Numerical Study of Shear Horizontal Electromagnetic Acoustic Transducers for Generation of Ultrasonic Guided Waves

Liang Cheng
18/09/2014
Outline

• Introduction of BIC
• Theoretic background of EMAT
• EMAT modelling for EMAT
• Conclusions
1. Brunel Innovation Centre (BIC)

- Brunel Innovation Center (BIC) is part of the School of Engineering and Design faculty of Brunel University.

- BIC is based in Cambridge.

- The research carried out at BIC is predominantly in the field of NDT and related areas, including:
  - SHM / CM (Acoustic emission & guided waves)
  - Ultrasonic Detection / Cleaning
  - Smart NDT (automation, wireless, IMUs)
  - Sensors and transducers (aggressive environments; high temperature)
  - Signal / Image processing
  - Pattern Recognition
  - Systems (hardware-software) integration
1.2 COMSOL Simulation at BIC

Ultrasonic cleaning

Cable inspection

Ultrasonic & vibration De-icing
2 Theoretic Background of EMAT

Theory: \( f = \mathbf{J}_e \times \mathbf{B}_s \)

- \( f \): Lorentz force \( \rightarrow \) ‘Solid mechanics’ module \( \rightarrow \) Body load
- \( \mathbf{J}_e \): Eddy current density \( \rightarrow \) ‘AC/DC-Magnetic Fields’ module
- \( \mathbf{B}_s \): static magnetic flux density \( \rightarrow \) ‘AC/DC-Magnetic Fields (No Current)’

\[
\begin{align*}
    f_x &= J_y B_z - J_z B_y \\
    f_y &= J_z B_x - J_x B_z \\
    f_z &= J_x B_y - J_y B_x
\end{align*}
\]
2.2 Ultrasound generation of EMAT

Top view of EMAT

Eddy Current

Lorentz Force

Magnetic Flux

Ultrasound

\( \lambda = 12 \text{mm} \)

Eddy Current

\( \lambda = 12 \text{mm} \)
3.1 Design for EMAT

“racetrack” shaped spiral of 0.315mm diameter lacquered copper wire

15 x 5 x 5mm SmCo Magnets

Maximum temperature 200°C

“racetrack” coil (curved ends folded around magnet array)
3.3 COMSOL Model

Excitation \( J(t) = \begin{cases} \frac{J_0 \sin(2\pi ft)}{N} \left(1 - \cos \frac{2\pi ft}{N}\right), & \text{for } t \leq N/f \\ 0, & \text{for } t > N/f \end{cases} \)

\( J_0 = 1A/(0.315\text{mm})^2, f = 256.7 \text{ kHz}, N = 5 \text{ cycles} \)

<table>
<thead>
<tr>
<th>Property</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Density (kg/m(^3))</td>
<td>8000</td>
</tr>
<tr>
<td>AISI 316Ti steel</td>
<td></td>
</tr>
<tr>
<td>Relative permeability</td>
<td>1.008</td>
</tr>
<tr>
<td>Relative permittivity</td>
<td>1</td>
</tr>
<tr>
<td>Young’s modulus (Pa)</td>
<td>195e9</td>
</tr>
<tr>
<td>Poisson’s ratio</td>
<td>0.285</td>
</tr>
</tbody>
</table>
3.4 Direction of Bs in the plate

Arrow Volume: Magnetic flux density (Spatial)
3.6 Eddy current density distribution on the surface of the sample

Arrow Line: Induced current density (Spatial)
3.7 Displacement in x and z direction at a location 75mm away from the EMAT

Point of interest

$d=75\text{mm}$
3.8 Displacement on a plate
Conclusion

• Design of EMAT transducer
  – Periodic permanent magnet (PPM)
  – Race track coil

• Simulation results of EMAT
  – Eddy current distribution
  – Magnetic flux density distribution
  – Ultrasonic wave (displacement)
  – Wave propagation
    • Concentrated in x and y direction
Acknowledgements

- This study is funded by the FP7 INTERSOLAR project under the Research for the benefit of SMEs programme, Grant Agreement Number 605028. The project is coordinated by CIT Limited. The partners in this project include:
  - CIT Limited (UK), Applied Inspection Limited (UK)
  - Technology Assistance BCNA 2010 S.L. (Spain)
  - PSP S.A. (Greece)
  - INGETEAM Service S.A. (Spain)
  - Brunel University (UK), Universidad de Castilla-La Mancha (Spain)
  - ENGITEC Limited (Cyprus)

- The authors would like to thank Sonemat Limited (UK) for their contributions on the design of EMAT transducer.