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Comparative Study of Coil Arrangements for the EC Testing of Small Breaking Surface Defects

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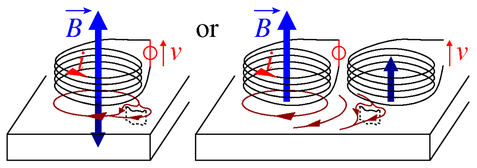
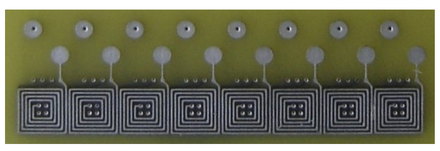
EC Measurements



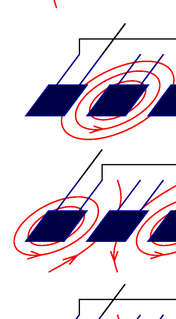
Coils

- PCB technology
- 8 layers
- 3x3 mm², square
- 2µH, 3.5Ω



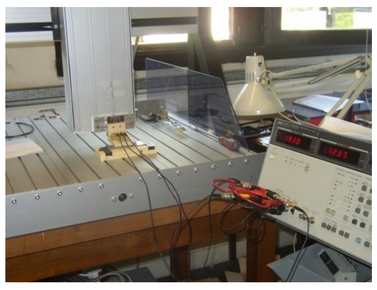
Transmit/Receive Strategies

- T/R — Signal is the coil impedance
- TR — Separate functions; Absolute measurement
- RTR — R voltages are subtracted; Differential measurement
- TRT+ — Magnetic fluxes are added; Superposition of two TR; Absolute measurement
- TRT- — Magnetic fluxes are subtracted; Superposition of two shifted TR; Differential measurement



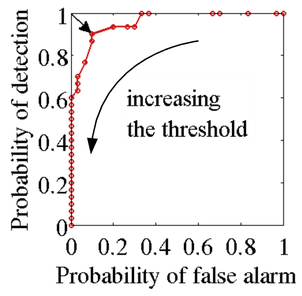
Experimental Set-up

- Nickel based alloy mockup ($\mu = 4\pi\ 10^{-7}$ H m^{-1} ; $\sigma = 0.76$ MS m^{-1})
- 30 surface breaking rectilinear defects
  - 5 lengths (0.1 mm, 0.2 mm, 0.4 mm, 0.6 mm, 0.8 mm)
  - 3 depths (0.1 mm, 0.2 mm, 0.4 mm)
  - 1 width (0.1 mm)
  - 2 orientations: perpendicular and parallel to the main orientation of the sensor array
- PC-controlled 3-axis robot; scan of surface with 0.2 mm step
- Several frequencies, from 500kHz to 6MHz



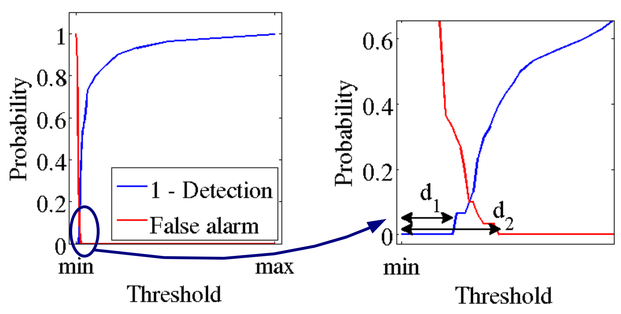
Receiver Operating Characteristic

For a given value of threshold,
30 defect areas → 30-level discretized Probability Of Detection (POD) ⇒
30 defect-free areas → 30-level discretized Probability of False Alarm (PFA)



Criteria = distance between the ROC curve and the «optimal point»

How to discriminate two «equidistant» curves?



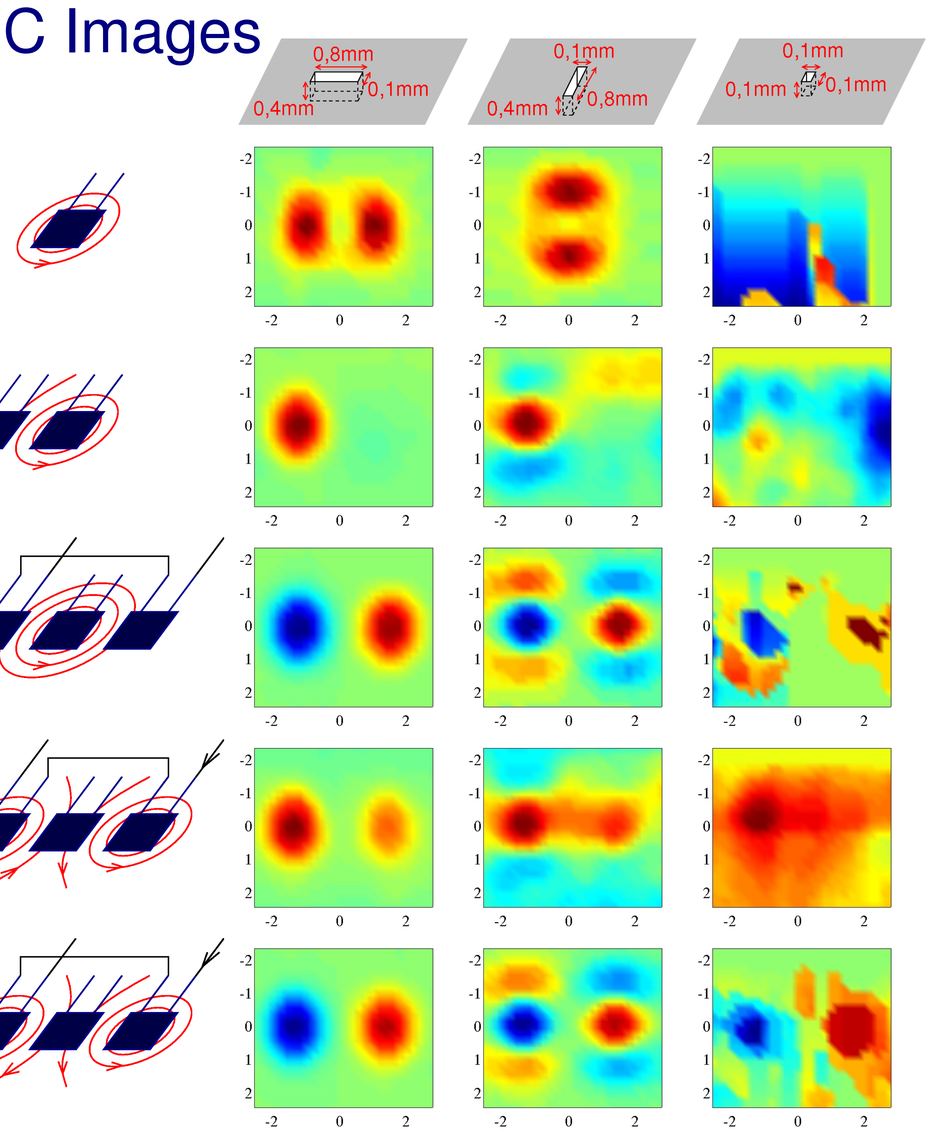
Threshold ratio = d_1/d_2

It represents the separability between detections and false alarms.

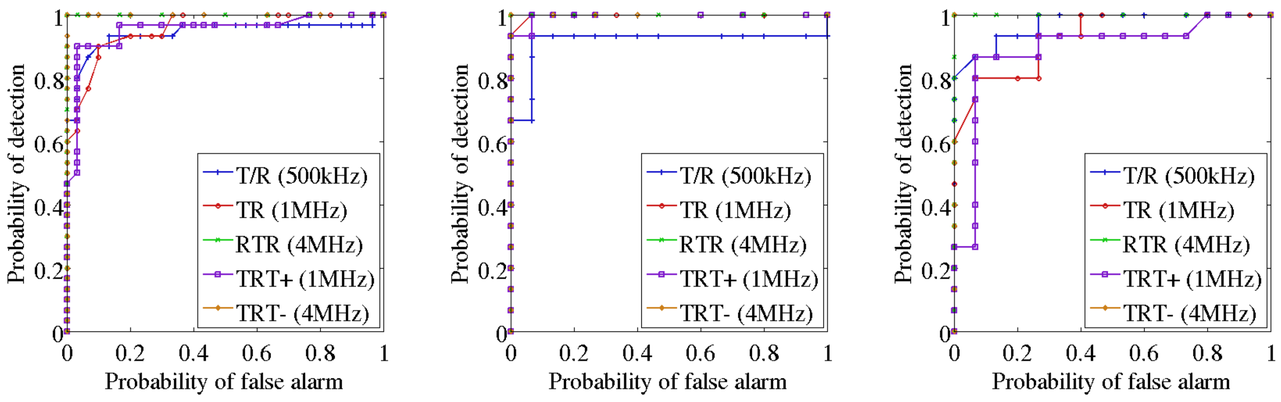
The highest it is, the most efficient the strategy is.

If $d_1/d_2 \geq 1$, the maximum efficiency point can be reached.

EC Images



Results



All defects

Only horizontal defects (parallel to the main array orientation)

Only vertical defects (perpendicular to the main array orientation)

- RTR and TRT- strategies are far more efficient than the others
- RTR and TRT- strategies both allow to reach to maximum efficiency point: there is at least one threshold which permits defects as small as 0.1x0.1x0.1 mm³ to be detected without any false alarm
- Parallel defects are better detected than perpendicular ones since EC flow is perpendicular to the main array orientation

Threshold ratio computation shows that TRT- is the most efficient strategy.

Strategies	Distance to (0,1)	Threshold ratio
T/R	0.141	0.46
TR	0.141	0.62
RTR	0	1.64
TRT+	0.105	0.30
TRT-	0	1.71

Conclusion

- An elementary array of 3 coils in line is studied and 5 transmit/receive strategies were carried out for the detection of small surface breaking defects.
- Two strategies (RTR and TRT-) permit defects as small as 0.1x0.1x0.1 mm³ to be detected without any false alarm. The TRT- strategy is the most efficient.
- The obtained EC signals are very promising and further work will focus on 2-D multicoil array using the TRT- strategy, implemented in different orientations. This should maximize the sensitivity regardless of the orientation of the defects, and thus could improve the detectability of the perpendicular defects.