2008
Eddy Current Benchmarks

The World Federation of NDE Centers is pleased to announce the availability of a series of eddy current (EC) problems for a 2008 benchmark study. There are three configurations considered in this study, which are outlined in more detail below. The first two configurations involve the inspection of tubes using either an internal or external bobbin coil. The probe is centred along the tube’s axis and operates in differential mode. The three types of flaws considered are 1) a through-wall notch, 2) external or internal notches, whose orientations are longitudinal or circumferential, and 3) an external groove. The third configuration involves an air-core coil test of a slab which contains parallelepiped notches. The coil’s axis is perpendicular to the slab.

Work pieces considered here are non magnetic (inconel), and all flaws are considered as voids. The experimental results given for all the flaws are values of X and Y (Real and Imaginary) parts of the EC signal, as function of the scanning displacement along the axis of the tube or along a line parallel to the slab.

Experimental responses for these problems have been obtained by the Commissariat a l’Energie Atomique (CEA) in France. We would like you to simulate these experimental responses with EC models and compare your model-based responses to the experimental data. We would also like to invite you to participate in the 35th Annual Review of Progress in Quantitative Nondestructive Evaluation (RPQNDE) meeting, which will be held July 20-25, 2008 at the University of Illinois – Chicago. We plan to hold an eddy current benchmark session at that meeting for these problems. To present your benchmark results at that session, please note that the deadline for submitting an abstract is May 2, 2008 (mark on your abstract that it is for the EC benchmark session). Also, the advance registration deadline for the conference is June 27, 2008. For more details of the RPQNDE conference, please visit the website at www.cnde.iastate.edu/qnde/qnde.html.

The experimental data for the problems described below is available on the Center for NDE, Iowa State University ftp site (ftp.cnde.iastate.edu) together with a copy of this benchmark description. This is a protected ftp site so you will need a username and password. Please e-mail Professor Lester Schmerr (lschmerr@cnde.iastate.edu) for this information to retrieve the data. The data is in folder named 2008 EC Benchmark in the public directory named pub.
In addition to comparing your results to this experimental data in impedance plane or strip chart format, we would ask you to provide a set of text files of your model-based simulations in the same format as used for the experimental data so that we can do a summary comparison. This summary comparison will be part of a paper written for the RPQND Proceedings by a World Federation representative. All benchmark participants who provide such text file data will be listed as co-authors on this summary paper and have an opportunity to review its contents.

I am sure the members of the World Federation of NDE Centers will agree with me that your participation in these benchmarking activities is greatly appreciated. We feel that by making such comparisons we can demonstrate to the world-wide NDE community the capability modeling has to predict the signals we see in actual tests. Such comparisons will also aid in the process of making modeling an accepted engineering tool in the NDE field. We also want to thank all the folks at CEA who have designed this study and acquired the necessary data.

If you have any questions on these problems, please contact Professor Schmerr at the Center for NDE, Iowa State University (lschmerr@cnde.iastate.edu).

Lester W. Schmerr Jr.
Permanent Secretary, World Federation of NDE Centers
April, 2008
Three configurations are listed below for the 2008 Eddy Current Benchmarks. The first two deal with the inspection of tubes using an internal or external bobbin coil. The third configuration involves the inspection of a slab with an air coil probe.

1. Tube inspection using an internal bobbin coil

**Specimen**

**Tube**
Material = Inconel  
Conductivity = $10^6$ S/m, (i.e. 1 MS/m)  
Relative permeability = 1  
Dimensions :  
  - Internal radius = 9.84 mm  
  - Thickness = 1.27 mm

**Probe**
The sensor is an internal axial probe operating in differential mode. It's made of two identical internal coils centered along the tube axis.

**Diagram**

**Table**

<table>
<thead>
<tr>
<th>Specimen</th>
<th>Tube</th>
<th>Probe</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Material</strong></td>
<td>Inconel</td>
<td></td>
</tr>
<tr>
<td><strong>Conductivity</strong></td>
<td>$10^6$ S/m</td>
<td></td>
</tr>
<tr>
<td><strong>Relative permeability</strong></td>
<td>1</td>
<td></td>
</tr>
<tr>
<td><strong>Dimensions</strong></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
  - Internal radius | 9.84 mm | |  
  - Thickness | 1.27 mm | |  
| **Probe Details** | |  
  - Internal radius ($R_{\text{min}}$) | 7.83 mm | |  
  - External radius ($R_{\text{max}}$) | 8.50 mm | |  
  - Height ($h$) | 2.00 mm | |  
  - Gap between the two coils ($d$) | 0.50 mm | |  
  - Number of turns (N spires) | 70 | |
Electrical coils connection

![Diagram of electrical coils connection](image)

**Flaws**
Flaws considered here are voids:
- Conductivity = 0 MS/m,
- Relative permeability = 1.

Two grooves and two longitudinal through-wall notches are modelled in this case. The external groove is used for calibration.

1) **External 360° groove**

![Diagram of external 360° groove](image)

This flaw n°1 is referred as “GE40” in the experimental files:
- outer groove,
- 40% of the tube thickness,
- height of 1 mm (along the tube’s axis y).
2) 3D Notches

These notches are defined in the cylindrical coordinates system \((r, \phi, y)\) of the tube (see figure below) by their dimensions \(\Delta r, \Delta \phi\) and \(\Delta y\), which are detailed in the following table. Flaw n° 2 is called “ELE6”, flaw n° 3 is called “ELI6” and flaw n° 4 is called “GI10”.

![Diagram of 3D Notches](image)

<table>
<thead>
<tr>
<th>Flaws</th>
<th>Descriptions</th>
<th>(\Delta r)</th>
<th>(\Delta \phi)</th>
<th>(\Delta y)</th>
</tr>
</thead>
<tbody>
<tr>
<td>ELE6</td>
<td>External Longitudinal trough-wall notch, length of 6 mm</td>
<td>0.66 mm (52%)</td>
<td>0.63° (opening: 0.12 mm)</td>
<td>6 mm</td>
</tr>
<tr>
<td>ELI6</td>
<td>Internal Longitudinal trough-wall notch, length of 6 mm</td>
<td>0.279 mm (22%)</td>
<td>0.54° (opening: 0.093 mm)</td>
<td>6 mm</td>
</tr>
<tr>
<td>GI10</td>
<td>Internal groove 10% of the tube thickness</td>
<td>0.127 mm (10%)</td>
<td>360°</td>
<td>1 mm</td>
</tr>
</tbody>
</table>

**Inspection procedure:**
The inspection is carried out at the frequency $f = 100$ kHz. EC signals are balanced when the probe is out of the range affected by the defects, and have been calibrated on the flaw n°1 (external groove) so that we obtain for this flaw the following amplitude $A$ and phase $\varphi$:

<table>
<thead>
<tr>
<th>Canal</th>
<th>Frequency</th>
<th>F</th>
<th>A (V)</th>
<th>$\varphi$ (°)</th>
</tr>
</thead>
<tbody>
<tr>
<td>GE40</td>
<td>100 kHz (diff.)</td>
<td>2.814</td>
<td>+141.8</td>
<td></td>
</tr>
</tbody>
</table>

Amplitude and phase measured in the impedance plane are shown below.

**Experimental results**

Experimental data are all stored in text files (.txt). The example below is given for the file corresponding to defect “GE40” at the frequency of 100 kHz.
The composition of the file is the following:
Name: “SAX_100kHz_GE40”
The values (in scientific notation) are presented in 3 columns respectively corresponding to:
- A point in mm along the tube axis: labeled “Y (mm)”
- The real component of the eddy current signal in volts: labeled “Real (V)”
- The imaginary component of the eddy current signal in volts: labelled “Imag (V)”

<table>
<thead>
<tr>
<th>File Name</th>
<th>Flaw</th>
<th>Initial point (in mm)</th>
<th>Last point (in mm)</th>
<th>Step (in mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>SAX_100kHz_GE40</td>
<td>GE40</td>
<td>14.0</td>
<td>34.5</td>
<td>0.5</td>
</tr>
<tr>
<td>SAX_100kHz_ELE6</td>
<td>ELE6</td>
<td>15.3</td>
<td>34.5</td>
<td>0.1</td>
</tr>
<tr>
<td>SAX_100kHz_EL16</td>
<td>EL16</td>
<td>14.0</td>
<td>34.6</td>
<td>0.2</td>
</tr>
<tr>
<td>SAX_100kHz_G140</td>
<td>G140</td>
<td>14.0</td>
<td>34.5</td>
<td>0.1</td>
</tr>
</tbody>
</table>

2. Tube inspection using an external bobbin coil

Flaws considered in this case are a through-wall borehole, as well as longitudinal and circumferential notches.

**Specimen**

![Diagram of tube and flaw](image)

Tube:
- Material = Inconel
- Conductivity = 10^6 S/m, (i.e. 1 MS/m)
- Relative permeability = 1
- Dimensions:
  - Internal radius = 9.84 mm
  - Thickness = 1.27 mm

**Probe**

The probe is made of two identical external coils centred along the tube axis (see figure below).

![Diagram of probe](image)

- Internal radius (R_min) = 11.3 mm
- External radius (R_max) = 12.313 mm
- Height (h) = 2.01 mm
- Gap between the two coils (d) = 0.99 mm
- Number of turns (N spires) = 20
Electrical coils connection:

Flaws

Flaws considered here are voids:
- Conductivity = 0 MS/m,
- Relative permeability= 1.

Calibration is made on the through-wall borehole, and then simulations are carried out with two through-wall longitudinal notches and a circumferential one.

1) Through-wall borehole

Flaw n° 1: through-wall borehole with a diameter of 1 mm, called “TFP1”.
2) 3D Notches

Flaw n° 2 is called “ELE6”, flaw n° 3 is called “ELE10” and flaw n° 4 is called “ET82”. Their respective dimensions along the cylindrical coordinates system of the tube are listed below.

<table>
<thead>
<tr>
<th>Flaws</th>
<th>Descriptions</th>
<th>Δr</th>
<th>ΔΦ</th>
<th>Δy</th>
</tr>
</thead>
<tbody>
<tr>
<td>ELE6</td>
<td>External Longitudinal trough wall notch, length of 6 mm</td>
<td>0.66 mm (52%)</td>
<td>0.63° (opening: 0.12 mm)</td>
<td>6 mm</td>
</tr>
<tr>
<td>ELE10</td>
<td>External Longitudinal trough wall notch length of 10 mm</td>
<td>0.69 mm (54%)</td>
<td>0.60° (opening: 0.1 mm)</td>
<td>10 mm</td>
</tr>
<tr>
<td>ET82</td>
<td>Transversal through wall notch, angular extension 82°</td>
<td>1.27 mm (100%)</td>
<td>82° (extension: 15.9 mm)</td>
<td>0.133 mm ± 0.02 mm</td>
</tr>
</tbody>
</table>

**Inspection procedure**
The inspection is carried out at the frequency $f = 120$ kHz. EC signals are balanced when the probe is out of the range affected by the defects, and have been calibrated on the flaw n°1 (borehole TFP1) so that we obtain for this flaw the following amplitude $A$ and phase $\phi$:

<table>
<thead>
<tr>
<th>Canal</th>
<th>F</th>
<th>A (V)</th>
<th>$\phi$ (°)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>120 kHz (diff.)</td>
<td>0.980</td>
<td>-169.8</td>
</tr>
</tbody>
</table>

Amplitude and phase measured in the impedance plane are shown below.

**Experimental results**

Experimental data are stored in text files (.txt). The example below is given for the file corresponding to defect “TFP1” at the frequency of 120 kHz.
The composition of the file is the following:
Name: “SEXT_120kHz_TFP1”
The values (in scientific notation) are presented in 3 columns respectively corresponding to:
- A point in mm along the tube axis: labeled “Y (mm)”
- The real component of the eddy current signal in volts: labeled “Real (V)”
- The imaginary component of the eddy current signal in volts: labeled “Imag (V)”

The flaw is centered at $Z = 25$ mm, only points on both sides are indicated

<table>
<thead>
<tr>
<th>File Name</th>
<th>Flaw</th>
<th>Data Acquisition (along Y axis)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SEXT_120kHz_TFP1</td>
<td>TFP1</td>
<td>Initial point (in mm) Last point (in mm) Step (in mm)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>15.0 34.5 0.1</td>
</tr>
<tr>
<td>SEXT_120kHz_ELE6</td>
<td>ELE6</td>
<td>10.0 39.7 0.1</td>
</tr>
<tr>
<td>SEXT_120kHz_ELE10</td>
<td>ELE10</td>
<td>10.0 40.0 0.1</td>
</tr>
<tr>
<td>SEXT_120kHz_ET82</td>
<td>ET82</td>
<td>15.0 35.0 0.1</td>
</tr>
</tbody>
</table>

3. Slab inspection using an air-core coil

Flaws involved in this configuration are 20 mm long notches, which are either through-wall, surface-breaking or buried. The probe is a single emitting and receiving air-cored coil. The figure below illustrates the ECT configuration considered.

Specimen

The specimen is planar and homogeneous:
- Conductivity = $10^6$ S/m, (i.e. 1 MS/m),
- Relative permeability = 1,
- Dimensions: Height $h = 1.55$ mm.
Note: The length and the width of the plane specimen are considered as infinite in front of the dimensions of the defect and the zone of movement of the sensor.

**Probe**

The sensor is a simple coil, without ferrite, with its axe perpendicular to the surface of specimen.

![Sensor Diagram](image)

Internal Diameter (Di) = 2.00 mm  
Outer Diameter (De) = 3.25 mm  
Height (h) = 2.00 mm  
Number of turns (N spires) = 328  
The position of the sensor (defined by its axis) is at X = 20 mm and Y = 20 mm. The origin of the frame is represented on the first figure.

**Flaws**

Flaws considered here are void (conductivity = 0 MS/m, relative permeability= 1), parallelepiped notches of 20 mm length and 0.11 (or 0.14 mm) width. Their centers are positioned at (X = 25 mm, Y = 20 mm) and their orientation with respect to the sensor is shown on the first figure of this section.

![Flaw Diagram](image)

Flaw n° 1 is a through-wall notch called “100-20mm-011”, flaws n° 2 (called “80I-20mm-014”) and flaw n° 3 (called “40I-20mm-011”) are internal ones (that is they break the slab’s surface on the probe’s side) and flaw n° 4 (called “80E-20mm-014”) is an external one (that is it breaks the slab’s surface on the side opposite the probe).
<table>
<thead>
<tr>
<th>Flaws</th>
<th>Descriptions</th>
<th>Dimensions</th>
</tr>
</thead>
<tbody>
<tr>
<td>100-20mm-011</td>
<td>Length 20mm 100% of the tube thickness</td>
<td>L (mm) 20  l (mm) 0.11  h (mm) 1.55 (100%)</td>
</tr>
<tr>
<td>80I-20mm-014</td>
<td>Length 20mm</td>
<td>L (mm) 20  l (mm) 0.14  h (mm) 1.24 (80% in surface)</td>
</tr>
<tr>
<td>40I-20mm-011</td>
<td>Length 20mm</td>
<td>L (mm) 20  l (mm) 0.11  h (mm) 0.62 (40% in surface)</td>
</tr>
<tr>
<td>80E-20mm-014</td>
<td>Length 20mm</td>
<td>L (mm) 20  l (mm) 0.14  h (mm) 1.24 (80% in backwall)</td>
</tr>
</tbody>
</table>

**Inspection procedure**

The inspection is carried out at the frequency $f = 300$ kHz. Real and imaginary impedance variations of the coil are measured with an impedance analyzer; therefore no calibration procedure is involved in this case. The sensor moves on a line on both sides of the defect, so that the defect is in the center of the acquisition. The lift-off ($e$) is 0.303 mm and the scanning step is 0.1 mm. The first position is $X = 20$ mm and its final position is $X = 30$ mm.
Experimental results
Experimental data are stored in text files (.txt). The example below is given for the file corresponding to defect “100-20mm-011” at the frequency of 300 kHz.

The composition of the file is the following:
Name: “Plane_Exp_100-20mm-011”
The values (in scientific notation) are presented in 3 columns respectively corresponding to:
- A point in mm along the tube axis: labeled “X (mm)”
- The real component of the impedance signal in Ohms: labeled “Real (Ohms)”
- The imaginary component of the impedance signal in Ohms: labeled “Imag (Ohms)”