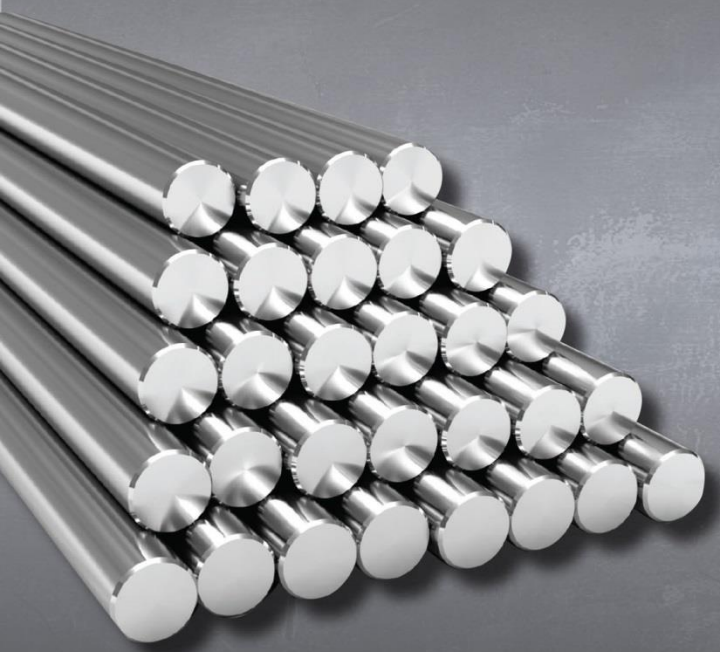
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Vibration Energy Harvesting using PZT Wafers

Anand. S **Dr. A. Arockiarajan**

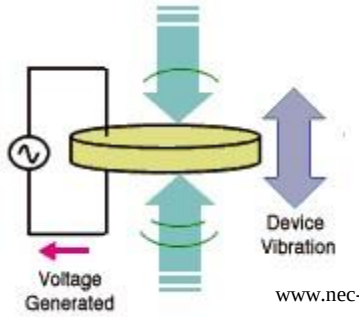
INDIAN INSTITUTE OF TECHNOLOGY-MADRAS
CHENNAI, INDIA

Outline

- **Introduction**
  - **Piezoelectricity**
  - **Piezo Wafer**
- **Application of Piezo-wafers**
- **Objective**
- **Experiment**
  - **Geometric Configuration & Material Properties**
  - **Layout of Experimental Setup**
  - **Result**
- **Numerical Model**
  - **Steps Involved**
  - **Result**
- **Comparison of Experimental and Numerical Results**
- **Inference**

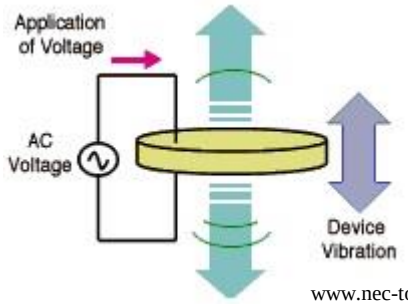
Introduction to Piezoelectricity

Direct



Mechanical ⟶ Electrical

Inverse



Electrical ⟶ Mechanical

Direct

$$D = d : \sigma + \kappa \cdot E$$

Electrical

Inverse

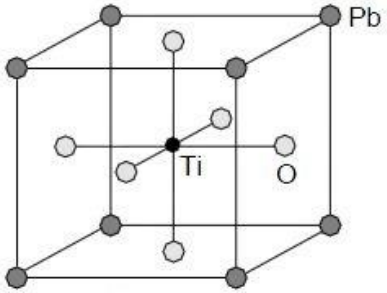
$$\varepsilon = C : \sigma + d^T \cdot E$$

Mechanical

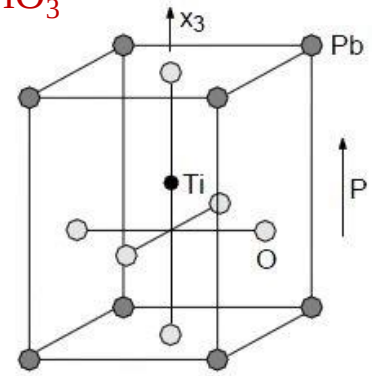
D	=	Dielectric displacement	(C/m^2)
d	=	Piezo-electric coupling coefficient	(C/N or m/V)
σ	=	Stress	(N/m^2)
C	=	Compliance Coefficients	(m^2/N)
κ	=	Dielectric Permittivity	(F/m)
E	=	Electric Field	(V/m)

Overview of PZT

Crystal Structure of $PbTiO_3$

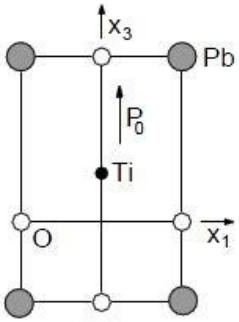


Cubic structure of $PbTiO_3$ above T_c

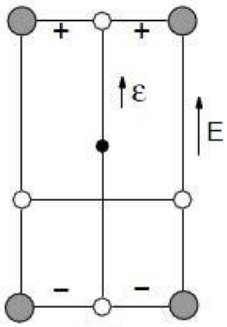


Tetragonal structure of $PbTiO_3$ below T_c

Converse Piezo-electric effect

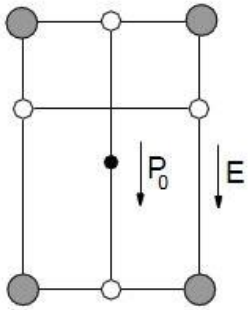


Tetragonal structure of $PbTiO_3$



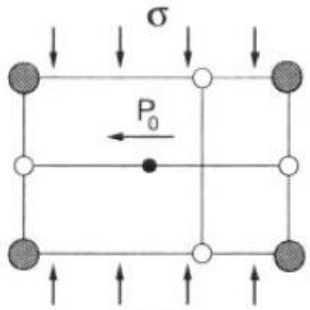
Converse piezoelectric effect $= \mathcal{E} d_{33} E$

180° Switching



Ferroelectric 180°polarization switch due to an applied electric Field $E > E_c$,

90° Switching

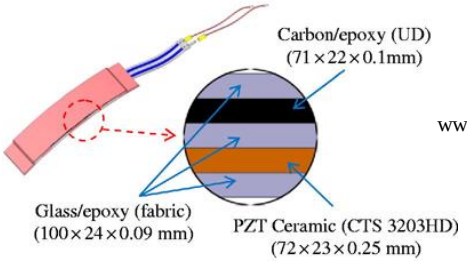


Ferroelastic 90°polarization switch due to an applied stress $\sigma > \sigma_c$

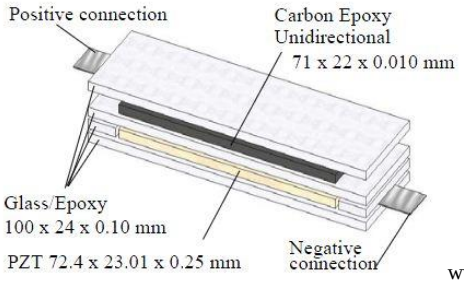
Courtesy: Ralph Smith ; Smart Material Systems: Model Development

Introduction to Piezo-Wafer

- Thickness less than 0.3mm
- Brittle in nature
- Surface-mounted, inserted between the layers of lap joints.
- Intrinsic electromechanical (E/M) coupling, so can be used as sensors and actuators.
- Used as elements of intelligent structures, MEMS, structural health monitoring systems, PWAS etc.
- Difficult to use as actuator due to less blocking force. Recognizing this, major elements based on the single wafer, the unimorph and stack were developed.

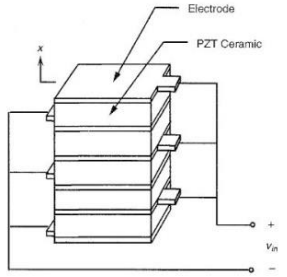


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LIPCA- Unimorph Actuators

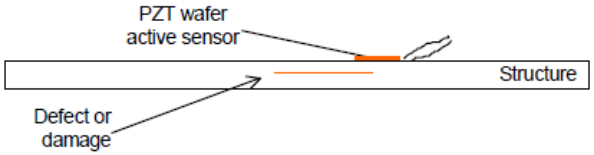
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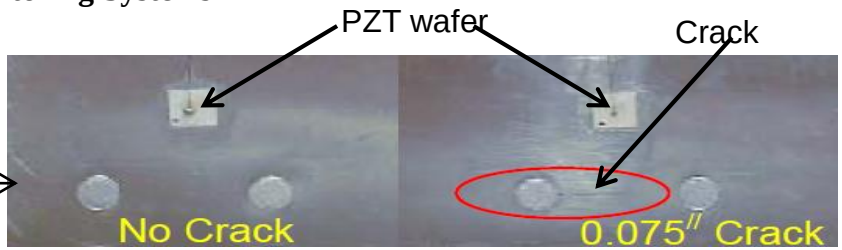
Piezo Stack

Application of Piezo-Wafers

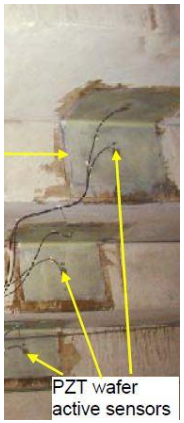
Structural Health Monitoring Systems



Application of PZT wafers for structural health monitoring[3]

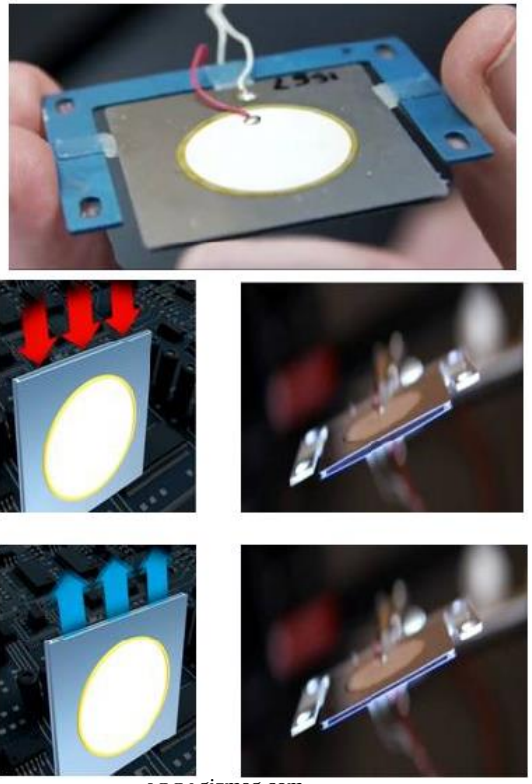






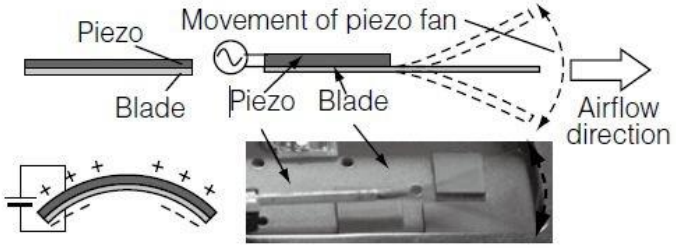
PZT Wafer Active Sensors attached to Aircraft wings & Civil Structures

Dual Piezoelectric Cooling Jets (DCJ) developed by GE

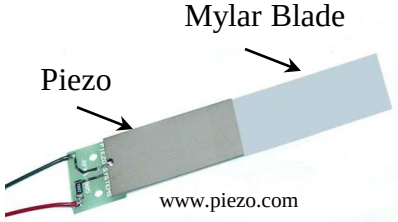


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Piezo Fan Technology



[10]



Objective

- The intrinsic electro-mechanical coupling property and quick response time of PZT wafer makes it operational in energy harvesting applications.

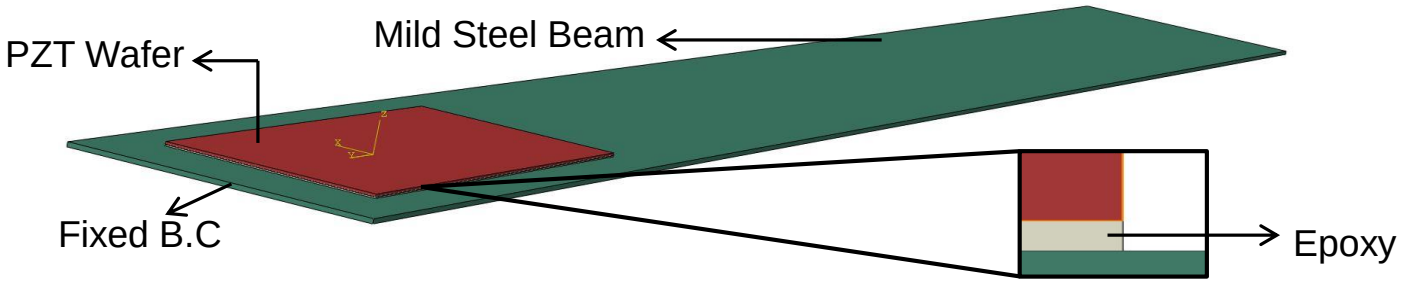
- An experiment is performed to demonstrate the generation of electrical energy with the aid of harvestable ambient vibration energy.

- Examination on how the electrical energy output varies with different vibrating frequencies is carried out in open circuit.

- The experimentally obtained results are numerically modelled using Finite Element in ABAQUS.

Experiment

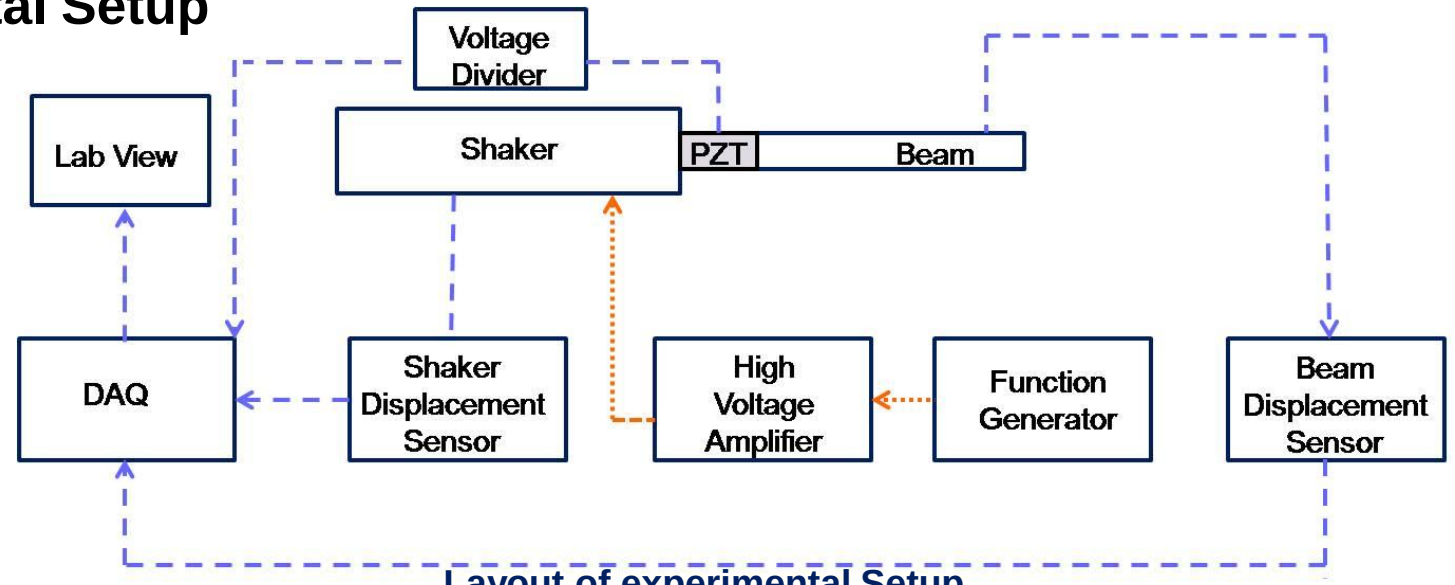
Geometric configuration of cantilever beam with PZT wafer patch



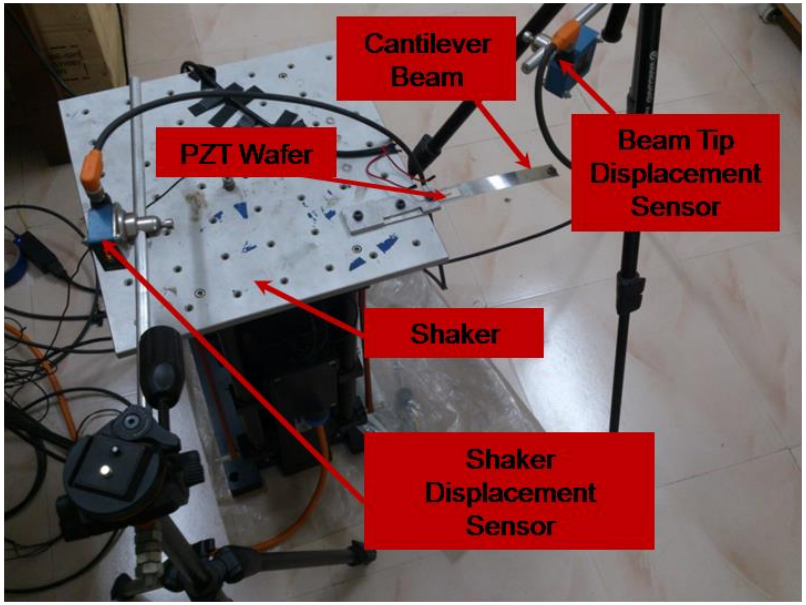
Material and geometric parameters of PZT wafer and Cantilever beam

Item	Value
Mild Steel- Beam dimensions	155 x 20 x 0.35 mm
Mild Steel- density	7798 kg/m^3
Mild Steel- elastic constants	E= 210 Gpa, v= 0.3
PZT- wafer dimensions	28 x 14 x 0.2 mm
PZT- dielectric constants	κ11=1.53e-8 κ22=1.53e-8 κ33=1.50e-8
PZT- piezoelectric stress constants	d31=-171e-12 m/V d33= 274e-12 m/V
PZT- density	7800 kg/m^3
Epoxy dimensions	28 x 14 x 0.2 mm
Epoxy density	2200 kg/m^3
Epoxy elastic constants	E= 0.1 Gpa, v= 0.38
End Mass	1.2 gm

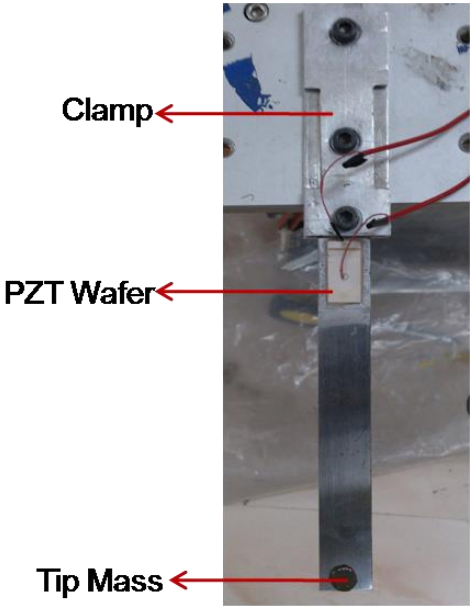
Experimental Setup



Layout of experimental Setup



Photograph of experimental Setup



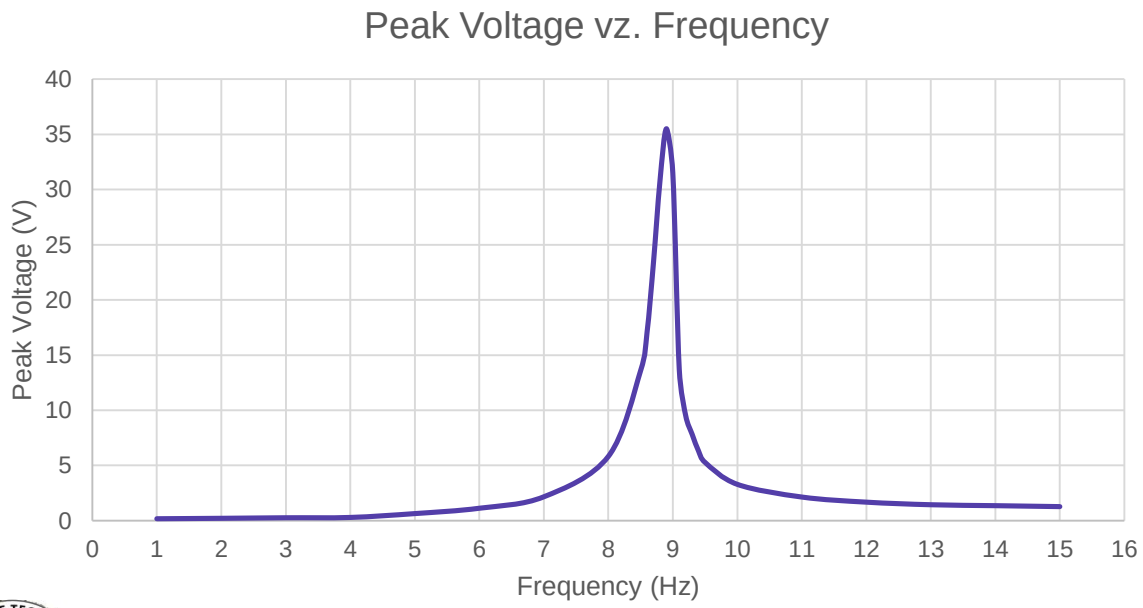
Photograph of Cantilever Setup

Result- Experiment

❖Experiments are conducted to measure the electrical voltage along the thickness direction (poling direction) of the PZT wafer while applying transverse vibration.

❖The beam bonded with the PZT wafer is attached to the shaker (exciter) as a cantilever arrangement.

❖The shaker is made to excite with a displacement of 1mm at several different frequencies (1Hz to 15Hz)



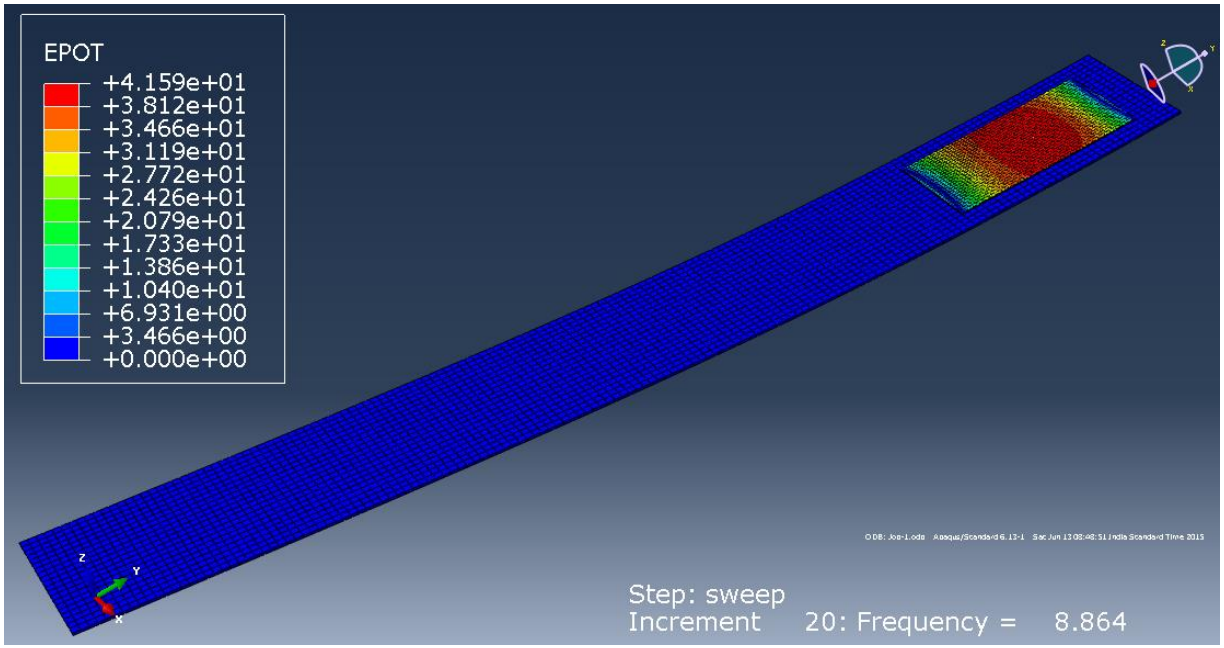
Peak Voltage (V)	Natural Frequency (Hz)
35.51176	8.9

Numerical Model using ABAQUS

- Experimental result is used to validate the model
- Later in model, parameters of beam and Piezo wafer can be changed to optimize the harvester efficiency.

Type of elements used in the analysis

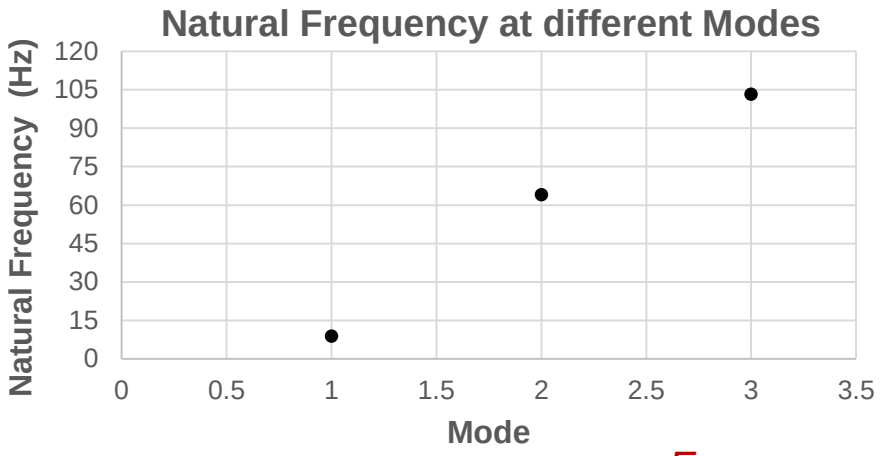
- Piezo Wafer - Piezoelectric Quadratic Element (C3D20RE)
- Beam - 3d-Stress Quadratic Element (C3D20R)



Electric Potential distribution at first natural frequency

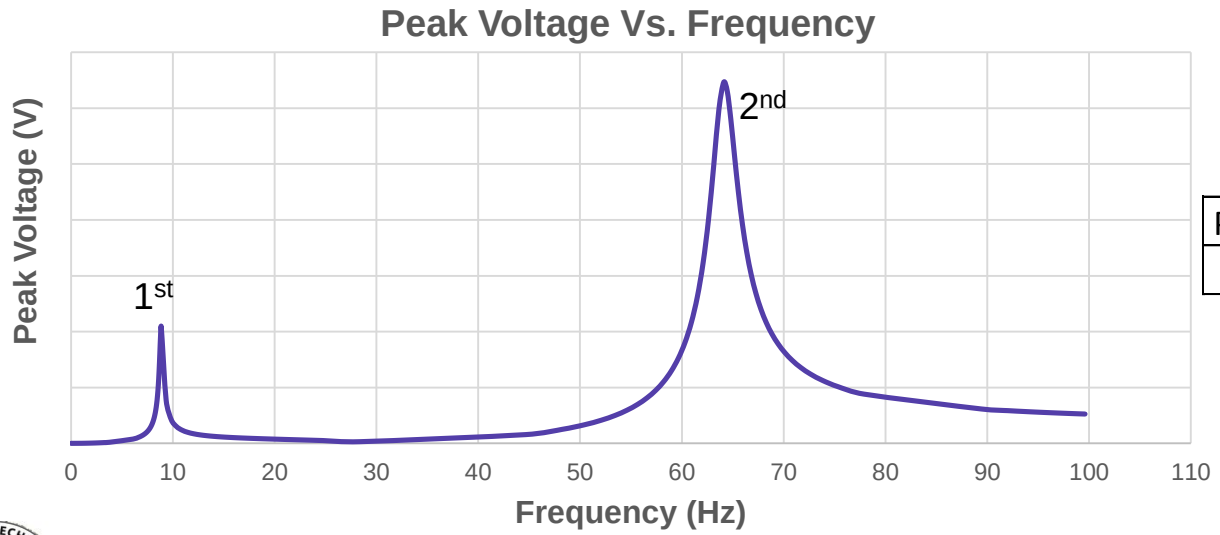
Result- Numerical Model

Natural Frequency Extraction



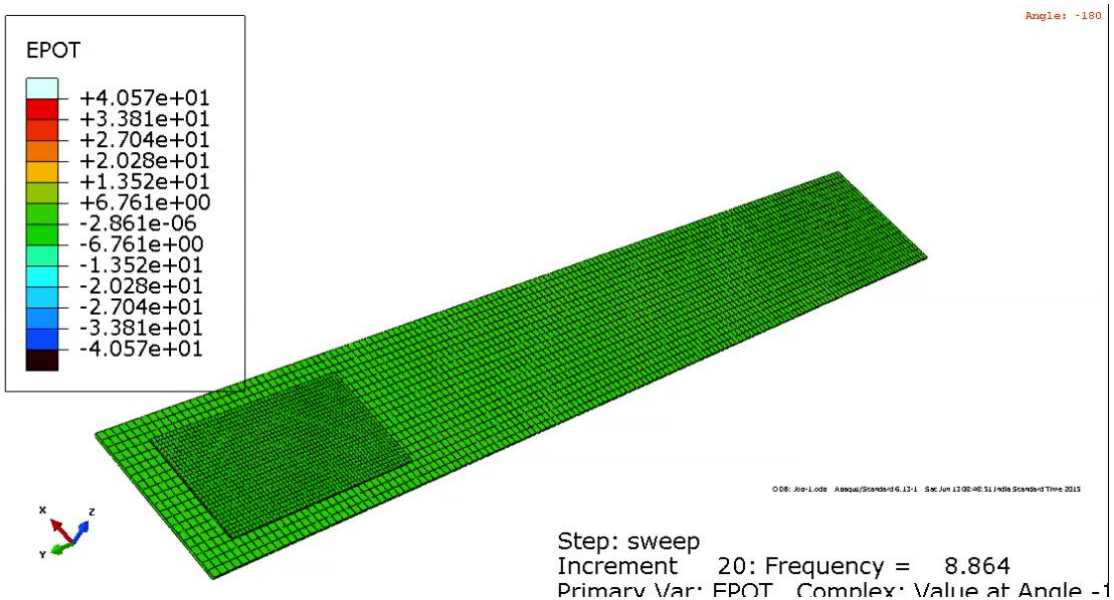
Mode	Frequency
1	8.8642
2	64.12
3	103.25

Frequency Sweep Analysis



Peak Voltage (V)	1st Natural Frequency
41.5867	8.8642

Simulated Result

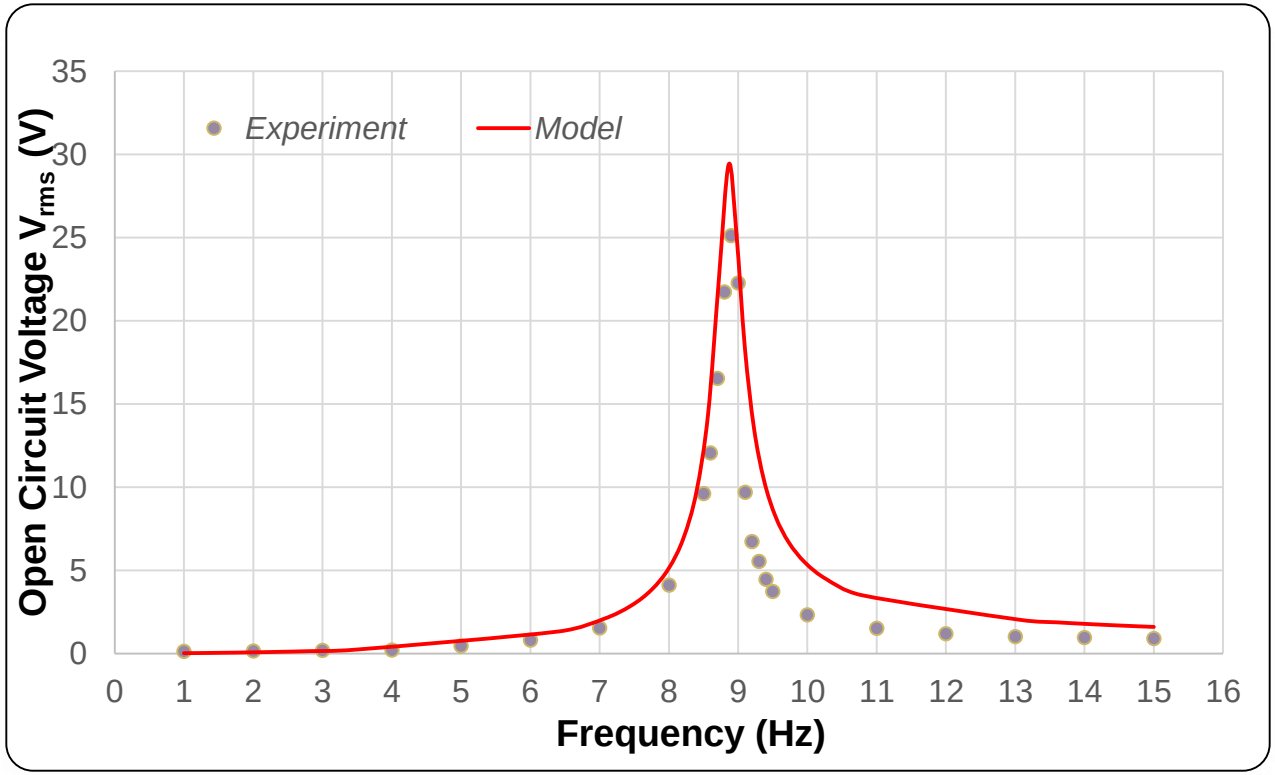


Simulated Harmonic Motion 1st natural Frequency

Piezo wafer energy harvester vibrating at 1st natural Frequency



Comparison of Experiment and Numerical Model Results



Comparison of Experimental and numerical model V_{rms} Value at different frequencies

Parameter	Experiment	Numerical Model
Natural Frequency (Hz)	8.9	8.864
Vrms (V)	25.11	29.406

Inference

- The Numerical model is able to qualitatively capture the voltage output of the Piezo wafer energy harvester.
- The error could be attributed to the fact that cantilever may not be perfectly clamped.
- Modeling of Epoxy mere close to reality may even more reduce the error.

Future Scope

- Optimization study could be carried out by changing the beam and Piezo wafer parameters to obtain maximum harvester efficiency.
- The model can be extended to MFC energy harvesters and can be compared with Piezo wafer energy harvester

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Thank You!
Anand S