DESIGN OPTIMIZATION OF PIEZOELECTRIC ENERGY HARVESTING FOR SMALL-SCALE ENERGY SOURCES

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ABSTRACT

Energy harvester is an energy-generating device that the energy is derived from ambient energy such as solar power, thermal energy, wind energy, tide/wave energy, kinetic energy, strain energy and so on. Besides of large-scale energy harvesting, small-scale energy harvesting on a level that is sufficient for wireless sensors for the internet of things (IoT), remote monitoring device, and wearable electronic devices, is considered. Piezoelectric energy harvesting which converts strain energy to electricity has been attracted great attention due to high energy density and high energy conversion efficiency, ease of implementation, and miniaturization. Piezoelectric energy harvesters using strain energy from vibration and magnetic energy from AC power line are designed by using optimization method. Design processes of road-compatible piezoelectric energy harvester and a magneto-piezoelectric energy harvester are illustrated.

PIEZOELECTRICITY

The piezoelectricity is the electric charge from the linear electromechanical interaction between the mechanical and electrical states in crystalline materials with no inversion symmetry. Therefore, the governing equation of piezoelectricity is based on the equations of linear piezoelectricity, which is composed as electromechanical interaction in piezoelectric materials and effects. The coupled equation given as strain-charge form is as follows:

\[ S_{ij} = s_{ijkl}T_{kl} + d_{kij}E_k \]
\[ D_i = d_{ijk}T_{jk} + \varepsilon_{ij}E_j \]

where \( S_{ij}, T_{kl}, D_i, \) and \( E_j \) are the mechanical strain, mechanical stress, electric charge density displacement, and electric field vectors, respectively. \( s_{ijkl} \) and \( \varepsilon_{ij} \) are the compliance and permittivity of the piezoelectric materials, respectively. \( d_{kij} \) and \( d_{ijk} \) are the matrix for the direct piezoelectric effect and the matrix for the converse piezoelectric effect, respectively [1].

The piezoelectric device consisted of two parts; piezoelectric ceramic plate, and a stainless-steel substrate. The piezoelectric ceramic plate was made from a well-known material, PZT-PZNM [2]. This ceramic plate was attached to the substrate, which was an AISI type stainless-steel plate. For finite element analysis, the substrate plate is modeled using shell elements, and the PZT plate is modeled using linear piezoelectric solid elements. The binding between the substrate and the PZT plate was modeled using the tie constraint in the simulation software [3].
ENERGY HARVESTING

Energy source for the piezoelectric energy harvesting is given as an external force term, \( f(t) \), in the equations of motion:

\[
\mathbf{M}\ddot{\mathbf{u}} + \mathbf{K}\mathbf{u} = f(t)
\]

The external forces for excitation of the device can be used as a mechanical vibration or magnetic forces. Mechanical vibration can directly excite the piezoelectric energy harvester. Magneto-piezoelectric energy harvesting uses torque-mode magnetic coupling, and the magnetic force experienced by the tip mass (permanent magnet), which originates from the forced alignment of the remnant moment with an external AC magnetic field.

OPTIMIZATION

To achieve maximum energy harvest from ambient energy, we employ the optimization techniques. One of optimization problems can be defined as follows [1, 5]:

\[
\begin{align*}
\text{Min}_x & \quad \frac{1}{W_{RMS}} + (f_N - 60)^2 \\
\text{s. t.} & \quad \text{Mass}_{PEH}^{PM} \leq \text{Mass}_{0}^{PEH} \\
& \quad \text{Mass}_{PM}^{PM} \leq \text{Mass}_{0}^{PM} \\
& \quad \sigma_{\text{max}}^{PZT} \leq \sigma_{\text{UT}}^{PZT} \\
& \quad \sigma_{\text{max}}^{\text{SUS}} \leq \sigma_{\text{Y}}^{\text{SUS}}
\end{align*}
\]

which will harvest maximum power without failure of the device while using specified resources. In the above optimization problem, \( W_{RMS} \) and \( f_N \) represent the root mean squares of energy harvesting power and the natural frequency of the energy harvester, respectively. \( \sigma_{\text{UT}}^{PZT} \) and \( \sigma_{\text{Y}}^{\text{SUS}} \) denote the ultimate tensile stress of PZT and the yield strength of SUS, respectively. \( \sigma_{\text{max}} \) becomes the maximum stress occurred on the PZT and SUS.
At the lecture we will show some design cases such as road-compatible piezoelectric energy harvester [1, 4] and a magneto-piezoelectric energy harvester.

REFERENCES


