Energy Harvesting From Pavement via PVDF: Hybrid Piezo-Pyroelectric Effects

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Background

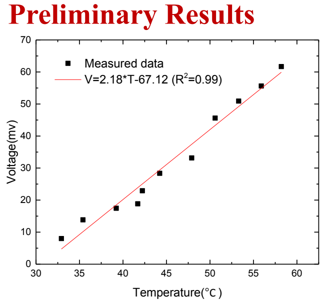
In the U.S., there are over 4 million miles (6 million km) of roadways and more than 250 million registered vehicles. The energy lost in the pavement system due to traffic-induced vibration and deformation is enormous. If effectively harvested, such energy can serve as an alternative sustainable energy source that can be easily integrated to the transportation system.

Objective

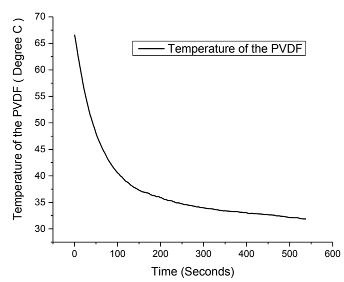
In this study, the electrical response of PVDF under coupled mechanical and thermal stimulations are studied. It is well known that most piezoelectric materials are also pyroelectric materials, which convert temperature change into electricity. However, the potential of PVDF as a hybrid piezo-pyroelectric energy harvester has been seldom studied. This study aims to

1) uncover the coupling between piezoelectric and pyroelectric effects of PVDF through laboratory experiments.
2) Estimate the energy output of PVDF harvester under real life traffic and temperature conditions

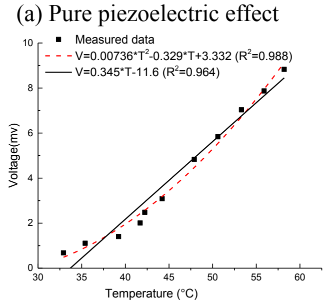
Preliminary Results



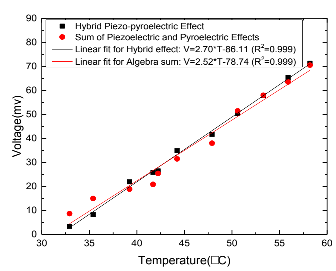
(a) Pure piezoelectric effect



(b) Temperature profile



(c) Pure pyroelectric effect



(d) Hybrid piezo-pyroelectric effect

The total charges induced by the hybrid effect can be expressed as:

$$Q = Q_T + Q_M$$

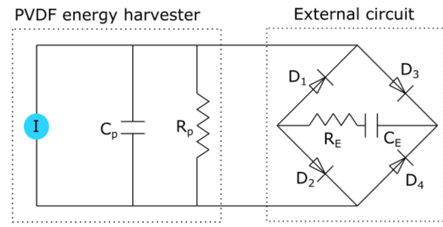
where Q, Q_T and Q_M is the total charges induced by the hybrid effect, the pure pyroelectric effect and the pure piezoelectric effect, respectively.

Modeling of The Harvested Energy Considering Hybrid Pizeo-Pyroelectric Effects

Model of pyroelectric effect induced charge:

$$Q_T = \rho \Delta T A_{PVDF}$$

where Q_T pyroelectric effect induced charge, ρ is pyroelectric coefficient, ΔT is the temperature change and A_{PVDF} is the surface area of the harvester



Standard circuit for energy harvesting. C_p and R_p is the capacitance and resistance of PVDF harvester, C_E and R_E is external capacitance and resistance,. D_1, D_2, D_3 and D_4 are four diodes.

Model of piezoelectric effect induced charge:

$$Q_M = d_{33} \sigma_z A_{cont}$$

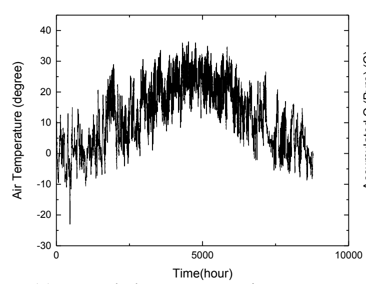
where Q_M piezoelectric induced charge, d_{33} is piezoelectric coefficient, σ_Z is stress applied on PVDF harvester, A_{cont} is contact area between tire and PVDF harvester.

Model of total charges induced by the hybrid piezo-pyroelectric effect in a day:

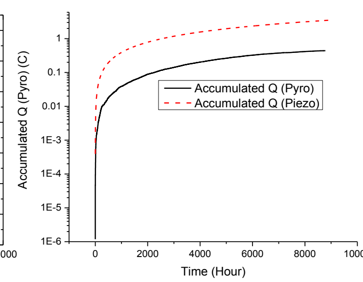
$$Q_{day} = Q_{T\_day} + Q_{M\_day} = \rho A_{PVDF} \sum_{day} |\Delta T| + 4N d_{33} \sigma_z A_{cont}$$

where N is traffic volume per day.

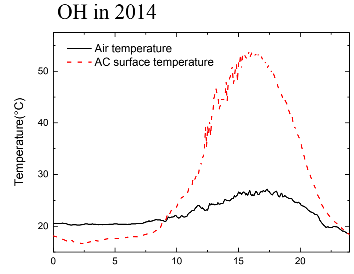
Case Study Results



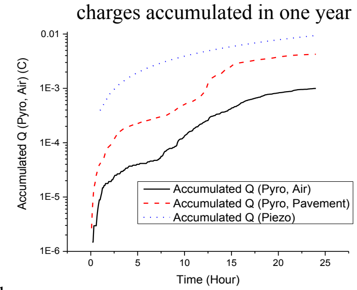
(a) Recorded temperature in Wooster OH in 2014



(b) Comparison of piezo and pyro charges accumulated in one year



(c) Comparison of air temperature and pavement temperature in a summer day in Cleveland OH



(d) Comparison of pyro charges calculated using air and pavement temperature

Future Research

- Develop novel new materials, such as combining PVDF with nanoparticles

Reference

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- CUADRAS, A., GASULLA, M. & FERRARI, V. 2010. Thermal energy harvesting through pyroelectricity. Sensors and Actuators A: Physical, 158, 132-139.