# Evaluation of Joint Losses in Langevin Style High Power Transducers

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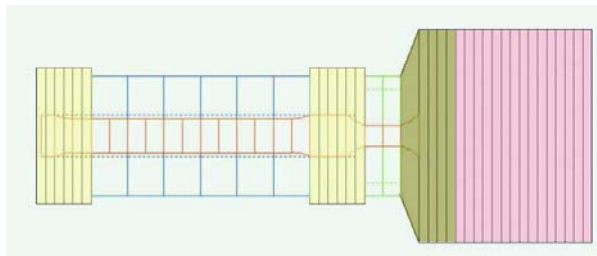
# Background

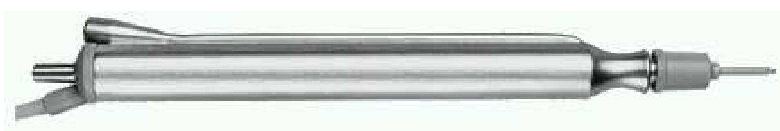
Heat generated in the joints of Langevin piezo stacks limits output power

- Navy: New wide bandwidth transducers.



Triple resonant Rodrigo/ Butler design

- Medical/Dental: New smaller ultrasonic handpieces



Ultrasonic “jack-hammer” for cataract removal (Phacoemulsification)

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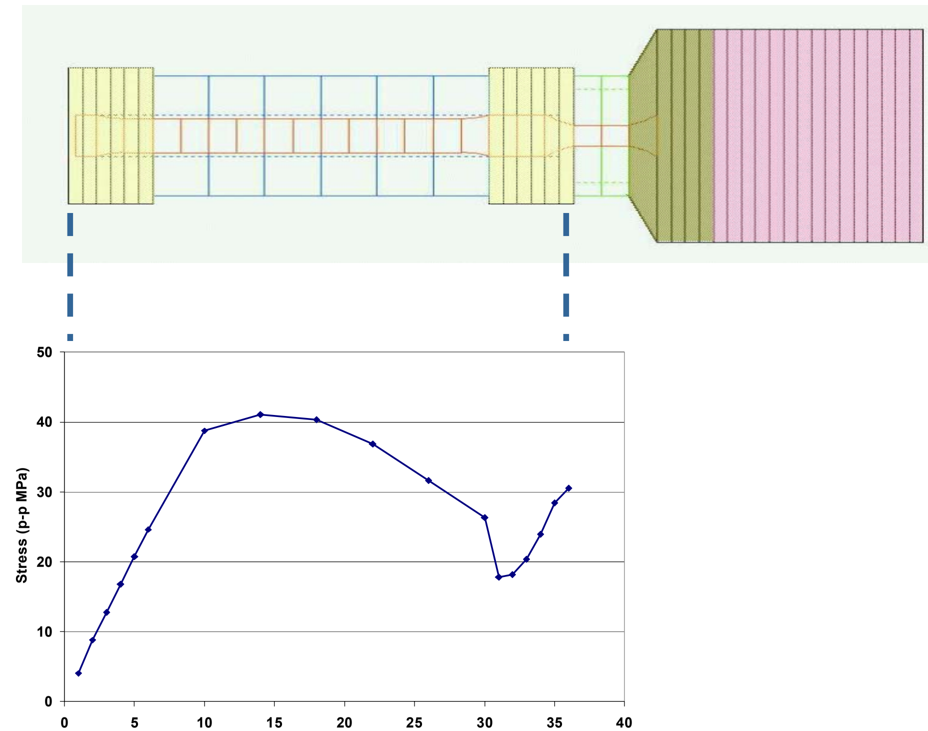
# Concept Broadband Design




- PiezoTran™ Model Inputs
  - Voltage 3 kV/cm
  - Transducer in an array
- PiezoTran™ Model Output
  - Performance at 35 kHz (mid resonant frequency)
  - Peak-to-peak stack  stress 40 MPa

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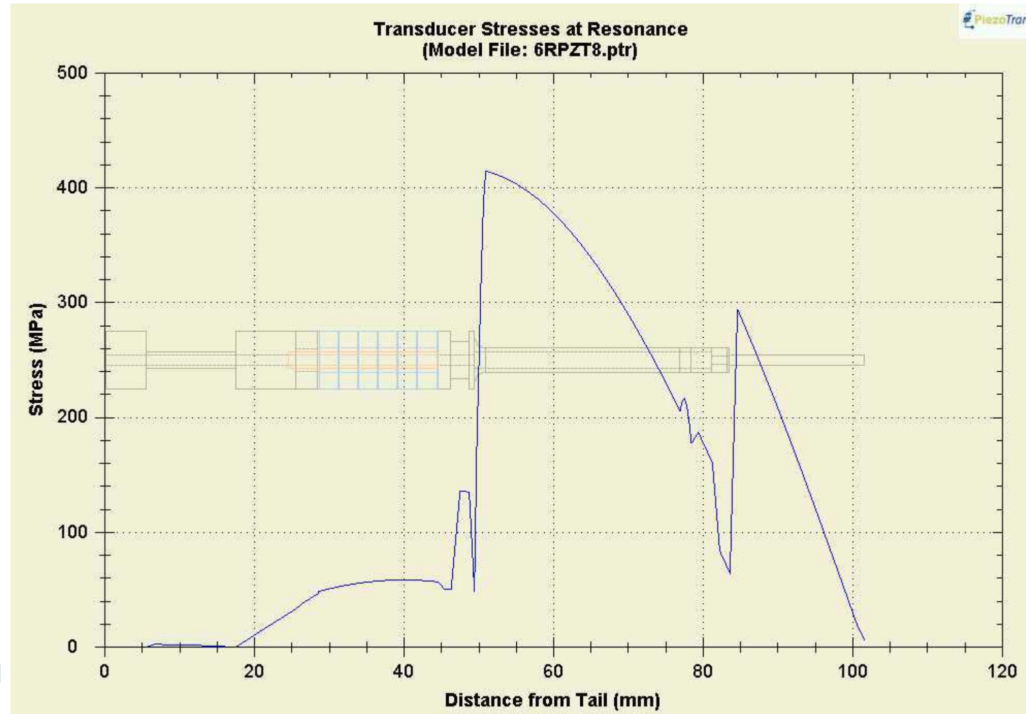
# Medical Transducer




- Objective
  - Reduce piezo stack diameter from 10mm to 8mm. Maintain 127 µm tip displacement
- PiezoTran™ Model Output
  - Performance at 28 kHz (resonant frequency)
  - Peak-to-peak stack stress 58 MPa

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# Quiescent Power Loss

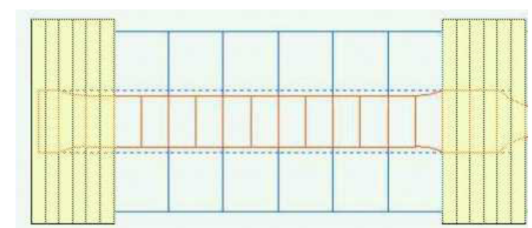
Negligible radiated power transducer measured in air

$$P_r(thin\ element) = \frac{\omega \sigma_M^2 l S}{2QE}$$

E = Young's Modulus — $\sigma_M$ = Peak cyclic stress

l = length — S = Cross section area

Q α 1/frictional loss



- Measure
  - Input power (sum of elemental power)
  - Front/rear mass velocity and frequency
- Calculate
  - Elemental cyclic stress using PiezoTran™ computer model
  - Combined Q of piezo + joint (iterate to bring into agreement with measured value)

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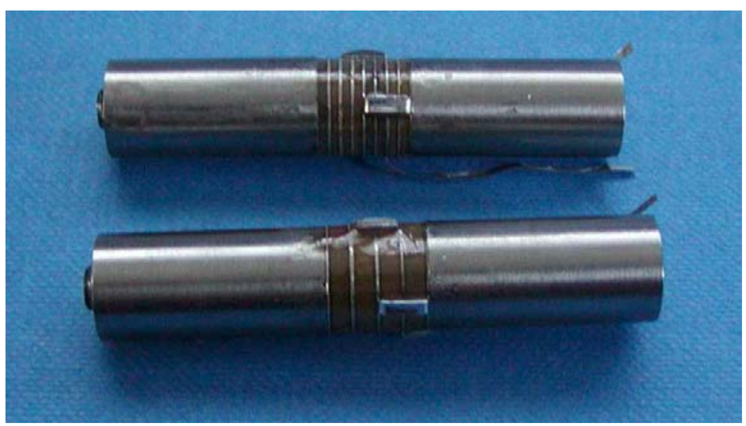
# Quantify Piezo and Joint Loss

Using 40 kHz dumbbell test transducers

- Transducer # 1: Four Type III rings (0.375 X 0.197 X 0.080)
  - Rings electrically connected in parallel
  - Five joints
- Transducer # 2: Eight Type III rings (0.375 X 0.197 X 0.040)
  - A pair of rings are electrically connected in series (+ to -)
  - The four pairs are electrically connected in parallel
  - Nine joints



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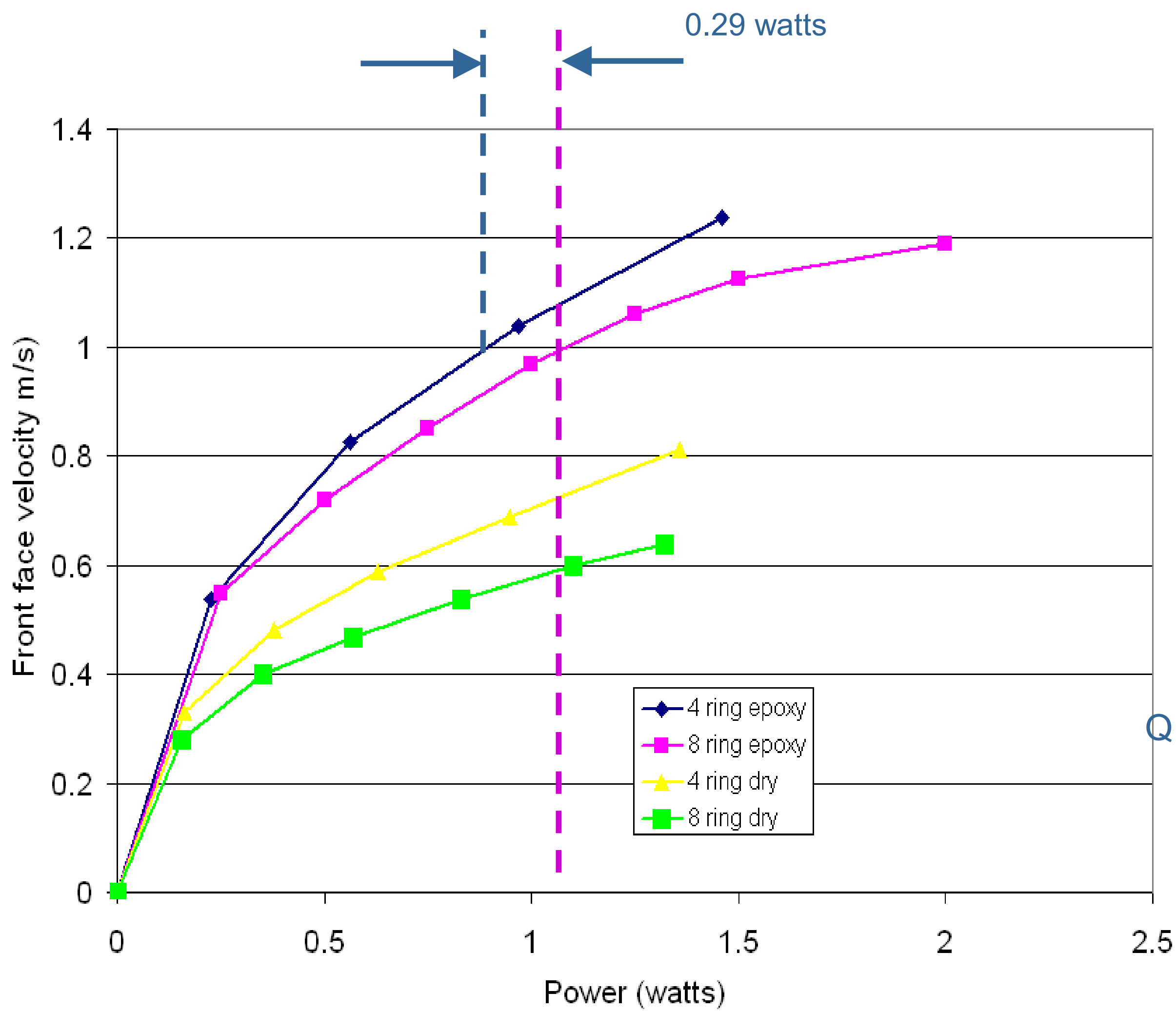
# Test Data




9 joints - 5 joints = 290m watts

1 joint = 72.5m watts

9 joints = 653 m watts

8 rings + 9 joints = 1.1 watts

1 Piezo Ring = 56 m watts

4 Ring Transducer

Q of piezo/joint combination = 370

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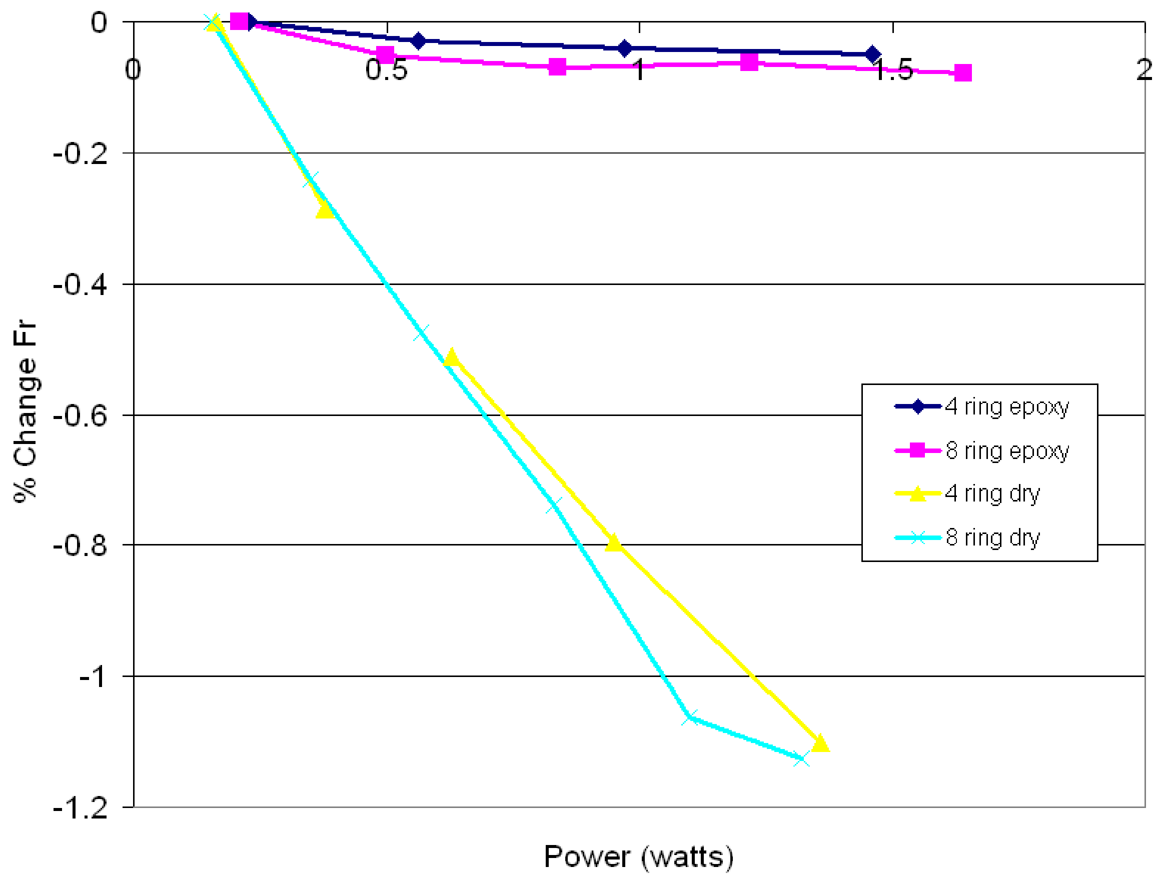
# Test Data

## % change in resonant frequency

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# Factors That Affect Joint Losses

- Piezo flatness and surface finish
  - Flatness is more difficult to control on larger parts
- Piezo electrode material
  - Relatively thick (5μm) fired on silver. Thin plating such as electroless nickel or sputtered gold (0.2μm to 0.5μm)
- Shim electrode
  - Surface finish, hardness
  - Piezo interface/coupling material
    - None (dry), epoxy, soft aluminum crush foils (Dukane), thick soft plating material 5μm to 30μm (Morgan), thin plating materials such as tin, silver or nickel < 5μm
- Bias and cyclic stress

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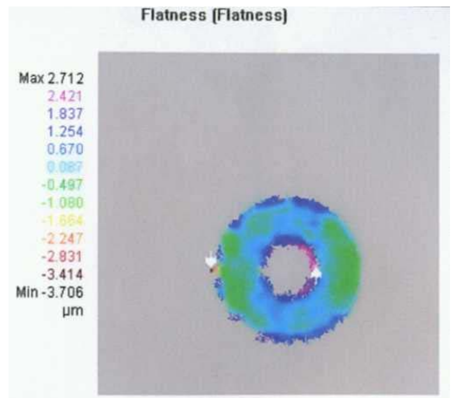
# Ideal Attributes of a Piezo Stack Assembly

- Sub-assembly
  - Piezo rings, end insulators, shim electrodes bonded together and aligned using an external fixture.
  - Lower cost than traditional spatula  applied epoxy methods
- Low mechanical losses
  - Navy type III piezo
  - Low joint losses
- Withstand high electric fields in harsh environments
  - Application of both external and internal conformal stack coating

# PiezoBond™

proprietary stack assembly method

- Ensure piezo rings are flat
  - Ideally measure each ring




Tropel Flatmaster image provided by PKI

- Use a conventional silvered piezo ring
  - Do not abrade the surface

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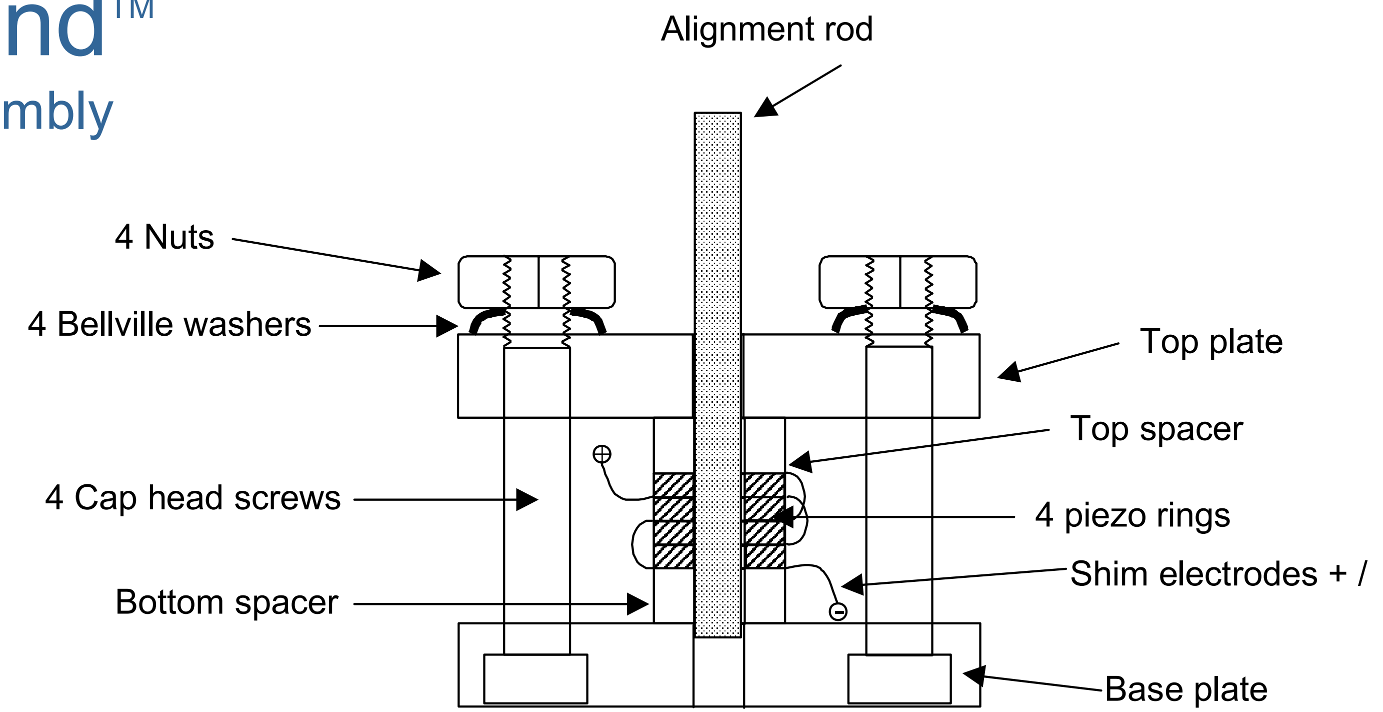
## stack sub-assembly




- Method
  - Assemble components over alignment rod as shown in the diagram
  - Torque nuts evenly to apply pre-stress

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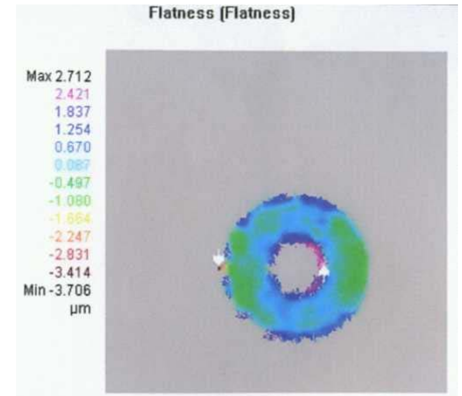
# PiezoBond™

## Assembly method continued

- Soft silver surface acts as gasket and provides good mechanical coupling in higher blue region
- Remove alignment rod and plug hole in base
- Fill the internal cavity with a low viscosity epoxy
- Coat the external surface with the low viscosity epoxy
- Gel and facilitate capillary action to wick epoxy into the lower green region
- Remove plug, drain epoxy, oven cure
- Remove bonded sub-assembly from jig

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# Benchmarking Performance

## Q of piezo/joint combination and % change in Fr

Stress = 19 MPa p-p

Velocity = 0.5 m/s

Nominal resonant frequency = 40 kHz

| | Q | % Change Fr |
|---|---|---|
| **Type III PiezoBond™** | **378** | **.04** |
| **Type III filled epoxy Stycast 2651** | **176** | **1.0** |
| **Type III low viscosity epoxy Eccoseal W19** | **119** | **1.0** |
| **Type III dry with beryllium cu. shim** | **117** | **0.9** |
| **Type III dry with 3μm plated shim** | **157** | **0.7** |
| **Type I PiezoBond™** | **148** | **0.4** |
| **Barium titanate PiezoBond™** | **260** | **0.16** |

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# Conclusions

- Joint Losses
  - Cause heat and limit the performance of navy, medical and industrial Langevin style transducers
  - They can be quantified by measuring/calculating the mechanical Q of a piezo/joint combination
  - An experimental method to determine the relative loss within the joint and piezo ring has been demonstrated

- PiezoBond™
  - A proprietary cost effective piezo stack assembly method
  - Low mechanical losses & relatively stable resonant frequency
  - Epoxy conformal coating is applied to the internal and external exposed surfaces of the stack . Stacks have been tested at 3kVrms (30 v/mil or 11.8 kV/cm)

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- Piezo Innovations
  - This research has been internally funded by PI and is protected by a patent application

- References

David Wuchinich. “A practical evaluation of elastic power loss in harmonically strained structures”, oral presentation to the Ultrasonic Industry Association Meeting May 15, 1998 King of Prussia, Pennsylvania).

Underwater Electroacoustic Transducers by D. Stansfield published by Peninsula Publishing

M. J. Earwicker, Mathematical Modelling of Piezoelectric Transducers, and Sean Winterer for developing the PiezoTran software based on this model

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