Efficiency Improvement
For Power Ultrasonic Transducer Systems
Case studies
by using a simplified loading model

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Company Profile

- **Established in 1999**
  Beijing Cheng-cheng Weiye Ultrasonic Science and Technology Co., Ltd
  (CHENG-CHENG ULTRASONICS)

- **Professional manufacturer**
  Ultrasonic transducers, ultrasonic apparatus and piezoelectric ceramics.

- **Locations**
  Headquarter - Beijing, China
  Factory - Baoding, capital of Hebei province
  Departments - R&D, production, domestic sales, international and after-sales service
  Domestic - two branches: Zhangjiagang and Shenzhen
  International – representatives: Japan and USA

- **Partnership**
  Institute of Acoustics, Chinese Academy of Science
  Tsinghua University
  Consultants – renown ultrasonic experts within China
Power Ultrasonic Applications – Major Categories

- Cleaning, liquid processing, sono-chemistry, cell disruptor
- Plastic joining, metal welding, machining
- Wire bonding, therapy, surgical
Performance – General Scope

- Rough illustration of power, amplitude and loading scopes for different applications in general
Limitation of the Transducers

Thermal –
Temperature at the source area, affected by mechanical loss, dielectric loss, coupling loss, duty cycle, cooling

Mechanical –
Nonlinear stress, preload screw, stress concentration

Electrical –
Voltage, generator

Size –
Space, automation, movement

Loading –
Output under load, sensitivity

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General rule
Based on the vibration output requirement (amplitude, frequency, area), use the drive source to its full extent (heating, mechanical, electrical)

Ideal
Small vibration at drive source area
Large vibration at large radiation surface
i.e. high efficiency,
Balance –
gain, bandwidth, loading capability, size
Prior Works

Simple Model for Efficiency Estimation

Resistance component: simulate by opposite force, monitor by the amplitude drop

Variable: \( F/S \) (N/mm\(^2\))
Efficiency = \( 1 - \frac{V_{\text{load}}}{V_0} \)

\( F \): force, \( V \): velocity, \( S \): area

Reactance component: simulate by constrained mass, monitor by the frequency shift

Variable: \( E \) (Gpa) in the constrained mass
Efficiency = \( \frac{V_{\text{load}} \cdot V_0^{\text{PZT}}}{V_0^{\text{PZT}} \cdot V_{\text{load}}^{\text{PZT}}} \)

\( E \): Elastic Modulus, \( V \): velocity
Efficiency Improvement (EI) for Ultrasonic Cleaning

- Less critical areas: Thermal, mechanical, electrical, size
- Area to improve: efficiency, bandwidth
- Areas to look: Increase loading, optimize structure, large radiation surface, position of drive source.

**Effect of the slot depth**

![Graph showing the effect of slot depth on efficiency.](image-url)
- High amplitude
- Light load (heavy load for ultrasonic machining, drilling)
- Increase the gain, increase the booster input area, position of drive source

**Effect of the horn input area (diameter)**

![Diagram showing the effect of horn input area on efficiency]
EI for Surgical System

- High amplitude, high velocity, varying load
- Material selection, size, stability, loading capability
- Large driving source, shape of the horn

Effect of the horn shape

- Exponential
- Step
- Cone
- Gaussian

Resistance load [N/mm^2]

Efficiency

0% 10% 20% 30% 40% 50% 60% 70% 80% 90%

0 0.5 1 1.5
High amplitude, large radiation surface, heavy load, high power
High gain, increase the radiation surface, large driving source, multi-stack drive elements, mode conversion – longitudinal to radial, to strip transverse

Effect of the radiator length

- 0 mm
- 50 mm
- 75 mm
- 100 mm

Resistance load [N/mm^2] vs Efficiency
EI for Metal Welding

- High power, heavy load, moderate gain
- Parasite modes, cartridge (driver) material, drive element location and volume, less frequency shift

**Effect of the cartridge material vs. resistance load**

![Graph showing the effect of the cartridge material on efficiency vs. resistance load. The graph compares the efficiency of S.S. and Al materials at various resistance loads.](image)
Metal Welding VS. Reactance Load

Efficiency

Frequency Shift

Reactance load [GPa]

Efficiency

Frequency shift [kHz]

S.S.
Al
- High power, large radiation area, heavy loading
- Cartridge (driver) material, drive element location and volume, less frequency shift

Effect of the drive length vs. resistance load
Plastic Joining VS. Reactance Load

**Efficiency**

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<table>
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<tr>
<th>Frequency shift [kHz]</th>
<th>0</th>
<th>0.5</th>
<th>1</th>
<th>1.5</th>
<th>2</th>
<th>2.5</th>
<th>3</th>
<th>3.5</th>
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</thead>
<tbody>
<tr>
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<td>0.5</td>
<td>1</td>
<td>1.5</td>
<td>2</td>
<td>2.5</td>
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<tr>
<td>10mm</td>
<td>Δ</td>
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<td>30mm</td>
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**Frequency Shift**

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<table>
<thead>
<tr>
<th>Efficiency</th>
<th>0%</th>
<th>10%</th>
<th>20%</th>
<th>30%</th>
<th>40%</th>
<th>50%</th>
<th>60%</th>
<th>70%</th>
<th>80%</th>
<th>90%</th>
<th>100%</th>
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<tbody>
<tr>
<td>Reactance load [GPa]</td>
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<td>4</td>
<td>6</td>
<td>8</td>
<td>10</td>
<td>12</td>
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<tr>
<td>30mm</td>
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</tbody>
</table>
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- Certain gain, certain loading capability, mounting location, size, generator input
- Drive source volume and location, cartridge material, parasite modes

**Effect of the drive location vs. resistance load**

- Efficiency vs. resistance load [N/mm^2]
- 0, 5mm, 8.5mm
Wire Bonding VS. Reactance Load

**Efficiency**

- Efficiency vs. Reactance load [GPa]
  - Data points for 0, 5mm, and 8.5mm load conditions.

**Frequency Shift**

- Frequency shift [kHz] vs. Reactance load [GPa]
  - Data points for 0, 5mm, and 8.5mm load conditions.
✓ Variety of power ultrasonic applications
✓ Simplified Design by using mechanical FEA
✓ Improved analysis by using the load model
✓ Analysis of the old designs and optimization of the new power ultrasonic transducers are made easy!
✓ Mass production and lowered cost are available by Cheng-Cheng Ultrasonics
Thanks!