Electromagnetic Attractive Bulging of Small Pipe Fittings: Fundamentals and Simulations

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Research background

Light-weighting

5kg loss of aircraft body weight can increase the payload by 50kg.

10% loss of car weight reduce the fuel consumption by 6%-8%.
Aluminum alloy is an ideal lightweight material because of excellent material performance and low density.
Electromagnetic forming is an optimum forming method for aluminum alloy.

### Comparison of forming methods

<table>
<thead>
<tr>
<th>Traditional forming</th>
<th>EMF</th>
</tr>
</thead>
<tbody>
<tr>
<td>◆ Mechanical force</td>
<td>◆ Electromagnetic force</td>
</tr>
<tr>
<td>◆ Hydraulic pressure</td>
<td>◆ Non-contact</td>
</tr>
<tr>
<td>◆ Quasi static</td>
<td>◆ High rate</td>
</tr>
</tbody>
</table>

### Advantages of EMF

- Improve the forming limit of materials 5-10 times
- Improve surface integrity and fatigue life
- Strong flexibility and Simple tool
Research background

Lenz's law

\[ \mathbf{F} = \mathbf{J} \times \mathbf{B} \]

Fig. 1 Discharge current of EMF process.
Research objective

(a) Conventional tube bulging.

(b) Attractive bulging.

Tube

Coil

Epoxy

Repulsive → Attractive
Forming Coil

Fig. 2 Electromagnetic force of the traditional EMF.
Research objective

1. $\vec{F}_r = \vec{J}_e \times \vec{B}_z$

2. $\varepsilon = \frac{d\psi}{dt}$, $\psi = L \cdot i$

3. $\vec{J}_e = i_e / S$

4. $\varepsilon \propto \frac{di}{dt}$

5. $i_e \propto \varepsilon$

6. $\vec{F}_r = \alpha \frac{di}{dt} \times \vec{B}_z$

Fig. 1 The ideal waveform of discharge current.

\[ \frac{di}{dt} > 0 \quad \implies \quad F_r > 0 \]
\[ \frac{di}{dt} < 0 \quad \implies \quad F_r < 0 \]
Fig. 1  The geometry of the finite element model.

Fig. 2  Flowchart of the implemented algorithm
Fig. 1  The circuit schematic diagram of dual-power system.

Fig. 2  Double pulse width current and its equivalent current.

Fig. 3  Axial magnetic flux density and radial electromagnetic force of new tube bulging.
Fig. 1 The waveform of combine current in narrow power system with different inductance values.

Fig. 2 Radial displacement of tube in narrow power system with different inductance values.

**TABLE I**

<table>
<thead>
<tr>
<th>Material</th>
<th>Parameters</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>A1060-H28</td>
<td>Density</td>
<td>2.71 g/cm³</td>
</tr>
<tr>
<td></td>
<td>Electrical conductivity</td>
<td>3.6e7 S/m</td>
</tr>
<tr>
<td></td>
<td>Relative permittivity</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>Relative permeability</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>Young’s modulus</td>
<td>6.9e10 Pa</td>
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<tr>
<td></td>
<td>Poisson’s ratio</td>
<td>0.34</td>
</tr>
<tr>
<td></td>
<td>Initial yield tensile strength</td>
<td>9.8e7 Pa</td>
</tr>
</tbody>
</table>
Fig. 1  Radial displacement of tube in narrow power system with different inductance and different discharge voltage.

Fig. 2  Discharge current of three case.
Axis of symmetry

Tube

(a) before

(b) after

4.19mm @ 16kV, 60μH
Summary:

✓ Attractive bulging is not impossible
✓ A maximum expansion of the tube with a diameter of 20 mm was got: 4.19 mm@16kV, 60μH.

Prospect:

✓ Experiments
✓ Less energy, larger deformation
THANK YOU