Measurement techniques for magnetic pulse welding*

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Nantes, 1st December 2016
Motivation for measurements during MPW

<table>
<thead>
<tr>
<th>Process development</th>
<th>Quality assurance</th>
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<td>Aim</td>
<td>Elaborate optimal welding parameters</td>
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<td>Typical methods</td>
<td>In situ detection of non-welded parts</td>
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<td>Photon Doppler velocimetry, current measurements, high speed imaging</td>
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Bellmann et al., “Effects of surface coatings on the joint formation during magnetic pulse welding in tube-to-cylinder configuration,” 7th Int. Conference on High Speed Forming, 2016
Challenges for measurements during MPW

- Pulsed high magnetic field
- High pressure at the welding interface
- Jet
- Process light
- …
Established measurement methods

- **Current**
  - e.g. Rogowski pick-up coil

- **Magnetic field**
  - e.g. Hall sensors

- **Collision behaviour**
  - e.g. High speed camera

- **Flyer movement**
  - e.g. PDV

Increasing prediction capabilities of a sound weld
New ideas for the measurement of the collision behavior

**Aim:** Consolidation of process insights

1. PDV
2. Indentation test
3. Flash detection
1. PDV – tube to tube configuration

**Concept:** In situ velocity measurement

Key figure: $v_{p,\text{max}} / v_{f,\text{max}}$ in %
Result: MPW possible despite parent deformation

Pulse generator: Maxwell Magneform 7000
Timeshift between collision and parent deformation $\rightarrow$ weld strength established within 20 µs
2. New indentation test

Mapping of the flyer’s kinetic energy

$P_{mag}(t)$

Pins

Soft material

Slot of the working coil

Indentation mark

Measurement techniques for magnetic pulse welding
**Result:** Influence of the slot and flyer thickness

![Diagram showing indentation depth vs. flyer thickness with a pulse generator and constant radial impact velocity](image)

- **Pulse generator:** Bmax MPW 50/25
- **Constant radial impact velocity:** (350 m/s at 180°)
- **Slot of the working coil:**
3. Flash detection – new possibilities
Characteristic values of the flash

1. Flash appearance time
2. Max. intensity
3. Flash duration

Graph showing:
- Current in kA
- Voltage equivalent for light emission in V
- Time in μs

Legend:
- Light emission
- Tool coil current
✓ Detection of failures during acceleration
✓ Detection of asymmetries (part / tool related)
✓ Good accessibility

<table>
<thead>
<tr>
<th></th>
<th>Flash Appearance Time (µs)</th>
<th>Flash Duration (µs)</th>
<th>Maximum Light Intensity (V)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average (n=4)</td>
<td>10.59</td>
<td>145</td>
<td>6.5</td>
</tr>
<tr>
<td>Variation coefficient</td>
<td>1.7%</td>
<td>4.2%</td>
<td>5.4%</td>
</tr>
<tr>
<td>Slot of the working coil</td>
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</table>

Circumferential weld

Pulse generator: Bmax MPW 50/25
Correlation of the flash with the weld seam formation

- Pulse generator: Bmax MPW 50/25

Chart showing the correlation between flash duration, weld seam length, and flash intensity with collision velocity.
Suitable for detection of surface disturbances (e.g. oil)
Measurement of the weld front propagation

<table>
<thead>
<tr>
<th>Location</th>
<th>Weld front propagation velocity $v_c$ (m/s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>2326</td>
</tr>
<tr>
<td>II</td>
<td>1449</td>
</tr>
<tr>
<td>III</td>
<td>1351</td>
</tr>
</tbody>
</table>

Pulse generator: Bmax MPW 50/25
Summary

Insights into MPW:
1. Weld strength is established before parent deformation is completed (tubes)
2. Impact energy of the flyer varies over the circumference
3. Hypervelocity impact flash is a suitable tool for the measurement of collision parameters, detection of asymmetries,...*

*DE102016217758.3 (patents pending)
Acknowledgements

- For your interest in magnetic pulse welding
- For the financial support from the German Research Foundation (DFG)