ROBOTIC NOZZLE INSPECTION WITH A FLEXIBLE PHASED ARRAY

Loïc de ROUMILLY, Blandine DOBIGNY, Olivier WATTIAU - EDF

Sébastien BEY, Arnaud VANHOYE - CEA

Patrick ANCRENAZ - AREVA

Philippe DUMAS, Laurent FOURNIER - IMASONIC
OUTLINE

1. **INTRODUCTION OF THE ISSUE**

2. **DESIGN OF THE NDE PROBE, SETTINGS INFLUENTIAL PARAMETERS ROBOT**

3. **EXPERIMENTAL RESULTS**
INTRODUCTION

- **Component:** Chemical and Volume Control System nozzle
  - 3” nozzle
  - Stainless steel material
  - Mixing area between cold and hot fluids
    → potential radial defects on inner surface of the nozzle

- **NDE requirements:**
  - Detection
    Target: 10 x 60 mm planar defect
    - Based on corner effect
    - No diffraction echo
      - Weld
      - Long path in the austenitic material
  - Characterization

**Issue**
- How to size a potential defect?
SIZING METHOD
BASIC PRINCIPLES

- Detection of the corner echo
- Detection of tip diffraction

- Distance corner echo/tip diffraction
  ↓
  Height

- Length of corner echo
  ↓
  Length

- Probe as close as possible to the defect
- UT Beam orthogonal to the defect
Benefits of 3D flexible array probe for ultrasonic inspection of a weld nozzle

Robotic tool required to ensure accuracy in positioning

SIZING METHOD
SEARCH FOR SOLUTIONS IN LABS
NUCLEAR APPLICATIONS OF SMART FLEXIBLE PROBES, CEA-EDF - ICNDT 2010
SOLUTION

- **New transducer**
  Flexible surface to match the complex shape

- **Specific simulation tools**
  - To optimize the settings
  - To evaluate the influential parameters
  - To compute the trajectory
  - To analyse experimental data

- **Robotic tool**
  Translation and rotation
DESIGN OF THE PROBE

- **Characteristics**
  - frequency: 2 MHz
  - 84 elements
  - elements dimensions: 1.8 mm x 2.5 mm;
  - spacing between 2 elements: 1 mm x 1.5 mm
  - 13 pistons

- **Allowed deformations**
  - $r = 30$ mm
  - $10$ mm
**Settings of the probe**

- **Objective**
  - Optimize the echoes amplitudes
    - Refracted beam perpendicular to defect → 0° skew
    - Optimization of the refraction angle
  
- **Amplitude maps of defect reflectivity with different refraction angle**
  - dedicated simulation CIVA tool

![Amplitude maps of defect reflectivity with different refraction angle](image)

Example for a defect located à 0° along the pipe

Great homogeneity for θ = 40° LW refracted beam
**DESIGN OF THE PATH**

- Simulation of the path
  - Assumptions:
    - defect position
    - 40° refracted LW beam – 0° skew
  - Optimized path

- At each position, computation of the Delay Laws
  - Beam steering: focusing on the defect

Delay laws embedded in the UT system and path sent to the robot software.

At least 30 positions

11 delay laws
INFLUENTIAL PARAMETERS

- Illustration on a defect parallel to the axis of the pipe (0°)
- Real geometry vs CAD profile

Comparison between
- simulations on parametric profile as input parameters (black)
- simulations on a real CAD profile as input parameters (red) - unchanged delay laws

Conclusion
- Difference between both configurations : 11 dB
- Important impact on defect sizing
  → Need for taking into account real geometry for delay laws computation
INFLUENTIAL PARAMETERS

- **Off-set of rotation; comparison between**
  - simulation on the optimized path and a correct probe orientation
  - simulation with a misorientation of the probe unchanged delay laws

**Conclusion**
- Impact on echoes amplitudes
- Impact on length sizing
- Requirement on the robot accuracy
**Influential Parameters**

- Influence of the position of the defect
  - Simulations with a defect located at $0^\circ \pm 10^\circ$
  - Unchanged delay laws

- Impact on echoes amplitudes
- Impact on length sizing

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**Conclusion**

**Raster scan** to cover the whole area (for instance 5 lines)
ROBOTICS: DESIGN AND SETTINGS

- **Développement**
  - CIVA trajectories in the nozzle frame, on the real CAD
  - Kinematics studies → position of the robot on the pipe
  - Template to ensure an accurate positioning of the robot in the nozzle frame

- **Criteria for selecting the robot STAUBLI TX40**
  - accuracy
  - light weight - compact
  - (ease to be decontaminated)
EXPERIMENTAL TESTS

Representative model of the nozzle

Robotic arm and flexible probe

Surrounding obstacles
5 lines
36 positions per line
5 lines
36 positions per line
11 delay laws per position

1980 shots
EXPERIMENTAL RESULTS

Corner effect
EXPERIMENTAL RESULTS

Diffraction echo
### Tests results

<table>
<thead>
<tr>
<th>Length (mm)</th>
<th>Height (mm)</th>
<th>Depth (mm)</th>
<th>Angular position (°)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Actual</td>
<td>Measured</td>
<td>Actual</td>
<td>Measured</td>
</tr>
<tr>
<td>60</td>
<td>50.3-50.7</td>
<td>10</td>
<td>11.6 – 11.9</td>
</tr>
<tr>
<td>30</td>
<td>29.7</td>
<td>8</td>
<td>8.5</td>
</tr>
<tr>
<td>20</td>
<td>18.7</td>
<td>5</td>
<td>4.9</td>
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**SUMMARY**

**DETECTION**
- Position of the defect

**SIMULATION**
- Robot trajectory and robot frame

**ACQUISITION**
- Optimized path and Raster scan
- Synchronisation between robot positions and UT shots
- 1980 acquisitions

**ANALYSIS**
- Delay laws
- Automatic choice of relevant acquisitions and reconstruction

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Cf. communication Réf. WED.2.B.4 - *CIVA inspection planning tools for the definition of complex components proper inspection parameters*
CONCLUSION

- Development of an innovative solution
  - Available for sizing potential defects in a CVCS nozzle
  - Tested in representative conditions
  - Good agreement between experimental results and theory

- Possible uses
  - Other nozzles (4” for example)
  - Other complex geometries (bent piping)
THANK YOU