Development of Low-Profile Peizoelectric Energy Harvester for High Load Application

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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.

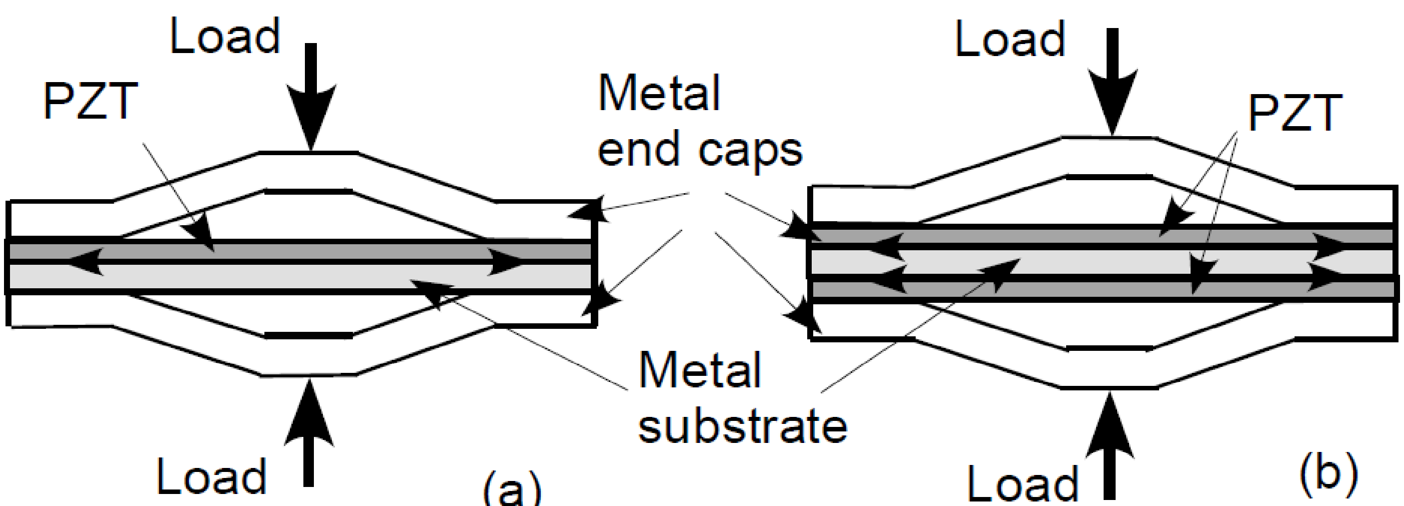
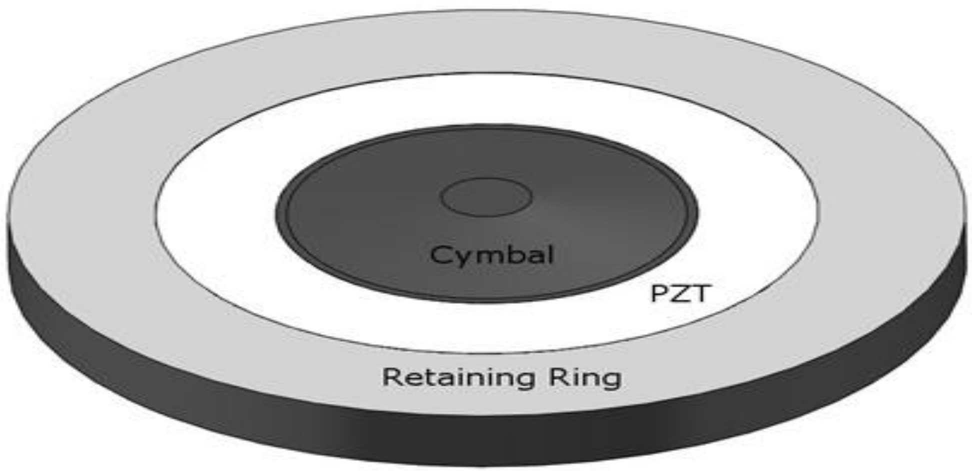
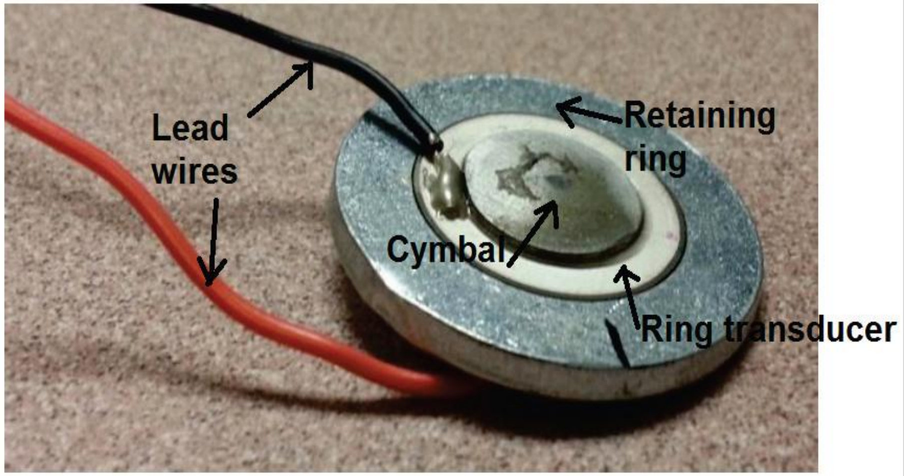


Figure 1: Comparison of Previously Explored PZT Cymbal Structures: (a) Unimorph [1-3] and (b) Bimorph [4].

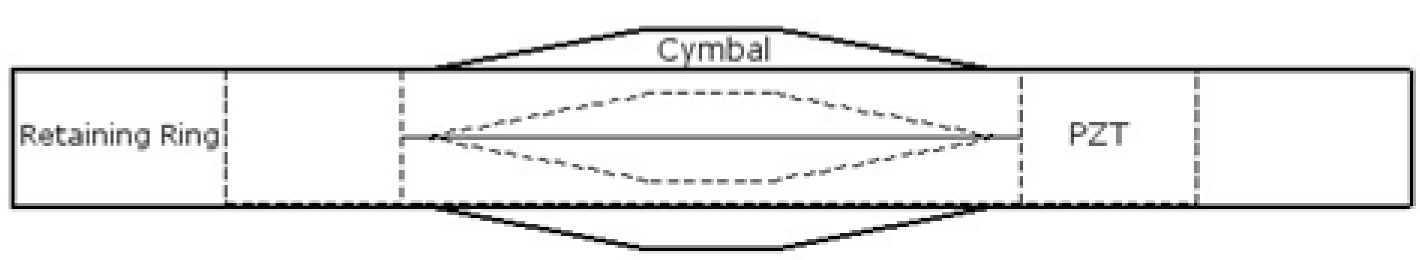
Iteration one



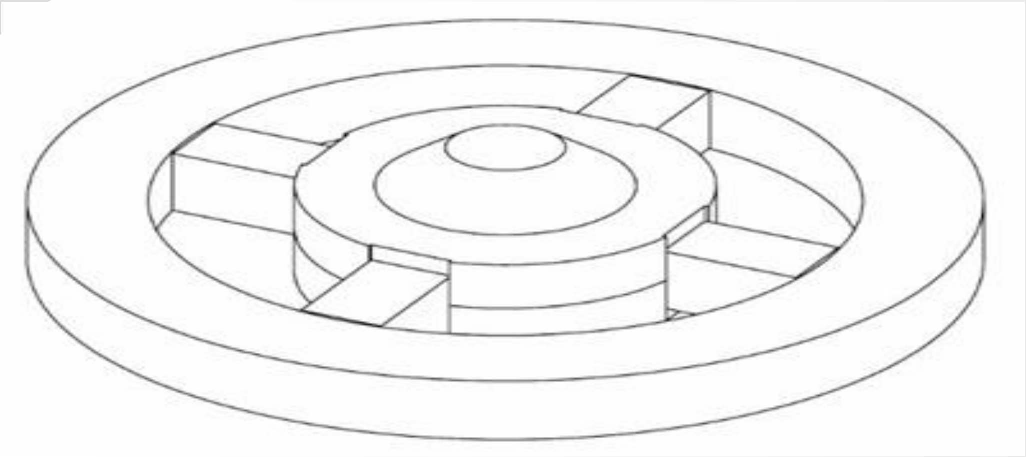


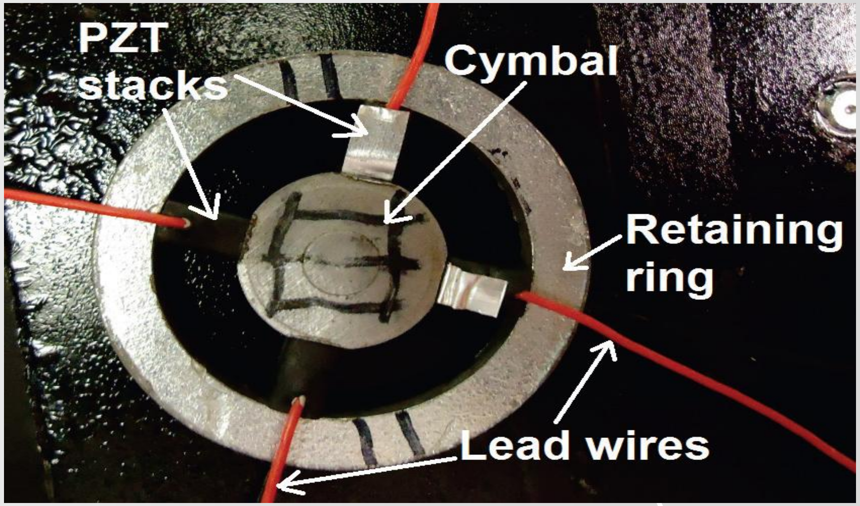
- Places the PZT material in compression rather than tension

- Slight inadvertent hoop stresses in tension was a limiting factor

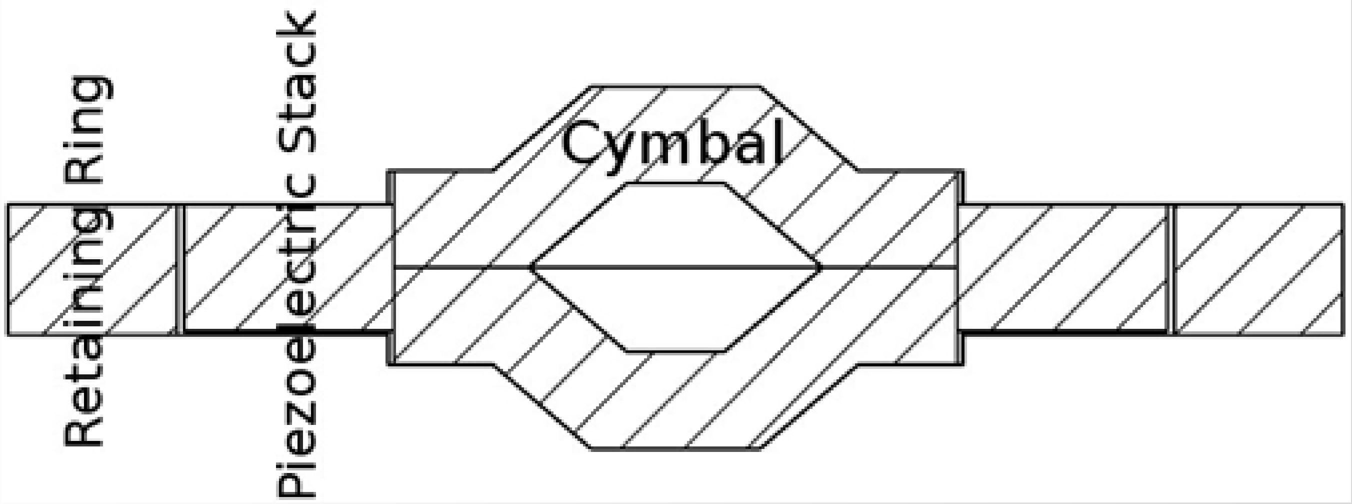


Iteration two





All PZT Material is in compression



Second Iteration Fabrication Design

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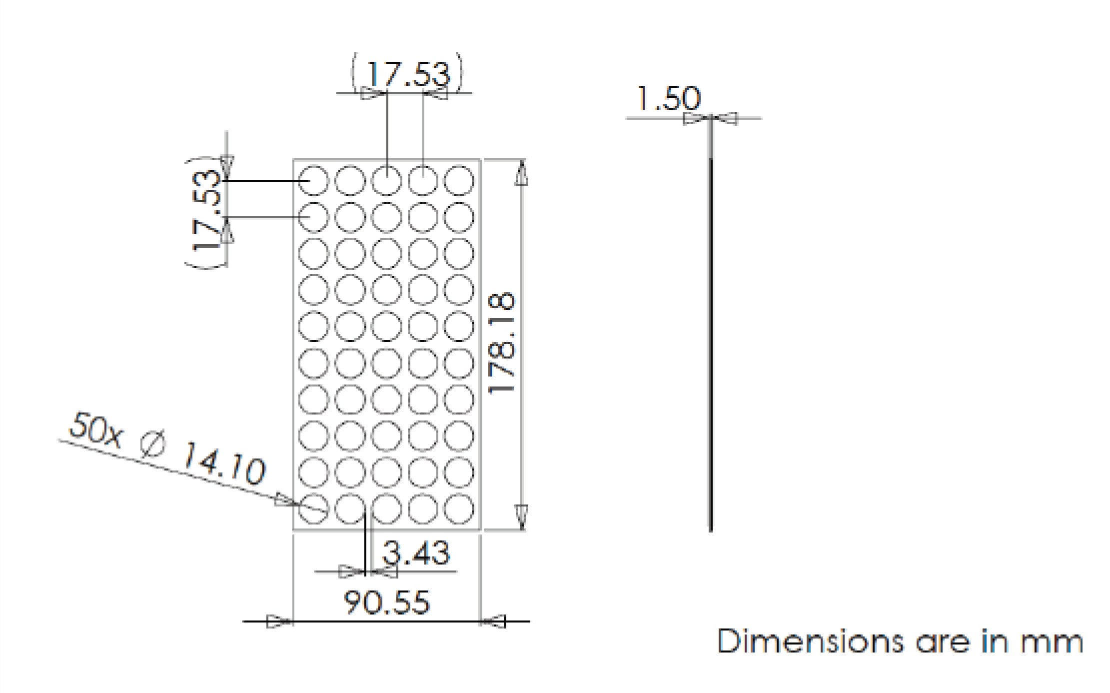
- The cymbals were fabricated from circular metal discs cut out by a water jet
- Discs were cut out from a sheet of 1.5mm thick 4140 alloy steel
- Discs were then pressed in a die to form the cymbal shape



Second Iteration Assembly

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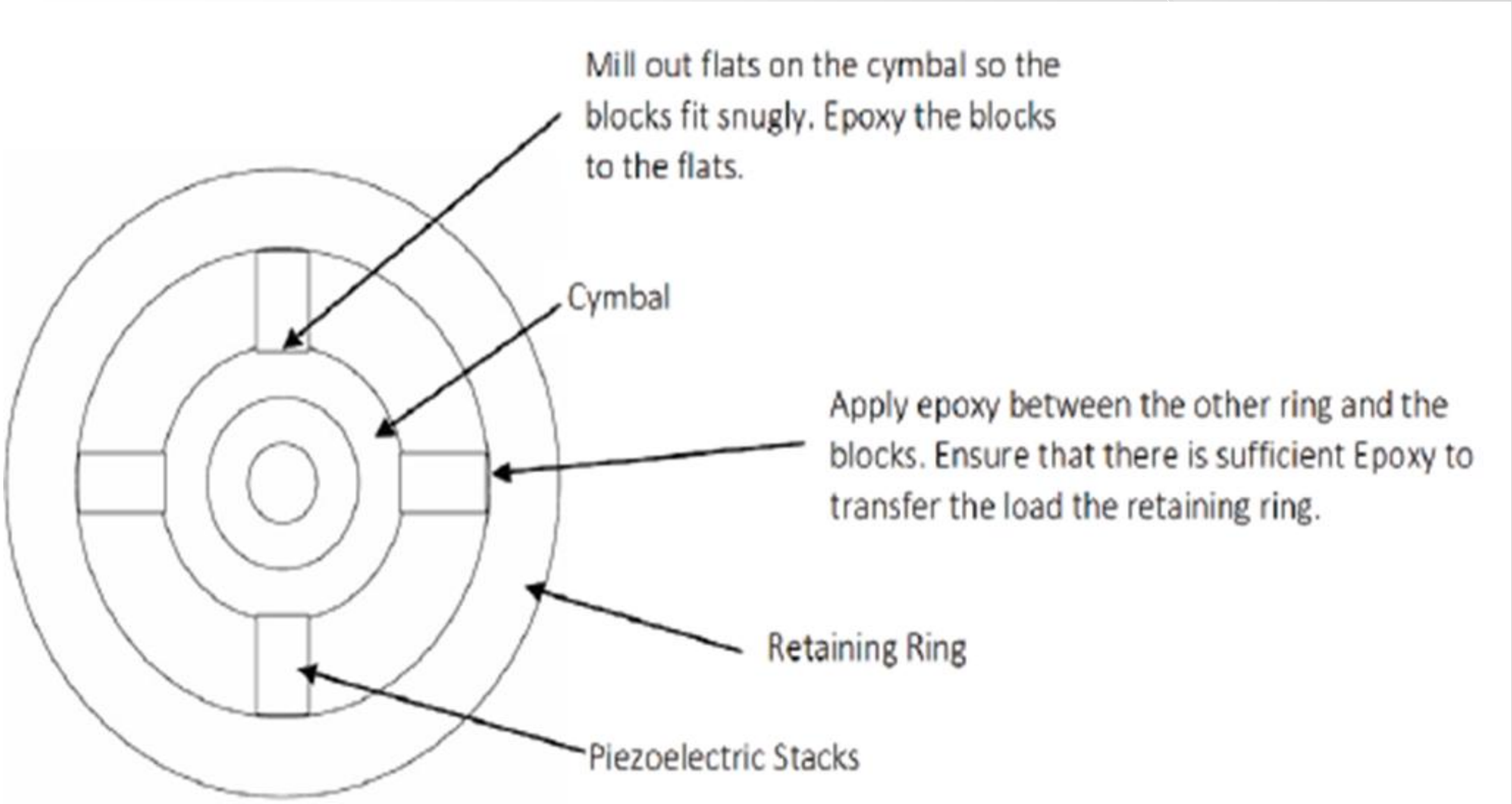
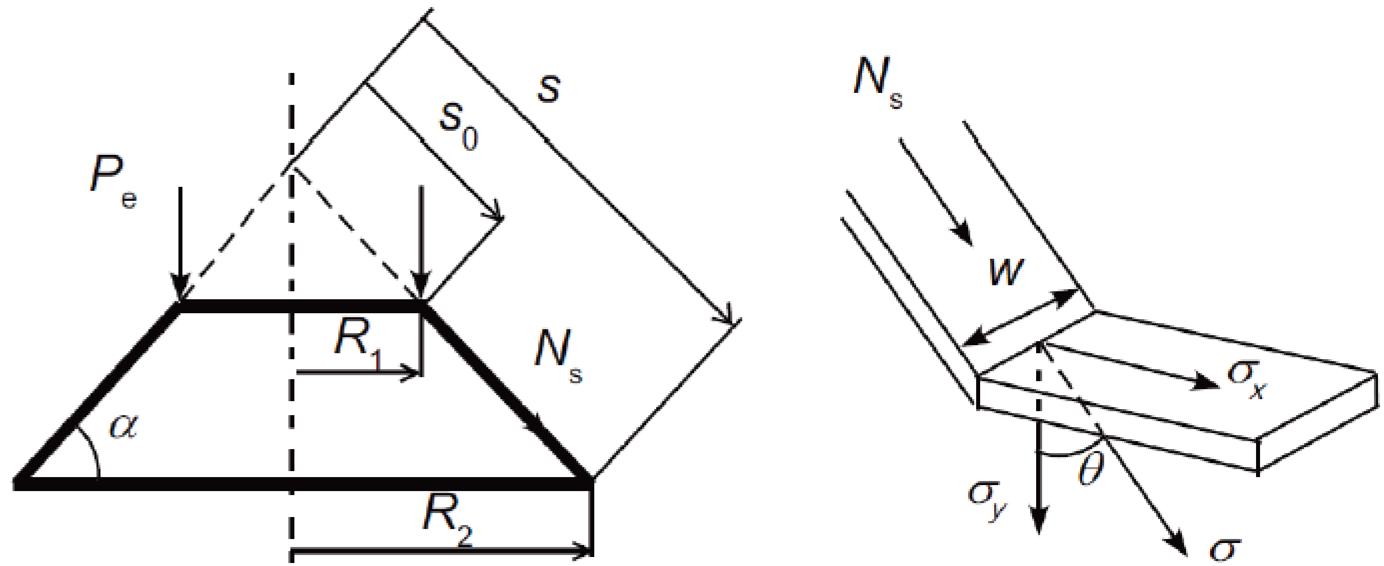


Analysis

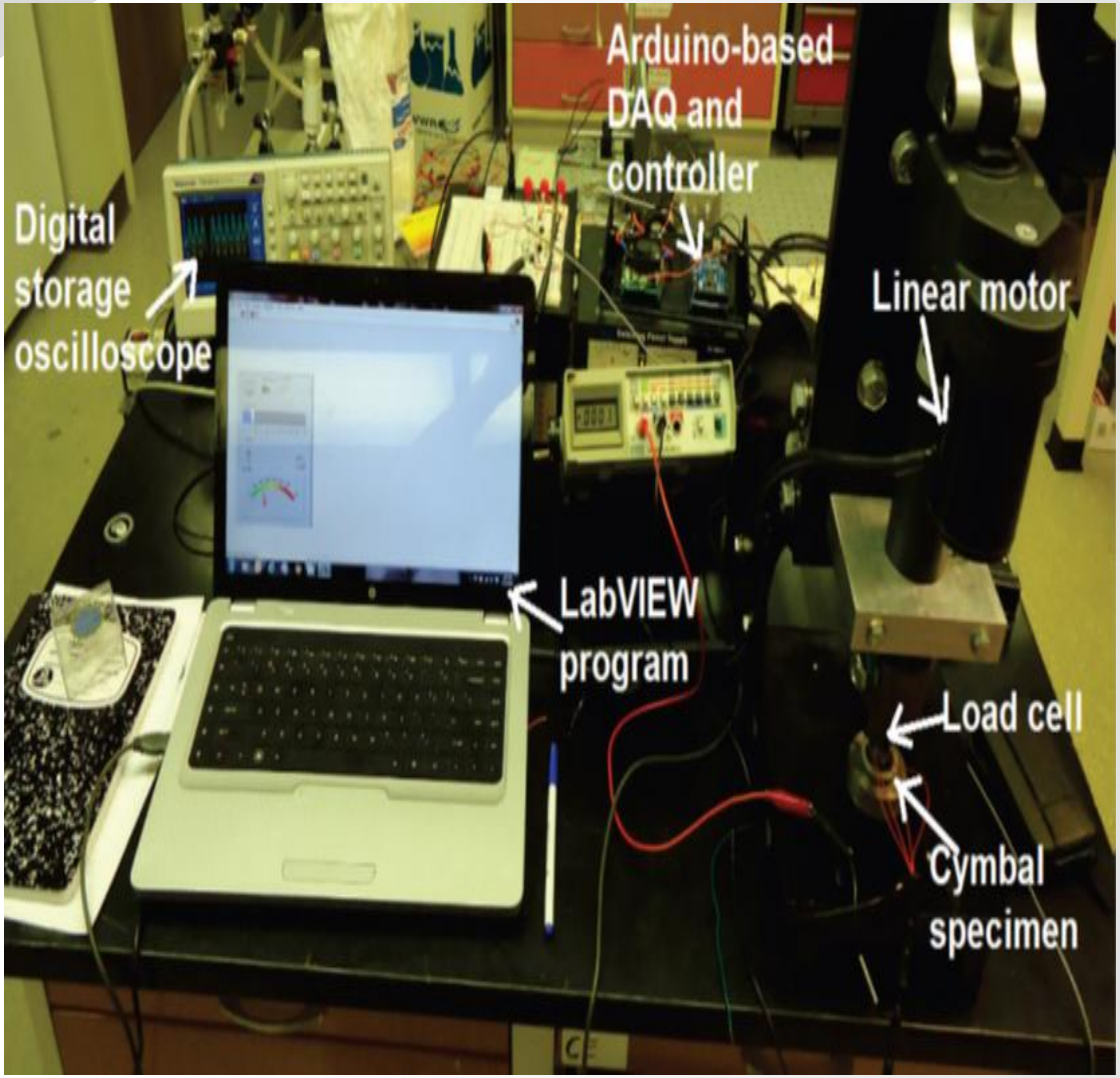
- The cymbal can be viewed as a truncated conical shell to calculate stress in the radial direction



- 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

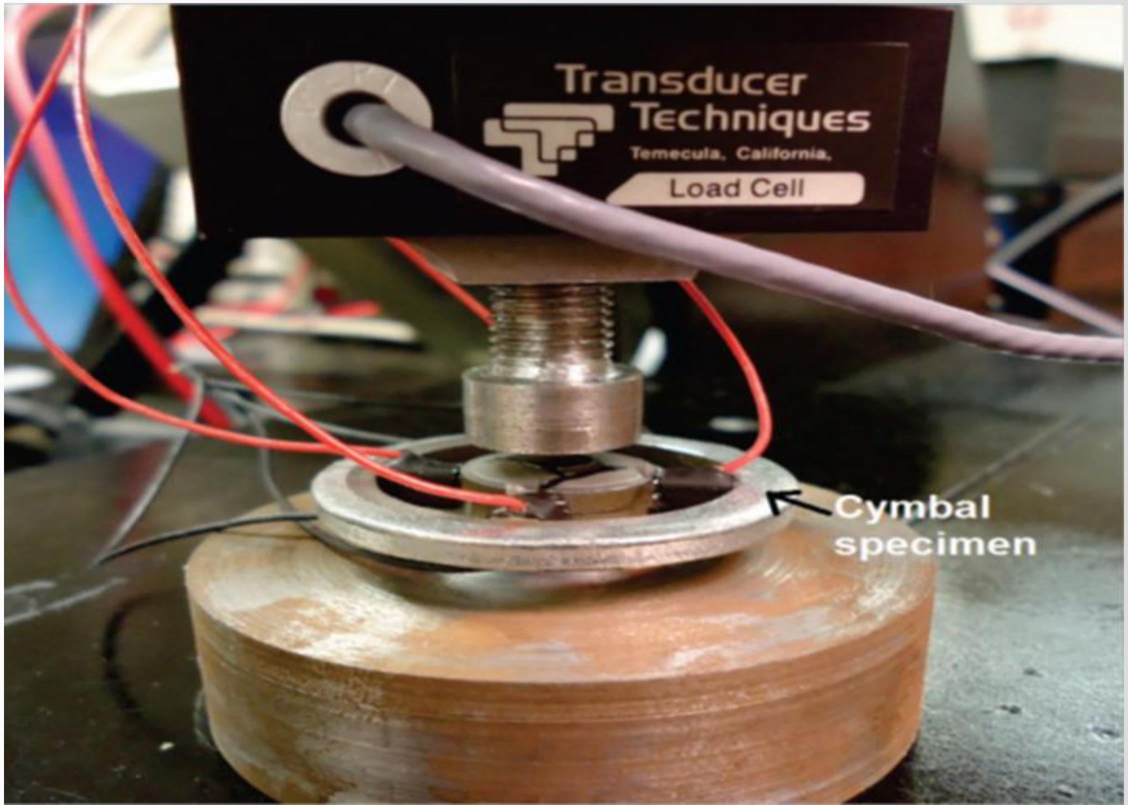


- Load applied by linear motor through load cell
- Controlled by LabVIEW
- Arduino interface
- Data acquired through digital storage oscilloscope

Experiment

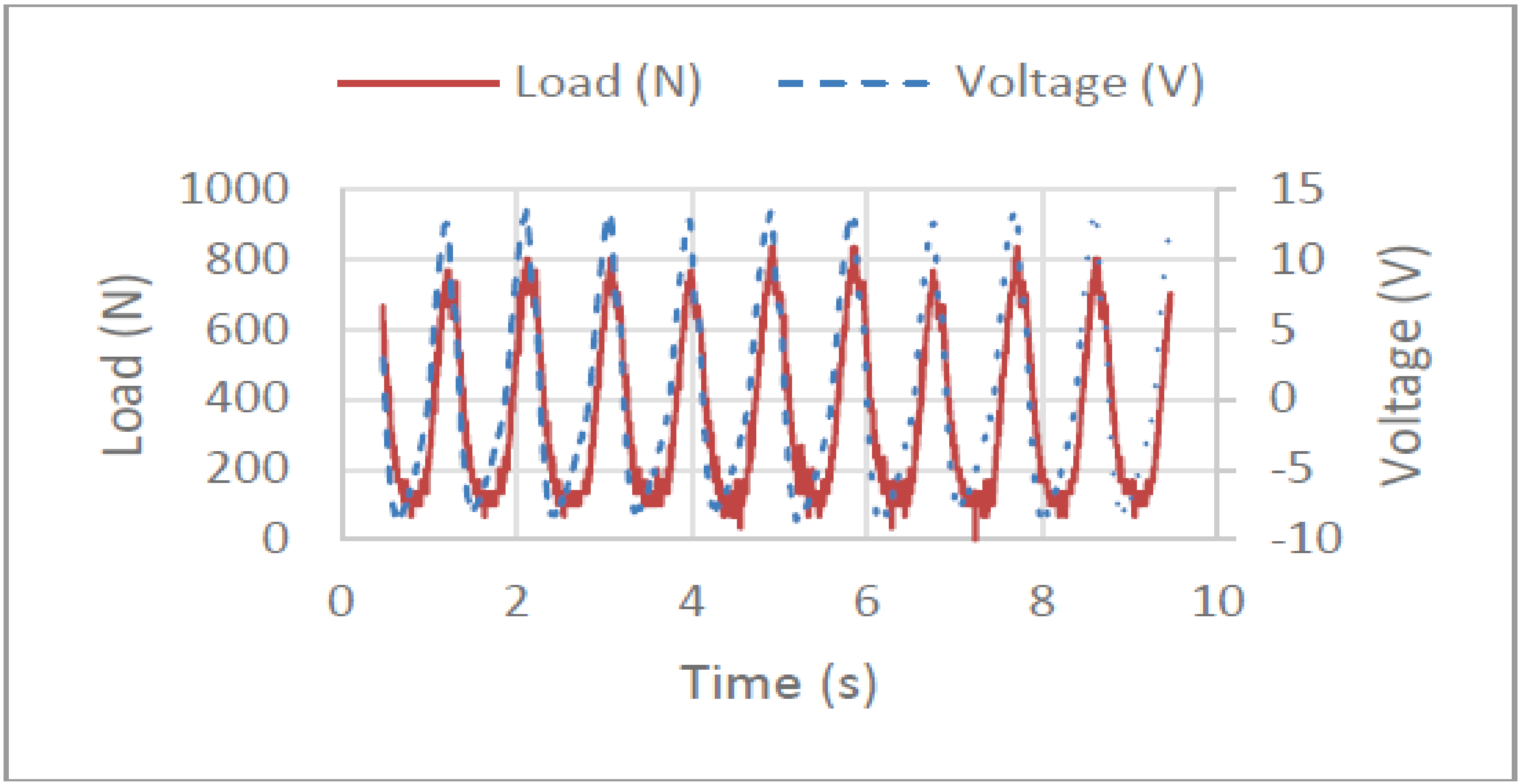
- Cymbal specimen was tested on the test apparatus using cyclic loads of 800 N, 1500 N, and 2100 N at a frequency of 1 Hz

- Tested with two configurations in parallel and in series



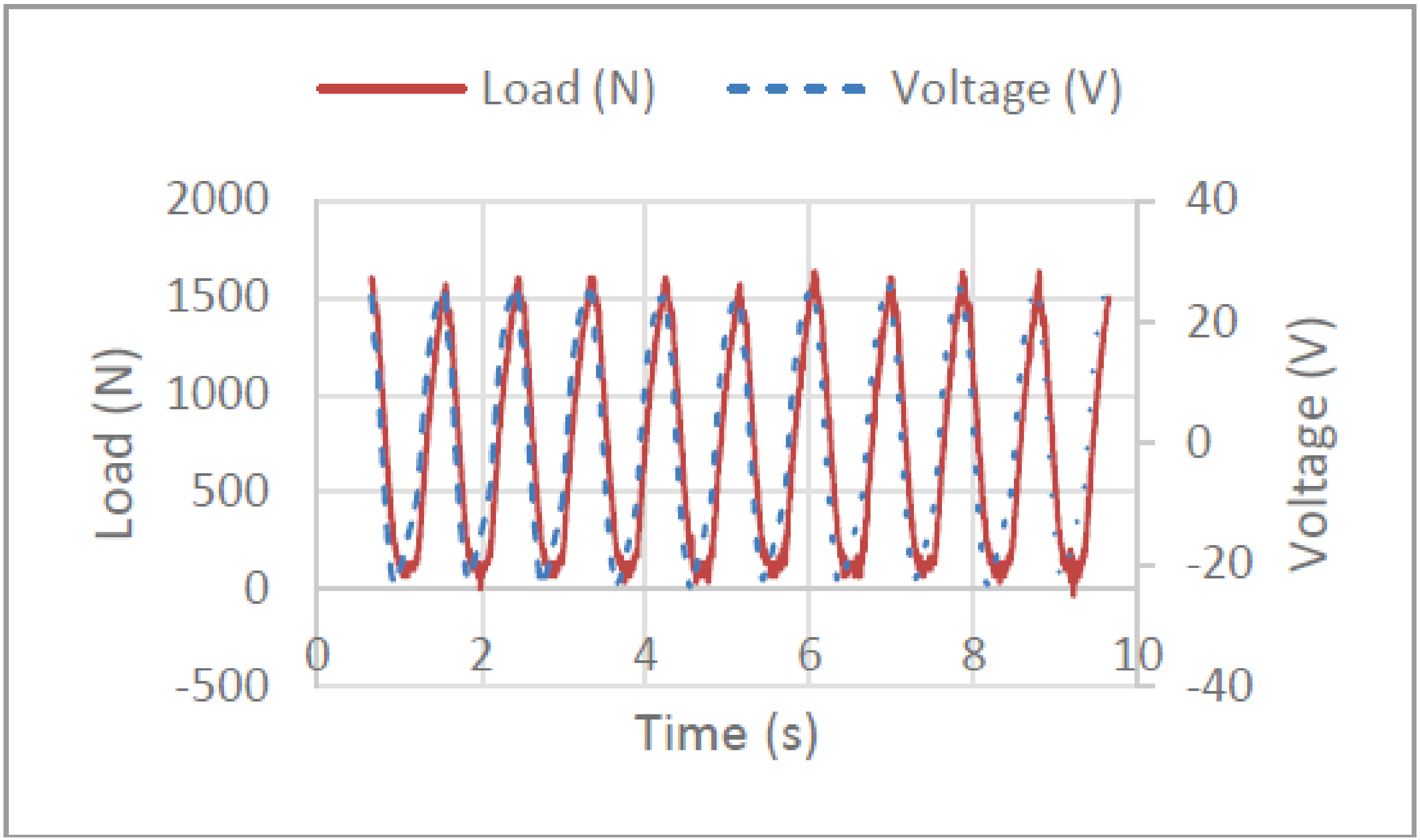
Test Results for Iteration Two

- Measured cyclic load and open circuit voltage for 800N in series configuration



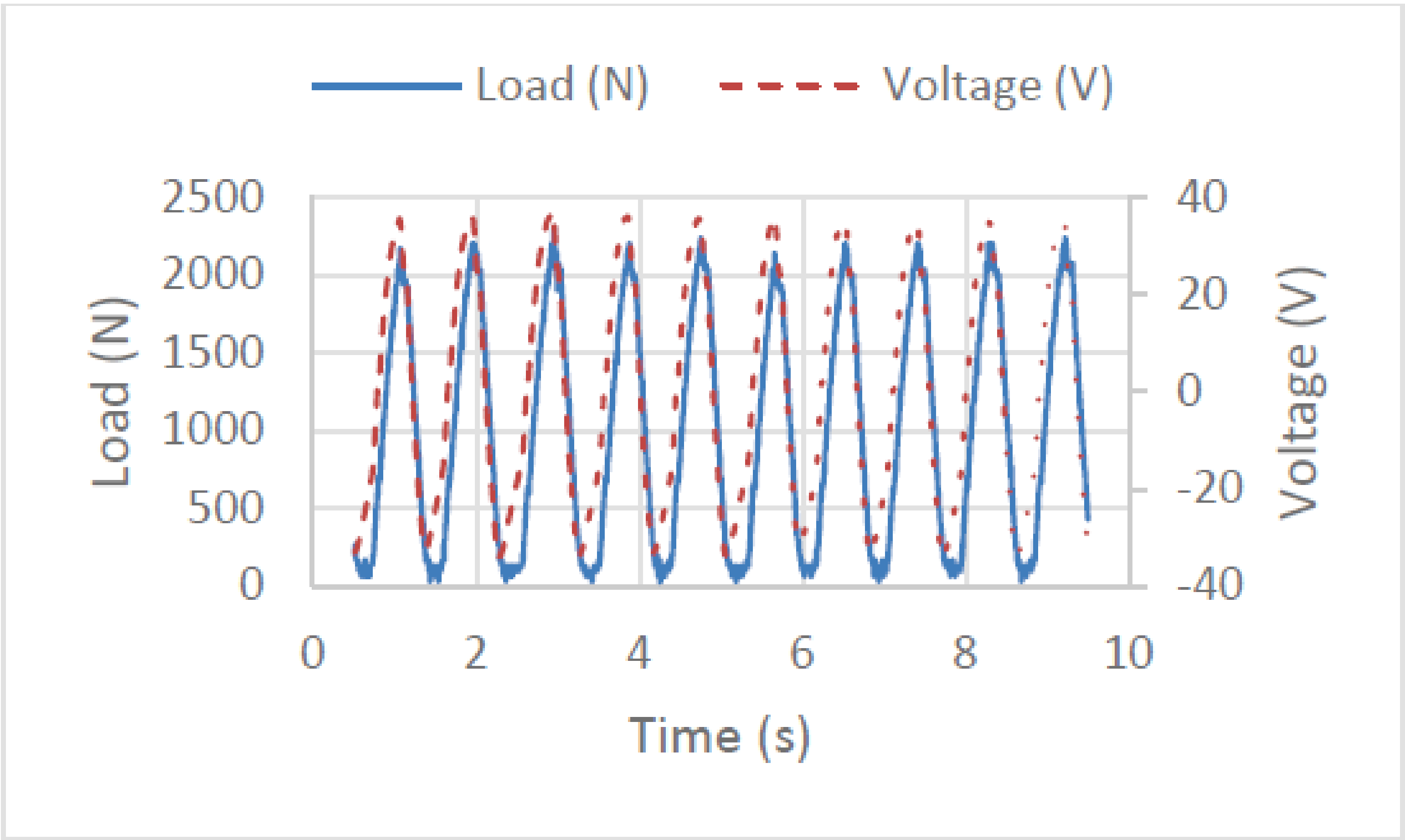
Test Results for Iteration Two

- 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

Load (N)	Measured output voltage (V)
800	10.58 ± 2.67
1500	23.9 ± 1.38
2100	34.50 ± 1.33
$\pm$: sample standard deviation from nineteen peaks	

Conclusions

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- 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?