SIMULATED PROBABILITY OF DETECTION MAPS IN CASE OF NON-MONOTONIC EC SIGNAL RESPONSE

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OUTLINE

Context and motivation

Case study: ECT inspection of an Aluminum plate containing notches

Intensive simulation by means of surrogate models

Estimation of hit-miss ratios and calculation of POD curves by regression

Conclusions and perspectives
Use of Probability Of Detection (POD) for NDT performance demonstration

Interest in evaluating the POD versus different parameters:
- flaw size
- flaw location

Objective: evaluate the procedure performance with respect to the flaw location, which is not possible if this is taken into account as an uncertain parameter

Problematics:
- Estimation of 2D POD maps
- The shape of a 1D POD curve calculated versus the flaw location parameter may not be approximated with a standard cumulative lognormal function (usual functional approach proposed by Berens [1])

Context

- Use of Probability Of Detection (POD) for NDT performance demonstration
- New possibilities offered by simulation

Motivation and content

To address through an illustrative example several aspects:

- POD estimation vs more than one (namely 2) variables “POD surface”:
  - Size
  - Location

Objective: Evaluate the performance of the NDE method with respect to the position of the defect

- Estimation of POD when it cannot be approximated by a standard cumulative lognormal function (usual functional approach proposed by Berens [1])

**CONTEXT AND MOTIVATION**

**Context:** Development of new tools and methods for the use of simulation in Probability Of Detection (POD) studies

- **Simulation is an opportunity:**
  - To reduce the cost of POD studies (reduce number of mock-ups, optimizing the DOE)
  - To increase the reliability of POD (complementing experiments, more complex cases)

- **Various ways of using simulation for POD studies:**
  - NDT performances assessment at feasibility stage
  - Optimization of the design of experiments
  - Provide technical justifications when minor changes of the procedure occur
  - Identification of parameters for improvement of POD results

- **Active R&D during recent period:**
  - MAPOD Group directed by USAF at CNDE (2003-2011)
  - European Project PICASSO (2099-2013)
Motivation and content

To address through an illustrative (and basic) example several questions:

- POD estimation not only versus the size of the defect but also vs location of the defect:
  - When location is considered as one of uncertain parameter it may lead to misinterpretations
  - Importance of this parameter in qualification procedures
- POD estimation vs more than one (namely 2) variables “POD surface”
- Estimation of POD when it cannot be approximated by a standard cumulative lognormal function (usual functional approach proposed by Berens [1])
- Use of surrogate models for intensive computation

Methodology for POD curves estimation using simulation

1. To input in the simulation one “nominal” configuration describing the inspection.

\[ S(a) = \phi(a) + \varepsilon_a(M) \]
CASE OF STUDY: ECT INSPECTION

Inspection of an Aluminum slab with a single coil

Simulation result obtained with CIVA: cartography of the coil impedance
### CASE OF STUDY: ECT INSPECTION

#### Parameters of interest for the POD study

<table>
<thead>
<tr>
<th>PIECE</th>
<th>PROBE</th>
<th>FLAW</th>
</tr>
</thead>
<tbody>
<tr>
<td>Thickness</td>
<td>5 mm</td>
<td>Length 5 mm</td>
</tr>
<tr>
<td>Conductivity</td>
<td>18 MS/m</td>
<td>Opening 0.1 mm</td>
</tr>
<tr>
<td>Permeability</td>
<td>$4\pi \cdot 10^{-7}$</td>
<td>Height 1 mm</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Ligament 0.1 mm</td>
</tr>
<tr>
<td>Frequency</td>
<td>100 kHz</td>
<td></td>
</tr>
</tbody>
</table>

**Diagram:**

- **Flaw length**
- **Flaw height**
- **Coil lift-off**
- **Flaw ligament**
**CASE OF STUDY: ECT INSPECTION**

- Strong effect of the coil lift-off, which has to be mitigated by the calibration process and the choice of frequency

- "A test frequency where \( \delta \) (skin depth) is about equal to the expected defect depth provides good phase separation between lift-off and defect signals" [2]

- Effect with a gaussian distribution of the lift-off during the scan

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• Phase rotation imposed by the lift-off noise
• Only the imaginary part of the signal is used after calibration
• Effect of the flaw ligament on the calibrated signal:

Non monotonic behavior of the imaginary part with respect to the flaw ligament
A non monotonic POD curve is to be expected if this parameter is chosen as characteristic parameter
• Non monotonic POD curve → regression with standard cumulative distribution function not applicable anymore

• Solution proposed: non parametric regression of Hit/Miss ratios using kernel smoothing

  • This non parametric regression requires a large data set

  • Other objective: estimating POD with 2 characteristic values

• Large number of simulations needed
  • replacement of the direct solver by a surrogate model
INTENSIVE SIMULATION BY MEANS OF SURROGATE MODELS

- Surrogate model used: linear interpolation of a database of ~2800 ECT signals generated with CIVA

- Domain of definition:

<table>
<thead>
<tr>
<th>Variable</th>
<th>Min. value (mm)</th>
<th>Max. value (mm)</th>
</tr>
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<tbody>
<tr>
<td>Coil lift-off</td>
<td>0.7</td>
<td>1.3</td>
</tr>
<tr>
<td>Flaw ligament</td>
<td>0</td>
<td>0.5</td>
</tr>
<tr>
<td>Flaw length</td>
<td>5</td>
<td>10</td>
</tr>
<tr>
<td>Flaw height</td>
<td>1</td>
<td>2</td>
</tr>
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</table>

- Verification of the accuracy by comparing 100 signals calculated with CIVA and the surrogate model (randomly sampled inputs within the domain of definition)
• Standard method of regression, making no assumption on the functional form
• In this work, use of a Gaussian kernel with smoothing parameter \( b \)

\[
K(t, x) = e^{-\frac{(t - x)^2}{b^2}}
\]

• Expression of the regression using this kernel, starting from a set of noised data \((x_i, y_i)\)

\[
\hat{y}(t) = \frac{\sum_{i=1}^{N} K(t, x_i) y_i}{\sum_{i=1}^{N} K(t, x_i)}
\]
CALCULATION OF POD CURVES

- Characteristic parameter: flaw length

<table>
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<tr>
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<th>Distribution</th>
<th>Notes</th>
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<tr>
<td>Coil lift-off (mm)</td>
<td>$\mathcal{N}(1,0.02)$</td>
<td>Regression using a Gaussian kernel</td>
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<tr>
<td>Flaw ligament (mm)</td>
<td>$\mathcal{U}(0,0.05)$</td>
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Regression using a Gaussian kernel
CALCULATION OF POD CURVES

- 2D POD, with flaw ligament and flaw length as characteristic parameters

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Regression using a 2D Gaussian kernel.
CALCULATION OF POD CURVES

- 2D POD surface, with flaw ligament and flaw length as characteristic values

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Regression using a 2D Gaussian kernel
CALCULATION OF POD CURVES

- Characteristic value: flaw ligament

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Regression using a Gaussian kernel
### CALCULATION OF POD CURVES

- **Characteristic value:** flaw length

#### Data Distribution

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#### Regression Analysis

- **Max. value of imaginary part**
- **Hit/Miss Data and POD curve**

**Regression using a Gaussian kernel**
This study illustrates the importance of considering both size and location as characteristic parameters for POD estimation when location has strong influence.

Non parametric regression can be used to handle non classical behaviors of the defect response vs the characteristic parameter of POD.

Estimation of 2D POD with non standard shapes has been obtained with Gaussian kernel smoothing method.

The large data sets required have been generated by a metamodel built from a simulated database.

Part of this work done in the framework of French National Research Project ByPASS (Bayesian methods and Metamodells for POD).

Perspective: Application to a realistic applicative case.
THANK YOU FOR YOUR ATTENTION
CALCULATION OF POD CURVES

- Characteristic parameter: flaw ligament

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Regression using a Gaussian kernel.