Optimisation of the longitudinal-torsional output of a half-wavelength Langevin transducer

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Outline

- LT vibration.

- Applications.

- Method of producing LT vibration.

- New method, features and conclusion.
Longitudinal-torsional shape of motion (LT):

- Longitudinal mode (L)
- Torsional mode (T)
- Coupling of modes.
- Degeneration of longitudinal mode.
Ultrasonic applications:

- Ultrasonic motor
- Ultrasonic drilling
- Ultrasonic tissue dissection
- Ultrasonic welding
Coupling of modes:

- **L mode:**
  \[
  \lambda_L = \frac{C_L}{f}
  \]
  \[
  \lambda_L = n \lambda_T
  \]
  \[
  C_L = n C_T
  \]

- **T mode:**
  \[
  \lambda_T = \frac{C_T}{f}
  \]

- **Uniform cross-sectional parts:**
  \[
  C_L = \sqrt{\frac{E}{\rho}}
  \]
  \[
  C_T = \sqrt{\frac{E}{2\rho(1 + v)}}
  \]

- **Non-uniform cross-sectional parts: Exponential horn**
  \[
  C'_L = \frac{C_L}{\sqrt{1 - (\beta C_L/\omega)^2}}
  \]
  \[
  C'_T = \frac{C_T}{\sqrt{1 - (\beta C_T/\omega)^2}}
  \]
Coupling of modes in Langevin transducer:

- Two sets of piezoceramics.
- Determine the $f_r$, materials.
- $\beta$ calculated from L and T wave equations.
- $\beta = \frac{\ln\frac{R_1}{R_2}}{L}$
Coupling of modes:

**Advantages:**
- 1- produces high response.
- 2- produces high torsionality.
- 3- L and T response can be controlled independently.

**Disadvantages:**
- 1- requires two power generators.
- 2- requires expensive tangentially poled piezoceramics.
- 3- difficult to secure into an enclosure.
- 4- difficult to keep the same resonance frequency under different load conditions.
- 5- Working surface decided by the decay coefficient.
Degeneration of L mode:

- Modify the wave path of L transducer.
- Slots dimensions, location, the helix angle.
Degeneration method:

- **Advantages:**
  1. Requires only a longitudinal excitation.
  2. Inexpensive fabrication.
  3. Easy to secure into an enclosure.
  4. More resonance stability under different load conditions.

- **Disadvantages:**
  1. Low torsionality.
  2. Coupling with surrounding unwanted modes.
New approach:

- \( f_r, Z_a, Z_b, a \).

\[
\sum \frac{Z_a}{Z_b} \tan\left(\frac{\omega a}{v_a}\right) \tan\left(\frac{\omega b}{v_b}\right) = 1
\]

- Output surface is decided by the application requirement.
New approach
Design parameters:

- Depth of cut.
- Area of cut.
- Helix angle.
- Torsionality.
- Frequency spacing.
- Relative response.
- Nodal plane position.
Case 1

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
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<tbody>
<tr>
<td>Max. Torsionality</td>
<td>170%</td>
</tr>
<tr>
<td>Frequency spacing</td>
<td>3%</td>
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<tr>
<td>Max./Min. responses</td>
<td>4.3</td>
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</tbody>
</table>

![Graph showing frequency and torsionality vs helix angle](image)
Case 2

Max. Torsionality | 140%
Frequency spacing | 5%
Max./Min. responses | 4.0
Case 3

| Parameter                  | Value  
|----------------------------|--------
| Max. Torsionality          | 102%   
| Frequency spacing          | 12%    
| Max./Min. responses        | 3.7    

- Torsionality.
- Frequency spacing between modes.
- Nodal plane location.
- Design scaling.
Analysis techniques:

- Finite element analysis.
- Experimental analysis.
  * Modal analysis.
  * Harmonic analysis.
  * Electrical analysis.
1- Torsionality:

Numerical and experimental response peaks and torsionality for different excitation voltages
2- Frequency spacing:

<table>
<thead>
<tr>
<th>Modes</th>
<th>Model 1</th>
<th>Model 2</th>
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<tbody>
<tr>
<td>FE</td>
<td>LT-2F</td>
<td>20.8%</td>
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<tr>
<td></td>
<td>LT-3F</td>
<td>14.5%</td>
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<tr>
<td>Exp.</td>
<td>LT-2F</td>
<td>21.2%</td>
</tr>
<tr>
<td></td>
<td>LT-3F</td>
<td>18.1%</td>
</tr>
</tbody>
</table>

Numerical (left) and experimental (right) modal analysis of the desired and surrounding modes.
3- Location of nodal plane:

Numerical (FEA) contour results of longitudinal vibration response.

Experimental (EMA) wireframe results of LT vibration response.
4- Design scaling:

![Graph showing response and torsionality vs thickness of piezoceramic disc](image)
5- Electrical analysis:
Conclusions:

• Employing the advantages of two methods can produce a design which overcomes their disadvantages.

• The proposed model is simple in design, excitation and securing features.

• It can be designed in different sizes which are suitable for a range of ultrasonic applications.

• It has good dynamic characteristics including good separation between modes and stability under different operation conditions.
Thank you