Harvesting energy using piezoelectrics excited by Helmholtz resonance

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-with-

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**Smits’ lab: environmental research**

Alexander Smits
Eugene Higgins Professor of MAE

- Development of artificial atmospheric boundary layer generator for wind tunnel testing
- How do model buildings/structures interact with atmospheric flows?

**Artificial atmospheric boundary layer**

**Stratified flows**

- Turbulent boundary layers with temperature gradients
- Occurs during transitions between day and night
- On ↔ off shore breezes

**Vertical axis wind turbines**

- Many potential benefits
- Some drawbacks (e.g., dynamic stall, scaling to large sizes)
- Better understanding of dynamic stall and performance
ARE THERE OTHER VIABLE WAYS TO COLLECT WIND ENERGY?

Helmholtz resonator and piezoelectric concept
Helmholtz harvester

- Fundamentals:
  - Helmholtz resonators
  - Piezoelectric effect
- Harvester design

Applications

- Urban environments
  - Tall buildings, personal houses
- Powering remote sensors

Wind tunnel studies

- Feasibility tests
  - Does it produce meaningful energy?
- Better resonance
  - Can we improve it?
- Effect of geometry
THE CONCEPT
Helmholtz Harvester

Turn a surrounding wind into a vibrating pressure field to be converted to electricity and collected.

Wind

Sound (oscillating pressure)

Electricity

Helmholtz Resonator

Piezoelectric Effect
Helmholtz Resonator

This results in a characteristic frequency based on container geometry and fluid properties

\[ f_H = \frac{1}{2\pi} \sqrt{\frac{P_A A}{\gamma \rho V L}} = \frac{c}{2\pi} \sqrt{\frac{A}{V L}} \]

- Consider a container full of air with a small opening at the top
- The air in the neck acts as a mass
- The air inside the container acts as a spring.
- Apply a disturbance of pressure

A: Orifice Area
V: Cavity Volume
L: Orifice Neck Length
\( c \): speed of sound in air
Helmholtz Resonator

This results in a characteristic frequency based on container geometry and fluid properties.

\[ f_H = \frac{1}{2\pi} \sqrt{\frac{P_A A}{\gamma \rho VL} \frac{c}{2\pi} \sqrt{\frac{A}{VL}}} \]

- A: Orifice Area
- V: Cavity Volume
- L: Orifice Neck Length
- c: speed of sound in air

Consider a container full of air with a small opening at the top. The air inside the container acts as a mass, and the neck acts as a mass with an orifice. If a disturbance of pressure is applied, the air in the neck acts as a spring.
**Helmholtz Resonator: Origin**

Hermann von Helmholtz
1821-1894

“The Helmholtz resonator consists of a rigid container of a known volume, nearly spherical in shape, with a small neck and hole in one end and a larger hole in the other end to admit the sound.”

**Idealized resonator**

Now found in:
- musical instruments
- architectural acoustics
- dodge viper/ram engines
- aircraft drag reduction
Piezoelectric effect

- Piezoelectric crystals generate a voltage when under deformation.

- In our case, a disc shaped piezoelectric is driven by an oscillating pressure field.

- This disc shape that has a resonance that is a function of the disc geometry, stiffness, and boundary condition.
THINK REVERSE SPEAKER

Typical configuration

Voltage → Speaker → Sound → Ear
THINK REVERSE SPEAKER

Voltage → \[\text{Harvesting configuration}\]
A NOTE ON RESONANCE

One of the most important aspects of this design is that the system frequency is unchanged, thus:

\[ \text{Piezoelectric resonance} = \text{Acoustic resonance} \]

This maximizes efficiency of vibrational to electric energy independent of flow condition.
Helmholtz Harvester

Wind

Cavity Pressure

Piezoelectric

Voltage Meter
**Potential Application**

**Green energy solutions**

- Provide another distinct technology for harvesting wind energy

- Energy harvesting ability in urban areas (e.g. on city buildings)

**Remote sensor/device powering**

- Small device powering for with no alternative power sources

- Small scale harvesters to power devices in remote/impoverished areas

- Support from The Southern Company
Helmholtz Harvester

To turn a surrounding wind into a vibrating pressure field to be converted to electricity and collected.

Wind

Sound (oscillating pressure)

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Helmholtz Resonator

Piezoelectric Effect
WIND TUNNEL TESTS
Feasibility Testing

A research project by two undergraduate students, Lindsay Graff and Zachary McCourt, explored:

Is there enough energy to bother?

(a) Interchangeable neck designs
(b) Adjustable cavity volume
(c) Access port for pressure measurements via smart phone

\[ P_{\text{peak}} \sim 50 Pa \quad f_H \sim 85 Hz \text{ (theoretical: } f_H = 96 Hz) \]
Feasibility Testing

They also showed that they could simulate disk resonance frequencies (useful as a design tool) and predict voltage outputs from the piezo with cavity pressure information.
HOW DOES IT COMPARE?

WIND TURBINES

- Power: 1-5 W/m² (typical farm values)
- Large
- Limited to open areas
- Don’t respond quickly to changes in wind

PIEZO RESONATOR

- Power: up to 6 W/m² (so far)
- Small/compact
- Can be utilized in tight spaces (urban environments)
- Omni-directional with quick response
Emile Oshima and Jason Mulderrig conducted a parametric study trying to answer the question: **Can we improve resonance?**

Successful, simple resonance  

Not good resonance
INDUCING RESONANCE IN WIND

Using specially designed tops to improve resonance.
INDUCING RESONANCE IN WIND

Using specially designed tops to improve resonance

Keys to success

– Vectoring air into the neck
– Unsteady mechanisms like flow separation (musical instruments)
– Accelerating the flow over the top
**ONGOING WORK**

- Study successful tops and redesign based on what we learn
  - Flow visualization and measurement
- Change resonator geometry
  - Is there an ideal geometry or resonator orientation for maximizing resonance?
- Once converged on design, add piezo to collect energy
  - Requires custom piezos (collaboration with Midé Technologies)
    - Matching ideal piezo size/resonator size
- Field tests
ACADEMIC ACHIEVEMENTS

• Undergraduate **senior project**: Zachary McCourt and Lyndsay Graff

• Undergraduate **thesis**: Emile Oshima

• Undergraduate summer **internship**: Emile Oshima

• ACEE summer **fellowship**: Jason Mulderrig

• MAE: John Marshall II Memorial **Award**: Emile Oshima
Helmholtz harvester

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Wind tunnel studies

- Feasibility tests
  - Substantial possible energy available
- Better resonance
  - Resonance can be improved with geometry and neck design
QUESTIONS?