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# Non Destructive Evaluation of Small Defects using an Eddy Current Microcoil Sensor Array


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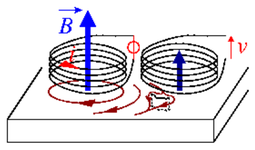
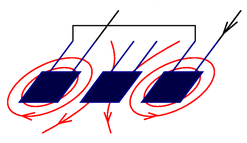
## EC Measurements

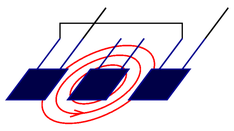
- Eddy current method: Transmission & Reception




- New design of multisensor 1-D array



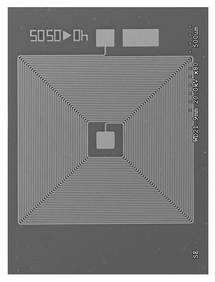
Central transmission
Differential measurement

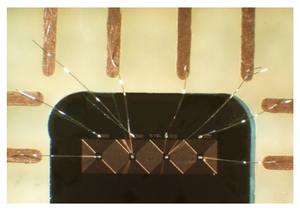


Central absolute measurement
“Differential” transmission

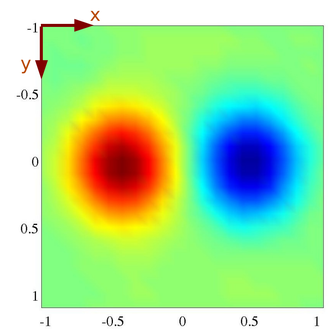
## Microcoils

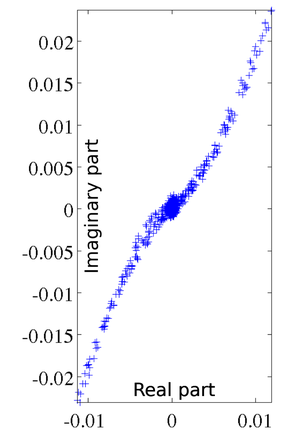
- Silicon substrate
- Copper micromoulding
- Attached to an epoxy board
- Microbonding by a 25 µm diameter aluminium wire
- Dimensions of the tracks:
  - 8 µm in thickness
  - 5 µm in width
  - 5 µm in spacing
- 1x1 mm², square
- 1±0,1 µH, 55±1 Ω





## Signal representations



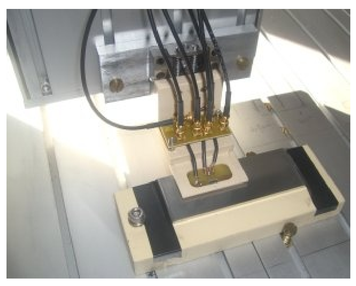




- C-Scan
- Complex signature

Here: 5MHz, 0.2x0.4x0.1 mm³ “parallel”

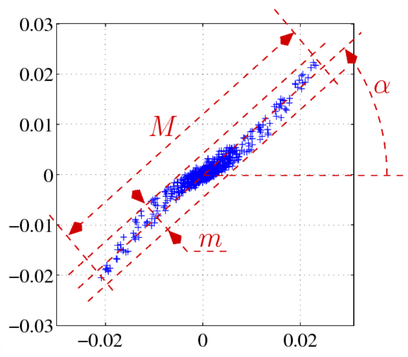
## Experimental Set-up

- Nickel based alloy mockup ($\mu = 4\pi\ 10^{-7}$ H m$^{-1}$ ; $\sigma = 0.76$ MS m$^{-1}$)
- 30 surface breaking rectilinear notches, 15 sets of dimensions
  - 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 0.1 mm step
- Frequency of excitation current: 1 to 10 MHz



## Parametrization

- Each signature is extremely simplified: only three parameters define the shape
- Signature shape depends on defect dimensions
- Parameters:
  - “Principal” amplitude *M*
  - “Secondary” amplitude *m*
  - Inclination angle $\alpha$
- Method: how to find the best projection?




Minimization of $\Delta = \sum d((x_i, y_i), D)^2$, $D : (x, y) \rightarrow a\,y + b\,x = 0$

$$\Delta = \sum \frac{|a\,x_i + b\,y_i|}{a^2+b^2} = \frac{1}{a^2+b^2}\left[a^2 \sum x_i^2 + b^2 \sum y_i^2 + 2\,a\,b \sum x_i\,y_i\right]$$

$$= \frac{n}{a^2+b^2}\left(a^2\,V(x) + b^2\,V(y) + 2\,a\,b\,\mathrm{cov}(x,y)\right) \text{ with } V(x) \text{ variance}, \mathrm{cov}(x,y) \text{ covariance}$$

By derivation and normalisation:

$$a = \frac{K}{\sqrt{1+K^2}} \quad \text{and} \quad b = \frac{1}{\sqrt{1+K^2}} \quad \text{with} \quad K = \frac{V(x) - V(y) - \sqrt{(V(x)-V(y))^2 + 4\,\mathrm{cov}(x,y)^2}}{2\,\mathrm{cov}(x,y)}$$

Finally, $\alpha = \arctan(-K)$ $M = \text{amplitude}\left(\frac{x - K\,y}{\sqrt{1+K^2}}\right)$ $m = \text{amplitude}\left(\frac{K\,x + y}{\sqrt{1+K^2}}\right)$

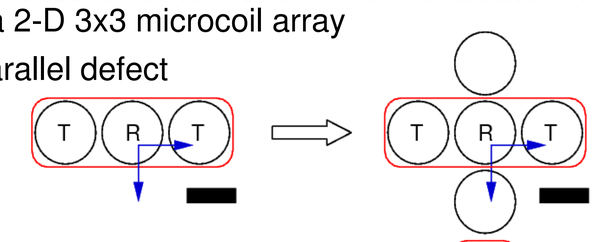
## Conclusions

- Evaluation of 15 defects with different dimensions are done thanks to an eddy current (EC) multicoil 1-D array. A new transmission-reception scheme is used, according to previous studies.
- EC complex signatures are visualized and parametrized, in order to both decrease the amount of data and characterized the evaluated defects. Results are promising:
  - mean absolute errors are very low (0.05 mm in length, 0.03 mm in depth)
  - 88% of EC signals give an estimated length with an error inferior to 0.05 mm
  - 100% of EC signals give an estimated depth with an error inferior to 0.05 mm
- Further works will focus on the improvement in the characterization method. Decimation must be increased without decreasing characterization quality.

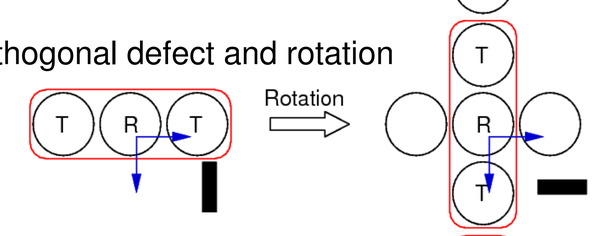
## Characterization

- Performed measurements allow to evaluate the behaviour of a 2-D 3x3 microcoil array

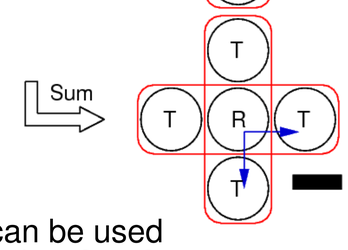
(1) Scan of parallel defect



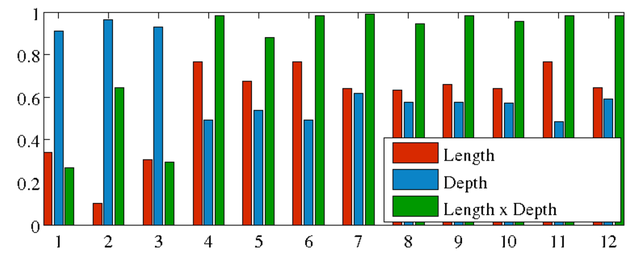

(2) Scan of orthogonal defect and rotation




(3) Sum of 1 & 2

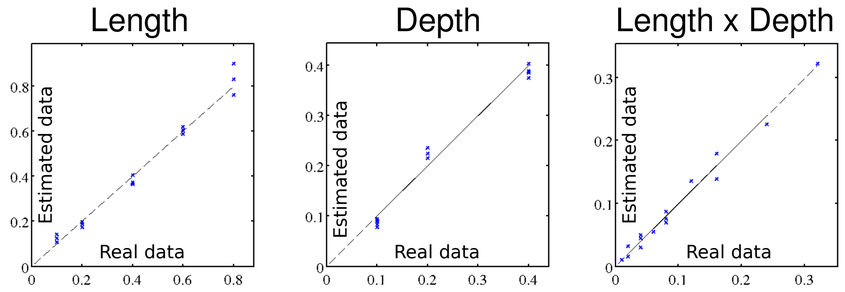



- Consequence: 12 parameters can be used
  1→3: M1, M2, M3  4→6: m1, m2, m3
  7→9: α1, α2, α3  10→12: M1/M2, m1/m2, α2-α1
- Dimensions to find : length and depth (all same width)
- Correlations with dimensions

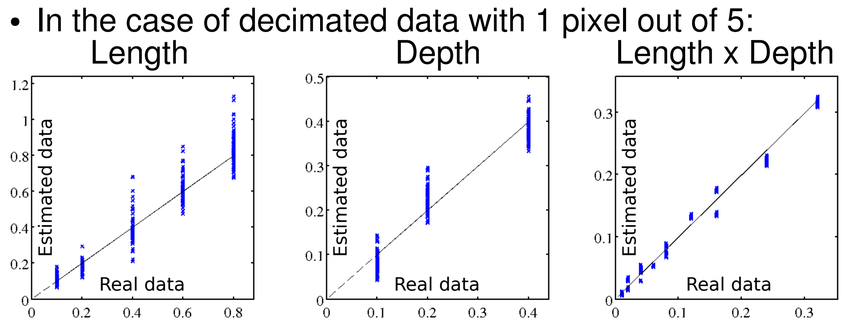



- Estimations by least-squares estimators:
with $X_{test} = \{Param_i\}$ corresponding to a known $Y$,

$$\hat{a} = (X_{test}^T\,X_{test})^{-1}\,X_{test}^T\,Y \quad \text{and} \quad \hat{Y} = X\,\hat{a}$$




- In the case of decimated data with 1 pixel out of 5:




- Mean relative and absolute error:
  14.4%,0.047mm  14.1%,0.025mm  15.8%,0.010mm²
- 88% of lengths and 100% of depths are in ±0.05mm.