Background

• Lead zirconate titanate (PZT)
  - Generates electrical energy when excited by mechanical load

• Harvest useful energy from existing mechanical loads
Possible Uses

- Orthopedic implants such as total knee replacement (TKR)
  - Imbedding space is typically confined but power is required to operate embedded sensors monitoring the state of implants
  - Analysis carried out based on this assumption
    - 2100N, 1Hz

- Low-profile power generator for floors and roadways could also be explored
Previous Designs

- Cymbal is used to transform mechanical load into a tensile force
- Tension yield strength of piezoelectric material is a limiting factor
  - Arrows in Fig. 1 represent the radial tensile stress due to compressive load applied to the metal end caps.

*Figure 1*: Comparison of Previously Explored PZT Cymbal Structures: (a) Unimorph [1-3] and (b) Bimorph [4].
Iteration one

- Places the PZT material in compression rather than tension

- Slight inadvertent hoop stresses in tension was a limiting factor
Iteration two

All PZT Material is in compression
Second Iteration Fabrication Design

- The cymbals were fabricated from circular metal discs cut out by a water jet.
- Discs were cut out from a sheet of 1.5mm thick 4140 alloy steel.
- Discs were then pressed in a die to form the cymbal shape.
Second Iteration Assembly

- Mill out flats on the cymbal so the blocks fit snugly. Epoxy the blocks to the flats.
- Apply epoxy between the other ring and the blocks. Ensure that there is sufficient Epoxy to transfer the load the retaining ring.
- Piezoelectric Stacks
- Retaining Ring
- Cymbal
Analysis

- The cymbal can be viewed as a truncated conical shell to calculate stress in the radial direction.

This radial stress is then combined with PZT properties.

After derivation, the power equation becomes:

\[ U_{gen} = \frac{1}{2} C_{free} V_{gen}^2 \]
Test Apparatus

- Load applied by linear motor through load cell
- Controlled by LabVIEW
- Arduino interface
- Data acquired through digital storage oscilloscope
Experiment

- Cymbal specimen was tested on the test apparatus using cyclic loads of 800 N, 1500 N, and 2100 N at a frequency of 1 Hz
- Tested with two configurations in parallel and in series
Test Results for Iteration Two

- Measured cyclic load and open circuit voltage for 800N in series configuration
Test Results for Iteration Two

- Measured cyclic load and open circuit voltage for 1500N in series configuration
Test Results for Iteration Two

• Measured cyclic load and open circuit voltage for 2100N in series configuration
Summary of Test Results

- Currents were also measured for each load. The measured currents were 2.9 μA, 6.8 μA, and 9.7 μA for 800 N, 1500 N, and 2100 N, respectively.

- Here is a summary of the actual measured output voltage from iteration two with a cyclic frequency of 1Hz.

<table>
<thead>
<tr>
<th>Load (N)</th>
<th>Measured output voltage (V)</th>
</tr>
</thead>
<tbody>
<tr>
<td>800</td>
<td>10.58 ± 2.67</td>
</tr>
<tr>
<td>1500</td>
<td>23.9 ± 1.38</td>
</tr>
<tr>
<td>2100</td>
<td>34.50 ± 1.33</td>
</tr>
</tbody>
</table>

±: sample standard deviation from nineteen peaks
Conclusions

• The restructured cymbal harvester with four sets of PZT stacks generates higher energy in parallel than that of unimorph cymbal design.

• May also provide better longevity performance because there is no bonding layer

• Longevity tests to be carried out in the near future.

• Comprehensive analysis to predict generating energy and parametric study for performance optimization is currently conducting
Questions?