electroscope

Resonant Structures For Energy Microgenerator

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Abstract:
There is a concept of self-powered devices using micro generator for energy production. These small power sources can be implemented into physical isolated devices like remote sensors chains etc. One part of this complex system is a resonant structure working on piezoelectric principle. It’s the main harvesting device on which depends the whole system efficiency. This paper shows different layouts and its electro-mechanical behavior during vibrations. The main focus is given on the lowest achievable resonant frequency of the structure.

INTRODUCTION

New electronic devices continue to push past boundaries of integration and functions concentration toward the completely autonomous, self-powered micro-systems (Fig.1). As systems continue to shrink, however, less energy is available on board, leading to short device lifetime. Research continues to develop higher-energy-density batteries, but the amount of energy available is not only finite but also low, limiting the system's life span, which is dominant in mobile electronics. Extended life is also mainly useful in systems with limited accessibility, such as medical implants and device-embedded micro-sensors. The ultimate long-lasting solution should therefore be independent of the limited energy available during startup of the device.

That's the area where a self-renewing energy source comes in, persistently replenishing the energy consumed by the micro-system.

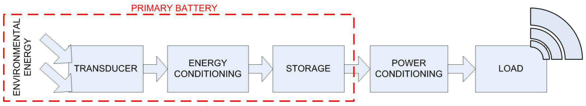

Fig.1 Block diagram of an autonomous system. The blocks inside the dashed red box form the energy harvester subsystem [1]

ENERGY SOURCES AND EXTRACTION

State-of-the-art MEMS generators and transducers can be such self-renewing sources, extracting energy e.g. from vibrations [1]. The energy extracted from these sources is stored in chip-compatible, rechargeable batteries such as thin-film lithium-ion types, which power the loading application (the sensor) via a power management circuit.

Figure 2 shows a diagram of a cantilever beam with piezoelectric plates bonded on a substrate and a proof mass at the end; multilayer piezoelectric plates and equivalent lumped spring mass with external excitation. Cantilever structure with tip mass is the most widely used configuration for piezoelectric energy harvesting device. The source of vibration is shown with an arrow at the base of the contact point. The stiffness of the structure depends on the loading condition, material, and cross-sectional area perpendicular to the direction of vibration. The governing equation of motion for the system shown in Fig. 2(c) can be obtained from energy balance equation or D’Alembert’s principle. This configuration applies to both the energy harvesting mechanisms shown in Fig. 2(a) and (b).

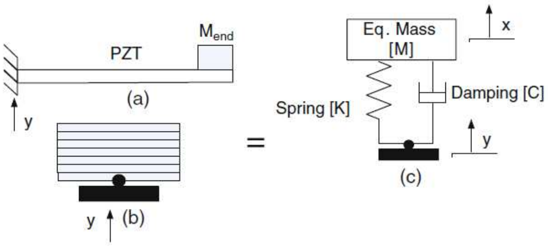

Fig.2 (**a**) Cantilever beam with tip mass, (**b**) multilayer PZT subjected to transverse vibration
excited at the base, and (**c**) equivalent lumped spring mass system of a vibrating rigid body[2]

Modeling

For The governing equation of motion of a lumped spring mass system can be written as[3] :

$$M\ddot{z} + C\dot{z} + Kz = -M\ddot{y} \qquad (1)$$

where $z = x - y$ is the net displacement of mass. Equation (1) can also be written in terms of damping constant and natural frequency. A damping factor, ζ, is a dimensionless number defined as the ratio of system damping to critical damping as:

$$\zeta = \frac{c}{c_c} = c/2\sqrt{mK} \qquad (2)$$

The natural frequency of a spring mass system is defined as:

$$\omega_n = \sqrt{K/M} \qquad (3)$$

where the stiffness K for each loading condition should be initially calculated. For example, in case of a cantilever beam, the stiffness K is given by $K = 3E\,I/L^3$, where E is the modulus of elasticity, I is the moment of inertia, and L is the length of beam. The moment of inertia for a rectangular cross-sectional can be obtained from expression, $I = (1/12)bh^3$, where b and h are the width and thickness of the beam in transverse direction, respectively. For the other cross-sectional area and stiffness, formulas are available in standard mechanical engineering handbook (Blevins, 1979). The power output of piezoelectric system will be higher if system is operating at natural frequency which dictates the selection of material and dimensions. The terms “natural frequency” and “resonant frequency” are used alternatively in literature, where natural frequency of piezoelectric system should not be confused with natural frequency of mechanical system.

PIEZOELECTRIC MICROACTUATORS

The piezoelectric principle can be used in many applications, such as electric fans, microphones, inkjet printers, control valves, micro pumps, tactile sensor, acoustic control and micro motors, etc. Figure 3 shows a typical piezoelectric micro actuator. The main advantages of this actuation principle are its high precision, speed and mechanical power.

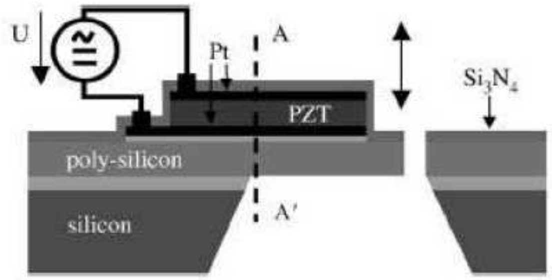

Fig. 3 Cross sectional view of a PZT microactuator.(Manohara, 1999).

In these applications, piezoelectric ceramic materials such as zinc oxide and PZT are most commonly used, because they exhibit large piezoelectric coefficients. However, there are also some difficulties associated with their use. Piezoelectric ceramic materials require advanced deposition facilities and technologies to prepare thin films, they are usually brittle, and have a relatively large Young’s modulus, thus limiting the achievable strain. Some composite active polymers (Friese *et al.*, 2003; Janos and Hagood, 2003) composed by piezoelectric ceramic materials and epoxy were fabricated to compensate for these disadvantages. Piezoelectric polymers such as PVDF and its copolymers can overcome some of these difficulties even though they have a relatively low piezoelectric coefficient. Low numerical Young’s modulus values of these polymers have the potential for enabling relatively large strain piezoelectric actuators. There are two extreme cases of the high-energy density material[3], PVDF piezoelectric polymer (d_{33} = 33 pC/N, $\varepsilon_{33}/\varepsilon_o$ = 13, g_{33} = 286.7×10^{-3} m^2/C), and relaxor piezoelectric single crystals such as PZN – 7%PT (d_{33} = 2500 pC/N, $\varepsilon_{33}/\varepsilon_o$ = 6700, g_{33} = 42.1 × 10^{-3} m^2/C). It can be seen from this data that piezoelectric polymer has the highest piezoelectric voltage constant, g_{33}, of 286.7 × 10^{-3} m^2/C and relaxor-based single crystals have the highest product ($d_{33}.g_{33}$) of the order of 105, 250×10^{-15} m^2/N.

Energy harvesting modules

For energy harvesting we use Advanced Linear Devices‘s EH300 series EPAD® energy harvestingTM modules. They include the energy conditioning and storage blocks in Fig. 1.The manufacturer claims that these modules can extract energy from any environmental energy source (ac or dc signals ranging from 0 V to ±500 V and from 200 nA to 400 mA). The storage unit is provided by a capacitor bank and then the output voltage linearly decreases for a constant output current. The manufacturer provides data of available energy and active time outputs for a rated current. From these data, the calculated capacitances are 950 µF and 6.25 mF.

GENERAL LAYOUT

Vibration energy harvesters can be employed to harvest energy from vibrations and vibrating structures, a general requirement independent of the energy transfer mechanism is that the vibration energy harvesting device operates in resonance at the excitation frequency[4]. Most energy harvesting devices are single resonance frequency based. To obtain the lowest possible resonant frequency it is necessary to design layout with long cantilevers. But this condition is limiting the resulting area occupied by the generator. There have been designed several different layouts (Fig.4) of the micro generator with different resonant frequency. Each of these layouts are usable in different environments.

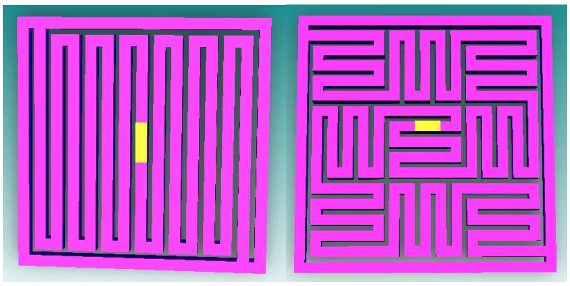

Fig.4 Different layouts of the piezo-generator

To find out how these layouts behave during vibrations there have been done some simulations in Coventor software. On Fig.5 are visible displacements magnitudes of 40µm with generated voltage of about 100V. The generated charge is much more crucial in the design of the whole sensor chain. In these simulations there is no load attached.

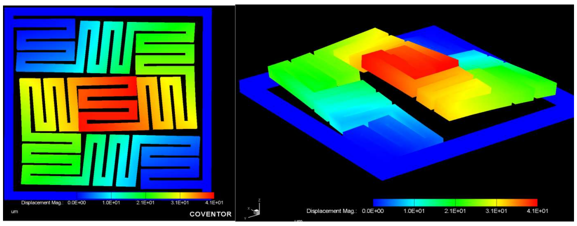

Fig.5 – Displacement magnitude simulation of generator (Layout 1)

CONCLUSIONS

The electro-mechanical model of the piezoelectric power generator is presented and used to predict and understand the behavior of the generator under quasi-static and dynamic stress conditions. Under quasi-static stress, the piezoelectric power generator produces a bidirectional (i.e., positive and negative peak) output voltage. In contrast to the quasi-static stress condition, the dynamic stress condition produces a unidirectional output voltage ca.10 times larger than the quasi-static case. This difference is caused by loading time of the capacitance created by the active piezo-material layer. This capacitance doesn’t have enough time to charge and subsequently recharge the generated voltage during the dynamic conditions and therefore it doesn’t decrease.

Resonant frequency of micro-generator is crucial parameter to obtain the maximum energy out from the design. There are tunable layouts in development which can be used in applications with broad frequency range.

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