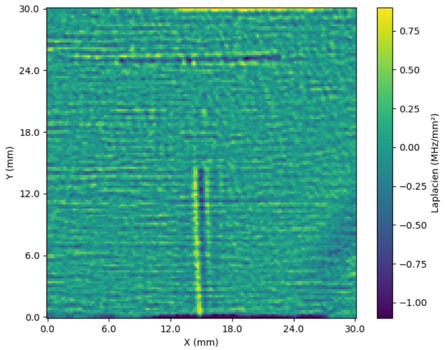
→ this opens new perspectives for applications

We think that diamond sensors can improve existing magnetic-based NDT techniques (MFL, EC …)

→ incremental change of the existing (cost efficient)

… which can still detect undetectable critical defects (hydrogen, nuclear, aeronautics…)





More sensitive, more efficient, not more complicated

Thank you

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